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Factors associated with the risk of in-hospital mortality following cardiovascular surgery

Factores asociados al riesgo de mortalidad hospitalaria en el posoperatorio de la cirugía cardiovascular

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ABSTRACT:
Introduction: With an overall mortality rate of up to 15%, cardiovascular surgery encompasses procedures such as valve surgery, myocardial revascularization, repair of congenital defects, and other interventions. Classification trees help guide future decision-making regarding preventive strategies. Objective: To develop a classification tree to assess the risk of in-hospital mortality during the postoperative period following cardiovascular surgery. Method: A cross-sectional descriptive study was conducted to identify factors associated with in-hospital postoperative mortality. A classification tree of risk factors was developed using the CHAID algorithm. Results: Six child classification nodes were obtained from the root node, "Discharge Status." The findings indicated that patients requiring mechanical ventilation for more than 24 hours had a 44.4% probability of death. When blood product transfusion was also present, this probability increased to 53.7%. Conversely, among patients requiring mechanical ventilation for less than 24 hours, the probability of death was only 1.7%, increasing to 20% in those with a history of chronic kidney disease. Conclusions: A classification tree was developed to rank the factors associated with mortality according to their proximity to the outcome variable. The most influential factor was mechanical ventilation lasting more than 24 hours.
Keywords: In-hospital mortality in cardiovascular surgery; Classification tree; Postoperative complications of cardiovascular surgery
RESUMEN:
Introducción: Con una mortalidad global que asciende al 15 %, la cirugía cardiovascular incluye la práctica de cirugía valvular, revascularización miocárdica, reparación de defectos congénitos y otras. Los árboles de clasificación ayudan en la futura toma de decisiones para la prevención. Objetivo: Elaborar un árbol de clasificación del riesgo de mortalidad hospitalaria en el posoperatorio de cirugía cardiovascular. Método: Estudio descriptivo transversal para identificar los factores relacionados con la muerte durante la hospitalización en el posoperatorio, que incluyó un árbol de clasifi-

cación de los factores de riesgo por el algoritmo CHAID. Resultados: Se obtuvieron 6 nodos de clasificación hijos a partir del nodo principal "Estado al egreso", los cuales indicaron, en el estudio realizado, que los pacientes con un tiempo de ventilación artificial mecánica mayor de 24 horas tuvieron una probabilidad de fallecer del 44,4 %; si se añade la transfusión de hemoderivados, la probabilidad se incrementa al 53,7 %. Por el contrario, cuando el tiempo de ventilación artificial mecánica fue menor de 24 horas, las probabilidades de fallecer fueron solamente de un 1,7 %, que se incrementan al 20 % en casos asociados a antecedentes de enfermedad renal crónica. Conclusiones: Se elaboró un árbol de clasificación que ordenó los factores relacionados con la mortalidad a partir de la variable con mayor cercanía, que fue el tiempo de ventilación artificial mecánica mayor de 24 horas.
Palabras clave: Mortalidad hospitalaria en cirugía cardiovascular; Árbol de clasificación; Complicaciones posoperatorias de la cirugía cardiovascular.

INTRODUCCIÓN

The development of cardiopulmonary bypass in 1953 and subsequent advances in this technology have shaped the evolution of cardiovascular surgery, alongside advances in surgical techniques and technologies.[1] However, postoperative complications and associated mortality have remained major subjects of research and have prompted the development of strategies to reduce their incidence.[2] Therefore, continuous improvement of postoperative care protocols is essential.[2]

In-hospital mortality is defined as the number of patients who die before hospital discharge following a surgical procedure. It is considered an important parameter for assessing treatment success. However, a more comprehensive assessment of mortality that takes into account patient risk is required, since cardiac surgery departments with highly skilled healthcare professionals perform surgical procedures on patients with high levels of complexity and risk, which may lead to increased in-hospital mortality rates. This could result in a misleading assessment of the quality of care if this parameter is considered in isolation. Conversely, departments with a risk-averse approach may operate on less complex patients and, due to their lower mortality rates, may be regarded as centers of excellence. This highlights the importance of risk-adjusted mortality assessment and preoperative evaluation.[3,4]

Furthermore, not all factors associated with in-hospital mortality are preoperative or inherent to the patient's underlying diagnosis. A considerable number of these factors are also related to the intraoperative and immediate postoperative periods.[2,3,5,6]

Despite significant advances over recent decades, cardiac surgery remains associated with postoperative in-hospital mortality rates ranging from 5% to 75%, depending on the type of surgical procedure performed, the patient's comorbidities and frailty status, as well as other related variables.[2,5-9]

Several mathematical models and scoring systems have been developed to estimate the risk of mortality in cardiovascular surgery. The most widely recognized include the Parsonnet score, EuroSCORE I and II, and the STS score, although limitations and inaccuracies have also been attributed to these models. Predictive models have been reported to perform better in the populations in which they were originally developed, while their discriminatory ability may decrease when applied to other settings due to differences between populations. This highlights the need to develop locally tailored prognostic systems.[10-12]

A classification or decision tree is a method that allows risk factors to be selected and ranked according to their association with the outcome variable under study. As classification nodes are generated, the factors are hierarchically organized, making it possible to identify those most closely associated with the outcome. These trees can serve as predictive models that account for the combined effects of risk factors, thereby supporting clinical decision-making and the implementation of preventive measures.[13,14]

Objectives:

1- To identify risk factors associated with in-hospital mortality during the postoperative period following cardiovascular surgery.
2- To determine the influence of risk factors when they occur in combination.

METHOD

A cross-sectional descriptive study was conducted at Hospital Universitario Cardiocentro "Ernesto Guevara", including patients who underwent cardiovascular surgery between 2019 and 2021. The study aimed to describe in-

hospital mortality and the factors associated with this outcome.

The study population comprised all patients who underwent surgery during the aforementioned period. The study sample consisted of 313 patients whose medical records contained the required study variables.

The dependent variable was discharge status, classified as alive or deceased.

The independent variables were: Sociodemographic variables: age and sex; preoperative variables: arterial hypertension (HTN), smoking, obesity, diabetes mellitus, chronic kidney disease (CKD), chronic obstructive pulmonary disease (COPD), pulmonary hypertension (PH), preoperative length of hospital stay, surgical priority, left ventricular ejection fraction (LVEF), diagnosis; Intraoperative variables: use and duration of cardiopulmonary bypass (CPB), use and duration of aortic cross-clamp (ACC), type of surgery; postoperative variables: blood product transfusion, duration of mechanical ventilation (MV), length of stay in the intensive care unit (ICU), and postoperative complications.

Statistical methods:

The data were entered into a Microsoft Office Excel spreadsheet and subsequently processed using the Statistical Package for the Social Sciences (SPSS), version 22.0 for Windows, on a personal computer running the Windows 10 operating system.

Univariate and bivariate analyses were performed, the latter to identify associations between variables. The nonparametric Chi-square test of independence was used. The results were reported as the chi-square test statistic and the corresponding p-value. Statistical significance was defined as follows:

- statistically significant: $p < 0.05$.
- not statistically significant: $p \geq 0.05$.

A multivariate statistical analysis was performed using a classification tree, specifically the Chi-square Automatic Interaction Detection (CHAID) algorithm, which allows risk factors to be selected and ranked according to their association with patients' discharge status following cardiovascular surgery. The analysis generated classification nodes, making it possible to identify the factors most closely associated with the outcome under study, namely, the discharge status of "death."

RESULTS

The study period was characterized by the COVID-19 pandemic, which led to a substantial reduction in elective surgical procedures, accompanied by an increase in patient complexity due to the prolonged progression of their diseases.

As illustrated in **figure 1**, in-hospital mortality in the study sample reached a high rate (12.8%). Therefore, associations with other variables were analyzed, along with the characteristics of the patients during this period.

As shown in **figure 2**, valve surgery was the most frequently performed procedure during the study period, accounting for 166 valve replacement procedures, with an in-hospital mortality rate of 9.6%. This was followed by myocardial revascularization in 85 patients, with a mortality rate of 9.4%. Additionally, a considerable number of patients (30) underwent surgery for infective endocarditis on an emergency basis due to their clinical condition at presentation, resulting in a high mortality rate of 23.3%. Although reoperations were infrequent, involving only five patients, they were performed due to prosthetic valve dysfunction; 60% of these patients died. The group classified as other surgical procedures included only 10 cases during this period, comprising cardiac myxomas and one case of Stanford type A aortic dissection. The latter patient died, representing 10% of this group.

The statistical association between preoperative variables and mortality is presented in **table 1**. Smoking, CKD, surgical priority, and LVEF showed the strongest associations with mortality.

Table 2 presents the intraoperative variables and their relationship with in-hospital mortality. Overall, the type of surgery was associated with mortality, as was the duration of CPB and of ACC.

The results of the association between postoperative variables and discharge status are presented in **table 3**. Blood product transfusion and duration of MV were found to be associated with mortality, showing particularly strong associations.

Following the assessment of the associations between the aforementioned variables and discharge status, a multivariate statistical analysis was performed using the CHAID algorithm, resulting in the classification tree shown in **figure 3**. The tree comprised six child nodes, four of which were terminal nodes, and correctly classified 88.5% of patients. The variables associated with death at hospital discharge were duration of MV, red blood cell transfusion, and a history of CKD. MV duration was the variable with the strongest association and, consequently, the one closest to the root node, representing the first classification criterion in the classification tree.

Patients requiring MV for 24 hours or longer had a 44.4 % probability of death. When blood product transfusion was also present, this probability increased to 53.7 %.

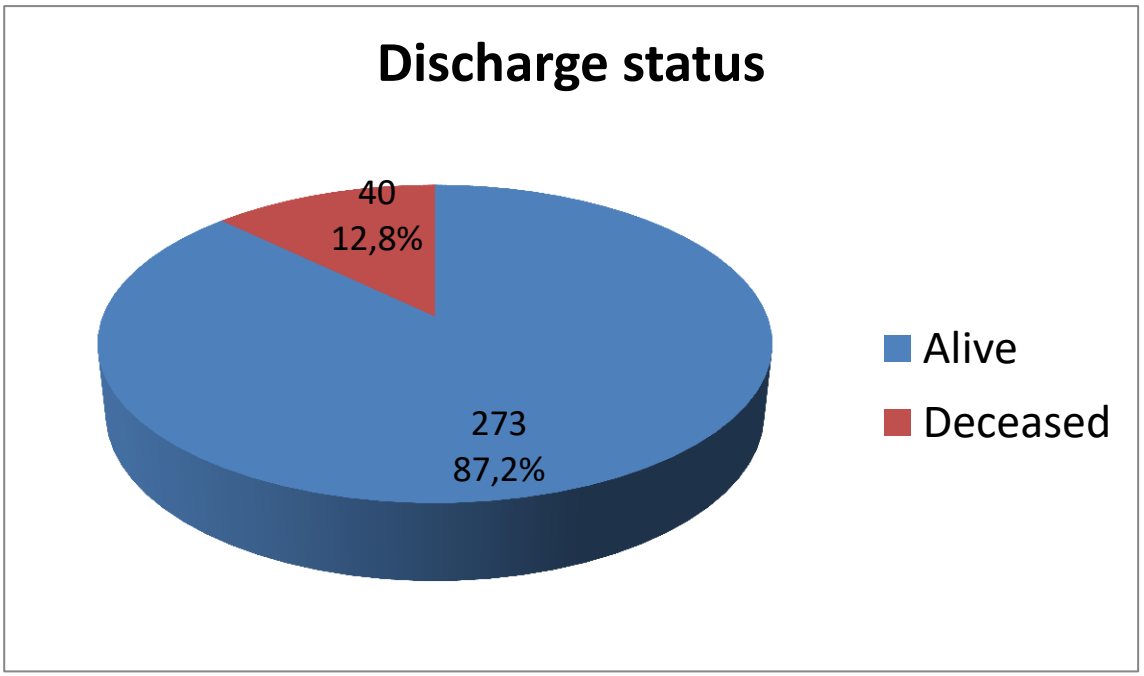


Figure 1- Discharge Status. In-Hospital Mortality

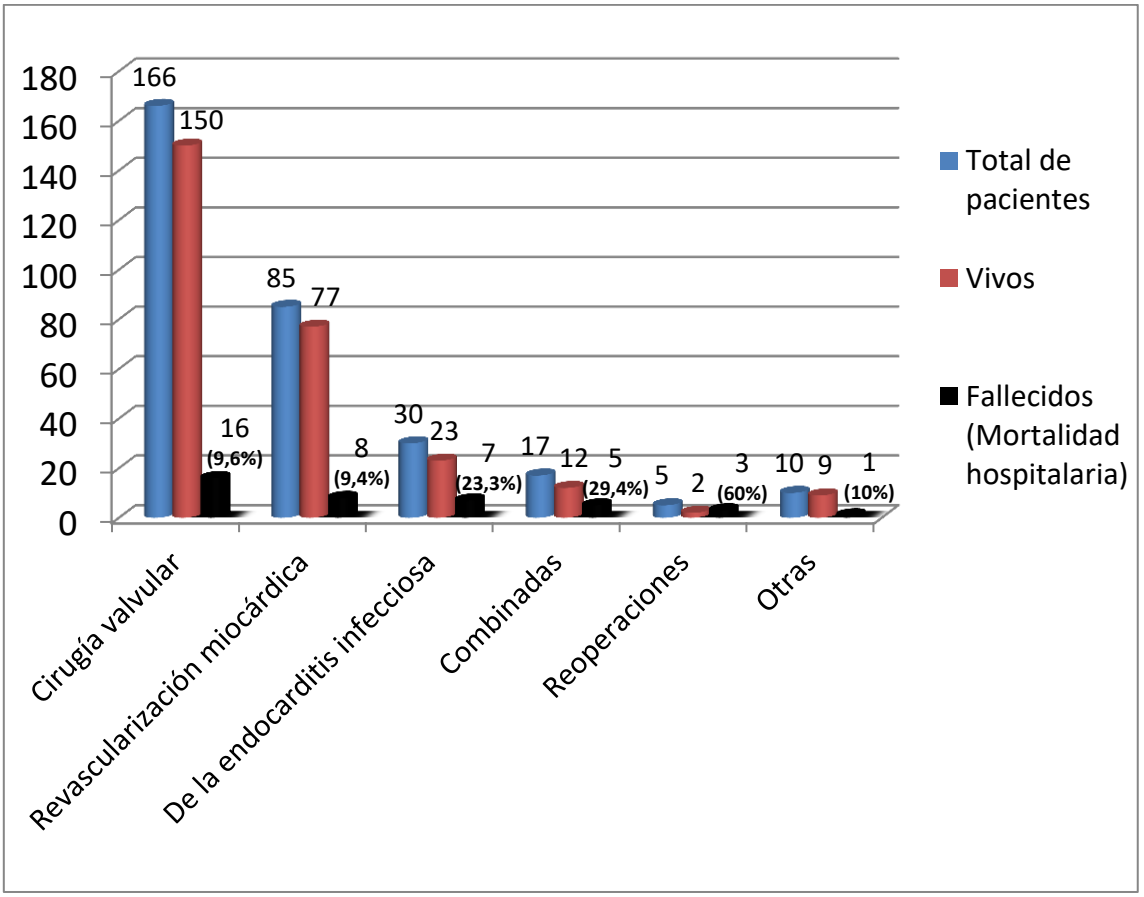


Figure 2- In-hospital mortality according to the different types of cardiac surgery performed during the study period

Table 1- Association between preoperative variables and hospital discharge status

Preoperative variables		Hospital discharge status						
		Alive		Deceased		Total		p
		Nro.	%	Nro.	%	Nro.	%	
HTN		169	87,1	25	12,9	194	62,0	0,942
Smoking		108	93,1	8	6,9	116	37,1	0,017
Obesity		67	85,9	11	14,1	78	24,9	0,686
Diabetes Mellitus		55	83,3	11	16,7	66	21,1	0,287
PH		47	81,0	11	19,0	58	18,5	0,118
CKD		19	76,0	6	24,0	25	8,0	0,000
COPD		19	79,2	5	20,8	24	7,7	0,219
Preoperative length of hospital stay	Less than 21 days	225	86,9	34	13,1	259	82,8	0,686
	21 days or longer	48	88,9	6	11,1	54	17,2	
Surgical priority	Urgent	21	60,0	14	40,0	35	4,8	0,001
	Elective	246	88,6	32	11,4	278	95,2	
Preoperative LVEF	Normal	239	90,9	24	9,1	263	84,0	0,000
	Reduced	34	68,0	16	32,0	50	16,0	

Source: Medical records registry
p: Chi-square test of homogeneity

Table 2- Association between intraoperative variables and hospital discharge status

Intraoperatives variables		Hospital discharge status						
		Alive		Deceased		Total		P
		Nro.	%	Nro.	%	Nro.	%	
Type of surgery	Valve surgery	147	90,2	16	9,8	163	52,1	0,000
	Myocardial revascularization	78	90,7	8	9,3	86	27,5	
	Surgery for infective endocarditis	25	78,1	7	21,9	32	10,2	
	Combinaded	12	70,6	5	29,4	17	5,4	
	Reoperations	2	40,0	3	60,0	5	1,6	
	Other surgeries	9	90,0	1	10,0	10	3,2	
Use of CBP	Yes	233	85,7	39	14,3	272	86,9	0,033
	No	40	97,6	1	2,4	41	13,1	
Duration of CBP	Less than 120 min	106	92,2	9	7,8	115	36,7	0,002
	120 min or longer	127	80,9	30	19,1	157	50,2	
Use of ACC	Yes	185	85,7	31	14,3	216	69,0	0,214
	No	88	90,7	9	9,3	97	31,0	
Duration of ACC	Less than 90 min	97	92,4	8	7,6	105	33,5	
	90 min or longer	88	79,3	23	20,7	111	35,5	0,007

Source: Medical Records Registry
p: Chi-square test of homogeneity; min: minutes

Table 3- Association Between Postoperative Variables and Hospital Discharge Status

Posoperatives variables		Hospital discharge status						
		Alive		Deceased		Total		p
		Nro.	%	Nro.	%	Nro.	%	
Blood product transfusion	Yes	75	71,4	30	28,6	105	33,6	0,000
	No	198	95,2	10	4,8	208	66,4	
Duration of MV	Less tan 24 hours	232	95,9	10	4,1	242	77,3	0,000
	24 hours or longer	41	57,8	30	42,2	71	22,7	
Length of stay in the ICU	Less tan 24 hours	8	44,4	10	55,6	18	5,8	0,342
	24 hours or longer	265	89,8	30	10,2	295	94,2	

Source: Medical Records Registry
p: Chi-square test of homogeneity

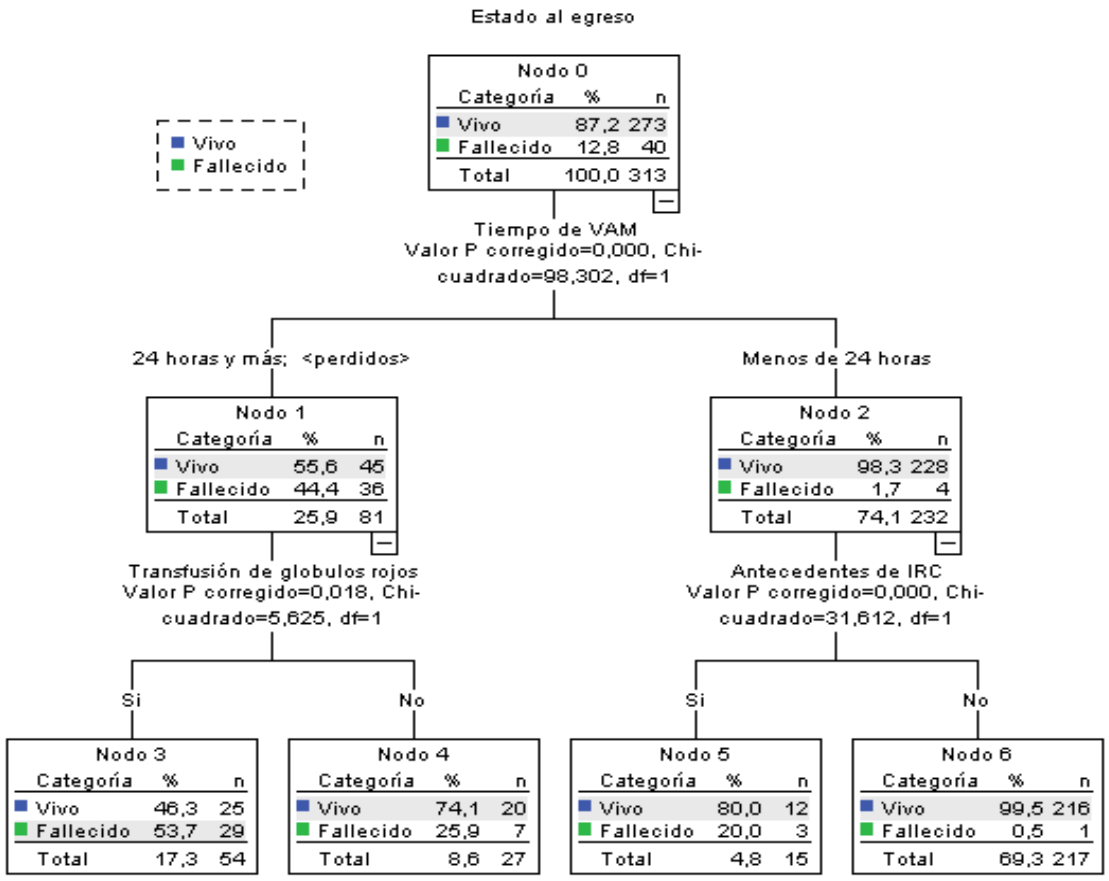


Figure 3- Classification tree for the risk of in-hospital mortality following cardiovascular surgery

Patients requiring MV for less than 24 hours had a probability of death of only 1.7%, which increased to 20% in patients with a history of CKD.

DISCUSSION:

During the study period, a high in-hospital mortality rate was observed. The devastating impact of the COVID-19 pandemic, the shortage of human resources, the high occupancy of intensive care units, the reduction in elective surgical activity, accompanied by increased patient complexity due to the prolonged progression of their diseases, were factors that contributed to these outcomes, not only in Cuba but also in other countries.[15]

According to Polo-Gutiérrez et al.[7] (Peru, 2022), in-hospital mortality was low among patients undergoing elective cardiovascular surgery, at 2.8%; however, it increased to 14.3% in emergency procedures, a rate similar to that observed in the present study, which, as shown in **figure 1**, was 12.8%. It is worth noting that a considerable number of emergency surgical procedures (35) were indicated during the study period, as shown in **table 1**.

A lower in-hospital mortality rates (8.75%) was reported in Mexico by Castañeda E. et al.[2] In Spain, during a period similar to that of the present study, an increase in overall in-hospital mortality, as well as in-hospital mortality by type of surgery, was reported across 60 participating hospitals.[15] Another Cuban study, conducted during a different period and under different circumstances, without the substantial impact of COVID-19, reported an overall in-hospital mortality rate of 8.4%, lower than that observed in the present study.[5] Similarly, a study conducted in Chile during another period reported an overall in-hospital mortality rate of 6.5%.[8]

The most frequently performed surgical procedures were valve surgery, followed by myocardial revascularization, as illustrated in **figure 2**. This distribution is consistent with reports from other authors.[2, 6, 8, 15]

In-hospital mortality across the different types of surgical procedures performed (**Figure 2**) was also high during the reported period, for the reasons previously discussed. Mortality rates for valve surgery and myocardial revascularization were 9.6% and 9.4%, respectively. In both groups, patients presented with advanced disease stages, severely compromised functional status, heart failure, and unstable angina. The remaining procedures showed higher mortality rates; however, most were performed on an emergency basis. These included surgical procedures for infective endocarditis, reoperations, and other interventions involving cardiac myxomas and one case of aortic dissection, all conditions associated with high expected mortality rates.

During a different period from that of the present study, the Instituto Nacional de Cardiología "Ignacio Chávez" in Mexico reported in-hospital mortality rates of 7.9% for valve surgery and 4.9% for myocardial revascularization. These were also the most frequently performed procedures, although both were associated with lower mortality rates.[6]

During a period, comparable to that of the present investigation, data from 60 hospitals in Spain showed in-hospital mortality rates of 3.61% for single-valve surgery and 10.09% for multivalve surgery. Among the surgical procedures included in the present study, valve surgery was not further subclassified; therefore, a comparison cannot be established. Nevertheless, when multiple valves were involved, figures similar to those observed in this study were reported. However, the in-hospital mortality rate for myocardial revascularization in the present study (9.4%) was high compared with the rate reported in the Spanish study (only 2.83%), even under the challenging circumstances of the pandemic.[15] Similarly, the report from the Instituto Nacional de Cardiología "Ignacio Chávez" did not further classify valve surgery according to the number of valves involved.[6]

The in-hospital mortality rate for combined procedures in the present study was high (29.4%). Other authors have reported considerably lower rates; for example, a study conducted in Peru reported a rate of 6.9%[7], which was very similar to the 6.34% reported in the Spanish registry.[15]

By combining different variables, a classification tree makes it possible to estimate mortality risk and use this information to guide future clinical decision-making. For the multivariate analysis used to construct the classification tree, the risk factors showing the strongest associations with discharge status were introduced, based on the bivariate analysis of preoperative, intraoperative, and postoperative variables, which are presented in **Tables 1**, **2**, and **3**, respectively.

Among the preoperative variables, only CKD was retained in the multivariate analysis and incorporated into one of the classification tree nodes. This risk factor has also been reported in other studies reviewed, although it is often described in terms of elevated serum creatinine levels or the need for hemodialysis, and has been associated with mortality.[3, 6]

Among the remaining preoperative variables, Martínez et al.[5] found a significant association between in-hospital mortality and LVEF. This variable has also been reported by other au-

thors as being associated with and predictive of in-hospital mortality, although exclusively in patients undergoing coronary surgery.[11]
Castañeda et al.[2] reported that a shorter preoperative hospital stay was significantly associated with mortality, contrary to what might be expected. As in the present study, they also found no association between mortality and COPD or diabetes mellitus.
In the present study, surgical priority showed a significant association with mortality, although it was not retained in the classification tree analysis because of the interaction among variables. Nevertheless, other studies have also reported this association.[6]
In the multivariable analysis, none of the intraoperative variables that were significantly associated with in-hospital mortality were selected as classification variables in the tree.
Among the postoperative variables, MV duration showed the strongest association with in-hospital mortality; therefore, it constituted the node closest to the root of the classification tree. Castañeda et al.[2] also found an association between mortality and MV duration in their bivariate analysis, although this variable was not retained in their multivariate model.
Blood product transfusion is associated with the occurrence of complications, particularly infectious complications, since transfusions may transmit pathogens and also affect immune function. Furthermore, transfusion is associated with acute lung injury, particularly following plasma transfusion, and has been linked to increased mortality.[16]
Classification trees represent an excellent tool for clinical decision-making and prediction, particularly when they correctly classify a high proportion of the study sample, as was the case in the present investigation.[13]
According to the classification tree developed in this study, MV lasting more than 24 hours should be avoided. Therefore, fast-track recovery protocols and strategies to prevent blood product transfusions are essential, particularly in patients with a history of CKD, in whom the risk of death increases even with shorter durations of MV.

CONCLUSIONS:

Risk factors associated with mortality were identified in the study sample, particularly smoking, CKD, emergency surgery, preoperative LVEF, duration of MV, and blood product transfusion.
Based on the classification according to MV duration (greater than or less than 24 hours), the risk of in-hospital mortality increases as mechanical ventilation is prolonged and when it is associated with blood product transfusion or CKD.

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Gustavo de J. Bermúdez Yera: conceptualization, research, data curation, original draft writing, supervision.
Gualberto Luna Cáceres, Jannet Y. Ramos Flores, Daniel Hernández Torres, José R. Valdés González: supervision, validation, writing - review and editing.
Gustavo de J. Bermúdez Yera, Margarita Puerto Díaz: methodology, writing - review and editing.
Margarita Puerto Díaz: formal analysis, data curation, methodology.

