HEART RATE VARIABILITY IN THE TIME DOMAIN DURING THE CHESTER STEP TEST AS A PREDICTOR OF HOSPITAL LENGTH OF STAY: A PROSPECTIVE OBSERVATIONAL STUDY

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Abstract

Introduction: Major abdominal and thoracic surgeries have a high rate of cardiopulmonary complications and prolonged hospital stays. The Chester Step Test (CST), combined with Heart Rate Variability (HRV) analysis, may assist in preoperative risk stratification. **Objective:** To verify whether the CST combined with HRV can predict postoperative hospital length of stay in oncological patients undergoing non-cardiac surgeries. **Methodology:** Prospective study with 24 oncological patients who underwent the CST with HRV monitoring and estimated VO_2max between May 2024 and January 2025. Sociodemographic, clinical variables and length of hospital stay were analyzed using multinomial logistic regression. **Results:** Mean RR was associated with hospital length of stay, increasing the chance of medium-length hospitalization by 2.4% for each 1 ms increase ($p = 0.031$). The short-stay group presented lower HRV and higher heart rate, with breast cancer being more prevalent among women (TIH-C) and colorectal cancer among men (TIH-L). **Conclusion:** HRV analysis proved to be a practical and effective tool for predicting postoperative hospital length of stay, contributing to the planning and optimization of perioperative care in oncological patients.

Keywords: Heart Rate Variability; Chester Step Test; Oncological Surgery; Functional Capacity; Length of Hospital Stay.

Introduction

Annually, more than 312.9 million major surgical procedures are performed worldwide (Covre et al., 2019). Among these, moderate- to high-risk non-cardiac surgeries have a 30-day mortality rate exceeding 5%, as demonstrated in large cohort and population-based studies (Landesberg et al., 2009). In Brazil, approximately 8.8 million elective surgeries were performed in 2020, according to data from the Unified Health System (Brazil, 2021).

Cardiopulmonary complications are the leading cause of death following non-cardiac surgeries, with major abdominal and thoracic procedures being the categories associated with the highest risk of developing such complications (Sanaiha et al., 2018). Studies indicate that around 30% of patients undergoing major abdominal surgery experience significant postoperative complications (Gonçalves, 2019). Exudation resulting from visceral manipulation and abdominal distension alters the mechanical properties of the abdominal cavity, potentially triggering cardiopulmonary complications, worsening the clinical condition, and compromising patient prognosis (Rossi & Bromberg, 2005).

Although 1.5% of patients undergoing non-cardiac surgeries do not survive after 30 days, major adverse cardiac events remain the leading cause of morbidity and mortality (Devereaux, 2015). In this context, accurate prediction of perioperative risk of myocardial infarction (MI), cardiac arrest (CA), and acute respiratory failure (ARF) is essential for the selection of appropriate interventions and for guiding the informed consent process. Surgery itself provokes sympathetic nervous system activation, inflammatory responses, loss of vascular tone, and hemodynamic instability, resulting from hemorrhage and fluid balance disturbances (Gupta et al., 2013; Juo et al., 2017).

Beyond these outcomes, hospital length of stay, particularly when prolonged, is considered an objective indicator of postoperative morbidity, reflecting clinical complications, infectious events, and cardiovascular incidents that directly impact patient recovery. Length of stay beyond the expected period is frequently used in studies as a surrogate outcome for morbidity, as it captures complications not identified solely by mortality. It also serves as an indirect marker of higher hospital costs and functional impact on surgical patients (Schwarze et al., 2015). Moreover, prolonged hospitalization after oncologic and non-oncologic surgeries is associated with greater risk of functional decline, readmissions, and increased medium-term mortality (Kristjansson et al., 2010). Thus, monitoring length of stay is a relevant parameter for evaluating quality of care and postoperative risks.

Accordingly, several studies employ length of stay as a primary or secondary outcome to assess perioperative interventions and predictive variables of complications, such as functional capacity and cardiorespiratory fitness, reinforcing its value as an objective marker of postoperative morbidity (Wijeysundera et al., 2018; Lee et al., 2014).

Given the high occurrence of postoperative cardiopulmonary complications (PCCs) in major surgeries, preoperative cardiopulmonary assessment is essential. This step is important to identify patients at higher risk of developing complications, allowing intensification of preoperative care and risk minimization. Furthermore, preoperative exercise is crucial, as it enhances peripheral oxygen utilization and demands a coordinated response from the entire oxygen transport system, involving lungs, heart, and blood vessels. During exercise, lungs experience increased ventilation, oxygen uptake ($\dot{V}O_2$), carbon dioxide excretion, and blood flow, changes similar to those observed after pulmonary resection. This provides the opportunity to evaluate a large portion of the cardiopulmonary system with a single test (Brunelli et al., 2008).

During this phase, specific tests may be performed to assess lung volumes and capacities, respiratory muscle strength, and cardiopulmonary capacity (Szekely et al., 1997). Among these are maximal exercise tests, such as cardiopulmonary exercise testing (CPET), which measures oxygen consumption (VO_2), and submaximal exercise tests, such as the Stair-Climbing Test (SCT) and the Six-Minute Walk Test (6MWT) (Holden et al., 1992).

From this perspective, exercise tests such as the Six-Minute Walk Test, Stair-Climbing Test, and Step Test (ST) emerge as more practical and applicable options in the preoperative assessment of non-cardiac surgeries (Mangano, 1990). Among physical capacity indicators, peak maximal oxygen consumption (VO_2max), adjusted by body weight (ml/kg/min), is considered the most accurate (Beckles et al., 2003) and can be estimated through both cardiopulmonary exercise tests and physical tests.

The first Step Test protocol was described by Master and Oppenheimer in 1929, known as the Master two-step test. Its purpose was to create an exam that stimulated a daily activity, assessed physical effort in a practical way, and could be easily applied in hospitals and clinics. Since then, several protocols have been developed (Andrade et al., 2012a). When performed to symptom-limited exhaustion, the ST elicits a maximal cardiopulmonary and metabolic response, being well tolerated, reproducible (Dal Corso et al., 2013), and effective for evaluating exercise tolerance. Furthermore, it stands out for its low cost, simplicity, and portability—unlike other tests—making it feasible for hospital environments and allowing effective assessment of functional status in preoperative patients (Marrara et al., 2012).

Beyond traditional assessments, a complementary and effective preoperative approach for major surgeries is the analysis of Heart Rate Variability (HRV). HRV refers to the oscillations in the time intervals between consecutive heartbeats, known as R-R intervals. It is a noninvasive measure that evaluates the influence of the autonomic nervous system (ANS) on cardiac activity, reflecting the dynamic balance between its two main branches: the sympathetic and parasympathetic systems. For this reason, HRV is widely recognized as an indicator of cardiovascular health (Frandsen et al., 2022).

In the preoperative context, HRV assessment stands out as an objective and sensitive tool to identify patients with low autonomic physiological reserve, who are at greater risk of adverse postoperative outcomes. Patients with reduced HRV tend to have lower adaptive capacity to surgical stress, which may result in cardiopulmonary complications and compromised clinical prognosis.

Recent studies reinforce the relevance of HRV as an important predictor of adverse surgical events, suggesting that its incorporation into clinical practice can optimize perioperative management and improve clinical outcomes in patients undergoing major abdominal surgery (Reimer et al., 2017). Thus, HRV monitoring not only broadens the understanding of patient functional status but also contributes to implementing personalized care strategies, favoring safer and more efficient recovery.

Within cardiopulmonary assessment, combining HRV analysis with submaximal exercise testing, such as the Step Test, emerges as a promising tool. HRV is a sensitive indicator for detecting changes in cardiac autonomic modulation. Its analysis, before or after the ST, allows identification of patients at higher risk of surgical complications, such as arrhythmias or cardiovascular events. The combination of ST with HRV assessment provides valuable information about patients' cardiovascular status, contributing to more accurate preoperative risk stratification (Michael S. et al., 2017).

Based on the above, this study aims to evaluate whether the submaximal exercise Step Test, combined with HRV analysis, is effective in identifying patients at higher risk of developing postoperative complications in non-cardiac surgeries (upper abdominal and thoracic). The goal is to verify the ability of this approach to distinguish between high- and low-risk patients, contributing to safer and more individualized perioperative management.

Methods

Ethical Aspects

This research was conducted in accordance with the ethical principles established in Resolution 510 (April 7, 2016) of the National Health Council (CNS) and was approved by the Research Ethics Committee on Human Subjects of the João de Barros Barreto University Hospital of the Federal University of Pará (approval no. 5.282.029). All participants were fully informed about the objectives and procedures of the study and signed the Informed Consent Form (ICF) prior to participation.

Study Design

This is a prospective, observational cohort study, quantitative in nature, with both descriptive and inferential analyses.

Study Setting and Period

The study was conducted at the Surgical Clinic of the João de Barros Barreto University Hospital, from May 2024 to January 2025.

Population

The study population consisted of adult patients undergoing abdominal or pelvic surgical procedures performed at the Surgical Clinic of the João de Barros Barreto University Hospital, between May 2024 and January 2025.

Eligibility Criteria

Inclusion criteria were male and female patients over 18 years of age, diagnosed with neoplasms in the abdominal or pelvic region, and scheduled for surgery. Exclusion criteria were patients unable to perform the lightest level of the Chester Step Test, those with motor or cognitive impairments, confirmed metastasis, unstable preexisting cardiac or pulmonary disease, or those scheduled for surgical reoperation.

Sampling

Non-probabilistic purposive sampling was applied.

Sample

The partial R^2 for estimating the minimum predictive sample size of SCT was obtained from pilot data, with an effect size f^2 of 1.78. The sample size was calculated considering the total number of predictors (time domain; frequency domain; BMI; workload; VO_2max; level) of 6, with 3 positive predictors; α error probability of 0.05; and β of 0.20. A required sample size of 11 individuals was calculated.

The initial sample consisted of 59 patients, of whom 24 were selected after applying the eligibility criteria (Fig. 1).

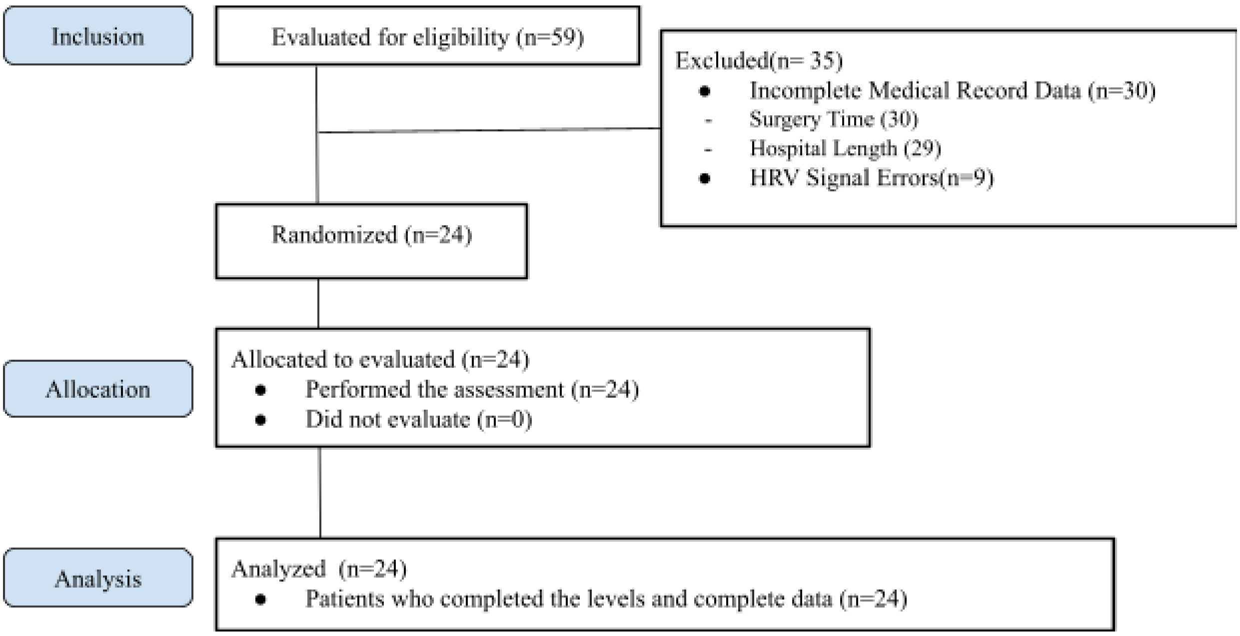

Figure 1. Flowchart of participant selection (N = 24).

Data Collection and Variables

Sociodemographic, anthropometric, and clinical data of all patients were collected using a form developed by the authors. Among the sociodemographic variables, the following were included: sex (female or male), age (in years), skin color (classified as White, Brown, or Black), educational level (primary, secondary, or higher education), marital status (single, married, or legally separated/divorced), and family income, categorized as no income, below one minimum wage, or above one minimum wage. For reference, the Brazilian minimum wage was considered as R$ 1,518.00.

Anthropometric variables included weight (in kilograms), height (in meters), and body mass index (BMI), calculated from patients' weight and height. Clinical variables investigated were the presence of comorbidities, such as hypertension, diabetes, heart disease, and obesity, in addition to current or past smoking and alcohol consumption habits. Main diagnostic hypotheses, surgeries performed, average postoperative hospital length of stay (in days), and time from diagnosis (in months) were also recorded.

Submaximal Exercise Test

The Chester Step Test (CST) was used as the submaximal exercise test. All participants wore a heart rate monitor (Cosspo model), fixed on the chest at the level of the xiphoid process of the sternum, to record oscillations in the intervals between consecutive heartbeats.

Participants were instructed to stand in front of a step measuring 20 cm × 40 cm × 60 cm and, at the examiner's voice command, step up and down in synchrony with beeps emitted by a digital metronome, set at a fixed frequency. The test protocol consisted of five stages, each lasting two minutes, for a total duration of 10 minutes. The initial metronome frequency was set at 15 steps per minute, increasing by 5 steps per minute every two minutes, as detailed below: Stage 1: 15 steps/minute; Stage 2: 20 steps/minute; Stage 3: 25 steps/minute; Stage 4: 30 steps/minute; Stage 5: 35 steps/minute (De Camargo et al., 2011).

During the test, heart rate (HR) and peripheral oxygen saturation (SpO_2) were monitored. Oxygen saturation was recorded using a pulse oximeter, while HR was measured with the heart rate monitor connected to the Elite HRV mobile application. In addition, the Modified Borg Rating of Perceived Exertion Scale was used to assess subjective perception of dyspnea and lower-limb fatigue during the test (Borg, 1982).

The test was interrupted if the participant presented any of the following criteria: severe fatigue, limiting dyspnea, chest pain, lower-limb pain, exhaustion, or inability to maintain the test rhythm for 15 consecutive seconds. The test was considered completed when the participant reached Stage 5, totaling 10 minutes of execution.

To predict hospital length of stay, CST performance was evaluated using two methods:

1. **Workload Calculation**: Workload was estimated using the following equation: *Work = Step height (m) × Total steps × Weight (kg) × 0.16357* (De Andrade et al., 2012b).

2. **VO_2max Estimation**: Maximal oxygen consumption (VO_2max) was estimated using the Chester Step Test Calculator software (Assist Creative Resources, Wrexham, UK), as described by Mackenzie (2016).

During the CST, the Elite HRV mobile application was used to collect data related to Heart Rate Variability (HRV), based on records from the chest-mounted heart rate monitor. After collection, HRV files were exported to a platform linked to Elite HRV and subsequently processed in Kubios software for data cleaning and analysis.

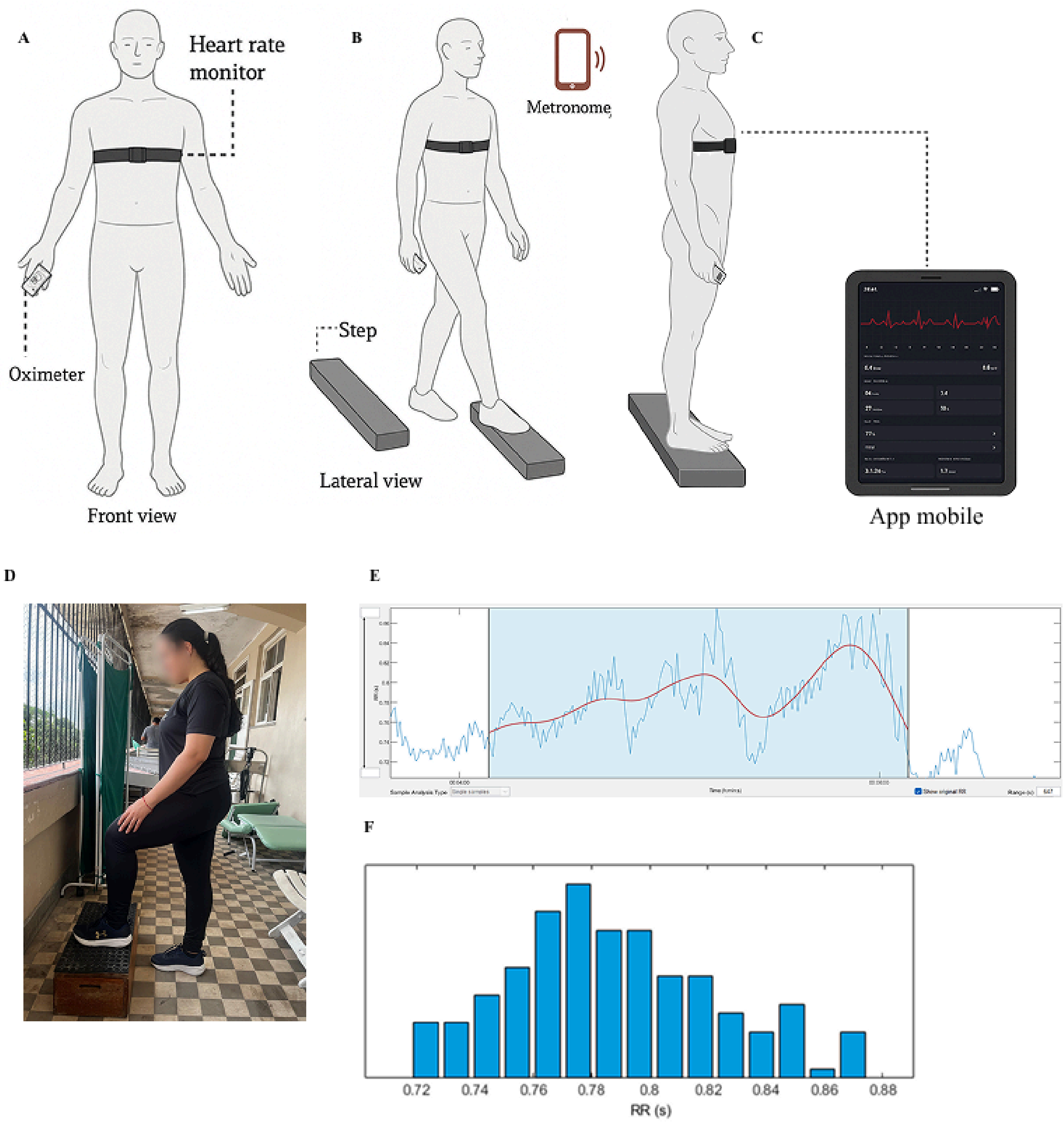

Figure 2. Patient monitoring (Fig. A), representative scheme of the test execution (Figs. B–D), Elite HRV application interface (Fig. C), HRV data obtained during the test using Elite HRV (Fig. E), and Time Domain analysis (Fig. F).

Statistical Analysis

Initially, descriptive and inferential analyses were performed to characterize the sample and investigate possible sociodemographic differences among the surgical intervention groups. Descriptive analyses of categorical variables were expressed as absolute and relative frequencies (%), in order to identify the distribution of characteristics among the TIH-C, TIH-M, and TIH-L groups.

Comparisons between groups were carried out using the Kruskal-Wallis test, a nonparametric approach suitable for ordinal or non-normally distributed data across three or more independent groups. Statistical significance was set at $p < 0.05$.

The statistical analysis of the anthropometric characterization of patients undergoing surgery is presented in Table 2. The variables analyzed were height (m), weight (kg), and body mass index (BMI; kg/m²), with the aim of investigating possible differences among the groups according to length of hospital stay (TIH-C, TIH-M, and TIH-L). Data were expressed as mean and standard deviation, and comparisons between groups were performed using nonparametric tests (Kruskal-Wallis), considering a significance level of $p < 0.05$.

Descriptive analyses were performed to characterize cardiovascular risk factors, oncological diagnoses, clinical history, and surgical procedures of the patients divided into the TIH-C, TIH-M, and TIH-L groups. Categorical variables were presented as absolute and relative frequencies (%). To compare the time to diagnosis among groups, the Kruskal-Wallis test was applied, which showed no significant difference ($\chi^2 = 4.047$; $p = 0.132$). The mean surgical time, expressed as mean ± standard deviation, was analyzed using One-way ANOVA.

One-way ANOVA (analysis of variance) was used to compare the means of continuous variables across the three independent groups (TIH-C, TIH-M, and TIH-L), in order to verify statistically significant differences among them. When significance was identified ($p < 0.05$), the Least Significant Difference (LSD) post-hoc test was applied for pairwise comparisons to determine which specific groups differed.

For the prediction of length of hospital stay, data were initially analyzed using Univariate Multinomial Logistic Regression, comparing the three hospital discharge periods, with the reference category being short duration (1–2 days). This statistical model allowed estimation of the probability of patients belonging to longer hospital stay categories according to the analyzed variables, providing Odds Ratios (OR), 95% confidence intervals (95% CI), and p-values for each comparison among the groups.

Variables with p-values < 0.25 were selected for further analysis. Collinearity was assessed using the Variance Inflation Factor (VIF) and tolerance index, with no collinearity identified (VIF < 10; Tolerance > 0.2). Subsequently, the eligible variables were included in a Multivariate Multinomial Logistic Regression model, applying the backward stepwise method to refine the final model fit.

Results

Sociodemographic characterization

The sample consisted of 24 participants (♀ = 13; ♂ = 11). Female sex was more frequently associated with TIH-C, whereas male sex predominated in TIH-L. The median age was 57 years (IQR = 19), with no significant difference among groups (TIH-C: 52 [15]; TIH-M: 51.5 [28]; TIH-L: 64 [23]; $\chi^2 = 1.310$; $p = 0.519$). Sociodemographic characteristics of patients undergoing CST are presented in Table 1, with no differences observed among TIH groups ($p > 0.05$).

Table 1. Sociodemographic characterization of patients undergoing surgery.

Variables	TIH-C (n = 11)	TIH-M (n = 4)	TIH-L (n =9)	**χ^2**	**p**
Sex					
Female	9 (81,8)[a]	2 (50)	2 (22,2)[a]	7,115	0,029*
Male	2 (18,2)[b]	2 (50)	7 (77,8)[b]		
Skin color					
Brown	10 (90,9)	4 (66,7)	4 (57,1)	6,132	0,189
Yellow	1 (9,1)	1 (16,7)	3 (42,9)		
White	0 (0)	1 (16,7)	0 (0)		
Monthly family income					
< one minimum wage	9 (81,8)	6 (100)	4 (57,1)	3,684	0,158
> one minimum wage	2 (18,2)	0 (0)	3 (42,9)		
Level of education					
No schooling	1 (9,1)	0 (0)	1 (11,3)	14,515	0,269
Incomplete elementary school	1 (9,1)	2 (50)	1 (11,1)		
Complete elementary school	1 (9,1)	0 (0)	4 (44,4)		
Incomplete high school	1 (9,1)	1 (25)	0 (0)		
Complete high school	3 (27,3)	1 (25)	3 (33,3)		
Complete higher education	2 (18.2)	0 (0)	0 (0)		
Master's or Doctorate	2 (18,2)	0 (0)	0 (0)		

Marital status (%)					
Single	2 (18.2)	1 (25)	4 (44,4)	4,055	0,669
Married	5 (45,5)	2 (50)	2 (22,2)		
Widowed	1 (9,1)	0 (0)	2 (22,2)		
Legal Separation	3 (27.3)	1 (25)	1 (11,1)		

$p < 0,05$ (statistically significant difference)

Anthropometric characterization

The anthropometric characterization of patients undergoing the CST is presented in Table 2, and no differences were observed among the length of hospital stay groups ($p > 0.05$). The median height (m) was 1.60 (0.11). The mean weight (kg) and BMI (kg/m²) were 64.43 ± 13.12 and 25.10 ± 4.88, respectively.

Table 2. Anthropometric characteristics of patients undergoing surgery.

Variables	**TIH-C (n = 11)**	**TIH-M (n = 4)**	**TIH-L (n =9)**	**F ou χ^2**	**p**
			Anthropometric variables		
Height (m)	1,56 (0,12)	1,64 (0,19)	1,66 (0,08)	3,562	0,168
Weight (kg)	66,27 ± 15,80	65,75 ± 9,98	61,25 ± 11,13	0,463	0,636
BMI (kg/m²)	26,82 ± 5,73	24,46 ± 2,41	23,06 ±3,97	1,476	0,252

Clinical characterization

Table 3 presents the cardiovascular risk factors, diagnosis, medical history, and surgeries of patients who underwent the CST. The most prevalent cardiovascular risk factors were hypertension and former smoking (36.4% each) in the TIH-C group; diabetes, former alcohol use, and hypertension (25% each) in the TIH-M group; and former smoking (55.6%) in the TIH-L group (33.3%). Breast cancer (27.3%) was the most significantly prevalent diagnosis in the TIH-C group, while intestinal cancer (56%) predominated in the TIH-L group. Regarding medical history, 25%, 64%, and 62.5% of participants had previously undergone chemotherapy, radiotherapy, and surgery, respectively. The time to diagnosis in the TIH-C, TIH-M, and TIH-L groups was 36 (56), 4 (14), and 9 (28) months, respectively, with no significant differences between the groups ($\chi^2 = 4.047$; $p = 0.132$; Kruskal–Wallis test). The most frequent surgeries were laparoscopic cholecystectomy (20%) and total colectomy (12%). The most common type of anesthesia was general anesthesia (62.5%). Regarding contamination potential, the category “potentially contaminated” (58.3%) was the most frequent. The mean surgery time in the TIH-C, TIH-M, and TIH-L groups was 93.78 ± 28.19, 153 ± 81.10, and 117.5 ± 89.24 minutes, respectively, with no significant differences among the groups ($F = 0.934$; $p = 0.412$; One-way ANOVA).

Table 3. Cardiovascular risk factors, diagnosis, previous medical history, and surgeries of patients undergoing surgery.

Variables	**TIH-C (n = 11)**	**TIH-M (n = 4)**	**TIH-L (n =9)**	χ^2	**p**
		Cardiovascular risk factors			
Alcoholism	0 (0)	0 (0)	2 (2,22)	3,407	0,182
Diabetes	2 (18,2)	2 (50)	2 (22,2)	1,643	0,440
Former alcoholic	1 (10)	2 (50)	4 (44,4)	3,530	0,171
Former smoker	4 (36,4)	1 (25)	5 (55,6)	1,299	0,522
Smoker	1 (9,1)	0 (0)	1 (11,1)	0,463	0,793
Hypertension	4 (36,4)	2 (50)	3 (33,3)	0,339	0,844
Obesity	0 (0)	1 (25)	0 (0)	5,217	0,074
		Diagnosis			
Stomach cancer	1 (9)	1 (25)	2 (22)	32,652	0,037*
Bowel cancer	0 (0)[a]	0 (0)	5 (56)[a]		
Breast cancer	3 (27,3)[a]	0 (0)	0 (0)		
Gallstones	4 (36,4)	1 (25)	0 (0)		
Others[#]	3 (27,3)	2 (50)	2 (22)		
		Previous medical history			
Chemotherapy	1 (9,1)	1 (25)	4 (44,4)	3,300	0,192
Radiotherapy	3 (27,3)	0 (0)	2 (40)	0,085	0,771
Surgery	8 (72,7)	3 (75)	4 (44,4)	2,009	0,366
		Surgery			
Type				33,209	0,408
Laparoscopic cholecystectomy	4 (36,4)	1 (25)	0 (0)		
Total colectomy	0 (0)	0 (0)	3 (33,3)		
Diagnostic laparoscopy	1 (9,1)	0 (0)	1 (11,1)		

Others#	6 (54,5)	3 (75)	3 (56,6)		
Anesthesia				4,639	0,795
General	6 (54,5)	3 (75)	6 (66,7)		
Raqui	1 (9,1)	0 (0)	1 (11,1)		
Others#	4 (36,4)	1 (25)	2 (22,2)		
Contamination potential				4,665	0,323
Potentially contaminated	5 (62,5)	2 (66,7)	7 (87,5)		
Clean	3 (37,5)	1 (33,3)	0 (0)		
Contaminated	0 (0)	0 (0)	1 (12,5)		

* $p < 0,05$. # Group of categories with information from only one event.

Differences in variables in relation to length of hospital stay

Table 4 shows the differences among the CST variables according to the length of hospital stay. It was observed that the values of Mean RR (ms) and Mean HR (beats/min) were lower and higher, respectively, in the TIH-C group compared with the TIH-M and TIH-L groups.

Table 4. Comparison of Chester Step Test variables according to length of hospital stay.

	TIH-C (n = 11)	TIH-M (n = 4)	TIH-L (n =9)	F ou χ^2	p
Level	3 (2)	3,5 (3)	3 (3)	0,803	0,669
Work (kcal)	1,50 ± 0,47	1,63 ± 0,69	1,50 ± 0,41	0,126	0,882
VO_2máx ($mL \cdot kg^{-1} \cdot min^{-1}$)	6,05 ± 1,48	7,94 ±1,94	7,01 ± 1,83	2,023	0,157
Mean RR (ms)	570 ± 76[a]	682 ± 99[b]	638 ± 54[b]	4,275	0,028*
Mean HR (beats/min)	110 ± 18[a]	90 ± 15[b]	95 ± 8[b]	3,776	0,040*
RMSSD (ms)	10 ± 5	18 ± 18	11 ± 5	1,578	0,230
Stress index	42 ± 19	31 ± 15	34 ± 11	0,872	0,433

* $p < 0,05$. [a, b] represent statistical differences between groups using the Least Significant Difference post-test.

Prediction of Length of Hospital Stay

Initially, the data were submitted to Univariate Multinomial Logistic Regression comparing the three discharge periods, with the reference category being short duration (Table 5).

Table 5. Univariate Multinomial Logistic Regression comparing the three periods of hospitalization (reference category = short duration).

Variables	OR	IC95%	p
TIH-C vs TIH-M			
Level	1,328	0,524-3,363	0,550
Work (kcal)	1,881	0,161-21,975	0,614
VO_2máx ($mL \cdot kg^{-1} \cdot min^{-1}$)	2,025	0,920-4,454	0,080#
Mean RR (ms)	1,024	1,002-1,046	0,031#
Mean HR (beats/min)	0,883	0,772-1,009	0,068#
RMSSD (ms)	1,106	0,946-1,294	0,207#
Stress index	0,951	0,867-1,044	0,951
TIH-C vs TIH-L			
Level	1,399	0,676-2,898	0,365
Work (kcal)	1,029	0,146-7,273	0,977
VO_2máx ($mL \cdot kg^{-1} \cdot min^{-1}$)	1,446	0,814-2,568	0,208#
Mean RR (ms)	1,014	0,999-1,030	0,066#
Mean HR (beats/min)	0,923	0,846-1,006	0,069#
RMSSD (ms)	1,018	0,869-1,193	0,825
Stress index	0,969	0,911-1,030	0,308

$p \leq 0,25$; * $p < 0,05$. OR - Odds Ratio.

During the TIH-C vs. TIH-M analysis (VO_2max [$mL \cdot kg^{-1} \cdot min^{-1}$], Mean RR [ms], Mean HR [beats/min], and RMSSD [ms]) and TIH-C vs. TIH-L analysis (VO_2max [$mL \cdot kg^{-1} \cdot min^{-1}$], Mean RR [ms], and Mean HR [beats/min]), the variables with $p < 0.25$ were selected and subjected to collinearity tests. No collinearity was identified (VIF < 10; Tolerance < 0.2). The variables were then tested using Multivariate Multinomial Logistic Regression with the "backward stepwise" method, in which the final model was found to be significant (χ^2 = 8.045; df = 2; p = 0.018).

In the comparison between medium length of stay (3–5 days) and short length of stay (1–2 days), the variable Mean RR (ms) showed a statistically significant association with hospital length of stay ($\beta = 0.024$; standard error = 0.011; Wald = 4.651; $p = 0.031$). The OR value was 1.024, indicating that each one-unit increase in heart rate variability was associated with a 2.4% increase (95% CI: 1.002–1.046) in the likelihood of medium hospital stay compared with short stay ($p = 0.031$). The other variables were excluded from the final TIH-C vs. TIH-M model. No significant results were observed for the TIH-C vs. TIH-L analysis.

Discussion

The results of this study demonstrated that, in the comparisons between TIH-C vs. TIH-M and TIH-C vs. TIH-L, significant associations were identified, indicating a valid relationship between heart rate variability (HRV) parameters and hospital length of stay, which may serve as a screening tool to estimate postoperative hospitalization time.

The step test is a valid and acceptable method to monitor changes in cardiorespiratory fitness due to its high test–retest reliability, low cost, ease of execution, and portability, making it feasible in hospital settings and providing efficient assessment of functional status before surgery (Nascimento, 2024; Marrara et al., 2012). HRV measures as predictors of disease risk and mortality have been investigated from several perspectives for decades (Jarczok et al., 2022). HRV indices can be used to anticipate both prolonged ICU stays after surgery and mortality risk. Moreover, studies report that preoperative HRV assessment has the potential to predict complications that may occur during the perioperative period (Lai Y, 2025).

One study found that HRV correlated positively with postoperative pulmonary function recovery up to 30 days after surgery (Lai Y, 2025). Systematic reviews have shown that preoperative HRV assessment can identify patients at higher risk of hemodynamic instability during surgical procedures and is also correlated with prolonged ICU stays and mortality (Frandsen et al., 2022; Lai Y, 2025). HRV describes the oscillation of intervals between consecutive heartbeats (RR intervals), which reflect autonomic nervous system (ANS) influences on the sinus node. It is a non-invasive measurement used to detect ANS-related phenomena in healthy individuals, athletes, and patients with diseases (Vanderlei et al., 2009). The mean RR interval represents the average coupling intervals of all consecutive normal beats (Kawaguchi et al., 2007).

In this study, **Mean RR (ms)** showed a statistically significant association with hospital stay, specifically increasing the likelihood of medium stay (3–5 days) compared with short stay (1–2 days). For every 1 ms increase in Mean RR, there was a 2.4% rise in the likelihood of longer hospitalization. Short-term HRV parameters such as Mean RR have been extensively studied as predictors of adverse clinical outcomes and hospitalization duration in different clinical contexts. Previous studies demonstrated stronger correlations between prolonged hospitalization and short-term HRV parameters, particularly Mean RR, in populations with coronary artery disease and heart failure (Míková et al., 2025). Higher Mean RR values may reflect altered autonomic balance or greater physiological burden, leading to slower clinical recovery and, consequently, longer hospital stays. Recent research, such as that by Aagaard et al. (2024), showed that Mean RR has strong prognostic value for adverse hospital events and clinical complications, being considered one of the most sensitive individual parameters for detecting early clinical instability. This reinforces the clinical applicability of Mean RR as a complementary marker for risk stratification and prediction of hospital stay length.

The Chester Step Test (CST) is a promising tool for assessing cardiovascular fitness in cancer patients. CST evaluates several components, including heart rate (HR), perceived exertion (RPE), estimated age-predicted maximal heart rate (HRmax), and estimated oxygen uptake (VO_2) at each test stage (Nascimento Aq, 2024). In the present study, HRV analysis was combined with CST to evaluate hospital stay; however, only Mean RR and Mean HR showed significant results. The TIH-C group had a lower Mean RR (shorter interval between beats), indicating higher resting HR and higher mean HR during the test.

This corroborates the findings of Niu et al. (2023), who reported that higher mean HR was associated with increased risk of postoperative ICU stay. Similarly, Stein et al. (2001) found that patients hospitalized for more than 7 days had reduced Mean RR. These findings highlight that Mean HR and Mean RR reflect physical activity levels and sympathetic–vagal balance, often linked to slower recovery, complications, or prolonged hospitalization. Lower HRV has consistently been associated with longer hospital stays and worse prognoses in conditions of stress, acute pain, and perioperative inflammatory processes (Shaffer & Ginsberg, 2017; Sztajzel, 2004; Järvelin-Pasanen, 2018).

The findings of this study—female sex associated with short hospital stay (TIH-C) and male sex with long hospital stay (TIH-L), with breast cancer more prevalent in TIH-C and colorectal cancer in TIH-L—are consistent with the literature. Breast cancer, more common in women, has shown progressively reduced hospital stays due to less invasive procedures, early discharge, and perioperative advances (Bonnema et al., 1998; Yates et al., 2005). INCA (2022) data also highlight the high incidence of breast cancer in Brazil, with early screening and diagnosis contributing to shorter and less complex hospitalizations.

On the other hand, colorectal cancer, more prevalent in men and often diagnosed at advanced stages, is associated with longer hospital stays and higher readmission rates, reflecting the complexity of surgical and clinical management (Priego et al., 2005; Majek et al., 2013). Comorbidities, postoperative complications, and intensive care requirements may also prolong hospitalization, explaining the predominance of men in the TIH-L group. Thus, the present study's findings reinforce that tumor characteristics, sex, and oncological management strategies directly influence hospitalization duration, which is crucial for planning patient care, safe discharge, and resource optimization.

In summary, our findings reinforce the role of HRV as a complementary tool in preoperative evaluation and monitoring of hospital stay in surgical patients. Moreover, the step test proved to be a valid, practical, and low-cost method for assessing preoperative cardiorespiratory fitness and functional status, capable of predicting hospital stay and assisting in rehabilitation planning (Nascimento, 2024; Bennett, 2016; Marrara et al., 2012). Combining these tools provides a more comprehensive and personalized approach, identifying patients with greater physiological and functional vulnerability, which may contribute to optimizing perioperative care and reducing complications and hospital stay.

Therefore, it is recommended that HRV assessment—particularly frequency-domain indices—together with functional tests such as the step test, be incorporated into clinical practice for risk stratification in surgical and oncological patients. Future research should aim to standardize assessment protocols and include larger samples to strengthen the applicability of these markers as prognostic and screening tools.

Study Limitations

This study presents some limitations. First, the sample size was relatively small, which may limit the generalizability of the findings to other populations or clinical contexts. In addition, uncontrolled external factors such as eating habits, sleep quality, and stress levels may have influenced the results, representing potential sources of bias. Another limitation was the short intervention and/or follow-up period, which may have been insufficient to detect longer-term effects of the analyzed variables. Future studies should include larger samples, stricter control of external variables, and longer follow-up periods to increase validity and applicability of the results.

Conclusion

The findings of this study indicate that female sex was more associated with short hospital stay (TIH-C), whereas male sex predominated in long hospital stay (TIH-L). Breast cancer was more prevalent in the TIH-C group, while colorectal cancer was more prevalent in TIH-L. Additionally, the TIH-C group had lower Mean RR (ms) and higher Mean HR (bpm), suggesting lower HRV in this group. Logistic regression revealed that HRV, represented by Mean RR, was significantly associated with length of stay, indicating that each one-unit increase in Mean RR increased by 2.4% the chance of medium hospital stay compared with short stay. These findings reinforce the potential of HRV as a relevant clinical marker to estimate hospital stay duration.

Conflict of Interest

The authors declare that there is no conflict of interest.

Declaração de disponibilidade de dados

Os dados de pesquisa estão disponíveis em um repositório de dados e também podem ser obtidos mediante solicitação ao autor correspondente, conforme justificado neste manuscrito.

Data Availability Statement

The research data are available in a data repository and can also be obtained upon request from the corresponding author, as justified in this manuscript.

Declaración de disponibilidad de datos

Los datos de investigación están disponibles en un repositorio de datos y también pueden obtenerse previa solicitud al autor correspondiente, según lo justificado en este manuscrito.

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