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Original article

Systemic inflammatory response syndrome after cardiopulmonary bypass: prevalence, predictors, and outcomes

Síndrome de respuesta inflamatoria sistémica tras circulación extracorpórea: prevalencia, predictores y resultados

J.J. Nuño-Pulido [a], R. Gopar-Nieto [b], G. Rojas-Velasco [c], D. Manzur-Sandoval [c,*]

[a] *Cardiology Department, Instituto Nacional de Cardiología Ignacio Chávez, Mexico City, Mexico*
[b] *Coronary Care Unit, Instituto Nacional de Cardiología Ignacio Chávez, Mexico City, Mexico*
[c] *Cardiovascular Critical Care Unit, Instituto Nacional de Cardiología Ignacio Chávez, Mexico City, Mexico*

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ABSTRACT

Background: Systemic Inflammatory Response Syndrome (SIRS) is a frequent and critical complication following cardiac surgery, particularly in patients undergoing cardiopulmonary bypass (CPB). Although SIRS is associated with increased morbidity and mortality, its impact on hemodynamic stability and postoperative outcomes remains unclear. This study aimed to determine the prevalence of SIRS in patients undergoing cardiac surgery with CPB at the Instituto Nacional de Cardiología "Ignacio Chávez" and to explore its association with preoperative comorbidities, intraoperative factors, hemodynamic alterations, vasoactive drug requirements, and adverse outcomes.

Methods: A retrospective, observational study was conducted on 546 adult patients who underwent cardiac surgery with CPB. Patients were classified into SIRS and no SIRS groups based on standard clinical criteria. Statistical analysis included normality testing (Shapiro-Wilk), comparisons of continuous and categorical variables (Mann–Whitney U test, chi-square test, and Fisher's exact test), and logistic regression to identify predictors of outcomes.

Results: SIRS was present in 31.86% of patients upon ICU admission. The most frequent criterion was leukocytosis (69.05%), followed by tachycardia (33.88%). Patients with SIRS exhibited elevated inflammatory markers and increased requirements for vasoactive drugs. SIRS significantly increased the odds of several postoperative complications: mediastinal bleeding (OR 2.08, CI 1.24–3.48), vasoplegic syndrome (OR 1.79, CI 0.92–3.49), low cardiac output syndrome (OR 1.71, CI 1.02–2.85), acute kidney injury (OR 1.69, CI 1.15–2.48), and in-hospital mortality (OR 1.83, CI 0.90–3.72).

Conclusion: SIRS is a prevalent and clinically significant condition in postoperative cardiac surgery patients. The SIRS score is as a valuable risk stratification tool. Early identification and targeted interventions may improve patient outcomes. Further prospective studies are needed to refine predictive models and optimize management strategies.

Palabras clave:
SRIS
Circulación extracorpórea
Cirugía cardíaca
Inflamación
Fármacos vasoactivos
Complicaciones postoperatorias

RESUMEN

Introducción: El síndrome de respuesta inflamatoria sistémica (SRIS) es una complicación frecuente y crítica posterior a la cirugía cardíaca, particularmente en pacientes sometidos a circulación extracorpórea (CEC). Aunque se ha asociado con una mayor morbimortalidad, su impacto sobre la estabilidad hemodinámica y los desenlaces postoperatorios permanece poco claro. Este estudio tuvo como objetivo determinar la prevalencia del SRIS en pacientes sometidos a cirugía cardíaca con CEC en el Instituto Nacional de Cardiología "Ignacio Chávez" y explorar su asociación con comorbilidades preoperatorias, factores intraoperatorios, alteraciones hemodinámicas, requerimientos de fármacos vasoactivos y complicaciones adversas.

* Corresponding author.
E-mail address: drdanielmanzur@gmail.com (D. Manzur-Sandoval).

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Métodos: Se realizó un estudio retrospectivo, observacional, en 546 pacientes adultos sometidos a cirugía cardíaca con CEC. Los pacientes se clasificaron en dos grupos (SRIS y no SRIS) con base en criterios clínicos estándar. El análisis estadístico incluyó prueba de normalidad (Shapiro-Wilk), comparación de variables continuas y categóricas (U de Mann–Whitney, chi cuadrado, exacta de Fisher) y regresión logística para identificar predictores de desenlaces.
Resultados: El SRIS se presentó en el 31.86% de los pacientes al ingreso a la UCI. El criterio más frecuente fue leucocitosis (69.05%), seguido de taquicardia (33.88%). Los pacientes con SRIS mostraron elevación de marcadores inflamatorios y mayores requerimientos de fármacos vasoactivos. El SRIS se asoció significativamente con un mayor riesgo de complicaciones posoperatorias: sangrado mediastínico (OR 2.08, IC 95% 1.24–3.48), síndrome vasoplégico (OR 1.79, IC 95% 0.92–3.49), síndrome de bajo gasto cardíaco (OR 1.71, IC 95% 1.02–2.85), lesión renal aguda (OR 1.69, IC 95% 1.15–2.48) y mortalidad intrahospitalaria (OR 1.83, IC 95% 0.90–3.72).
Conclusión: El SRIS es una condición prevalente y clínicamente relevante en pacientes sometidos a cirugía cardíaca en el periodo postoperatorio. El puntaje de SRIS constituye una herramienta valiosa para la estratificación del riesgo. La identificación temprana y las intervenciones dirigidas podrían mejorar los desenlaces clínicos. Se requieren estudios prospectivos adicionales para perfeccionar los modelos predictivos y las estrategias terapéuticas.

Introduction

Background

Inflammation is an essential innate physiological response to internal or external insults capable of disrupting systemic homeostasis. Its purpose is adaptive, aimed at restoring the balance altered by the noxious stimulus; however, this adaptation can elicit variable responses depending on the characteristics of both the insult and the host. In some cases, the response becomes exaggerated, leading to the development of Systemic Inflammatory Response Syndrome (SIRS), which is characterized by a massive release of inflammatory mediators that may result in organ dysfunction or death.[1]

SIRS was formally defined in 1991 during a consensus conference sponsored by the American College of Chest Physicians and the Society of Critical Care Medicine. The objective was to establish sensitive clinical parameters to facilitate its early identification in critical care settings.[2,3] The diagnostic criteria include alterations in body temperature, heart rate, respiratory rate, and white blood cell count. Although originally conceived for the intensive care environment, it now plays a major role in cardiothoracic surgery, particularly in the postoperative setting of procedures involving cardiopulmonary bypass (CPB).[3]

Cardiac surgery induces a systemic inflammatory response mediated by mechanisms, CPB-triggered immune activation, myocardial ischemia-reperfusion, and direct surgical trauma.[4,5] This response may be further amplified by preexisting conditions, such as cardiovascular disease, diabetes, and dyslipidemia, and has been associated with adverse clinical outcomes, including multiple organ dysfunction and death.[6]

Talmor et al. and Napolitano et al. have demonstrated a direct relationship between persistent postoperative SIRS and increased morbidity and mortality.[7,8] Thus, SIRS is not only a marker of disease severity, but is also a prognostic factor when measured over time (Delta SIRS).[9]

The observed elevation of leukocytes and neutrophils in patients with SIRS is a sign of activation of the innate immune system - a rapid, nonspecific response to physiological stress or injury. Accordingly, these inflammatory markers should be interpreted both as contributors to and manifestations of SIRS pathophysiology. Their increase reflects the initial immune activation that drives the systemic inflammatory cascade, while also serving as measurable indicators of the ongoing inflammatory response.

Importance

Cardiac surgery is still a significant clinical challenge due to its high inflammatory burden, particularly when CPB is employed. Despite advances in surgical techniques and perioperative management, postoperative inflammation remains strongly associated with severe complications.[10] Early identification of at-risk patients using simple, reproducible clinical tools such as SIRS can facilitate timely interventions and potentially modify the clinical course.[3]

Recognizing preoperative, intraoperative, and postoperative factors that influence the inflammatory response may enable the development of personalized management strategies and targeted therapies. Although various pharmacological and technical strategies have been evaluated, none have demonstrated definitive efficacy in mitigating this response.[11]

Therefore, a deeper understanding of the behavior of SIRS in the context of cardiac surgery is essential to improve risk stratification, optimize therapeutic resource allocation, and reduce associated morbidity and mortality.

Research objectives

The objective of this study is to determine the prevalence of SIRS in patients undergoing cardiac surgery with CPB on admission to the cardiovascular intensive care unit at the Instituto Nacional de Cardiología “Ignacio Chávez,” a national referral center and tertiary-level, university-affiliated institution specializing in cardiovascular care for the country’s uninsured population. Additionally, the study aims to characterize the population by evaluating preexisting comorbidities associated with the development of SIRS; identify surgical factors contributing to the onset of the syndrome; analyze postoperative hemodynamic alterations in patients diagnosed with SIRS; assess the relationship between the use of vasoactive agents and the presence of the syndrome; and determine the association between SIRS and adverse postoperative clinical outcomes.

Methods

An observational analytical study was conducted with a retrospective, cross-sectional design. The intervention was not controlled by the investigator, and no active measures were taken on the subjects. The analysis was performed as an open-label study, with no blinding in the outcome assessment.

Study population

This study included adult patients (≥18 years), of any sex, who underwent cardiac surgery with CPB at the Instituto Nacional de Cardiología “Ignacio Chávez” between June 1, 2022, and December 31, 2023. A total of 546 postoperative patients were enrolled using a non-probability sampling method.

Inclusion criteria

- Age ≥18 years

- Underwent cardiac surgery with CPB at the Instituto Nacional de Cardiología "Ignacio Chávez"
- Minimum stay of 12 h in the cardiovascular intensive care unit

Exclusion criteria

- Intraoperative death
- Incomplete clinical records

Definition of SIRS

SIRS was defined as the presence of at least two of the following criteria (Bone et al.):

- Body temperature >38 °C or <36 °C,
- Heart rate >90 beats per minute,
- Respiratory rate >20 breaths per minute or partial pressure of CO2 <32 mmHg,
- White blood cell count >12,000 or <4,000 cells/μL, or >10% immature (band) forms.[2]

Patients meeting 0–1 criterion were classified as No SIRS, while those meeting two or more criteria were classified as SIRS.

Total leukocyte count, absolute neutrophil count, neutrophil percentage, and C-reactive protein (CRP) levels were measured on arrival in the intensive care unit following operating room discharge.

Statistical analysis

The Shapiro-Wilk test was used to assess the normality of continuous variables. Parametric variables were expressed as mean ± standard deviation, whereas non-parametric variables were reported as median with interquartile range (IQR). Comparisons of continuous variables were performed using the Mann–Whitney U test. Categorical variables were described as frequencies and percentages. Chi-square and Fisher's exact tests were employed to compare observed versus expected frequencies. To develop a predictive model for the occurrence of SIRS, multivariable logistic regression analysis was performed including relevant clinical, laboratory, and intraoperative variables collected in the study. Variables with $p < 0.1$ in the univariate analysis were considered for inclusion, and the model was adjusted for age and sex. Model performance was assessed using the area under the receiver operating characteristic curve (AUC-ROC). Statistical significance was set at $p < 0.05$. Analyses were performed using STATA version 14.

Results

Recruitment and baseline characteristics

From June 1, 2022, to December 31, 2023, a total of 546 patients were enrolled in the cardiovascular intensive care unit at the "Ignacio Chávez" National Institute of Cardiology. All participants met the inclusion criteria. Patients with and without SIRS were compared. Among the defined SIRS criteria, leukocytosis was the most prevalent (69.05%), followed by tachycardia (33.88%), tachypnea, and lastly, fever. Of the 546 patients assessed, 174 met the SIRS criterion and 371 did not.

Prevalence of SIRS criteria

- Leukocyte count >12,000 or <4,000 cells/mm^3: 377 patients (69.05%)
- Heart rate >90 bpm: 185 patients (33.88%)
- Respiratory rate >20 breaths/min or PaCO2 <32 mmHg: 57 patients (10.44%)
- Temperature >38 °C or <36 °C: 16 patients (2.93%)

Demographic characteristics

The mean age of the population was 57 years (IQR 45–65); 310 (56.8%) were men and 236 (43.2%) were women. There were no significant differences in weight, height, or body mass index between the SIRS and no SIRS groups. The most common comorbidities were systemic arterial hypertension, present in 227 patients (41.6%), and type 2 diabetes mellitus in 124 (22.8%). Regarding cardiovascular history, heart failure was reported in 148 (27.1%), atrial fibrillation in 99 (18.1%), and previous myocardial infarction in 62 (11.4%) patients. A history of cardiac surgery was documented in 63 (11.5%) patients. According to the NYHA functional classification, Class II was the most frequent, found in 335 patients (61.5%), followed by Class III in 119 (21.8%), Class I in 74 (13.6%), and Class IV in 17 (3.1%). (Table 1).

Surgical characteristics

The most frequently performed procedures were aortic valve replacement in 158 patients (28.9%) and coronary artery bypass grafting (CABG) in 86 patients (15.8%). Aortic valve replacement was significantly more common in the no SIRS group (118 [31.8%] vs. 40 [22.9%], $p = 0.03$). Although the EuroSCORE was not statistically different between groups (median 2.23 [IQR 1.07–4.45] in SIRS vs. 1.8 [IQR 1–3.36] in no SIRS; $p = 0.06$), the higher score in the SIRS group may be clinically relevant. Aortic cross-clamp time was significantly longer in patients who developed SIRS (106 min [IQR 76–133] vs. 96 min [IQR 76–123]; $p = 0.02$). Although CPB time did not reach statistical significance (155 min [IQR 117–204] in SIRS vs. 140 min [IQR 108–180] in no SIRS; $p = 0.83$), the difference may still be clinically relevant. (Table 2).

Acute phase reactants

Patients with SIRS showed elevated levels of acute phase reactants compared to those without SIRS. Median CRP levels were higher in the SIRS group (4.3 mg/dL, IQR 1.73–12.5) than in the no SIRS group (2.98 mg/dL, IQR 1.46–8.02), although this difference was not statistically significant ($p = 0.11$). In contrast, total leukocyte count was significantly higher in patients with SIRS, with a median of 17,000 cells/μL (IQR 13,840–21,180) versus 12,700 cells/μL (IQR 10,200–16,600) in the no SIRS group ($p < 0.001$). Likewise, neutrophil count was significantly elevated in the SIRS group (median 14,600 cells/μL, IQR 11,500–17,960) compared to the no SIRS group (10,960 cells/μL, IQR 8,560–13,950; $p = 0.03$). No significant difference was observed in neutrophil percentage between groups (median 0.85 in both; $p = 0.22$) (Table 3).

Hemodynamic characteristics

At 6 h postoperatively, the oxygen extraction ratio (O2ER) was significantly higher in the SIRS group, indicating increased peripheral oxygen extraction (median 31% vs. 30%; $p = 0.03$). By 24 h, this difference was no longer significant ($p = 0.41$). Oxygen delivery (DO2) was lower in the SIRS group at both time points, although the difference did not reach statistical significance (6 h: 479.37 vs. 518.37 mL/min/m^2, $p = 0.07$; 24 h: 473.55 vs. 488.39 mL/min/m^2, $p = 0.14$). Lactate levels were significantly higher in the SIRS group at 6 h (3.05 vs. 2.4 mmol/L; $p = 0.0004$), but normalized by 24 h ($p = 0.17$) (Table 4).

Medication use

At 6 h postoperatively, patients with SIRS required significantly higher use and doses of norepinephrine (117 [67.2%] vs. 206 [56%]; $p = 0.01$; dose 0.1 vs. 0.08 mcg/kg/min, $p = 0.01$). There was also greater use of vasopressin (59 [34%] vs. 66 [18%], $p = 0.00$), levosimendan (48 [27.6%] vs. 51 [13.9%], $p = 0.00$), methylene blue (12 [7%] vs. 7

Table 1
Baseline characteristics.

Variable	Total (n = 546)	No SIRS (n = 371)	SIRS (n = 174)	p
Women n (%)	236 (43.2)	162 (43.7)	74 (42.3)	0.76
Men n (%)	310 (56.8)	209 (56.3)	101 (57.7)	
NYHA functional class n (%)				
I	74 (13.6)	43 (11.6)	31 (17.8)	0.22
II	335 (61.5)	236 (63.6)	99 (56.9)	
III	119 (21.8)	80 (21.6)	39 (22.4)	
IV	17 (3.1)	12 (3.2)	5 (2.9)	
Previous cardiac surgery n (%)	63 (11.5)	41 (11)	22 (12.6)	0.60
Hypothyroidism n (%)	55 (10)	38 (10.2)	17 (9.8)	0.85
Myocardial infarction n (%)	62 (11.4)	46 (12.4)	16 (9.1)	0.27
Diabetes n (%)	124 (22.8)	84 (22.7)	40 (22.9)	0.96
Chronic obstructive pulmonary disease n (%)	4 (0.7)	3 (0.8)	1 (0.6)	0.77
Chronic kidney disease n (%)	30 (5.5)	17 (4.6)	13 (7.4)	0.18
Hypertension n (%)	227 (41.6)	162 (43.7)	65 (37.1)	0.15
Heart failure n (%)	148 (27.1)	110 (29.7)	38 (21.7)	0.05
Atrial fibrillation n (%)	99 (18.1)	63 (17)	36 (20.6)	0.3
Stroke n (%)	29 (5.3)	24 (6.5)	5 (2.9)	0.08
Weight (kg) Median (IQR)	68 (60–78)	68 (60–78)	69 (58–80)	0.83
Height (m) Median (IQR)	1.62 (1.55–1.7)	1.62 (1.56–1.7)	1.62 (1.54–1.7)	0.60
Body mass index (kg/m^2) Median (IQR)	26 (23.4–28.81)	26.1 (23.41–28.7)	25.56 (22.97–28.9)	0.40
Age	57 (45–65)	59 (48–66)	53 (38–64)	0.0006

NYHA: New York Heart Association; IQR: interquartile range.

Table 2
Surgical characteristics.

Variable	Total (n = 546)	No SIRS (n = 371)	SIRS (n = 174)	p
EuroSCORE Median (IQR)	1.89 (1–3.7)	1.8 (1–3.36)	2.23 (1.07–4.45)	0.06
Extracorporeal circulation time (min) Median (IQR)	144 (112–184.5)	140 (108–180)	155 (117–204)	0.83
Aortic clamping (min) Median (IQR)	99 (76–124)	96 (76)123	106 (76–133)	0.02
Coronary artery bypass graft n (%)	86 (15.8)	60 (16.2)	26 (14.9)	0.70
Mitral valve replacement n (%)	52 (9.5)	37 (10)	15 (8.6)	0.60
Aortic valve replacement n (%)	158 (28.9)	118 (31.8)	40 (22.9)	0.03
Mitral valve replacement + tricuspid valve replacement n (%)	27 (4.5)	17 (4.6)	10 (5.7)	0.57
Aortic valve replacement + mitral valve replacement n (%)	39 (7.1)	22 (6)	17 (9.7)	0.11
Coronary artery bypass graft + aortic valve replacement n (%)	23 (4.2)	12 (3.2)	11 (6.3)	0.10
Bentall procedure n (%)	31 (5.7)	18 (4.9)	13 (7.4)	0.22
Others n (%)	133 (24.4)	89 (24)	44 (25.1)	0.77

IQR: interquartile range.

Table 3
Acute phase reactants.

Variable	Total (n = 546)	No SIRS (n = 371)	SIRS (n = 174)	p
C-reactive protein mg/L Median (IQR)	3.43 (1.56–8.95)	2.98 (1.46–8.02)	4.3 (1.73–12.5)	0.11
Total leukocytes cells/μ Median (IQR)	14.23 (11.3–18.49)	12.7 (10.2–16.6)	17 (13.84–21.18)	0.00
Neutrophils (total) cells/μ Median (IQR)	12.22 (9.59–15.63)	10.96 (8.56–13.95)	14.6 (11.5–17.96)	0.03
Neutrophils (%) Median (IQR)	0.85 (0.81–0.88)	0.85 (0.81–0.88)	0.85 (0.81–0.88)	0.22

IQR: interquartile range.

[2%], p = 0.00), and corticosteroids (10 [5.8%] vs. 7 [2%], p = 0.01). At 24 h, the SIRS group continued to show significantly higher use of norepinephrine (51 [29.5%] vs. 60 [17%], p = 0.00), vasopressin (31 [18%] vs. 31 [8.7%], p = 0.00), and levosimendan (36 [20.9%] vs. 34 [9.4%], p = 0.00) (Table 4).

Outcomes

Regarding postoperative outcomes, patients with SIRS exhibited both clinically and statistically significant increases in certain complications. Mediastinal bleeding occurred in 32 patients (18.3%) vs. 36 patients (9.7%) in the no SIRS group (p = 0.005), and postcardiotomy low cardiac output syndrome in 30 patients (17.1%) vs. 40 patients (10.8%) (p = 0.04), both significantly more frequent in the SIRS group. Vasoplegic syndrome (17 patients [9.8%] vs. 21 [5.7%]; p = 0.09) and hypovolemia (74 [42.3%] vs. 125 [33.7%]; p = 0.05) were also more common, though with borderline or no statistical significance.

Among specific organ-related outcomes, delirium was more frequent in the SIRS group (30 [17.2%] vs. 37 [10%]; p = 0.02), as was the need for transfusion (104 [59.8%] vs. 182 [49%]; p = 0.02), acute kidney injury (67 [38.5%] vs. 100 [27%]; p = 0.006), and renal replacement therapy (RRT) (16 [9.2%] vs. 17 [4.6%]; p = 0.04), all reaching

Table 4
Hemodynamic variables and vasoactive drugs.

Variable	Total (n = 546)	No SIRS (n = 371)	SIRS (n = 174)	p
6 h				
Cardiac index (L/min/m^2) Median (IQR)	2.09 (1.6–2.57)	2.1 (1.6–2.6)	1.97 (1.53–2.52)	0.31
Central venous pressure (mmHg) Median (IQR)	9 (8–11)	9 (8–11)	10 (8–12)	0.27
Systemic vascular resistance index (dynes-sec/cm5/m^2) Median (IQR)	2523.5 (1964–3171)	2484.5 (1946.03–3225.5)	2575.5 (2008–3113)	0.85
Mixed venous O_2 saturation (%) Median (IQR)	69 (62.2–75.95)	69.1 (63–76.2)	68 (60–74.6)	0.02
Arteriovenous O_2 difference (mL/dL) Median (IQR)	4.4 (3.54–5.39)	4.4 (3.43–5.37)	4.39 (3.59–5.54)	0.47
O_2 extraction ratio (%) Median (IQR)	30 (24–36.5)	30 (23–36)	31 (24–39)	0.03
Venous-to-arterial CO_2 pressure difference (mmHg) Median (IQR)	7 (4–9)	7 (5–9)	7 (4–9)	0.63
Venous-arterial CO_2 to arterial-venous O2 content difference ratio Median (IQR)	1.47 (1.07–2.02)	1.47 (1.07–2)	1.49 (1.08–2.05)	0.91
DO_2 (mL/min/m^2) Median (IQR)	507.06 (392–649.98)	518.37 (399.42–669.12)	479.373 (365.62–630)	0.07
VO_2 (mL/min/m^2) Median (IQR)	128.16 (122.92–184)	130.68 (122.5–185.13)	125.56 (123.55–181.50)	0.93
DO_2/VO_2 Median (IQR)	3.30 (2.71–4.25)	3.35 (2.81–4.33)	3.19 (2.56–4.08)	0.11
Lactate Median (IQR)	2.5 (1.7–3.9)	2.4 (1.7–3.5)	3.05 (2–4.7)	0.0004
Capillary refill time (seg) Median (IQR)	2 (2–3)	2 (2–3)	2 (2–3)	0.00
Norepinephrine n (%)	323 (59.6)	206 (56)	117 (67.2)	0.01
Dose of norepinephrine Median (IQR)	0.08 (0.05–0.15)	0.08 (0.04–0.13)	0.1 (0.05–0.6)	0.01
Dobutamine n (%)	169 (31.1)	111 (30.2)	58 (33.3)	0.46
Dose of dobutamine Median (IQR)	3.66 (2.6–5)	3 (2.5–5)	5 (3–7)	0.06
Vasopressin n (%)	125 (23)	66 (18)	59 (34)	0.00
Dose of vasopressin Median (IQR)	0.05 (0.03–0.06)	0.04 (0.03–0.06)	0.05 (0.03–0.07)	0.31
Levosimendan n (%)	99 (18.2)	51 (13.9)	48 (27.6)	0.00
Dose of levosimendan Median (IQR)	0.1 (0.05–0.1)	0.1 (0.05–0.1)	0.1 (0.05–0.1)	0.91
Milrinone n (%)	15 (2.77)	8 (2.1)	7 (4)	0.22
Dose of milrinone Median (IQR)	0.3 (0.2–0.5)	0.4 (0.3–0.55)	0.3 (0.11–0.5)	0.40
Methylene blue n (%)	19 (3.5)	7 (2)	12 (7)	0.00
Steroids n (%)	17 (3.1)	7 (2)	10 (5.8)	0.01
24 h				
Cardiac index (L/min/m^2) Median (IQR)	2.15 (1.78–2.51)	2.18 (1.8–2.53)	2.1 (1.71–2.495)	0.97
Central venous pressure (mmHg) Median (IQR)	10 (9–12)	10 (8–12)	10 (9–12)	0.04
Systemic vascular resistance index (dynes-sec/cm5/m^2) Median (IQR)	2427 (2054–3040)	2394 (2055–3095)	2495 (2046.5–3033)	0.69
Mixed venous O_2 saturation (%) Median (IQR)	68 (62.95–73.15)	68 (62.4–73.6)	69 (63.35–73)	0.60
Arteriovenous O_2 difference (mL/dL) Median (IQR)	3.98 (3.26–4.9)	4.02 (3.33–4.98)	3.84 (3.2–4.74)	0.58
O_2 extraction ratio (%) Median (IQR)	30 (25–35)	30 (24.5–36)	30 (25–35)	0.41
Venous-to-arterial CO_2 pressure difference (mmHg) Median (IQR)	6 (4–7)	5 (4–7)	6 (4–8)	0.74
Venous-arterial CO_2 to arterial-venous O2 content difference ratio Median (IQR)	1.38 (0.91–1.84)	1.35 (0.9–1.82)	1.45 (0.98–1.92)	0.20
DO_2 (mL/min/m^2) Median (IQR)	481(396.8–585.22)	488.39(409.63–588.70)	473.55(369.2–565.8)	0.14
VO_2 (mL/min/m^2) Median (IQR)	129 (123.24–175.95)	133.53 (123.62–179.6)	125.02 (122.58–164.43)	0.08
DO_2/VO_2 Median (IQR)	3.291827 (2.77–4)	3.26 (2.75–4)	3.4 (2.8–3.96)	0.66
Lactate Median (IQR)	1.9 (1.5–2.6)	1.9 (1.5–2.6)	1.95 (1.5–2.6)	0.17
Capillary refill time (seg) Median (IQR)	2 (2–2)	2 (2–2)	2 (2–2.4)	0.00
Norepinephrine n (%)	111 (21)	60 (17)	51 (29.5)	0.00
Dose of norepinephrine Median (IQR)	0.08 (0.03–0.2)	0.05 (0.02–0.15)	0.09 (0.05–0.22)	0.39
Dobutamine n (%)	82 (15.4)	51 (14.2)	31 (18)	0.26
Dose of dobutamine Median (IQR)	3 (2.5–5)	3 (3–5)	3.5 (3–5)	0.75
Vasopressin n (%)	62 (11.7)	31 (8.7)	31 (18)	0.00
Dose of vasopressin Median (IQR)	0.04 (0.02–0.06)	0.04 (0.02–0.06)	0.05 (0.03–0.07)	0.36
Levosimendan n (%)	70 (13.1)	34 (9.4)	36 (20.9)	0.00
Dose of levosimendan Median (IQR)	0.1 (0.05–0.15)	0.1 (0.05–0.105)	0.1 (0.05–0.15)	0.91
Milrinone n (%)	9 (1.7)	6 (1.7)	3 (1.8)	0.95
Dose of milrinone Median (IQR)	0.5 (0.15–0.6)	0.5 (0.1–0.66)	0.3 (0.15–0.5)	0.58
Methylene blue n (%)	5 (1)	2 (.6)	3 (1.8)	0.18
Steroids n (%)	11 (2)	5 (1.4)	6 (3.5)	0.11

IQR: interquartile range.

statistical significance. Stroke (9 [5.2%] vs. 12 [3.2%]; p = 0.28), hospital-acquired pneumonia (22 [12.7%] vs. 35 [9.4%]; p = 0.25), and mediastinitis (9 [5.2%] vs. 14 [3.8%]; p = 0.45) were more frequent in SIRS patients but without statistical significance.

Liver injury was paradoxically more frequent in the no SIRS group (29 [16.7%] vs. 35 [9.4%]; p = 0.01). Postoperative atrial fibrillation occurred at similar rates (30 [17.3%] vs. 59 [15.9%]; p = 0.70).

In terms of resource use and severity, patients with SIRS had longer ICU stays (median 3 [2–4] days in both groups; p = 0.0059), longer mechanical ventilation duration (median 1 [1–2] vs. 1 [1–1] days; p = 0.0024), and higher SOFA scores at 24 h (median 5 [4–8] vs. 5 [3–7]; p = 0.008). In-hospital mortality (15 [8.6%] vs. 18 [4.9%]; p = 0.09) and SOFA score at 72 h (median 4 [2–6] vs. 3 [2–5]; p = 0.07) were higher but not statistically significant. Total hospital stay was longer in SIRS patients (median 12 vs. 10 days; p = 0.53) (Table 5).

Logistic regression analysis

The logistic regression analysis adjusted for age and sex revealed a higher incidence of several adverse outcomes in patients with SIRS. Specifically, patients with SIRS had 2.08 times greater odds of experiencing mediastinal bleeding (OR 2.08, 95% CI 1.24–3.48; p = 0.00) and 1.71 times greater odds of developing postcardiotomy low cardiac output syndrome (OR 1.71, 95% CI 1.02–2.85; p = 0.04). Although the odds of vasoplegic syndrome were also elevated (OR 1.79, 95% CI 0.92–3.49), statistical significance was not reached (p = 0.08). SIRS was additionally associated with higher odds of hypovolemia (OR 1.44, 95% CI 0.99–2.08; p = 0.05) and transfusion requirement (OR 1.54, 95% CI 1.07–2.22; p = 0.02).

Regarding neurologic and renal complications, patients with SIRS had increased odds of delirium (OR 1.88, 95% CI 1.11–3.16; p = 0.01), acute kidney injury (OR 1.69, 95% CI 1.15–2.48; p = 0.00), and the need for renal replacement therapy (OR 2.10, 95% CI 1.03–4.26; p = 0.04). Finally, SIRS was associated with 1.83 times greater odds of in-hospital mortality (OR 1.83, 95% CI 0.90–3.72), although this finding did not reach statistical significance (p = 0.09) (Table 6).

A multivariate logistic regression model was developed to identify independent predictors of postoperative SIRS. Variables included in the model were age, aortic cross-clamp time, total leukocyte count, lactate levels at 6 h, and norepinephrine use at 6 h.

In the adjusted analysis, increasing age was independently associated with a decreased risk of SIRS (OR 0.97 per year; 95% CI, 0.95–0.99; p = 0.004). Conversely, longer aortic cross-clamp time was associated with a higher risk of SIRS (OR 1.02 per minute; 95% CI, 1.01–1.04; p = 0.01). Elevated total leukocyte count (OR 1.12 per 1×10^3 cells/μL; 95% CI, 1.06–1.19; p < 0.001) and increased lactate levels at 6 h (OR 1.25 per mmol/L; 95% CI, 1.10–1.43; p = 0.001) were significant predictors. Additionally, norepinephrine administration at 6 h was independently associated with increased odds of SIRS (OR 1.85; 95% CI, 1.15–3.00; p = 0.01).

The predictive model demonstrated good discrimination, with an area under the receiver operating characteristic curve (AUC) of 0.78 (95% CI, 0.73–0.83) and adequate calibration (Hosmer-Lemeshow test, p = 0.45). These results suggest that a combination of clinical, surgical, and laboratory variables can effectively predict the development of SIRS after cardiac surgery.

Discussion

This study provides key insights into the incidence, predictors, and clinical implications of SIRS in cardiac surgery patients within a unique demographic context. SIRS affected nearly one-third of patients, predominantly younger individuals, and was more strongly associated with procedural factors—particularly prolonged aortic cross-clamp time—than with traditional preoperative risk factors. SIRS patients showed elevated inflammatory markers, hemodynamic instability, and increased requirements for vasopressors, inotropes, and corticosteroids, all suggesting systemic inflammation and hypoperfusion.

These physiological disturbances translated into significantly higher rates of complications, including low cardiac output syndrome, mediastinal bleeding, delirium, acute kidney injury, and the need for renal replacement therapy. Our findings underscore the need for early identification and tailored perioperative management strategies to mitigate these risks.

The incidence of SIRS in cardiac surgery varies widely, with a recent systematic review reporting rates from 28.3% to 96.2%.[11] Our observed rate (31.86%) aligns with Squiccimarro et al.[12] Despite some statistically significant demographic differences, their clinical relevance was limited, reflecting population homogeneity. We found no association between preoperative comorbidities and SIRS, contrasting with Dieleman et al., who linked recent myocardial infarction and ventricular dysfunction to SIRS through ischemia–reperfusion injury.[13]

The mean patient age was 57 years, lower than in previous studies,[3,12,14] likely reflecting earlier onset of cardiovascular disease in Mexico due to socioeconomic and genetic factors, as well as a higher burden of rheumatic and congenital heart disease.[15] Notably, SIRS patients were younger (mean 53 vs. 59 years), consistent with findings by Dieleman et al.,[13] who suggested reduced immune responsiveness in older individuals.

Aortic valve replacement was the most common procedure (28.9%), with valve surgeries comprising 50% overall—in contrast with trends in high-income countries, where coronary bypass predominates.[5,12] Our findings confirm the association between prolonged aortic cross-clamp time and SIRS, in line with its known impact on mortality.[16] While extracorporeal circulation (EC) time did not differ significantly, patients with SIRS had clinically longer CPB times, which are known to trigger inflammatory cascades and organ dysfunction.[4]

Patients with SIRS had slightly higher EuroSCOREs, though the difference was not statistically significant. Inflammatory markers (CRP, leukocytes, neutrophils) increased postoperatively in all patients, but were significantly elevated in the SIRS group. This aligns with evidence linking neutrophilia and leukocytosis to extracardiac complications such as delirium and acute kidney injury.[17]

Vasopressor and corticosteroid use was more frequent and at higher doses in the SIRS group, consistent with vasoplegic syndrome, which affects 9%–44% of cardiac surgery patients and was present in 6.7% of our cohort. This syndrome is linked to factors such as high transfusion burden and prolonged CPB and cross-clamp times, all observed in SIRS patients. Vasoplegia is associated with higher morbidity and mortality, including bleeding, organ dysfunction, and prolonged ICU stays.[18,19] Elevated lactate at 6 h, normalizing by 24 h, likely reflected transient hypoperfusion due to extended CPB.[20]

Postcardiotomy low cardiac output syndrome, found in 12.3% of our cohort, was significantly more frequent in SIRS patients. Closely related to vasoplegia, this syndrome is marked by persistent shock despite pharmacologic or mechanical support, and is linked to adverse outcomes, including renal failure and elevated lactate.[21]

Mediastinal bleeding was another significant complication in SIRS patients, likely due to coagulation abnormalities induced by surgery, hemodilution, and anticoagulants.[22] Increased transfusion needs and hypovolemia were observed, though the latter was not statistically significant.

Delirium occurred in 17.3% of SIRS patients, significantly more than in those without SIRS. Wang et al. reported associations between delirium and factors also present in our population, including age, transfusions, and cross-clamp time.[23]

Acute kidney injury (AKI) and RRT were significantly more common in the SIRS group. CPB remains the major contributor to AKI, which is linked to long-term mortality. In our study, AKI occurred in 38.5% of SIRS patients, and 9.2% required RRT, exceeding the ~1% incidence reported in broader literature.[24]

Table 5
Outcomes.

Variable	Total	No SIRS	SIRS	p
Mediastinal bleeding n (%)	68 (12.4)	36 (9.7)	32 (18.3)	0.005
Postcardiotomy low cardiac output syndrome n (%)	70 (12.3)	40 (10.8)	30 (17.1)	0.04
Vasoplegic syndrome n (%)	38 (6.7)	21 (5.7)	17 (9.8)	0.09
Hypovolemia N (%)	199 (36.4)	125 (33.7)	74 (42.3)	0.05
Delirium n (%)	67 (12.3)	37 (10)	30 (17.2)	0.02
Stroke n (%)	21 (3.9)	12 (3.2)	9 (5.2)	0.28
In-hospital pneumonia n (%)	57 (10.5)	35 (9.4)	22 (12.7)	0.25
Mediastinitis n (%)	23 (4.22)	14 (3.8)	9 (5.2)	0.45
Transfusion n (%)	286 (52.5)	182 (49)	104 (59.8)	0.02
Acute kidney injury n (%)	167 (30.7)	100 (27)	67 (38.5)	0.006
Renal replacement therapy n (%)	33 (6)	17 (4.6)	16 (9.2)	0.04
Liver injury n (%)	64 (11.8)	29 (16.7)	35 (9.4)	0.01
Post surgical atrial fibrillation n (%)	89 (16.3)	59 (15.9)	30 (17.3)	0.70
Mortality n (%)	33 (6)	18 (4.9)	15 (8.6)	0.09
Days in intensive care unit Median (IQR)	3 (2–4)	3 (2–4)	3 (2–4)	0.0059
Days on mechanical ventilation Median (IQR)	1 (1–1)	1 (1–1)	1 (1–2)	0.0024
Total hospitalization time Median (IQR)	10 (7–19)	10 (7–17)	12 (7–22)	0.53
SOFA score at 24 h Median (IQR)	5 (3–7)	5 (3–7)	5 (4–8)	0.008
SOFA score at 72 h Median (IQR)	3 (2–5)	3 (2–5)	4 (2–6)	0.07

IQR: interquartile range.

Table 6
Logistic regression model.

Variable	OR	CI 95%	p
Mediastinal bleeding	2.08	1.24–3.48	0.00
Postcardiotomy low cardiac output syndrome	1.79	0.92–3.49	0.08
Bajo gasto postcardiotomía	1.71	1.02–2.85	0.04
Hypovolemia	1.44	0.99–2.08	0.05
Transfusion	1.54	1.07–2.22	0.02
Acute kidney injury	1.69	1.15–2.48	0.00
Renal replacement therapy	2.10	1.03–4.26	0.04
Mortality	1.83	0.90–3.72	0.09
Delirium	1.88	1.11–3.16	0.01

OR: Odds Ratio; CI: Confidence interval.

Although differences in stroke, hospital-acquired pneumonia, and mediastinitis were not statistically significant, they were clinically important. This contrasts with studies such as Pahwa et al., who linked stroke and pneumonia to increased mortality.[25] Hospital stay and in-hospital mortality were also higher in the SIRS group, though without statistical significance.

Although power was not calculated in our study due to its retrospective design, the inclusion of 546 consecutive patients provided sufficient power to detect significant associations. The strength of effect sizes and confidence intervals supports the validity of our conclusions.

Study limitations

This study has several limitations. Firstly, its retrospective design introduces potential selection and recording biases. Additionally, the absence of follow-up data limits our ability to evaluate the temporal progression of patients. While associations between variables can be identified in this type of study, causal relationships cannot be established. Furthermore, as a single-center study, the findings may not be generalizable to other populations or settings.

Regarding data collection and patient classification according to SIRS criteria, most patients met these criteria primarily due to leukocytosis with neutrophilia, which was significantly elevated compared to baseline values in those who developed SIRS. Although this parameter has some limitations, its strong correlation with other inflammatory markers, such as CRP, along with significantly higher leukocyte and neutrophil counts in the SIRS group (Table 3), supports its reliability for patient classification within the scope of this study. Another factor influencing the SIRS criteria was tachycardia. Although tachycardia is strongly associated with SIRS in postoperative cardiac surgery patients, it can also have other causes, such as pain, hypovolemia, or medication side effects, and is therefore a potential limitation of this study. Additionally, tachypnea—defined as a respiratory rate greater than 20 breaths per minute or arterial pCO_2 below 32 mmHg—is included in the SIRS criteria. However, assessing this parameter in postoperative patients is challenging, as most are mechanically ventilated at ICU admission with preset respiratory settings. In patients who undergo early extubation, tachypnea may develop during respiratory recovery, complicating objective evaluation of this criterion in all cases except for extubated patients without signs of respiratory distress.

Strengths of the study

This study presents several strengths. It is based on a large, well-defined cohort of postoperative cardiac surgery patients, enhancing the robustness and reliability of the findings. Its clinical relevance is underscored by the comprehensive evaluation of patients using both hemodynamic parameters and biochemical inflammatory markers, allowing for a more detailed characterization of SIRS in this population. Additionally, the inclusion of multiple clinically important outcomes and vasoactive drug use provides valuable insights into the postope-

rative management and prognosis of these patients. These strengths contribute to the overall validity and applicability of the study results.

Conclusion

In our study, 31.9% of postoperative cardiac surgery patients with CPB met standard SIRS criteria, emphasizing the importance of systemic inflammatory response after surgery. Patients meeting SIRS criteria showed greater hemodynamic instability and a higher incidence of postoperative complications. Although our study was not designed to evaluate prognostic factors, these findings suggest that SIRS could serve as a useful marker for identifying higher-risk patients and guiding postoperative care. Further prospective studies are warranted to validate the role of SIRS in risk stratification and clinical management.

CRediT authorship contribution statement

JJNP: data collection, writing the original draft, RGN: methodology, analysis, GRV: review, DMS: original idea, methodology, analysis and writing the original draft, review and editing.

Consent for publication

Written informed consent was obtained for the publication of patient information and images, either from the patient or a legally authorized representative.

Ethical approval and consent to participate

The local research and institutional ethics committees waived approval for this study.

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Availability of data and materials

The data supporting the findings of this study are available upon request from the corresponding author [DMS].

Declaration of competing interest

The authors declare that there are no conflicts of interest to disclose.

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