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Proposal and validation of a predictive model of in-hospital mortality in patients with infective endocarditis

Propuesta y validación de un modelo predictivo de mortalidad hospitalaria en pacientes con endocarditis infecciosa

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Abstract:
Introduction: Infective endocarditis is a potentially fatal disease with a complex diagnosis. Despite advances in prevention, diagnosis, and treatment, its mortality rate remains high. Objective: To develop a predictive model for in-hospital mortality in patients with infective endocarditis. Method: An observational, analytical study was conducted at the Institute of Cardiology and Cardiovascular Surgery between January 2018 and December 2024. Eighty-one adult patients with infective endocarditis were included. A logistic regression model was developed, and the NAIPES score was constructed from its predictors. Discriminative capacity was assessed using the area under the receiver operating characteristic (ROC) curve, and its internal validity was assessed using bootstrap method. Results: Eighty-one patients were studied, predominantly male with 71.6%. In-hospital mortality was 29.6%. The main variables associated with mortality were heart failure, shock, neutrophilia, and embolic complications. The NAIPES score incorporated six variables and showed high discriminatory capacity, with a sensitivity of 95.8%, specificity of 59.6%, and the area under ROC curve in 0.942 (95% CI: 0.877–0.996; p < 0.001). In internal validation, the mean bootstrap area was 0.944 and corrected area was in 0,941 and the mean value for optimism was 0.001. Conclusions: The NAIPES score showed high discriminatory capacity and maintained its performance after internal validation. External validation is required before its clinical implementation.
Keywords: infective endocarditis; in-hospital mortality; predictive model; risk stratification.

RESUMEN
Introducción: La endocarditis infecciosa es una enfermedad potencialmente letal y de diagnóstico complejo. A pesar de los avances en prevención, diagnóstico y tratamiento, su mortalidad continúa elevada. Objetivo: Desarrollar un modelo predictivo de mortalidad hospitalaria en pacientes con endocarditis infecciosa. Método: Se realizó un estudio observacional, analítico, en el Instituto de Cardiología y Cirugía Cardiovascular, entre enero de 2018 y diciembre de 2024. Se incluyeron 81 pacientes adultos con endocarditis infecciosa. Se desarrolló un modelo de regresión logística y se construyó el *score* NAIPES a partir de sus predictores. La capacidad discriminativa se evaluó mediante el área bajo la curva operador receptor (ROC) y su validación interna mediante el método bootstrap. Resultados: Se estudiaron 81 pacientes. Hubo predominio del sexo masculino con el 71,6 %. La mortalidad hospitalaria fue de 29,6 %. Las principales variables asociadas a mor-

talidad fueron insuficiencia cardíaca, *shock*, neutrofilia y complicaciones embólicas. El s*core* NAIPES incorporó seis variables y mostró elevada capacidad discriminativa, con sensibilidad de 95,8 %, especificidad de 59,6 % y área bajo la curva ROC de 0,942 (Intervalo de confianza del 95 %: 0,877–0,996; p < 0,001). En la validación interna, esta área tuvo una media de 0,944 que corregida estuvo en 0,941 y el optimismo medio fue de 0,001. Conclusiones: El *score* NAIPES mostró elevada capacidad discriminativa y estabilidad interna para la estratificación del riesgo de mortalidad hospitalaria. Se requiere validación externa antes de su implementación clínica.

Palabras clave: Endocarditis infecciosa; Mortalidad hospitalaria; Modelo predictivo; Estratificación de riesgo.

INTRODUCCIÓN

Infective endocarditis is a life-threatening disease that is difficult to diagnose. Despite advances in prevention, diagnosis and treatment; neither its incidence nor its mortality rate has declined substantially over the past 30 years. This situation is largely attributable to changes in the epidemiological and microbiological profile of the disease.[1–4]

In Cuba, infective endocarditis has specific characteristics related to the structure of the healthcare system and the centralization of complex cases to tertiary care institutions. Studies conducted at individual hospitals have reported a predominance of male patients and a mean age exceeding 50 years, together with a high prevalence of healthcare-related cases and the presence of prosthetic material. Reported mortality rates in Cuban case series range from 8% to 30%.[1,4,6,7]

Since 2007, several predictive models and risk scores have been developed to try to estimate in-hospital mortality among patients with infective endocarditis.[8,9] These tools incorporate clinical, microbiological and hemodynamic parameters.

Among these models, the Costa score, developed in Brazil, was designed using a retrospective study of 186 patients with definite infective endocarditis. It incorporates seven predictors of in-hospital mortality. [10]

The PALSUSE score includes the presence of a prosthetic valve, age ≥70 years, extensive intracardiac destruction, *Staphylococcus spp*., emergency surgery, female sex and an EuroSCORE ≥1. This score allows to predict in-hospital mortality with acceptable accuracy.[8,11,12] However, it has not been validated in other populations.

Another model is the SHARPEN score, whose name is derived from the following variables: Systolic blood pressure, Heart failure, Age, Elevated creatinine, Pneumonia, Elevated peak C-reactive protein level and No history of intrave nous drug use. It was developed from a unicenter study conducted in Singapore that included 233 patients with definite infective endocarditis over an 11-year period.[13]

The ICE score, derived from the International Collaboration on Endocarditis cohort, incorporates variables such as age, heart failure, microbiological etiology and the presence of intracardiac complications. It has been used to predict short- and intermediate-term mortality. [14]

Moreover, the EuroSCORE II is used to estimate surgical risk in patients requiring valve surgery,[8] whereas the Charlson Comorbidity Index assesses the impact of co-existing diseases on long-term survival.[15]

More recently, Wei *et al*.[16] developed the ASSESS-IE score, based on a cohort of 1 549 patients in China enrolled between 2009 and 2020. Six variables were identified as independent predictors of in-hospital mortality: clinical evolution of less than one month, prosthetic valve, New York Heart Association (NYHA) functional class III–IV, elevated direct bilirubin levels, anemia and aortic valve involvement. As with some of the previously described models, external validation in other populations is required.

Despite the availability of several predictive models, their applicability may vary according to the epidemiological, clinical and healthcare-related characteristics of each population. Furthermore, none of the aforementioned international scores has been validated in the Cuban population. Therefore, developing a predictive tool tailored to the national context results of clinical interest. The aim of this study was to develop a predictive model for in-hospital mortality in patients with infective endocarditis.

MÉTODO

An observational, analytical study was conducted, using a retrospective review of the medical records of a cohort of patients treated at the *Instituto de Cardiología y Cirugía Cardiovascular,* between January 2018 and December 2024.

Inclusion criteria: Patients older than 18 years who were admitted during the study period, who met the criteria for definite or possible infective endocarditis according to the Duke criteria modifications[17]; as well as those who had complete medical records containing clinical, microbiological and echocardiographic information.

Exclusion criteria: Patients with incomplete medical records and those transferred to another institution before completion of clinical follow-up.

All eligible cases identified during the study period were included using total population sampling. The final study sample comprised 81 patients.

A data collection form was developed based on a review of the relevant literature and available sources. The form included the study variables, which were classified as follows:

1. Dependent: Status at hospital discharge, classified as alive or deceased. In-hospital mortality was the primary study outcome.
2. Independent: Age ≥65 years, sex, comorbidity burden (presence of two or more comorbidities), prosthetic valve endocarditis (presence of infective endocarditis involving a prosthetic heart valve), anemia, neutrophilia, blood culture results (positive or negative), presence of *Staphylococcus aureus* (*S. aureus*) in blood cultures, heart failure, shock (septic, cardiogenic, or mixed), surgical treatment (received or not), antimicrobial treatment duration of less than four weeks, renal complications, embolic complications, neurological manifestations at admission, site of infection acquisition (healthcare-associated or community-acquired) and high-risk echocardiographic findings.

Missing data management: A complete-case analysis was performed. Because the inclusion criteria required complete medical records containing clinical, microbiological and echocardiographic data; no missing data was identified in the final study cohort (n = 81).

Data collection.

Data was obtained through a review of medical records and recorded using a study-specific data collection form based on the previously defined variables. The information was entered into an electronic database, and patient confidentiality was maintained.

Statistical analysis.

Data was analyzed using Statistical Package for the Social Sciences (SPSS) software, version 27.0; and R software, version 3.6.3.

Descriptive statistics for categorical variables were reported as frequencies (percentages). To assess the association between individual factors and patient status at discharge, each variable was categorized according to predefined operational definitions.

Bivariate analyses were performed using the two-sided chi-square test, with a significance level of $p < 0.05$. The phi-coefficient was calculated in each case to quantify the strength of the association between each factor and patient status at discharge. Multivariable binary logistic regression was used to identify variables associated with in-hospital mortality. Variables with $p \leq 0.10$ in the bivariate analysis, as well as those considered clinically relevant, were considered candidates for inclusion in the model.

Before constructing the multivariable model, potential multicollinearity among predictor variables was assessed using the variance inflation factor (VIF), tolerance and condition index. A tolerance value <0.20 and/or a VIF >5 was considered indicative of relevant multicollinearity.

To develop a clinically practical tool, an additive scoring model was constructed using the predictors included in the multivariable model. The β coefficients of variables that did not exhibit separation were transformed by normalization relative to the smallest absolute coefficient. Because separation was observed for shock and neutrophilia in the conventional model, clinically weighted point assignments were established for these variables using a clinical truncation criterion, rather than directly incorporating their unstable estimates.

As a sensitivity analysis, penalized logistic regression was performed using the AS_mean estimator (mean bias-reducing adjusted score) implemented in the brglm2 package. This approach, based on Firth's logistic regresion, was used to assess the stability of the estimates in the presence of separation.

Internal validation of the model was performed using 1 000 bootstrap resamples to estimate optimism in discrimination, measured by the area under the receiver operating characteristic (ROC) curve, and predictive performance, assessed using the Brier score.

The logistic regression model and the *NAIPES* score were validated independently because the latter is an additive scoring system with fixed weights derived from the model. The internal validity of the *NAIPES* score was assessed using 1 000 bootstrap replicates. In each replicate, 81 observations were sampled with replacement, and the score was calculated using the prespecified weights assigned to its six components.

Discriminative capacity was assessed using the area under the ROC curve. Optimism was calcu-

lated as the difference between the area obtained in each resample and the one obtained by applying the same score to the original cohort. The corrected area was calculated by subtracting the mean optimism from the apparent area. The 95% confidence interval was estimated using the 2.5th and 97.5th percentiles of the bootstrap distribution.

Model calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test. Nagelkerke's R^2 was calculated as a measure of model fit.

The optimal cutoff progression point was determined using Youden's index. However, clinical sensitivity was prioritized when selecting the cutoff point to favor the identification of patients at high risk.

For risk stratification, patients were classified into three risk categories (low, moderate, and high) based on the observed distribution of mortality across score values. The validity of this risk was assessed using the chi-square test for linear trend (linear-by-linear association). A p value <0.05 was considered statistically significant.

The results were expressed as odds ratios (ORs) and risk ratios (RRs), with their corresponding 95% confidence intervals (CIs). A p value <0.05 was considered statistically significant. In the bivariate analysis, RRs were used because they provide a more direct clinical interpretation of the magnitude of the association between each factor and mortality. It is more intuitive and avoids overestimating associations, particularly when the outcome is common. In the multivariable analysis, binary logistic regression was employed, for which the natural estimator measure is the OR, as this model estimates odds rather than risks. When outcomes are common, ORs may differ substantially from RRs and may overestimate the magnitude of the association.

The study was reported in accordance with the TRIPOD+AI (Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis + Artificial Intelligence)[18] guidelines for the development and validation of clinical prediction models.

Ethical considerations:

The study was conducted in accordance with the principles of the Declaration of Helsinki of the World Medical Association, including its latest revision, adopted at the 75th World Medical Association General Assembly in October 2024[19]. The protection of patients' life, health, dignity, integrity, privacy and confidentiality of personal information was ensured. The study protocol was reviewed and approved by the Ethics Committee of the *Instituto de Cardiología y Cirugía Cardiovascular*.

RESULTS

Table 1 presents the general characteristics of the study population. The mean age was 58 years, and 63% of patients were younger than 65 years. Male patients predominated, accounting for 71.6% of the cohort. In-hospital mortality was high, with 24 deaths (29.6%). Prosthetic valve endocarditis was a prevalent characteristic of the study population and was associated with mortality. Most patients presented with fever, and a substantial proportion experienced nonspecific symptoms. Although heart failure occurred in only 19.8% of patients, it was an important factor. Blood cultures were negative in 64.2% of patients. Among patients with positive blood cultures, *Staphylococcus aureus* was a notable pathogen. High-risk echocardiographic findings were frequent and played an important role in decision-making. Anemia and neutrophilia were prominent hematological abnormalities. Surgical treatment was required in 46.9% of patients. Some patients did not receive the required four-week course of antimicrobial therapy, a circumstance associated with mortality. Renal and cardiovascular complications were prevalent, while shock and embolic events were also important complications.

Bivariate analysis of risk factors (Forest Plot)

The bivariate analysis assessed the association of clinical, microbiological and paraclinical variables with in-hospital mortality by calculating RRs and their corresponding 95% confidence intervals (CIs); as shown in Figure 1.

Shock showed the strongest association with in-hospital mortality (RR = 9.14), for a CI of 95 % with statistical significance. Neutrophilia was also associated with an increased risk of mortality (RR = 7.07), likewise reaching statistical significance. However, the 95% CI was wider, indicating lower precision of the estimate.

Regarding clinical complications and therapeutic management, heart failure and embolic complications were each associated with more than a threefold increase in mortality risk, and both associations were highly statistically significant.

Antimicrobial treatment lasting less than four weeks was also identified as a relevant contributing factor, with an RR of 3.31 and a relatively narrow 95% CI. This association should be interpreted cautiously because of the possibility of reverse causation: early death may prevent completion of antimicrobial therapy, making shorter treatment duration a marker of disease severity rather than a causal factor.

Regarding the microbiological and infectious profile, both the isolation of *Staphylococcus aureus* and blood culture-positive were significantly associated with higher in-hospital mortality. Similarly, healthcare-associated infection

was significantly associated with the outcome. In all these cases, the risk of death increased more than twofold.

Notably, neurological manifestations at admission were associated with an estimated increase in mortality risk of more than twofold; however, this association did not reach statistical significance, as the p value exceeded 0.05.

Finally, the presence of two or more comorbidities, high-risk echocardiographic findings, renal complications and surgical treatment did not show a significant association. Their respective 95% CIs included null value. Demographic factors, including age ≥65 years, also failed to demonstrate being determinant of risk in the bivariate analysis.

The presence of a prosthetic valve showed a trend toward increased mortality risk, although the association did not reach conventional statistical significance. Nevertheless, given its clinical relevance and the available evidence regarding its potential association with the prognosis of infective endocarditis, this variable was retained as a candidate for inclusion in the multivariable logistic regression model.

Development and validation of the predictive mortality score

Following multivariable analysis (Table 2), a conventional logistic regression model was developed and its performance evaluated. The model included six predictors: heart failure, shock, neutrophilia, *Staphylococcus aureus* infection, prosthetic valve and embolic complications. No evidence of substantial multicollinearity was identified among the included variables, with tolerance values ranging from 0.71 to 0.92, VIF values ranging from 1.08 to 1.42, and a maximum condition index of 5.51. However, complete separation was observed for shock and neutrophilia; therefore penalized logistic regression with bias reduction was performed using the AS_mean estimator (mean bias-reducing adjusted score) implemented in the brglm2 package, based on Firth's logistic regresion, to assess the stability of the estimates in the presence of separation.

The discriminative performance of the logistic regression model was assessed using the area under the ROC curve, which was 0.951 (95% CI, 0.894–1.000). At a predicted probability cutoff point of ≥0.80, sensitivity was 87.5% and specificity was 94.7%.

Internal validation using 1 000 bootstrap resamples yielded a mean optimism of 0.033 and an optimism-corrected area under the ROC curve of 0.917 (bootstrap interval: 0.844–0.986). The Brier score for the original model was 0.048. Bootstrap internal validation yielded a mean optimism of −0.023 and an optimism-corrected Brier score of 0.071. Because the Brier score is a measurement error, lower values indicate better predictive performance. The increase observed after optimism correction reflects adjustment for the estimated optimism in the derived sample.

Presentation of the *NAIPES* score

This study proposes the *NAIPES* score, a simplified additive scoring system based on the six predictors identified in the logistic regression model. Points were assigned through proportional transformation of the β coefficients for variables that did not exhibit separation, whereas shock and neutrophilia were assigned prespecified clinically weighted points because of the instability of their estimates in the conventional model. The acronym *NAIPES* encompasses six clinical and biological domains (Neutrophilia, *Staphilococcus aureus*, Heart Failure, Prosthetic Valve, Embolism and Shock) associated with the prognosis of infective endocarditis.

The score had a theoretical range of 0–16 points. In the study cohort, observed scores ranged from 0 to 14 points, as shown in Table 3.

The assignment of five points to shock was based on the strong association observed in the bivariate analysis and the concentration of mortality events among patients who experienced this complication. As shown in Figure 2, the distribution of shock differed markedly between survivors and nonsurvivors, supporting its greater weighting within the *NAIPES* score.

To facilitate clinical interpretation, the *NAIPES* score was applied to all 81 patients, who were subsequently classified into three risk strata, as presented in Table 4. The cutoff points were established at the 45th and 85th percentiles according to the observed distribution of events. An increasing linear trend in in-hospital mortality was observed with increasing scores.

Following transformation of the coefficients into an additive scoring system, the *NAIPES* score retained high discriminative capacity, with an area under the ROC curve of 0.942, as shown in Figure 3. Internal validation using 1 000 bootstrap replicates yielded a mean area of 0.944 and mean optimism of 0.001. After optimism correction, the estimated area under the ROC curve was 0.941, indicating minimal loss of discriminative performance relative to the apparent estimate. The *NAIPES* score had a Nagelkerke´s R^2 of 0.762, lower than that of the original multivariable model (0.824), consistent with model simplification to enhance clinical applicability.

Table 1- Characteristics of patients with infective endocarditis

Characteristic	Total (%) (n = 81)	Deceased (%) N = 24 (29.6)	Alive (%) N = 57 (70.4)	p-value
Age				0,484*
Mean age (years)	58			
Less than 65 years	51 (63,0)	17(33,3)	34(66,7)	
Age≥ 65	30 (37,0)	7(23,3)	23(76,7)	
Sex				0,363*
Male	58 (71,6)	15(25,9)	43(74,1)	
Female	23 (28,4)	9(39,1)	14(60,9)	
Specific characteristics				0,475*
Native valve endocarditis	31 (38,3)	10(32,3)	21(67,7)	
Prosthetic valve endocarditis	33 (40,7)	11(33,3)	22(66,7)	
Cardiac device-associated endo-carditis	17 (21,0)	3(17,6)	14(82,4)	
Healthcare-associated	27 (33,3)	12(44,4)	15(55,6)	0,071*
Community-acquired	54 (66,7)	12(22,2)	42(77,8)	
Clinical manifestations at ad-mission				
Fever	71 (87,7)	18(25,4)	53(74,6)	0,057**
General syndrome	42 (51,9)	7(16,7)	35(83,3)	0,016*
Cardiac murmur	39 (48,2)	13(33,3)	26(66,7)	0,646*
Heart failure	16 (19,8)	11(68,8)	5(31,2)	<0,001**
Neurological manifestations	11 (13,6)	6(54,5)	5(45,5)	0,075**
Microbiological profile				0,013*
Blood culture-negative	52 (64,2)	10(19,2)	42(80,8)	
Blood culture-positive	29 (35,8)	14(48,3)	15(51,7)	
. *Staphylococcus aureus*	14 (48,3)	9(64,3)	5(35,8)	
. Gram-negative bacteria	8 (27,6)	2(25)	6(75)	
. Other Gram-positive	7 (24,1)	3(42,8)	4(57,2)	
Echocardiographic findings				0,324*
High-risk	49(60,5)	17(34,7)	32(65,3)	
Low-risk	32(39,5)	7(21,9)	25(78,1)	
Analytical abnormalities				
Neutrophilia	62 (76,5)	23(37,1)	39(62,9)	0,018*
Anemia	60 (74,1)	18(30)	42(70)	1,000*
Treatment				0,545*
Surgical	38 (46,9)	13(34,2)	25(65,8)	
Medical	43 (53,1)	11(25,6)	32(74,4)	
Treatment duration <4 weeks	51 (67,9)	21(41,2)	30(58,8)	
Complications				
Renal complications	47 (58,0)	16(34)	31(66)	0,438*
Cardiovascular complications	43 (53,1)	16(37,2)	27(62,8)	0,179*
Shock	17 (21,0)	17(100)	0(0)	<0,001**
Embolic complications	9 (11,1)	7(77,8)	2(22,2)	0,002**

*** Pearson's chi-square test, ** Fisher's exact test. Fisher's exact test was used when any expected recount was <5.**

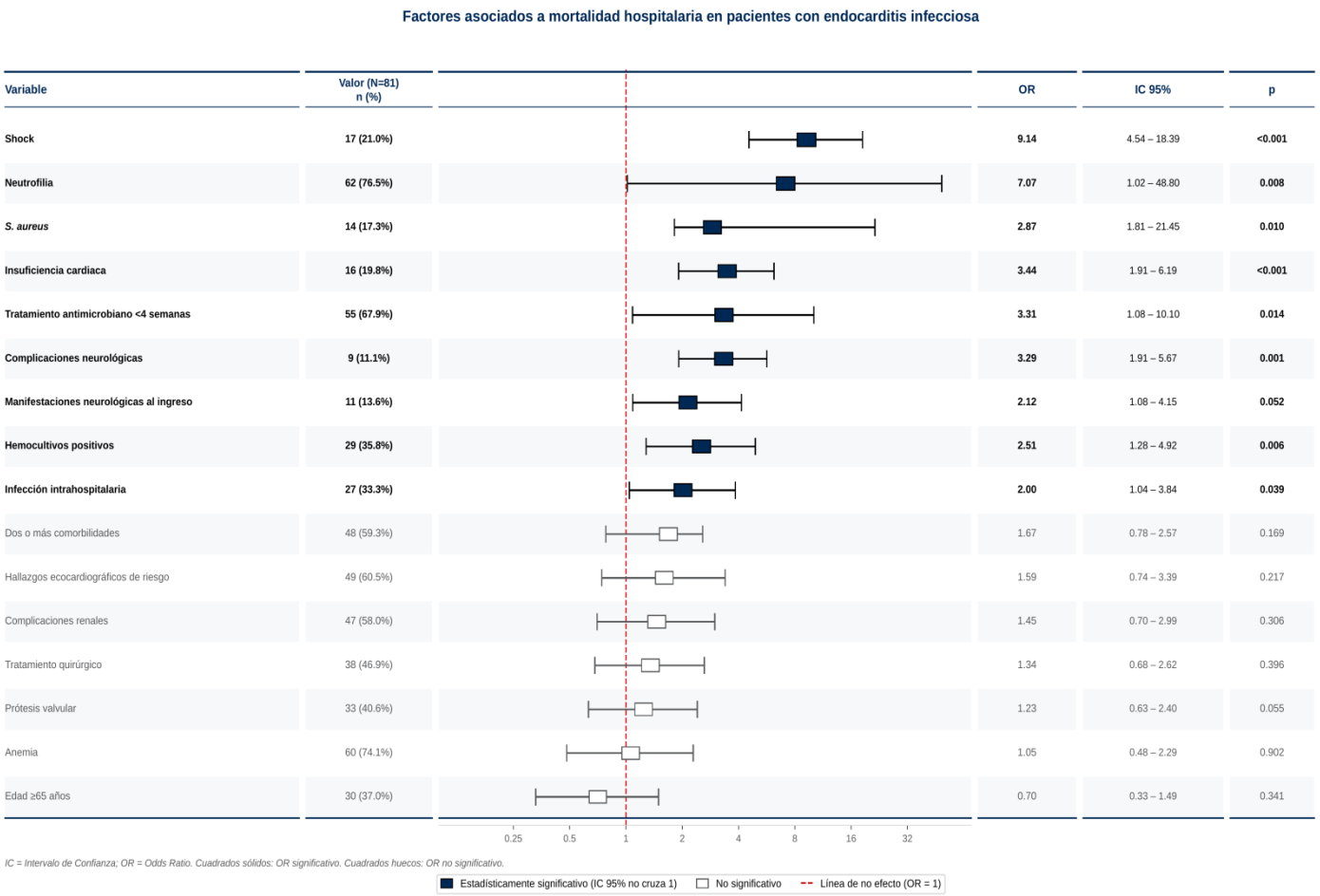


Figure 1: Bivariate analysis of factors associated with in-hospital mortality (Forest Plot).

The maximum cutoff point with Youden's index (J = 0.774, sensitivity: 79%, specificity: 98%) was six points, representing the best balance between sensitivity and specificity. However, for clinical application of the *NAIPES* score, a cutoff value of five points was selected to prioritize sensitivity (95.8%) over specificity (59.6%). This approach favors the early identification of high-risk patients and reduces the likelihood of false-negative classifications during initial triage. The performance measures used to evaluate the score are presented in Table 5.

This stratification revealed a progressive increase in mortality with higher scores. Patients classified as low risk had more favorable outcomes, whereas those with scores ≥5 accounted for a greater proportion of fatal events. Mortality in the high-risk stratum was 100% in this cohort.

The Hosmer–Lemeshow test for the *NAIPES* score showed no evidence of a significant discrepancy between observed and expected frequencies (χ^2 = 1.738, p = 0.942). Nevertheless, this finding should be interpreted cautiously because of the separation observed during development of the derivative model and the instability of calibration estimates identified in the bootstrap resamples.

DISCUSSION

In the study cohort, shock was identified as one of the main factors associated with in-hospital mortality, highlighting the importance of hemodynamic compromise in determining the prognosis of patients with infective endocarditis. This finding is consistent with the inherent clinical severity of shock, which reflects advanced circulatory compromise and may be accompanied by multiorgan dysfunction. Recent studies have reported high mortality rates among patients with infective endocarditis who develop shock, supporting the magnitude of the association observed in this cohort.[20–22]

Heart failure is associated with a poorer prognosis in patients with infective endocarditis. This relationship may be explained by infection-related valve destruction and the resulting acute valve regurgitation, which can contribute to progressive organ dysfunction and death.[21–24]

Comparison of the present findings with those reported by Habit *et al*.[25] and Seguel *et al*.[1] reveals consistency with the progressive epidemiological shift in infective endocarditis, characterized by an increasing contribution of *Staphylococcus aureus* as a causative pathogen in more acute and severe presentations. The findings of the present study, together with the

available literature, support the relevance of this microorganism, which is characterized by high virulence, rapid disease progression and an increased incidence of systemic complications.[22,26,28]

Table 2 Multivariable analysis of factors associated with in-hospital mortality using conventional and bias-reduced logistic regression

Variable	Conventional logistic regression			Bias-reduced regression (AS_mean)**		
	OR	IC 95%	p	OR	IC 95%	p
Heart failure	5,70	(0,29-111,6)	,251	3,61	(0,37–35,51)	0,272
Shock	>999*	(0,00-Inf)	,997	220,86	(9,99–4881,70)	<0,001
Neutrophilia	>999*	(0,00-Inf)	,997	4,95	(0,34–71,44)	0,240
S. aureus	2,94	(0,31-27,6)	,345	2,64	(0,35–19,75)	0,345
Prosthetic valve	2,21	(0,19-25,72)	,527	1,45	(0,23–9,21)	0,691
Embolic complications	34,64	(1,58-758,9)	,024	13,88	(1,24–155,51)	0,033

Abbreviations: p: statistical significance, OR: odds ratio, 95 % CI: 95 % confidence interval, *S. aureus*, *Staphylococcus aureus*

Interestingly, blood culture-positive were associated with a significant RR of 2.51 (p = 0.006). This finding may appear counterintuitive, as negative cultures would be expected to have a poorer prognosis because of diagnostic delays and the greater reliance on empirical therapies, as reported in many published studies.[28,29] However, some authors[22] have noted that when the culture is positive for organisms such as the *Staphylococcus aureus*, may substantially increase the risk of death. In the present cohort, blood culture-positive were associated with more acute and critical presentations. Among positive isolates, *Staphylococcus aureus* accounted for 48.3% and Gram-negative organisms accounted for 27.6%. Conversely, culture-negative cases may have included more subacute presentations modified by prior antimicrobial therapy.

Embolic complications were also associated with a poorer prognosis, consistent with studies identifying embolic events as markers of increased mortality risk.[22,30,31] In this context, neurological manifestations at admission showed a trend toward statistical significance. The magnitude of the observed association supports considering these variables clinically relevant when assessing patients at initial presentation.[22,32]

Although neutrophilia has not been consistently evaluated as a predictor of mortality in infective endocarditis, its association with severe septic states has previously been described, supporting its potential value as a marker of disease severity. González *et al.*[33], Sari *et al.*[34] and Arruda *et al.*[35] have investigated the prognostic significance of the neutrophil-to-lymphocyte ratio in both infectious and non-infectious diseases. However, evaluating neutrophilia itself as a factor associated with in-hospital mortality provides more precise data on the dysregulated immune response in infective endocarditis. The mortality risk associated with neutrophilia in the present study may reflect an intense systemic inflammatory response and help identify patients with greater clinical severity. This finding differs from that of Siciliano *et al.*[36], whose study did not include neutrophilia among the biomarkers used to predict mortality.

Table 3- Point allocation for the *NAIPES* mortality risk score

Clinical factor	Points assigned
Shock	5
Neutrophilia	4
Embolic complications	3
Heart failure	2
S. aureus	1
Prosthetic valve	1

Abbreviations: S. aureus: Staphylococcus aureus

Antimicrobial treatment lasting less than four weeks was associated with higher in-hospital mortality, a finding that might initially be interpreted as a consequence of insufficient treatment duration. Previous studies have also iden-

tified this factor as being associated with a poorer prognosis.[24] However, this association must also be interpreted in the context of early mortality, as the severity of the initial clinical presentation may prevent patients from completing the prescribed treatment regimen. In such cases, premature treatment discontinuation may result from early fatal evolution, a phenomenon known as reverse causation. Therefore, an antimicrobial treatment duration of less than four weeks may represent a marker of disease severity rather than an independent causal risk factor.

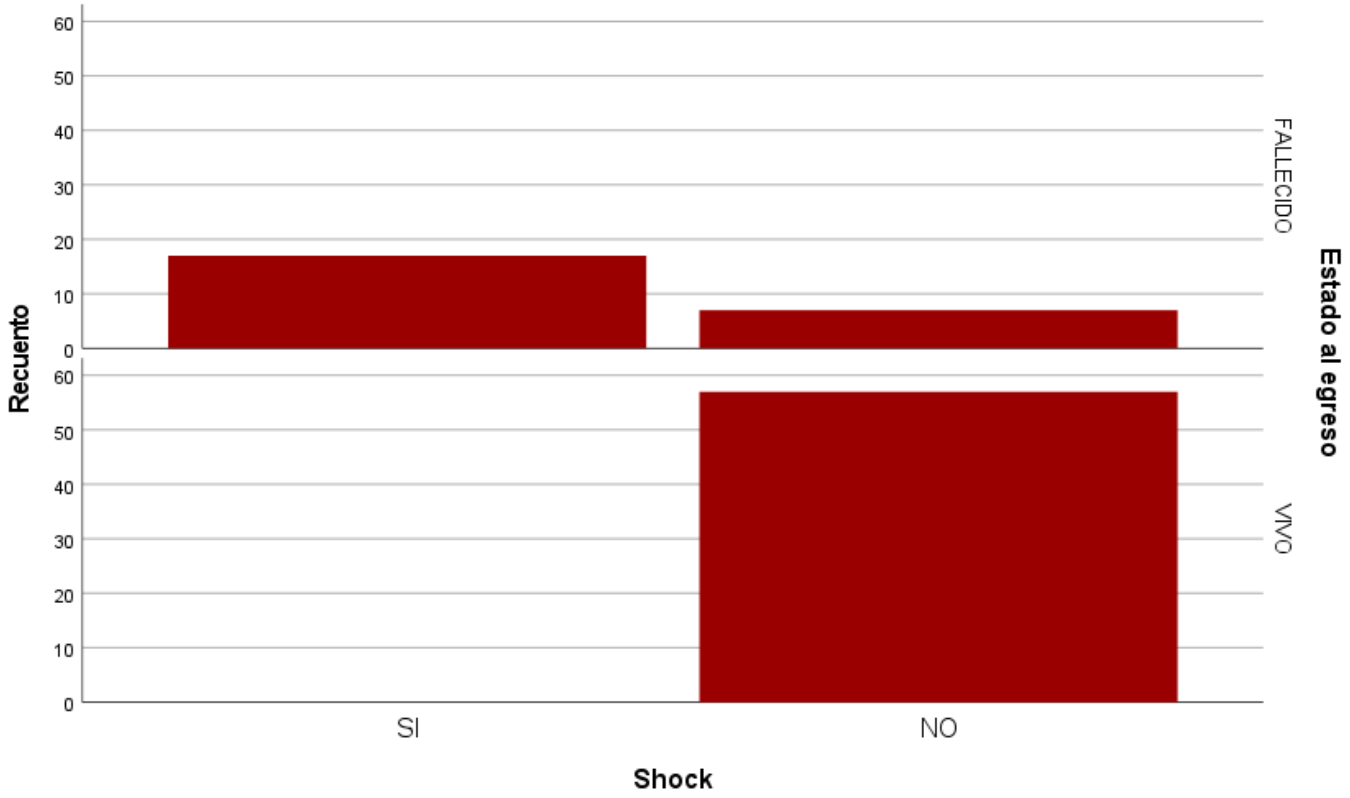


Figure 2: Distribution of mortality according to the presence of shock

Table 4- Risk stratification levels

Risk strata	Score	Mortality (%)	n/Total
Low risk	0 - 4	2,9	1/35
Intermediate risk	5 - 9	34,3	12/35
High risk	10 - 16	100	11/11
Linear-by-linear association: $\chi^2 = 35.66$, $p < 0.001$			

Healthcare-associated infection was associated with an increased risk of death, consistent with previous literature.[21] This association may be related to the microbiological and clinical profile of nosocomial endocarditis, which may involve more resistant pathogens, greater complexity of care and a higher burden of comorbidities.

Conversely, variables such as age ≥65 years, comorbidity burden, high-risk echocardiographic findings, renal complications and surgical treatment were not significantly associated with in-hospital mortality. Although these factors have been identified in other studies as being associated with the prognosis of infective endocarditis,[20,21,37–40] the absence of statistically significant associations in the present cohort may be related to the limited sample size, the distribution of events and the specific characteristics of the study population.

Interestingly, despite their high prevalence, renal complications did not reach statistical significance as a factor associated with in-hospital mortality. This finding may suggest that, in the present cohort, renal involvement was not independently associated with the outcome. However, the available data does not establish

whether renal complications primarily reflect systemic disease severity or contribute independently to mortality.

The *NAIPES* Score for In-Hospital Mortality Risk.

The *NAIPES* score was developed in response to the need for a simple and accessible risk stratification tool that can be applied early during hospitalization. It integrates clinical, microbiological and analytical variables available during the initial patient assessment to facilitate the identification of individuals at increased risk of in-hospital mortality.

Since 2007, several risk scores have been developed to predict in-hospital mortality in patients with infective endocarditis.[8,9] Most have focused on surgical treatment and therefore may not be directly applicable to estimating risk in patients managed with antimicrobial therapy. One such model is ANCLA,[41] published in 2017 and based on a retrospective review of 138 patients treated at an Italian cardiac surgery center between 1999 and 2015. Similarly, the RISK-E score[42], also published in 2017, was derived from a prospective cohort of 671 patients with infective endocarditis. Its development was restricted to patients who underwent surgery for definite left-sided infective endocarditis during the active phase of the disease. The STS-IE score[43], published in 2011, was developed in a large surgical cohort comprising 19 543 patients treated between 2002 and 2008; 70% of the patients were randomly selected for score development.

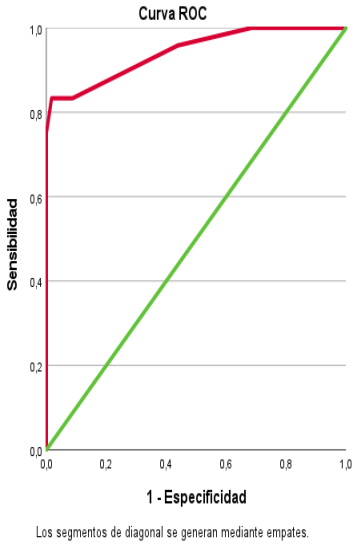


Figure 3: ROC curve and area under the curve (AUC) for the *NAIPES* score AUC = 0.942
ROC: Receiver operating characteristic

In 2012, De Feo and Cotrufo[44] studied 440 patients who underwent surgery and used multivariable logistic regression to identify predictors of early mortality. Their score was the only one subsequently cited in the 2015 European Society of Cardiology guidelines for infective endocarditis.

Other models have included broader populations or have been evaluated in different clinical settings. The PALSUSE score[11], developed in 2014 from a prospective, multicenter Spanish cohort, included 437 patients undergoing surgery for infective endocarditis (IE). It was notable for incorporating data from 26 Spanish hospitals and for including IE-specific variables in the development of its scoring system.

The SHARPEN score[13], published in 2015, was derived from a unicenter study in Singapore involving 233 patients with definite infective endocarditis over an 11-year period. This clinical risk score stratifies patients into low-, intermediate- and high-risk categories. A mortality rate of 100% was reported among patients with scores of 15 or higher, a finding that is comparable to the identification of a very-high-risk subgroup with the *NAIPES* score.

Tabla 5- Statistical performance and validation of the *NAIPES* score

Statistical parameter	Regression model	*NAIPES* score
AUC	0,951	0,942
Optimisms-corrected AUC	0,917	0,941*
Nagelkerke´s R^2	0,824	0,762
Cutoff point	0,8	≥ 5 puntos
Sensitivity	87,5 %	95,8 %
Specificity	94,7 %	59,6 %
Negative predictive value	94,7 %	97,1 %
Positive predictive value	87,5 %	50,0 %

Abbreviations: AUC: area under curve, R^2: Nagelkerke´s coefficient of determination
*Note: The optimism-corrected AUC for the *NAIPES* score was estimated using 1 000 bootstrap resamples; 95% CI: 0.876–0.998.

Gatti *et al.*[45] conducted a prospective, population-based observational study involving 361 patients from eight European cardiac centers over a 15-year period. They developed a risk score that was subsequently validated in a cohort of 161 patients from the *AEPEI* (acronym in Spanish for *Asociación* [Association] *para el Estudio* [for the Study] *y Prevención* [and Prevention] de la Endocarditis Infecciosa [of Infective Endocarditis]) registry, covering the period from 2001 to 2015, from which the score de-

rives its name. This model is among the relatively few to undergo external validation.

More recently, Wei *et al*.[16] developed the ASSESS-IE score using data from a cohort of 1 549 patients in China enrolled between 2009 and 2020. Six variables were identified as independent predictors of in-hospital mortality: clinical evolution of less than one month, prosthetic valve, New York Heart Association (NYHA) functional class III–IV, elevated direct bilirubin levels, anemia, and aortic valve involvement.

These models differ in their derivation populations, included variables, assessed outcomes and validation strategies; therefore, their results are not directly comparable.

A frequent limitation of existing prognostic models is the selection of specific populations, particularly cohorts restricted to patients undergoing surgery or to those with particular characteristics of the infectious process.

Furthermore, the epidemiological profile of the disease has evolved in recent years, with an increasing frequency of invasive cardiovascular procedures, intracardiac devices and certain bacterial etiologies. These characteristics were represented in the present cohort, in which prosthetic valve endocarditis accounted for 40.7% of cases, a substantial proportion of patients had infective endocarditis associated with cardiovascular implantable electronic devices (21.0%), and *Staphylococcus aureus* predominated among the isolated microorganisms (48.3%).

Analysis of the Predictive Performance

The *NAIPES* score demonstrated high discriminative capacity in the study cohort, with an area under ROC curve of 0.942. This value was numerically higher than those reported for several previously developed prognostic models, as shown in Figure 4, although their performance has varied across derivation and validation cohorts. The Costa score[9,10] reported an area under the ROC curve of 0.835, which decreased to under 0.596 in other studies[9]. The PALSUSE score[8,9,11] reporded 0.84; however, its performance declined to 0.74 in some studies involving surgical patients and to below 0.7 in other populations[9,12]. The SHARPEN score[8,9,13] had an area under the ROC curve of 0.86, with lower values reported in other studies. It has also been described as having a high negative predictive value but a relatively low positive predictive value, suggesting greater usefulness for ruling out risk than for confirming it.[8,9,46] The *AEPEI* score[45] demonstrated an area under the curve of 0.78, although it also decreased in other validation cohorts.[9,12] Similarly, the ASSESS-IE score[13], despite its ease of use, showed area under the ROC curve values below 0.8 and has not been validated in populations outside China. These comparisons should nevertheless be interpreted cautiously because of differences in study populations, inclusion criteria, outcomes and clinical settings. Accordingly, the available evidence does not support a direct conclusion that one model is superior to another.

A cutoff of five points was selected to prioritize sensitivity (95.8%) over specificity (59.6%). In a disease associated with substantial mortality, minimizing the proportion of high-risk patients who remain unidentified during the initial assessment may be clinically important. Thus, the *NAIPES* score may serve as a complementary tool for initial risk stratification. However, its clinical usefulness and generalizability must be confirmed through external validation.

CONCLUSIONS

In-hospital mortality was associated with variables reflecting hemodynamic compromise, inflammatory response, heart failure, embolic complications and *Staphylococcus aureus* infection. Based on a multivariable model incorporating six clinically relevant predictors, the *NAIPES* score was developed and demonstrated high discriminative capacity for in-hospital mortality risk stratification in the study cohort. Its performance was maintained after internal bootstrap validation, although its general applicability requires further evaluation in independent populations through external validation.

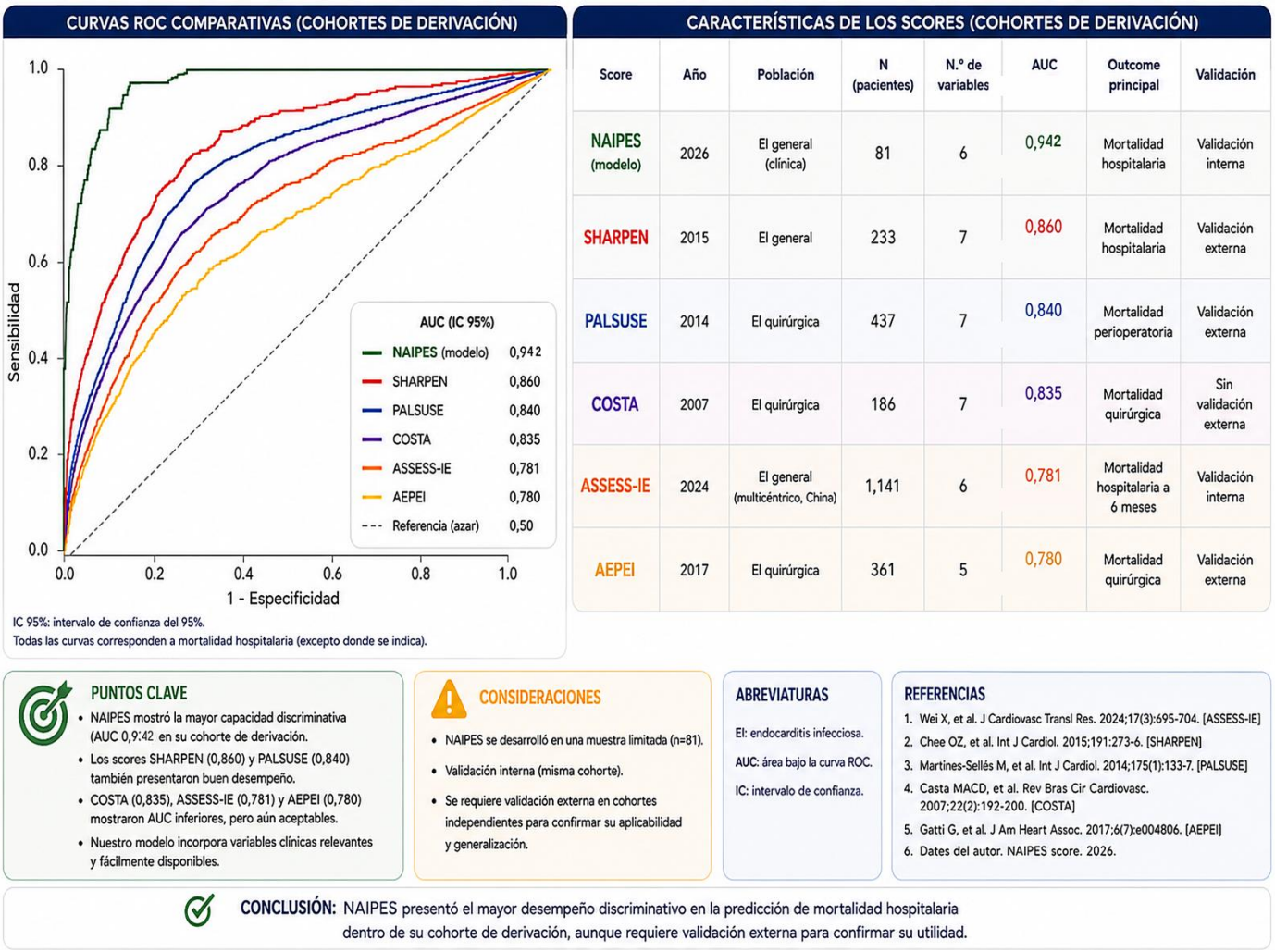


Figure 4: Descriptive comparison of the discriminative performance of the *NAIPES* score with previously published prognostic models for infective endocarditis.

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Grisel Guevara Mirabal, Ana María Barreda Pérez, Ander L. Arguelles Gámez, Damaris Hernández Véliz: supervisión de la investigación, validación de los resultados, revisión crítica del manuscrito.

Sandra Quintana Estévez, Wilfredo Roque Morán: metodología, revisión y edición del manuscrito.

Sandra Quintana Estévez: asesoría estadística, procesamiento y análisis de los datos, diseño metodológico, revisión del manuscrito.

