

Hemodynamic and respiratory variation in the six-minute walk test in patients undergoing cardiac surgery: a cross-sectional study

Variação hemodinâmica e respiratória no teste de caminhada em seis minutos em pacientes submetidos à cirurgia cardíaca: um estudo transversal

Variación hemodinámica y respiratoria en la prueba de caminata de seis minutos en pacientes sometidos a cirugía cardíaca: un estudio transversal

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ORIGINAL RESEARCH

ABSTRACT | The six-minute walk test (6MWT) is commonly prescribed for cardiac surgery patients, yet the hemodynamic and respiratory variations during the test remain insufficiently described in this population. This study aimed to compare the hemodynamic and respiratory data, dyspnea sensation variation, and perceived exertion in the lower limbs during the 6MWT between the pre- and post-test periods. It also sought to analyze whether there is a difference in the variation between the pre and postoperative periods of elective cardiac surgery for the same variables. This cross-sectional study included 113 individuals undergoing elective cardiac surgery. The 6MWT was conducted the day before surgery and on the fourth postoperative day. Results showed a significant increase in hemodynamic variables, including HR, SBP, DBP ($p \leq 0.01$) and dyspnea and lower limb exertion ($p \leq 0.01$), both pre and postoperatively; there was no variation in SpO₂ both pre- ($p=0.64$) and postoperatively ($p=0.45$). The average distance covered decreased from 346.98±107.51 to 252.06±107.17 m after surgery. There was a greater variation in the mean difference between the pre- and post- test for HR before surgery ($p=0.05$) and a greater feeling of perceived exertion in the lower limbs after surgery ($p=0.02$). Between the pre and post-test, there was a physiological increase in hemodynamic data, sensation of perceived exertion, without SpO₂ alteration,

and functional decline in the distance covered between the pre- and postoperative periods of cardiac surgery. HR showed greater variation preoperatively, while exertion perceived in the lower limbs did so postoperatively, although this was clinically irrelevant.

Keywords | Thoracic Surgery; Cardiovascular Diseases; Walking Test.

RESUMO | O teste de caminhada de seis minutos (TC6) é prescrito para pacientes que foram submetidos à cirurgia cardíaca, mas a variação hemodinâmica e respiratória ainda é pouco descrita nessa população. O objetivo deste estudo foi comparar a variação dos dados hemodinâmicos e respiratórios, sensação de dispneia, do esforço percebido nos membros inferiores durante o TC6 entre o pré e pós teste e analisar se existe diferença na variação entre o período pré e pós-operatório de cirurgia cardíaca eletiva. Trata-se de um estudo transversal com 113 indivíduos submetidos à cirurgia cardíaca eletiva. O TC6 foi realizado no dia anterior à cirurgia e no quarto dia pós-operatório. Verificou-se que, entre o pré e pós teste, houve aumento das variáveis hemodinâmicas incluindo FC, PAS, PAD ($p \leq 0,01$) e da dispneia e membros inferiores ($p \leq 0,01$), tanto no pré quanto no pós-operatório; não houve variação na SpO₂, tanto no pré-operatório ($p=0,64$) quanto no pós-operatório

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($p=0,45$); e houve diminuição da distância média percorrida no pré de $346,98 \pm 107,51$ para $252,06 \pm 107,17$ metros no pós-operatório. Houve maior variação de diferença de médias entre o pré e pós teste para a FC no período pré ($p=0,05$) e maior sensação de esforço percebido nos MMII no período pós-operatório ($p=0,02$). Entre o pré e o pós-teste, houve aumento fisiológico dos dados hemodinâmicos, sensação de esforço percebido, sem alteração em SpO_2 e no declínio funcional na distância percorrida entre o período pré para o pós-operatório de cirurgia cardíaca. A FC tem maior variação no pré e o esforço percebido nos MMII no período pós-operatório, embora clinicamente não relevante.

Descriptores | Cirugía Torácica; Doenças Cardiovasculares; Teste de Caminhada.

RESUMEN | La prueba de caminata de seis minutos (TC6) se prescribe a pacientes que se sometieron a cirugía cardíaca, pero la variación hemodinámica y respiratoria aún está mal descrita en esta población. Este estudio tuvo el objetivo de comparar la variación de los datos hemodinámicos y respiratorios, la sensación de disnea, el esfuerzo percibido en los miembros inferiores durante la TC6 entre el periodo previo y posterior a la prueba y analizar si hay diferencia en la variación entre el pre y posoperatorio de la

cirugía cardíaca electiva. Se trata de un estudio transversal con 113 personas sometidas a cirugía cardíaca electiva. La TC6 se realizó un día antes a la cirugía y, luego, en el cuarto día del posoperatorio. Se observó que, entre el periodo previo y posterior a la prueba, hubo un aumento en las variables hemodinámicas incluyendo FC, PAS, PAD ($p \leq 0,01$) y de la disnea y miembros inferiores ($p \leq 0,01$), tanto en el pre como en el posoperatorio; no hubo variación en la SpO_2 tanto en el preoperatorio ($p=0,64$) como en el posoperatorio ($p=0,45$); y hubo una reducción de la distancia media recorrida en el preoperatorio de $346,98 \pm 107,51$ a $252,06 \pm 107,17$ metros en el posoperatorio. Hubo una mayor variación en la diferencia de medias entre el periodo previo y posterior a la prueba para la FC en el periodo previo ($p=0,05$) y una mayor sensación de esfuerzo percibido en los MMII en el periodo posoperatorio ($p=0,02$). Entre el periodo previo y posterior a la prueba, hubo un aumento fisiológico de los datos hemodinámicos, la sensación de esfuerzo percibido, sin alterar la SpO_2 y la disminución funcional en la distancia recorrida entre el pre y el posoperatorio de la cirugía cardíaca. La FC tiene una mayor variación en el preoperatorio y el esfuerzo percibido en los MMII en el posoperatorio, aunque no es clínicamente relevante.

Palabras clave | Cirugía Torácica; Enfermedades Cardiovasculares; Prueba de Paso.

INTRODUCTION

Health promotion aimed at informing individuals about risk factors is crucial in preventing cardiovascular diseases¹; however, once such a disease has developed, treatment becomes necessary. Cardiac surgery is one form of treatment². Myocardial revascularization surgery (MRS) and valve replacement (VR) are elective cardiac surgeries commonly performed in clinical practice³.

Although cardiac surgery is an indicated treatment, it may lead to postoperative complications and even death⁴. Sternal wound infections, pneumonia, thromboembolic events, graft failure, atrial fibrillation, pulmonary hypertension, pericardial effusion, strokes, renal injury, gastrointestinal lesions, and hemodynamic instability appear among the potential complications of the surgery⁵.

Furthermore, patients typically experience a reduction in functional capacity immediately after cardiac surgery—as measured by the distance covered in the six-minute walk test (6MWT)⁶—, a decline in respiratory muscle strength—evaluated by maximum inspiratory and expiratory pressures—, and decreased lower limb resistance—assessed by the one-minute sit-to-stand test^{7,8}.

A decrease in functional performance, indicated by functional independence, and an increase in pain are also commonly observed⁹.

According to the American Thoracic Society (ATS)¹⁰, the 6MWT assesses the distance covered within a maximum of six minutes, while enabling the evaluation of the overall and integrated responses of all systems involved during the exercise, including the pulmonary and cardiovascular systems, systemic and peripheral circulation, neuromuscular units, and muscle metabolism.

It is commonly used to objectively assess exercise capacity^{10,11} and to monitor treatment response, as well as to predict morbidity and mortality¹⁰ in patients with moderate to severe pulmonary disease¹¹ and other conditions, such as heart disease⁶. This is a simple and safe test, which requires no specialized equipment¹¹, and can be conducted in both outpatient and hospital settings⁶.

In the literature, the evaluation of the distance covered in the 6MWT is widely described and recognized for assessing the functional capacity of individuals. Specifically in cardiac surgery, patients experience a reduction in the distance covered between the preoperative and postoperative periods, even when

undergoing physical therapy⁷. Additionally, the 6MWT distance has been shown to be a significant predictor of cardiovascular mortality (hazard ratio=0.89, 95% CI: 0.81–0.97, $p=0.01$) and hospitalizations for cardiac complications (hazard ratio=0.95, 95% CI: 0.90–0.99, $p=0.02$) in patients enrolled in an inpatient cardiovascular rehabilitation program following open-heart valve surgery. Therefore, the 6MWT has proven to be an independent prognostic tool¹². However, the variation in hemodynamic and respiratory data during the 6MWT in cardiac surgery patients has not yet been thoroughly evaluated. We hypothesize that this variation is minimal. Therefore, this study aimed to compare the variation in hemodynamic and respiratory data, dyspnea sensation, and perceived exertion in the lower limbs during the 6MWT between the pre- and post-test, and to determine whether there is a difference in these variations between the pre- and postoperative periods of elective cardiac surgery.

METHODOLOGY

Study design

This is a cross-sectional, analytical, and descriptive study.

Setting

Patients were recruited at the Hospital de Clínicas de Ijuí, in the Heart Institute Department, where data collection for the research was conducted. The study period was from March 2016 to November 2018.

Selection criteria

Individuals of both sexes, aged over 18 years, who underwent myocardial revascularization surgery (MRS), valve replacement (VR), or the combination of both procedures (MRS+VR) via sternotomy, were included in the study. Exclusion criteria included individuals with physical, functional, or cognitive impairments that were unable to complete the evaluation protocol, those who experienced postoperative complications delaying hospital discharge, those unable to complete the research protocol (first or second assessment), and those who refused to participate by not signing the informed consent form.

Data collection

Data were collected from the patient's medical records, including age, sex, family history, systemic arterial hypertension (SAH), diabetes mellitus (DM), dyslipidemia, heart failure (HF), chronic obstructive pulmonary disease (COPD), and acute myocardial infarction (AMI), as well as intraoperative data—type of cardiac surgery (MRS: myocardial revascularization surgery, VR: valve replacement, combined: MRS associated with VR), duration of surgery, extracorporeal circulation (ECC)—and postoperative data—duration of mechanical ventilation (MV) and total length of hospital stay.

The research protocol included the 6MWT, which was conducted the day before surgery (day of hospital admission) and on the fourth postoperative day (to ensure standardization of the postoperative tests before hospital discharge). The 6MWT was adapted according to ATS guidelines¹⁰, as the hospital corridor allowed for a 10-meter walk, and patients completed only one test instead of two, due to the hospital routine in the preoperative period, which did not allow sufficient time for two tests with a 30-minute interval. The evaluator explained the test by demonstrating it to the patients, who were asked about their physical and functional conditions to ensure they could complete the test.

Patients were verbally instructed to walk the maximum possible distance without running for six minutes. The evaluator positioned themselves behind the patient to avoid influencing walking speed, as per the guidelines. A chair was placed nearby in case the patient needed to rest. Standardized verbal encouragement was given every minute to stimulate the patient. The patient could stop walking if they were unable to continue or felt fatigued; however, the timer would continue running for the full six minutes. If the patient could not finish the total distance, the distance covered during the test was recorded as the maximum distance achieved. At the sixth minute, the patient was instructed to stop, sit down to record the distance covered, and once again, vital signs and dyspnea were checked using the Borg scale, along with the perceived fatigue in the lower limbs (LL)¹⁰.

Systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), and peripheral oxygen saturation (SpO₂) were recorded before (pre-test) and at the end of the test (post-test), with the variables measured using a sphygmomanometer, a Premium adult stethoscope (nylon with hook-and-loop fastener, Brazil) and a BIC fingertip pulse oximeter, model YK-80B. The assessment

of perceived exertion was done using the Borg scale¹³, as well as the perception of muscle fatigue in the lower limbs (Borg LL) and the sensation of shortness of breath (Borg dyspnea). The Borg scale ranges from zero to ten, with zero indicating no symptoms and ten indicating the worst sensation. We also calculated the percentages of the distance covered¹⁴.

Statistical analysis

The analysis was performed using the Statistical Package for Social Science (SPSS), version 23.0, Chicago, IL, USA. The Kolmogorov-Smirnov test was employed to assess normality. To analyze the difference between the pre- and post-test in the preoperative and postoperative periods of cardiac surgery, as well as to calculate the delta difference between the pre- and postoperative periods, a paired t-test was conducted. The delta difference was determined by calculating the mean difference between the post-test and the pre-test mean. A value of $p \leq 0.05$ was considered statistically significant. The sample size calculation was based on the study by Arenaza et al.⁸.

Ethical aspects

An analysis was conducted based on the institutional project “Flow incentive in spirometer training in patients in the postoperative period of Cardiac Surgery: what is the best load prescription?”.¹⁵

The study protocol was designed in accordance with the Guidelines and Regulatory Norms for Research Involving Human Subjects, according to the National Health Council (CNS) Resolution No. 466/12. All patients signed an informed consent form.

RESULTS

Out of the 307 individuals eligible for the study, 194 were excluded, resulting in a final sample of 113 individuals (Figure 1). The characteristics of the sample are presented in Table 1. Most underwent MRS (61.9%) and were male (61.9%). Family history and systemic arterial hypertension were the most prevalent risk factors for cardiovascular disease (71%), and acute myocardial infarction (AMI) was the most prevalent associated comorbidity (Table 1).

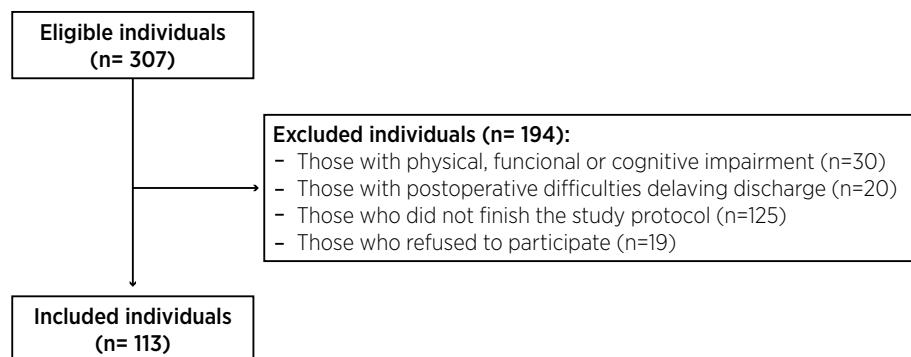


Figure 1. Study flowchart

Table 1. Characteristic of the sample of patients undergoing elective cardiac surgery

Parameter	Mean \pm SD
Age (years)	58.23 \pm 9.54
Total length of hospital stay (days)	6.11 \pm 1.67
MV time (hours)	10.42 \pm 4.85
ECC time (hours)	1.38 \pm 0.45
Surgery time (hours)	3.43 \pm 1.45
Sex	n (%)
Male/female	70(61.9)/43 (38.1)
Risk factors for CVDs	n (%)
Family history	81 (71.7)
SAH	81 (71.7)
DM type I/type II	10 (8.8)/25 (22.1)

Parameter	Mean \pm SD
Dyslipidemia	49 (43.4)
Associated comorbidities	n (%)
HF	8 (7.1)
COPD	10 (8.8)
AMI	41 (36.3)
Type of surgery	n (%)
MRS	70 (61.9)
VR	41 (36.3)
Combined (MRS+VR)	2 (1.8)

n: sample size; %: percentage of the sample; MV: mechanical ventilation; ECC: extracorporeal circulation; CVD: cardiovascular disease; SAH: systemic arterial hypertension; DM: diabetes mellitus; HF: heart failure; COPD: chronic obstructive pulmonary disease; AMI: acute myocardial infarction; MRS: myocardial revascularization surgery; VR: valve replacement. Data presented as mean \pm standard deviation or number and percentage.

The results in the preoperative period (Table 2) and the postoperative period (Table 3) describe the 6MWT concerning the variation of hemodynamic and respiratory data, comparing the variables before and after the test. It was observed that there was a physiological and clinically naive increase in hemodynamic variables, including HR, SBP, DBP ($p \leq 0.01$), as well as in dyspnea and lower limb exertion ($p \leq 0.01$), both in the pre- and postoperative periods. No variation was noted in SpO_2 in both the preoperative ($p=0.64$) and postoperative ($p=0.45$) periods.

Table 2. Variation of hemodynamic and respiratory data in the six-minute walk test in the pre- and post-test during the preoperative period of cardiac surgery.

Parameter	Pre-test	Post-test	p
	mean \pm SD	mean \pm SD	
HR (bpm)	71.35 \pm 12.80	85.28 \pm 18.30	$\leq 0.01^*$
SBP (mmHg)	126.55 \pm 17.46	134.87 \pm 19.28	$\leq 0.01^*$
DBP (mmHg)	76.64 \pm 13.86	78.85 \pm 13.94	$\leq 0.01^*$
SpO_2 (%)	96.65 \pm 2.42	96.51 \pm 2.70	0.64
Borg dyspnea (0-10)	0.18 \pm 0.66	0.87 \pm 1.91	$\leq 0.01^*$
Borg LL (0-10)	0.28 \pm 1.19	0.56 \pm 1.53	$\leq 0.01^*$

SD: standard deviation of the mean; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; SpO_2 : peripheral oxygen saturation; Borg dyspnea: sensation of shortness of breath; Borg LL: perceived exertion in the lower limbs; data presented as mean and standard deviation (SD); *Paired t-test; *: $p \leq 0.05$: statistically significant.

Table 3. Variation of hemodynamic and respiratory data in the six-minute walk test pre- and post-test during the postoperative period

Parameter	Pre-test	Post-test	P
	mean \pm SD	mean \pm SD	
HR (bpm)	86.12 \pm 14.34	98.25 \pm 17.33	$\leq 0.01^*$
SBP (mmHg)	120.18 \pm 14.45	129.47 \pm 17.97	$\leq 0.01^*$
DBP (mmHg)	75.22 \pm 10.10	78.41 \pm 14.37	$\leq 0.01^*$
SpO_2 (%)	95.37 \pm 2.67	95.09 \pm 3.84	0.45
Borg dyspnea (0-10)	0.23 \pm 0.75	0.71 \pm 1.40	$\leq 0.01^*$
Borg LL (0-10)	0.38 \pm 1.23	1.08 \pm 1.77	$\leq 0.01^*$

SD: standard deviation of the mean; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; SpO_2 : peripheral oxygen saturation; Borg dyspnea: sensation of shortness of breath; Borg LL: perceived exertion in the lower limbs; data presented as mean (SD); *Paired t-test; *: $p \leq 0.05$: statistically significant.

Table 4 shows the results of the mean difference of the variables between the pre- and post-6MWT, both for the pre-operative period (Table 2) and the post-operative period (Table 3). Although there was an expected physiological increase in HR during the 6MWT in both the pre- and post-operative moments, the variation was greater in the pre-operative phase, with a more pronounced increase in perceived exertion in the lower limbs (LL) during the post-operative period.

The distance walked in the 6MWT (Table 4) decreased between the pre- and post-operative periods ($p \leq 0.01$), with a reduction of 94.92 m.

No adverse events were observed during the test, indicating that it is a safe test to conduct in cardiac patients during both the pre- and post-operative periods.

Table 4. Delta of the difference in the variation of hemodynamic and respiratory data and the value of the distance covered between the pre- and post-six-minute walk test in the pre- and postoperative period of cardiac surgery.

Parameter	\neq Preoperative	\neq Postoperative	p
	mean \pm SD	mean \pm SD	
HR (bpm)	16.81 \pm 13.11	13.66 \pm 12.26	0.05*
SBP (mmHg)	12.92 \pm 11.07	12.12 \pm 10.04	0.54
DBP (mmHg)	6.46 \pm 8.12	6.37 \pm 9.45	0.94
SpO_2 (%)	1.80 \pm 2.42	2.35 \pm 3.19	0.08
Borg dyspnea (0-10)	0.70 \pm 1.79	0.65 \pm 1.28	0.81
Borg LL (0-10)	0.39 \pm 1.25	0.80 \pm 1.43	0.02*
Parameter	Preoperative	Postoperative	p
Distance covered in 6MWT (m)	346.98 \pm 107.51	252.06 \pm 107.17	
Percentage achieved in the distance covered relative to the predicted for the patient in the 6MWT	67.41 \pm 26.26	48.95 \pm 22.28	$\leq 0.01^*$

Delta of the difference: calculation of the post-test mean minus the pre-test mean; SD: standard deviation of the mean; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; SpO_2 : peripheral oxygen saturation; Borg dyspnea: sensation of shortness of breath; Borg LL: perceived exertion in the lower limbs; 6MWT: six-minute walk test. Data presented as mean and standard deviation (SD); *Paired t-test; *: $p \leq 0.05$: statistically significant.

DISCUSSION

In this study involving patients undergoing cardiac surgery, the results revealed variations in intra-test hemodynamic data during both the pre- and postoperative periods, demonstrating a significant increase in hemodynamic variables and perceived exertion for dyspnea and lower limb fatigue from the start to the end of the test. Additionally, the variation in mean differences between the pre- and postoperative tests was more pronounced, with heart rate showing the greatest variation in the preoperative phase, and perceived exertion in the lower limbs being higher in the postoperative phase. The distance covered during the 6MWT significantly decreased in the postoperative period.

The standardization of the 6MWT is valid and reliable for evaluating functional capacity for different pathologies, ranging from cardiac patients¹⁵, diabetic individuals¹⁶, to healthy individuals¹⁷, as well as for assessing the effectiveness of rehabilitation programs in patients undergoing

cardiac surgery¹⁸. This study shows that the increase, which is considered physiological and clinically irrelevant, occurs when the individual is subjected to physical exertion, in hemodynamic variables and perceived exertion for dyspnea and perceived exertion in lower limbs between the beginning and the end of the 6MWT, indicating that it is a safe test for these patients. Similar results are described by Cordeiro et al.¹⁹ who assessed the hemodynamic impact of ambulation on the third or fourth postoperative day after cardiac surgery. They observed a hemodynamic impact with significant variation in heart rate and respiratory rate and double product; however, this does not pose a risk to the patient, showing that it is a safe and feasible procedure for this patient profile. The blood pressure behavior triggered by the test shows an expected physiological increase within normal limits, suggesting that the test is safe^{20,21}.

The highest delta variation in the preoperative intra-test was in heart rate, but it was a physiological and clinically irrelevant increase. In the postoperative period, there was a greater variation in perceived exertion, which correlates with the higher absolute value of HR during this period and the shorter distance covered. On the other hand, the difference in variation of the other data between the pre- and postoperative periods (SBP, DBP, SpO₂, Borg dyspnea) was not significant ($p \geq 0.05$). Furthermore, the difference in variation of HR was a physiological increase without clinical repercussions. This is the point that leads us to confirm that the 6MWT is a safe test to be performed in clinical practice for patients in the pre- and postoperative phases of cardiac surgery.

The results of the 6MWT indicate a reduction in functional capacity in the preoperative phase, and this condition worsened in the postoperative phase. At this stage, patients had a distance of less than 300 m, which represents a percentage lower than 50% according to the predicted calculation for each patient¹⁴. This behavior is also described by other studies^{22,23}. It is important to remember that the average distance covered indicates a good prognosis when the patient walks more than 300 m^{11,23}. In the specific analysis of the 6MWT in patients after cardiac surgery, Opasich et al.²⁴ highlight reference values for test performance related to sex, age, comorbidity, and systolic function, which is important as it provides a specific reference for the test for these patients and mainly to support exercise prescription at the beginning of phase II cardiac rehabilitation.

Although reduced, the distance covered in the preoperative phase was greater than in the postoperative phase. The reduction in distance covered in the

postoperative period can be explained by the restrictions associated with major surgeries such as cardiac surgery, where the patient experiences an increase in perceived exertion in the lower limbs, resulting in greater difficulty in ambulation and consequently reducing their performance in distance covered during the 6MWT. In the postoperative period, the individual experiences pain, which results in respiratory, hemodynamic, and metabolic alterations²⁵.

This study is important for physical therapists as it reaffirms that this procedure can be performed safely in patients in the pre- and postoperative phases of cardiac surgery. However, some limitations can be noted, including:

- (1) Although the ATS recommends conducting two tests with a minimum interval of 30 minutes between them, the patients were instructed on how to perform the test and then the test was applied without prior learning.
- (2) The corridor was adapted to ten meters due to the physical space available in the hospital, which may reduce the distance covered due to decreased walking speed for returning.
- (3) The analysis included different types of surgical procedures.
- (4) Respiratory rate was not measured as a respiratory parameter.

CONCLUSION

Between the pre- and post-test, there was a physiological increase in hemodynamic data and perceived exertion, with no change in SpO₂. The delta variation was greater for heart rate in the preoperative phase and for perceived fatigue in the lower limbs in the postoperative period, although clinically irrelevant. A functional decline was observed due to the decrease in distance covered in the postoperative period, reinforcing the need for physical therapy intervention in patients undergoing cardiac surgery.

The study reinforces that the 6MWT is reliable and safe to perform in patients in the pre- and postoperative phases of cardiac surgery. It is a submaximal test, dependent on motivation, effort, and learning.

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