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ORIGINAL ARTICLE

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Risk stratification models for congenital heart surgery in children: Comparative single-center study

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Abstract

Objective: Three scores have been proposed to stratify the risk of mortality for each cardiac surgical procedure: The RACHS-1, the Aristotle Basic Complexity (ABC), and the STS-EACTS complexity scoring model. The aim was to compare the ability to predict mortality and morbidity of the three scores applied to a specific population.

Design: Retrospective, descriptive study.

Setting: Pediatric and neonatal intensive care units in a referral hospital.

Patients: Children under 18 years admitted to the intensive care unit after surgery.

Interventions: None.

Outcome measures: Demographic, clinical, and surgical data were assessed. Morbidity was considered as prolonged length of stay (LOS > 75 percentile), high respiratory (>72 hours of mechanical ventilation), and high hemodynamic support (inotropic support >20).

Results: One thousand and thirty-seven patients were included, in which 205 were newborns (18%). The category 2 was the most frequent in the three scores: In RACHS-1, ABC, 44.9%, and STS-EACTS, 40.8%. Newborns presented significant higher categories. Children required cardiopulmonary bypass in more occasions ($P < .001$) but the times of bypass and aortic cross-clamp were significantly higher in newborns ($P < .001$ and $P = .016$). Thirty-two patients died (2.8%). A quarter of patients had a prolonged LOS, 17%, a high respiratory support, and 7.1%, a high hemodynamic support. RACHS-1 (AUC 0.760) and STS-EACTS (AUC 0.763) were more powerful for predicting mortality and STS-EACTS for predicting prolonged LOS (AUC 0.733) and the need for high respiratory support (AUC 0.742).

Conclusions: STS-EACTS seems to stratify better risk of mortality, prolonged LOS, and need for respiratory support after surgery.

KEYWORDS
cardiac surgery, congenital heart disease, hospital mortality, intensive care, morbidity, risk adjustment

Authors disclose any potential financial or ethical conflicts of interest regarding the contents of this submission.

1 | INTRODUCTION

Congenital heart disease (CHD) is the most frequent congenital malformations (1% of live births).[1,2] Over the last two decades, important advances in the management of these patients, especially regarding the surgical techniques and the perioperative care,[3-5] have significantly improved their survival.[6] Nevertheless, severe forms of CHD that require complex surgical techniques and a high degree of expertise continue to associate high morbidity and high risk of mortality.[7,8] Moreover, interinstitutional variation in outcomes exists.[9] Different scores aiming to stratify the risk of mortality for each surgical procedure have been proposed. These scores are useful to define the presurgical risk of patients and they allow an appropriate benchmarking between centers. Benchmarking is of paramount importance for quality and improvement. It has become a powerful tool, considered now as a standard procedure in many areas, to facilitate and promote growth in CHD management.[10] Currently there are three similar scores, yet the indication of which one should be used has not been made. This is an additional difficulty for the comparative evaluation of surgical results between centers.

Two scores were initially published: The Risk Adjustment in Congenital Heart Surgery (RACHS-1) system[11] in 2002 and the Aristotle Basic Complexity score (ABC)[12] in 2004. These scores were developed based on expert consensus and later validation was carried out applying them to large databases. Many studies have validated and compared the predictive values of these two scores for evaluating mortality and morbidity. Each score has some peculiarities: RACHS-1 allows adjustment for factors such as age, prematurity, and noncardiac congenital structural abnormalities; ABC is calculated according to the sum of three subjective components (potential for mortality, potential for morbidity, and technical difficulty). A new version of ABC which incorporated the adjustment of individual patient data, the Aristotle Comprehensive Complexity (ACC), was proposed later in 2005[13] but its statistical validation has not yet been published. In 2009, a new score was published based on the empirical data of the Society of Thoracic Surgeons (STS) Congenital Heart Surgery Database and the European Association for Cardiothoracic Surgery (EACTS) Congenital Heart Surgery Database.[14] These big registries were used to evaluate and to stratify more than 77 000 CHD surgeries. The main advantage of the STS-EACTS score is its objective design based on real patient data rather than consensus from the panel of experts.

Data comparing the performance of the three scores is scant. The aim of the present study was to compare the performance of the three scores applied to pediatric and neonatal CHD patients from a specific pediatric hospital in order to evaluate which score could give us more information about the risk of mortality and morbidity in our patient population.

2 | MATERIAL AND METHODS

This was a retrospective, descriptive study from all patients under 18 years of age admitted to the intensive care unit after CHD surgery in a referral tertiary pediatric hospital, from January 2012 to January 2019. Patient data were obtained from the postcardiac surgery local registry. This database was created in 2004 and follows the strict rules of anonymization and security that are required nowadays. Low-birth-weight infants with isolated patent ductus arteriosus ligation were excluded. The study was conducted in accordance with the Helsinki Declaration recommendations and was approved by the Sant Joan de Déu Ethical Investigational Committee with a waiver of individual informed consent.

Baseline data variables were collected including: Age at surgery, gender, weight, type of CHD, and surgical details such as time of cardiopulmonary bypass, aortic cross-clamp time, and deep hypothermic circulatory arrest time. CHD was classified according to the international classifications[15] as: CHD with left-to-right shunt (septal defects without pulmonary obstruction and with left-to-right shunt); cyanotic CHD (septal defects with pulmonary obstruction and right-to-left shunt); CHD with obstruction to systemic flow; and other CHDs. Pediatric Risk Mortality Score (PRISM III) was calculated at admission in all pediatric patients. RACHS-1, ABC, and STS-EACTS scores were used to evaluate the risk of the surgery. If the surgery have included more than one procedure, then the higher procedure score was taken into account. Respiratory and hemodynamic supports were also evaluated including the need for mechanical ventilation (MV) and inotropic support (different from milrinone, in which per institutional protocol is administered to all patients in the first hours after cardiopulmonary bypass) at admission, the duration of MV, the vasoactive-inotropic score (VIS)[16] at 24, 48, and 72 hours of surgery and also the need for renal replacement therapies and extracorporeal membrane oxygenation. In hospital, the length of stay (LOS) was calculated as the time between surgery and final discharge from the hospital. Mortality was also registered.

The primary endpoint was to evaluate and to compare the behavior of the three different scores in predicting mortality and morbidity in our patient population. Mortality was described as any death occurring during the stay in the hospital (in-hospital mortality) or within the first 30 days postsurgery. Morbidity was evaluated as the LOS. LOS was also analyzed as a dichotomic variable: The prolonged LOS was considered as more than the 75 percentile of LOS, as in previous publications.[17]

Secondary endpoints were the relationship of the different scores with the respiratory and hemodynamic support requirements during the postoperative period, as well as their relationship with the need for renal replacement therapies and extracorporeal support. Respiratory and hemodynamic supports were also analyzed as dichotomic variables using previously published cutoff points: High respiratory support was considered as more than 72 of hours of MV[18,19] and high inotropic score at 24 hours was considered as more than 20 points of VIS.[20]

Statistical analysis was performed using SPSS 23.0 software (SPSS Inc., Chicago, Illinois, USA). Despite the size of the sample, the data followed a nonnormal distribution: Categorical variables were expressed as frequencies and percentages and continuous variables as medians and interquartile range (IQR). All data were analyzed with nonparametric tests (Chi-square test for the comparison of categorical variables and Kruskal-Wallis test and Mann-Whitney test for comparison of continuous variables). The discriminatory power was evaluated with curves of receiver operating characteristic (ROC) and the area under the curve (AUC). Sensitivity (Sn), specificity (Sp), positive predictive value (PPV), and negative predictive value (NPV) were evaluated. MedCalc 13.0 for Windows was used. A multivariate analysis with a backward stepwise logistic regression was performed to determine the independent influence of the scores in the different outcomes (mortality, prolonged LOS, and need for high respiratory and inotropic supports). In addition, sex and age were included in the model. Results were expressed as odds ratio and 95% confidence interval. A *P* value < .05 was considered significant.

3 | RESULTS

One thousand and thirty-seven patients were included, 626 (55.1%) were males. Two hundred and five patients (18%) were newborns (under 30 days of life). The global median age at the time of the surgery was 0.8 years (IQR 0.2-4.6): 1.4 years of pediatric patients (IQR 0.5-5.8) and 11 days of newborn patients (IQR 8-16). The median weight was 7.8 kg (IQR 4.15-16). Table 1 summarizes the baseline demographic characteristics and compares between newborn and pediatric patients. There were statistically significant differences according to the type of CHD. The most prevalent type of CHD was the CHD with left-to-right shunt (431 patients, 37.9%), followed by the cyanotic CHD (425 patients, 37.4%). The most frequent CHD were the ventricular septal defects (167 patients, 14.7%) and the tetralogy of Fallot (152 patients, 13.4%). The distribution of patients according to each score is shown in Figure 1. The RASCHS-1 risk category 2 was the most frequent with 523 cases (46%). The most frequent ABC level was 2, with 510 patients (44.9%) and the most frequent STS-EACTS mortality category was also the category 2 (464 patients, 40.8%). Newborn presented significantly higher values of the three scores (Table 1). The 82.9% (943) of the patients underwent cardiopulmonary bypass during the surgery. The median time of cardiopulmonary bypass was 75 minutes (IQR 50-105) and the aortic cross-clamp time was 41 minutes (IQR 25-65). Fifty-five patients required deep hypothermic circulatory arrest (4.8%) with a median time of 33 minutes (IQR 25-38). Pediatric patients required cardiopulmonary bypass in more occasions than newborns (*P* < .001) but the times of cardiopulmonary bypass and aortic cross-clamp were significantly higher in newborns (*P* < .001 and *P* = .016, respectively). The median PRISM III score at admission for pediatric patients was 3 points (IQR 2-6).

3.1 | Postoperative support

Half of the patients were admitted to the intensive care unit under MV (628 patients, 55.2%) with a median duration of invasive respiratory support of 24 hours (IQR 4-72). All patients received milrinone after surgery. The 32.4% of the patients (368) associated other inotropic support in the first 24 hours postsurgery. The median VIS score at 24 hours after the surgery was 3.7 points (IQR 3.7-8.7), at 48 hours was 3.7 (IQR 0-5), and at 72 hours was 0 (IQR 0-3.7). Thirty-two patients needed renal replacement therapy after surgery (2.8%) and only 10 patients (0.9%) needed extracorporeal support after surgery. Differences between newborn and pediatric patients are included in Table 1.

3.2 | Scores and mortality and LOS

Thirty-two patients died in the hospital after CHD surgery during the period of study (2.8%). The median days until death were 20 (IQR 3-42). The analysis of the distribution of in-hospital mortality in each category for each score and their relationship is summarized in Table 2. Patients with a higher score had a higher risk of mortality in each of the analyzed score. Figure 2 includes all the ROC curves. The AUC for each score for predicting in-hospital mortality was: RACHS-1 0.760, *P* < .001; ABC 0.658, *P* < .001, and STS-EACTS, 0.763, *P* < .001. There were statistically differences between two scores and in-hospital mortality: RACHS-1 vs ABC, *P* = .005 and ABC vs STS-EACTS, *P* = .013). No differences were detected between RACHS-1 vs STS-EACTS, *P* = .888. Sn, Sp, and predictive values of the three scores for predicting in-hospital mortality are included in Figure 2. RACHS-1 and STS-EACTS higher than 2 points were considered as the cutoffs for in-hospital mortality. Both scores also presented high NPV.

The median LOS was 8 days (IQR 6-15.5). The 25% of the patients (284) presented prolonged LOS. The power of each score for predicting prolonged LOS was analyzed and all the scores showed a good ability: A high category predicted a higher risk of more days in the hospital. All these data are summarized in Table 2. Figure 2 includes the ROC curve, Sn, Sp, and the predictive values. The AUC for each score and the predictive ability for prolonged LOS were: RACHS-1 0.714, *P* < .001; ABC: 0.673, *P* < .001, and STS-EACTS, 0.733, *P* < .001. There were statistically significant differences between the AUC of RACHS-1 and ABC (*P* = .011) and between ABC and STS-EACTS (*P* < .001). No differences were detected between RACHS-1 and STS-EACTS (*P* = .125). RACHS-1 and STS-EACTS higher than 2 points were considered as the cutoffs for predictive prolonged LOS.

3.3 | Scores and postoperative variables.

Table 3 summarizes the relationship between the different scores and the respiratory and hemodynamic supports after surgery. The three scores predicted the respiratory and hemodynamic support in 24 hours after surgery: A higher category, a higher number of hours of MV, and a higher VIS in the first 24 hours after surgery. MV support longer than 72 hours (193 patients, 17%) and VIS higher than 20 (81 patients, 7.1%) were considered as morbidity. Considering these points as markers of morbidity, the

TABLE 1 Baseline data, surgical details, and evolution in the intensive care unit

Baseline and surgical data	Total (n = 1137)	Newborn (n = 205)	Pediatric (n = 932)	P
Male*	626 (55.06)	125 (60.98)	501 (53.76)	.060
Weight (kg)#	7.8 (4.15-16)	3.2 (2.8-3.5)	9.6 (6-20)	<.001
Type of CHD*	*n* (%)	*n* (%)	*n* (%)	*P*
Shunt CDH	431 (37.91)	15 (7.32)	416 (44.64)	<.001
Cyanotic CDH	425 (37.38)	101 (49.27)	324 (34.76)	
Obstructive CDH	249 (21.90)	87 (42.44)	162 (17.38)	
Other CDH	32 (2.81)	2 (0.98)	30 (3.22)	
RACHS-1 risk category*				
1	167 (14.69)	0 (0.00)	167 (17.92)	<.001
2	523 (46.00)	58 (28.29)	465 (49.89)	
3	323 (28.41)	66 (32.20)	257 (27.58)	
4	100 (8.80)	68 (33.17)	32 (3.43)	
5	9 (0.79)	3 (1.46)	6 (0.64)	
6	13 (1.14)	10 (4.88)	3 (0.32)	
ABC level*				
1	208 (18.29)	0 (0.00)	208 (22.32)	<.001
2	510 (44.85)	57 (27.80)	453 (48.61)	
3	293 (25.77)	77 (37.56)	216 (23.18)	
4	124 (10.91)	71 (34.63)	53 (5.69)	
STS-EACTS mortality category*				
1	399 (35.09)	6 (2.93)	393 (42.17)	<.001
2	464 (40.81)	53 (25.85)	411 (44.10)	
3	90 (7.92)	9 (4.39)	81 (8.69)	
4	168 (14.78)	125 (60.98)	43 (4.61)	
5	14 (1.23)	12 (5.85)	2 (0.21)	
Characteristics of the surgery				
Need for CEC*	943 (82.94)	108 (52.68)	835 (89.59)	<.001
CEC time (minutes)#	75 (50-105)	115 (94-136.5)	72 (50-98)	<.001
Clamp time (minutes)#	41 (25-65)	50 (25-79.25)	40 (25-62)	.016
DHCA time (minutes)#	33 (25-38)	33 (26-38.5)	30 (21.5-36.75)	.379
Postoperative support				
MV at admission*	628 (55.23)	205 (100.00)	423 (45.39)	<.001
Duration of MV#	24 (4-72)	72 (48-120)	6 (3-48)	<.001
Need for inotropic*	368 (32.37)	165 (80.49)	203 (21.78)	<.001
VIS at 24 hours#	3.7 (3.7-8.7)	11 (7-17)	3.7 (3.7-7)	<.001
VIS at 48 hours#	3.7 (0-5)	7 (3.7-12)	3.7 (0-3.7)	<.001
VIS at 72 hours#	0 (0-3.7)	3.7 (0-5)	0 (0.00)	<.001
Need for RRT*	32 (2.81)	19 (9.27)	13 (1.39)	<.001
Need for ECMO*	10 (0.88)	4 (1.95)	6 (0.64)	.005
Outcomes				
LOS (days)#	8 (6-15.5)	21 (14-41)	7 (6-10)	<.001
Prolonged LOS*	284 (24.98)	141 (68.78)	143 (15.34)	<.001
In-hospital mortality*	32 (2.81)	18 (8.78)	14 (1.50)	<.001

Abbreviations: CEC, extracorporeal circulation; CHD, congenital heart disease; DHCA, deep hypothermic circulatory arrest; ECMO, extracorporeal membrane oxygenation; LOS, length of stay; MV, mechanical ventilation; RRT, renal replacement therapies; VIS, vasoactive-inotropic score.
*Qualitative values expressed by frequencies (Percentages) and compared with Chi-square test.
#Quantitative variables expressed by median (INTERQUARTILE RANG) and compared with Mann-Whitney test (*P*).

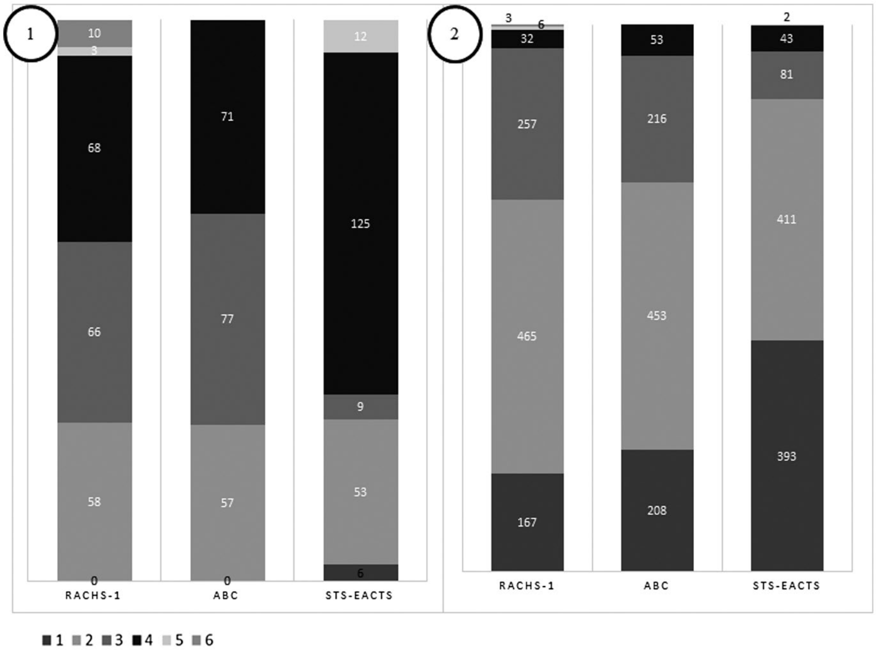


FIGURE 1 Summary of the distribution of the patients according to the category for each score. Graphic 1 represents the distribution of neonatal patients and graphic 2 represents the distribution of pediatric patients. RACHS-1 has six categories; ABC (Aristotle Basic score) has four levels and STS-EACTS has five categories

ROC curves were analyzed: Regarding respiratory support, STS-EACTS presented better AUC than the other two scores, but no statistically significant differences were detected (RACHS-1 vs ABC, P = .756; RACHS-1 vs STS-EACTS, P = 0.121 and ABC vs STS-EACTS P = .135). The cutoffs for the need for high respiratory support were considered as RACHS-1 and STS-EACTS higher than 2 points. All the predictive values, Sn and Sp, are included in Figure 3.

Regarding hemodynamic support, the three scores showed similar AUC and no statistically significant differences were detected between them. A category higher than 2 points for each score was considered as the cutoff for predicting a high hemodynamic support in the first 24 hours after surgery. Sn and Sp are included in Figure 3.

In the multivariable analysis, only STS-EACTS higher than 3 points was independently associated with all the outcomes (mortality, prolonged LOS, and need for high respiratory and inotropic supports). All these data are included in Table 4.

RACHS-1, ABC, and STS-EACTS predicted the need for renal replacement techniques with $P < .001$ in all cases. Also RACHS-1 and STS-EACTS predicted the need for ECMO in the postoperatory with $P < .001$ (ABC, P = .261). Table 3 includes those results.

4 | DISCUSSION

In this study, the performance of the three existing complexity scores for pediatric cardiac surgery was assessed in a specific population from a single-center institution. The three scores were found to be useful tools to stratify the presurgery risk of in-hospital mortality. In the univariate analysis, RACHS-1 and STS-EACTS were more powerful than ABC for predicting in-hospital mortality and STS-EACTS for predicting prolonged LOS and the need for high respiratory support after surgery. However, STS-EACTS was superior to the others in the multivariate analysis. As in previous studies, morbidity was analyzed using the prolonged LOS but also other variables not previously used in the stratification of postoperative risks such as duration of MV and the VIS score were also incorporated in the analysis of these three scores, as markers of severity.

To our knowledge, this is one of the few existing studies comparing the three available models to stratify the risk of mortality after CHD surgery and their power for predicting mortality and morbidity. The three models were developed years ago in an effort to organize and homogenize data for adequate benchmarking between surgical teams around the world. The aim of this study was not to validate any of these models because a large sample would have been necessary. Our purpose was to evaluate which score could give us more information about the risk of mortality and morbidity in our patient population in order to foster a better institutional presurgical risk assessment.

The endpoint of these scores was to stratify the risk of in-hospital mortality. There are several studies that compare RACHS-1 and ABC. Both scores were designed on the basis of experts' opinions according to the potential mortality of the different surgical procedures. Initially, RACHS-1 was not designed for predicting morbidity, but only mortality.[11] However, some studies have shown that this score is also valid to predict morbidity.[11,21-25] ABC seems to predict both mortality and morbidity.[26,27] There are few differences between these two methods according to their ability to predict mortality and morbidity. Al-Rady et al. found RACHS-1 to be superior to ABC in predicting mortality and LOS.[26] According to Jacob et al., ABC allows classifying more surgical procedures and RACHS-1 discriminates better the more complex procedures.[28] Our results also showed that RACHS-1 was significantly better than ABC to predict both, mortality and prolonged LOS in the

TABLE 2 Analysis of the mortality and length of stay for each category and score

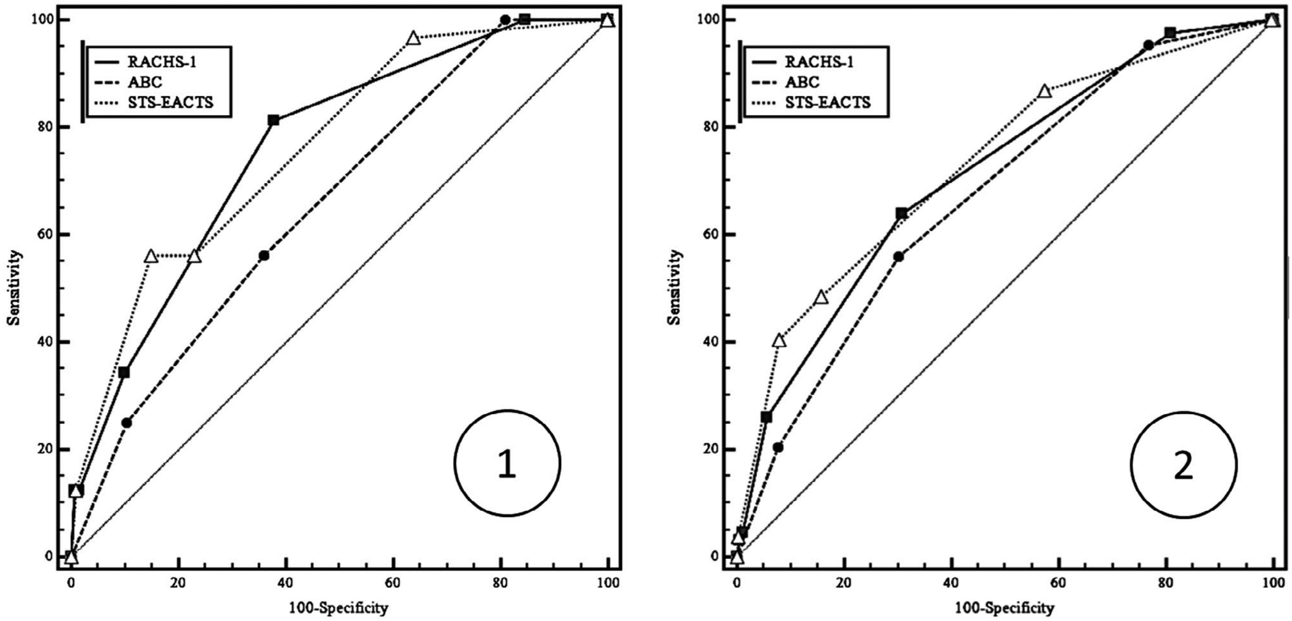
Scores	Total (*n* = 1137)		In-hospital mortality* (*n* = 32)			LOS #		Prolonged LOS* (*n* = 284)		
RACHS-1	*n*	(%)	*n*	(%)	*P*	Median (IQR)	*P*	*n*	(%)	*P*
1	167	(14.7)	0	(0.0)	<.001	6 (6-7)	<.001	7	(4.2)	<.001
2	523	(46.0)	6	(1.1)		8 (6-12)		95	(18.2)	
3	323	(28.4)	15	(4.6)		10 (7-22)		108	(33.4)	
4	100	(8.8)	7	(7.0)		18 (10-30.7)		61	(61.0)	
5	9	(0.8)	0	(0.0)		14 (8.5-26)		4	(44.4)	
6	13	(1.1)	4	(30.8)		34 (6-39.5)		9	(69.2)	
ABC										
1	208	(18.3)	0	(0.0)	.006	6 (6-7)	<0.001	13	(6.3)	<.001
2	510	(44.9)	14	(2.7)		8 (6-14)		112	(22.0)	
3	293	(25.8)	10	(3.4)		10 (7-20)		101	(34.5)	
4	124	(10.9)	8	(6.5)		14.5 (8.3-29.3)		58	(46.8)	
STS-EACTS										
1	399	(35.1)	1	(0.3)	<.001	7 (6-8)	<0.001	37	(9.3)	<.001
2	464	(40.8)	13	(2.8)		9 (7-14.8)		109	(23.5)	
3	90	(7.9)	0	(0.0)		9 (7-16)		23	(25.6)	
4	168	(14.8)	14	(8.3)		20 (10-39.5)		104	(61.9)	
5	14	(1.2)	4	(28.6)		34.5 (17.3-41.3)		11	(78.6)	

Notes: Qualitative values expressed by frequencies (Percentages) and compared with Pearson' Chi-square test (*). Quantitative variables expressed by median (INTERQUARTILE RANG) and compared with Kruskal-Wallis test (#). LOS: Length of stay.

univariate analysis. Modifications introduced in the scores in order to add the individual character of each patient allowed greater stratification of the risk of mortality and LOS. Adjusted-RACHS-1 includes three important individual factors: Age, prematurity, and major noncardiac anomalies. ACC, that adds the patient-adjusted complexity to the ABC,[29] has been found superior to RACHS-1.[30,31] However, no differences have been observed between ACC and adjusted-RACHS-1.[32] Cavalcanti et al., in a study published in 2015, did not find differences between ABC, RACHS-1, and STS-EACTS in predicting mortality.[33] Recently, Alam et al[34] reported STS-EACTS being more powerful for predicting in-hospital mortality and prolonged LOS in the intensive care unit (AUC 0.870 and 0.759, respectively) than RACHS-1 (AUC 0.766 and AUC 0.701, respectively) and ABC scores (AUC 0.817, AUC 0.743, respectively). In that study, the determination of the prolonged LOS was arbitrarily established as the 75 percentile of LOS as in our study, although they considered LOS in the intensive care unit instead of in-hospital LOS.

In our study, STS-EACTS was similar to RACHS-1 for predicting in-hospital mortality, and both were superior to ABC in the univariate analysis. However, in the multivariate analysis, only STS-EACTS risk category higher than 3 points was independently associated with mortality. Our registry did not include the individual-adjust complexity of the ACC thus, this score could have not been evaluated. The AUC for STS-EACTS and in-hospital mortality was higher than the AUC for the other two scores but lower than the previously published results.[34] This could be secondary to the main difference between our data and the other studies: A lower mortality in our series (2.8%) compared to previous results (around 3%-4%). The three scores showed high NPV, that is, a low category of each score is related to a low risk of mortality. Regarding a prolonged LOS, all three scores could predict a prolonged stay (a higher risk score and a greater number of days in the hospital) with STS-EACTS showing better results in the univariate and multivariate analyses.

Nowadays, more than 95% of the patients survive CHD surgery and almost 85% of the patients survive to adulthood thus, interest in quality of life of the survivors increases.[3] The need for standardization of the analysis of morbidity was proposed first in 2009.[28] Appropriate and pertinent morbidity risk stratification is yet to be defined though. Until now morbidity has been analyzed as prolonged LOS in most publications and it was established as the 75 percentile of LOS. This is a problem due to the differences between centers in factors that may modify LOS (mainly medical and institutional policy of discharge from hospital).[35] Patients with higher LOS use to be those with complications after surgery and higher costs are related to prolonged LOS.[36] Other morbidity scores have been proposed including postoperative complications and postoperative LOS. The score proposed by Jacobs et al. allows to predict the risk of morbidity after surgery.[37,38] Several complications may appear after CDH surgery, but only two objective complications have been included in this study: Respiratory and hemodynamic supports. The need for high respiratory and hemodynamic supports was analyzed as new markers of morbidity with the comparison of the hours of MV and the VIS score in each category. The three scores presented a good correlation between each category and the respiratory and hemodynamic supports. STS-EACTS had a better power to predict a higher



In-hospital death	AUC	95% CI	*p*
RACHS-1	0.760	(0.734-0.784)	<0.0001
ABC	0.658	(0.630-0.686)	<0.0001
STS-EACTS	0.763	(0.737-0.788)	<0.0001

Prolonged LOS	AUC	95% CI	*p*
RACHS-1	0.714	(0.687-0.740)	<0.0001
ABC	0.673	(0.645-0.700)	<0.0001
STS-EACTS	0.733	(0.706-0.758)	<0.0001

In-hospital mortality	Value	Sn (95% CI)	Sp (95% CI)	PPV (95% CI)	NPV (95% CI)
RACHS-1	>2	81.25 (63.6 - 92.8)	62.14 (59.2 - 65.0)	5.9 (3.9 - 8.5)	99.1 (98.1 - 99.7)
ABC	>2	56.25 (37.7 - 73.6)	63.95 (61.0 - 66.8)	4.3 (2.6 - 6.8)	98.1 (96.8 - 98.9)
STS-EACTS	>2	56.25 (37.7 - 73.6)	77.08 (74.5 - 79.5)	6.6 (4.0 - 10.3)	98.4 (97.3 - 99.1)

Prolonged LOS	Value	Sn (95% CI)	Sp (95% CI)	PPV (95% CI)	NPV (95% CI)
RACHS-1	>2	64.08 (58.2 - 69.7)	69.17 (65.9 - 72.3)	40.9(36.3 - 45.6)	85.3 (82.4 - 87.8)
ABC	>2	55.99 (50.0 - 61.8)	69.75 (66.5 - 72.8)	38.1(33.4 - 43.0)	82.6 (79.7 - 85.3)
STS-EACTS	>2	48.59 (42.6 - 54.6)	84.29 (81.7 - 86.7)	50.7(44.6 - 56.8)	83.1 (80.5 - 85.6)

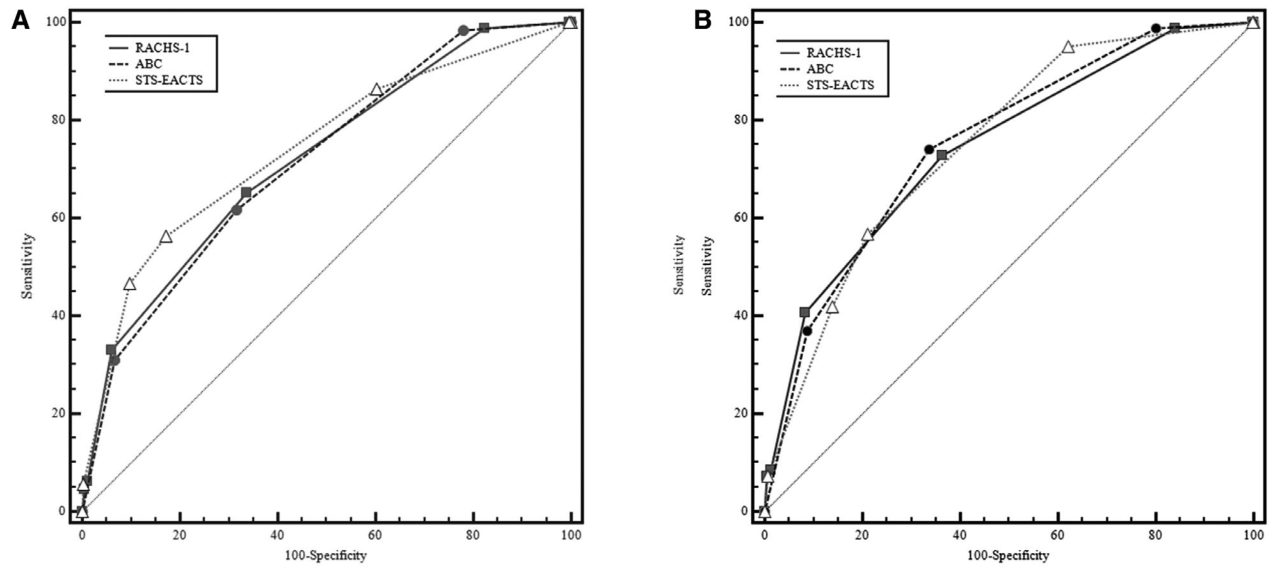
FIGURE 2 Curves of receiver operating characteristic (ROC) for analyzing the areas under the curve (AUC) for each score (RACHS-1, ABC, and STS-EACTS) and mortality (left) and morbidity (right). ROC 1 represents the in-hospital mortality. ROC 2 represents the prolonged length of stay. CI, confidence interval; LOS, length of stay; NPV, negative predictive value; PPV, positive predictive value; Sn, sensitivity; Sp, specificity

respiratory support (higher STS-EACTS category needs more hours of MV after surgery). Overall, RACHS-1 and STS-EACTS scores were more related to the need for greater hemodynamic support than ABC score. In the present study, although RACHS-1 and STS-EACTS had similar AUC for all the analyzed outcomes, RACHS-1 category higher than 2 points had better Sn, Sp, PPV, and NPV than the other two scores. The NPV for

TABLE 3 Analysis of the relationship between each score and the support needed after surgery. The hours of mechanical ventilation were used to evaluate the respiratory support and the VIS score at the 24 and 48 hours of surgery for hemodynamic support

	MV (*n* = 628)		Hours of MV		VIS 24 h		VIS 48 h		VIS 72 h		RRT (*n* = 32)		ECMO (*n* = 10)	
Scores	*n*	(%)	median (IQR)	*P*	median (IQR)	*P*	median (IQR)	*P*	median (IQR)	*P*	*n*	(%)	*n*	(%)
RACHS-1														
1	32	(19.2)	3.5 (3-17)	<.001	3.7 (3.7-3.7)	<0.001	0 (0-0)	<.001	0 (0-0)	<.001	0	(0.0)	0	(0.0)
2	265	(50.7)	12 (4-66)		3.7 (3.7-7)		3.7 (0-3.7)		0 (0-3)		9	(1.7)	1	(0.2)
3	216	(66.9)	24 (4-72)		5 (3.7-11.1)		3.7 (0-7)		0 (0-3.7)		8	(2.5)	5	(1.5)
4	94	(94.0)	72 (45-96)		14 (8.7-20)		8.7 (3.7-13)		3.7 (0-6.7)		9	(9.0)	3	(3.0)
5	8	(88.9)	36 (5.7-90)		8 (3.7-17)		3.7 (3.7-10.4)		0 (0-3.7)		1	(11.1)	0	(0.0)
6	13	(100)	144 (8.5-240)		18.7 (9.6-22)		10.7 (6.4-24)		3.7 (0-14.5)		5	(38.5)	1	(7.7)
ABC														
1	45	(21.6)	4 (3-16)	<.001	3.7 (3.7-3.7)	<0.001	0 (0-3.7)	<0.001	0 (0-0)	<0.001	0	(0.0)	0	(0.0)
2	283	(55.5)	12 (4-72)		3.7 (3.7-8)		3.7 (0-3.7)		0 (0-3.4)		5	(1.0)	3	(0.6)
3	192	(65.5)	24 (5-72)		5.85 (3.7-11.7)		3.7 (0-7)		0 (0-3.7)		15	(5.1)	5	(1.7)
4	108	(87.1)	72 (24-120)		13.7 (6.7-19)		7.4 (3.7-12)		3.7 (0-5.7)		12	(9.7)	2	(1.6)
STS-EACTS														
1	148	(37.1)	6 (3-24)	<.001	3.7 (3.7-3.7)	<.001	0 (0-3.7)	<.001	0 (0-0)	<.001	1	(0.3)	0	(0.0)
2	238	(51.3)	12 (4-72)		3.7 (3.7-8.7)		3.7 (0-5)		0 (0-3.7)		11	(2.4)	4	(0.9)
3	66	(73.3)	10 (3.5-72)		7 (3.7-11.6)		3.7 (3.7-7.2)		0 (0-3.7)		4	(4.4)	0	(0.0)
4	162	(96.4)	48 (31.5-96)		11.7 (5-17)		7 (3.7-12)		3.7 (0-5)		10	(6.0)	5	(3.0)
5	14	(100)	132 (71.7-240)		17.9 (10.4-22)		10.7 (5-22.5)		3.7 (0-14.3)		6	(42.9)	1	(7.1)

Abbreviations: ECMO, extracorporeal membrane oxygenation; MV, mechanical ventilation; RRT, renal replacement therapies; VIS, vasoactive-inotropic score.
*Qualitative values expressed by frequencies (Percentages).
#Quantitative variables expressed by median (INTERQUARTILE RANG) and compared with Kruskal-Wallis test (*P*).



High respiratory support	AUC	95% CI	*p*
RACHS-1	0.721	(0.694-0.747)	<0.0001
ABC	0.715	(0.688-0.741)	<0.0001
STS-EACTS	0.742	(0.715-0.767)	<0.0001

High inotropic support	AUC	95% CI	*p*
RACHS-1	0.745	(0.719-0.771)	<0.0001
ABC	0.754	(0.728-0.779)	<0.0001
STS-EACTS	0.749	(0.723-0.774)	<0.0001

High respiratory support	Value	Sn (95% CI)	Sp (95% CI)	PPV (95% CI)	NPV (95% CI)
RACHS-1	>2	65.28 (58.1 - 72.0)	66.21 (63.1 - 69.2)	28.3(24.2 - 32.7)	90.3 (87.9 - 92.4)
ABC	>2	61.66 (54.4 - 68.5)	68.43 (65.4 - 71.4)	28.5(24.2 - 33.1)	89.7 (87.3 - 91.8)
STS-EACTS	>2	56.48 (49.2 - 63.6)	82.73 (80.2 - 85.1)	40.1(34.2 - 46.2)	90.3 (88.1 - 92.2)

High inotropic support	Value	Sn (95% CI)	Sp (95% CI)	PPV (95% CI)	NPV (95% CI)
RACHS-1	>2	72.84 (61.8 – 82.1)	63.69 (60.7 - 66.6)	13.4 (10.3-16.9)	96.8 (95.2-98)
ABC	>2	74.07 (63.1-83.2)	66.35 (63.4-69.2)	14.5 (11.2-18.3)	97.1 (95.6-98.2)
STS-EACTS	>2	56.79 (45.3 - 67.8)	78.80 (76.2 – 81.2)	17.1 (12.8 – 22.1)	95.9 (94.4 – 97.2)

FIGURE 3 Curves of receiver operating characteristic (ROC) for analyzing the areas under the curve (AUC) for each score (RACHS-1, ABC, and STS-EACTS) and high respiratory support, ROC-A, and high hemodynamic support, represented in ROC-B. CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value; Sn, sensitivity; Sp, specificity

each cutoff was high, which means that patients with low-risk scores will not need respiratory or hemodynamic support in the postoperative period. However, parallelism between respiratory and hemodynamic supports and morbidity has not been established in the literature. The assignation of morbidity proposed in this article as high respiratory and inotropic supports tried to identify the most critically ill patients in the postoperative period. However, the lack of an optimal tool for evaluating morbidity could be the key. A definition of morbidity adjusted to this kind of patients should be considered in order to improve the analysis of the results between centers. The use of percentiles can condition the influence of multiple factors derived from institutional policy and this can hinder the benchmarking. An option could be to design a new score of morbidity considering different aspects that could affect these patients after CHD surgery, not only the prolonged LOS. Presurgical risk scores are useful tools and STS-EACTS seems to be better than the other two. But their power to stratify risk could be improved. Currently, efforts are being made to add a new approach to risk scores adding postoperative characteristics as in the recent article published by Tabbutt et al.[39]

TABLE 4 Multivariable model for the different outcomes

Outcomes	OR	95%CI	*P*
Mortality			
Sex (male)	2.89	(1.09-7.69)	.034
STS-EACTS>3	4.91	(1.97-12.25)	.001
Prolonged LOS			
STS-EACTS>3	4.51	(3.02-6.74)	<.001
ABC>2	1.72	(1.26-2.35)	.001
RACHS-1>2	1.83	(1.29-2.59)	.001
High respiratory support			
STS-EACTS>3	6.15	(4.23-8.93)	<.001
ABC>2	2.21	(2.21-3.14)	<.001
High inotropic support			
STS-EACTS>3	1.81	(1.04-3.15)	.037
ABC>2	3.64	(2.11-6.29)	<.001
RACHS-1>2	2.38	(1.31-4.30)	.004

Abbreviations: CI, confidence interval; LOS, length of stay; OR, odds ratio.

However, we consider that the situation of the patient before surgery may play an important role in the intraoperative and postoperative courses. That is why we suggest by adding the determination of biomarkers before surgery in future researches. An objective biomarker could help individualize the presurgical situation of each patient and thereby optimize the determination of the risk before surgery.

As is already known, neonatal CHD surgeries are frequently more complex than those performed in older children. Moreover, newborn surgery is associated with more severe low cardiac syndrome and systemic inflammatory response, both contributing to longer postoperative courses.[40] In our study, the three scores were higher in the newborn population as well as the surgical characteristics (cardiopulmonary bypass and aortic cross-clamp time). Aligned with this, neonatal patients required higher intensive support after surgery (respiratory and hemodynamic), needed renal replacement therapies and ECMO in more cases, and had higher LOS and risk of mortality than pediatric patients. These differences translate that newborns are a more vulnerable population with high risk of morbidity and mortality after cardiac surgery that needs special attention.[4] In our study, the three scores were equally able to stratify these risks.

This study presents several limitations. The most important is the size of the sample. This kind of study cannot compete with the studies based on large data coming from larger registries such as the EACTS Congenital Heart Surgery Database and the STS Congenital Heart Surgery Database, that are used for creating and validating the three evaluated scores. However, our study involves the practical application in a specific community of the three scores that have been developed analyzing those large databases. Besides, the design of our registry was not the evaluation of these scores, so the retrospective nature of the analysis cannot exclude the possibility of missing data.

In conclusion, the three actual methods for stratifying mortality risk after cardiac surgery were useful tools in our population. A higher category of each score was related to a higher intensive support, more LOS, and higher risk of mortality after surgery. In our population, an STS-EACTS risk category higher than 3 points was independently related to the risk of mortality, prolonged LOS, and high respiratory support.

CONFLICT OF INTEREST

None.

AUTHORS' CONTRIBUTIONS

Sara Bobillo-Perez, Joan Sanchez-de-Toledo, and Iolanda Jordan conceived and designed the research study. Sara Bobillo-Perez conducted statistical analyses and wrote the first draft of the manuscript. Susana Segura contributed to the study design and revised the manuscript. Monica Girona-Alarcon, Maria Mele, and Anna Solé-Ribalta analyzed the data. Debora Cañizo revised the manuscript. Francisco Jose Cambra revised the manuscript. All authors agree with the manuscript results and conclusions, jointly developed the structure and arguments for the article, made critical revisions, and reviewed and approved the final version of the manuscript.

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