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Enhanced Assessment of Perioperative Mortality Risk in Adults With Congenital Heart Disease

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ABSTRACT

BACKGROUND In-hospital mortality is a rare, yet feared complication following cardiac surgery in adult congenital heart disease (ACHD). A risk score, developed and validated in ACHD, can be helpful to optimize risk assessment.

OBJECTIVES The purpose of this study was to assess the performance of EuroSCORE II components and procedure-related Adult Congenital Heart Surgery (ACHS) score, identify additional risk factors, and develop a novel risk score for predicting in-hospital mortality after ACHD surgery.

METHODS We assessed perioperative survival in patients aged >16 years undergoing congenital heart surgery in a large tertiary center between 2003 and 2019. A risk variable-derived PEACH (PErioperative ACHd) score was calculated for each patient. Internal and external validation of the model was undertaken, including testing in a validation cohort of patients operated in a second European ACHD center.

RESULTS The development cohort comprised 1,782 procedures performed during the study period. Re-sternotomy was undertaken in 897 (50.3%). There were 31 (1.7%) in-hospital deaths. The PEACH score showed excellent discrimination ability (area under the curve [AUC]: 0.88; 95% CI: 0.83-0.94), and performed better than the ACHS score in our population (ACHS AUC: 0.69; 95% CI: 0.6-0.78; $P = 0.0003$). A simple 3-tiered risk stratification was formed: PEACH score 0 (in-hospital mortality 0.2%), 1-2 (3.6%), and ≥3 (17.2%). In a validation cohort of 975 procedures, the PEACH score retained its discriminative ability (AUC: 0.75; 95% CI: 0.72-0.77) and was well calibrated (Hosmer-Lemeshow chi-square goodness-of-fit $P = 0.55$). There was agreement in expected and observed perioperative mortality between cohorts.

CONCLUSIONS The PEACH score is a simple, novel perioperative risk score developed and validated specifically for ACHD patients undergoing cardiac surgery. (J Am Coll Cardiol 2021;78:234–42) © 2021 the American College of Cardiology Foundation. Published by Elsevier. All rights reserved.

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Advances in surgery over the last few decades have meant that the majority of children with congenital heart disease (CHD) survive into adulthood. The population of adults with congenital heart disease (ACHD) is, therefore, steadily expanding (1). Long-term sequelae are common and often require reintervention for residual hemodynamic defects, degeneration of previously implanted prostheses, and so on. Moreover, some congenital heart defects are diagnosed late and require surgical repair in adult life (2). Surgical interventions in adults are most often elective, and are performed for prognostic reasons or to improve symptoms. Estimating the mortality associated with cardiac surgery is, thus, essential in this setting, as it allows clinicians to better define the risk/benefit ratio and it guides the decision-making and informed consent.

Perioperative prognostic scores that perform well in children with CHD undergoing cardiac surgery are not suitable for the adult population (3-6). Moreover, ACHD patients were excluded when scoring systems in adults were developed, such as the widely used European System for Cardiac Operative Risk Evaluation II (EuroSCORE II), which was developed to reflect modern cardiac surgery in contemporary cohorts (7-11). We assessed the performance of the components of EuroSCORE II in predicting the outcome of surgery in ACHD patients and sought to identify additional risk factors for this population. We then developed and validated a novel risk score to better predict perioperative mortality around cardiac surgery in ACHD.

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METHODS

Data were collected retrospectively on consecutive patients above the age of 16 years who underwent congenital cardiac surgery in a high-volume tertiary center in the United Kingdom between April 2003 and April 2019. Patients were identified, and demographic and clinical information were extracted, from the Royal Brompton and Harefield NHS Foundation Trust Clinical Informatics Department, which included curated data from their clinical data warehouse and information submitted to the National Institute for the Cardiovascular Outcomes Research Congenital Audit. This was enriched with manual data collection from individual hospital records. The primary outcome was in-hospital mortality; survival status was retrieved from the Primary Care Mortality Database in April 2019. The validation cohort included ACHD patients undergoing congenital cardiac surgery at the IRCCS Policlinico San Donato in Milan, Italy, between January 2003 and December 2015. Diagnoses, procedures, and complications were classified according to the European Association of Cardio-Thoracic Surgery and Society of Thoracic Surgeons congenital heart surgery nomenclature (12). Patients who underwent long-term mechanical circulatory support or heart or heart-lung transplant were excluded. Patients requiring reoperation during the same hospital admission or within 30 days of the initial surgery were retained in the cohort, but only the index operation was included. If a patient underwent more than 1 cardiac surgery (during separate admissions to hospital and >30 days apart) during the study period, only the latest procedure was included in the analysis. The study was approved by the UK Health Research Authority and the Ethics Committee of the Policlinico San Donato.

ABBREVIATIONS AND ACRONYMS

ACHD = adult congenital heart disease

ACHS = Adult Congenital Heart Surgery

AUC = area under the curve

CHD = congenital heart disease

eGFR = estimated glomerular filtration rate

EuroSCORE = European System for Cardiac Operative Risk Evaluation

NYHA = New York Heart Association

The following variables from the EuroSCORE II were collected: biological sex, age at the time of surgery, ejection fraction of the systemic ventricle (assessed by echocardiography), New York Heart Association (NYHA) functional class, extracardiac arteriopathy (any 1 or more of claudication, carotid stenosis >50%, amputation for arterial disease, previous or planned intervention on the abdominal aorta, limb arteries, or carotids), poor mobility (defined as severe impairment of mobility secondary to musculoskeletal or neurological dysfunction), estimated glomerular filtration rate (eGFR) (calculated using the Modification of Diet in Renal Disease formula), presence of “active” infective endocarditis (endocarditis on current antibiotic therapy), chronic lung disease (based on long-term use of bronchodilators or steroids for lung disease), critical preoperative state (defined as ventricular tachycardia, ventricular fibrillation or aborted sudden cardiac death, preoperative cardiac massage, ventilation, use of inotropes or intra-aortic balloon pump, preoperative acute renal failure), angina at rest, myocardial infarction within the past 90 days and urgency of the intervention (categorized as urgent and nonurgent). However, clinical parameters that had a prevalence <1% in this population were not included in the analysis: extracardiac arteriopathy, poor mobility, chronic lung disease, diabetes mellitus on insulin, angina at rest, or recent myocardial infarction. Nonurgent surgery included elective and expedited procedures involving stable patients with conditions that were not an immediate threat to life, limb, or organ survival (13). Additional preoperative clinical characteristics were collected, including certain variables from the EuroSCORE II that required

TABLE 1 Demographic and Clinical Characteristics of the Development Cohort Stratified by Survival to Hospital Discharge

	All Patients (N = 1,782)	Survivors to Discharge (n = 1,751)	Nonsurvivors (n = 31)	*P* Value
Age at procedure, y	35.6 ± 14.4	35.5 ± 14.3	39.9 ± 15.1	0.09
Male	980 (55.0)	969 (55.3)	11 (35.5)	0.04
CHD complexity (Bethesda)				
Simple	540 (31.0)	537 (31.3)	3 (10.3)	0.05[a]
Moderate	1,040 (59.7)	1,018 (59.4)	22 (75.9)	
Great	163 (9.4)	159 (9.3)	4 (13.8)	
NYHA functional class				
I	433 (25.5)	433 (25.9)	0 (0.0)	<0.0001[a]
II	1,031 (60.5)	1,026 (61.1)	5 (20.0)	
III	231 (13.6)	215 (12.8)	16 (64.0)	
IV	6 (0.4)	2 (0.1)	4 (16.0)	
BMI, kg/m^2	25.1 ± 5.1	25.1 ± 5.1	24.5 ± 5.1	>0.2
<18.5	94 (5.6)	91 (5.5)	3 (10.3)	
≥30	282 (16.8)	277 (16.8)	5 (17.2)	
Renal function (eGFR), mL/min/1.73 m^2	97.1 ± 28.5	97.5 ± 28.1	76.5 ± 37	0.0002
≥60	1,532 (94.0)	1,512 (94.6)	20 (66.7)	
<60	97 (6.0)	87 (5.4)	10 (33.3)	
Hemoglobin level, g/L	141 (75-247)	141 (79-247)	132 (75-226)	0.01
<100	35 (2.2)	31 (2.0)	4 (14.3)	
>200	7 (0.4)	5 (0.3)	2 (7.1)	
sPAP, mm Hg				
<31	1,129 (84.0)	1,115 (84.3)	14 (63.6)	0.0009[a]
32-55	164 (12.2)	160 (12.1)	4 (18.2)	
>55	51 (3.8)	47 (3.6)	4 (18.2)	
Active endocarditis	53 (3.0)	49 (2.8)	4 (12.9)	0.006
Critical preoperative state	12 (0.7)	9 (0.5)	3 (9.7)	<0.0001
Procedural urgency				
Nonurgent	1,573 (91.6)	1,554 (92.1)	19 (63.3)	<0.0001
Urgent	145 (8.4)	134 (7.9)	11 (36.7)	
ACHS score				
0.1-0.6	1,406 (79.5)	1,386 (79.8)	20 (64.5)	0.0005[a]
0.7-1.5	336 (19.0)	328 (18.9)	8 (25.8)	
1.6-3.0	27 (1.5)	24 (1.4)	3 (9.7)	

Values are mean ± SD, n (%), and median (interquartile range). [a]*P* value derived from chi-square test using 2 by *n* contingency table. *P* values are derived from comparison between groups using either Wilcoxon rank sum test for continuous variables or chi-square test for categorical variables, with a value of <0.05 signifying statistical significance.

ACHS = Adult Congenital Heart Surgery; BMI = body mass index; CHD = congenital heart disease; eGFR = estimated glomerular filtration rate; NYHA = New York Heart Association; sPAP = Systolic pulmonary artery pressure.

modification in the current population: the number of previous sternotomies and thoracotomies, previous neurological insult (any previous cerebrovascular accident), and body mass index. Impaired systemic ventricular function was defined as at least moderate impairment on echocardiography, taken as a Simpson's biplane ejection fraction <42% for systemic left ventricles and moderate or severe impairment by visual assessment for systemic right ventricles. The presence of pulmonary hypertension was assessed noninvasively by echocardiography, with a severely raised pulmonary artery systolic pressure defined as >55 mm Hg accounting for the underlying anatomy. The preoperative hemoglobin concentration (Hb) was also collected, and patients were defined as having anemia when Hb <100 g/L or erythrocytosis when Hb >200 g/L. For ease of use, a combined variable of abnormal hemoglobin was defined, combining anemia and erythrocytosis. Although B-type natriuretic peptide values were available for approximately a third of our patients in the later era, the high level of missingness did not allow us to include this in the risk model. CHD was categorized according to anatomic severity using the classification developed by the American College of Cardiology Task Force 1, 32nd Bethesda conference (14). The Adult Congenital Heart Surgery (ACHS) score was used to group surgery according to procedure-related risk (15). The ACHS score was defined as "high" when above 1.5, which, according to Fuller et al. (15), corresponds to procedures with a mortality >5%. Where >1 procedure was performed during an episode of surgery, the procedure with the highest score/risk was used to calculate the risk score.

MODEL CREATION, VALIDATION, AND STATISTICAL ANALYSIS. Statistical analyses were performed using R Statistics version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria). All tests were 2-sided, and a *P* value <0.05 signified statistical significance. Initial univariate regression analysis was conducted to identify variables associated with in-hospital mortality. Variables were tested for collinearity before inclusion in the univariable model. Parameters significant on univariable analysis were then tested in a pairwise fashion, and variables were excluded when they were no longer significant on bivariable analysis. Moreover, variables were excluded when not contributing to the overall area under the curve (AUC) or Akaike Information Criterion of the PEACH versus in-hospital mortality model. Stepwise multiple regression modelling was not performed because of the relatively low number of outcome events in the development cohort. For the weighted model, weights were calculated based on the OR of a given variable from the univariable regression model/lowest OR. Receiver-operating characteristic curve analysis was performed for weighted and unweighted models, as well as for the ACHS score in our population. Differences between AUC were assessed using the method proposed by DeLong et al. (16). CIs for the AUC were generated using bootstrapping. For external validation, we tested our model to a validation cohort from a second, European tertiary center, using receiver-operating characteristic curve

TABLE 2 Univariate Regression Analysis Identifying Univariate Predictors of In-Hospital Mortality in the Development Cohort Only

Risk Factor	In-Hospital Mortality With Risk Factor	In-Hospital Mortality Without Risk Factor	OR (95% CI)	C-Statistic	*P* Value
NYHA functional class III or IV	8.4 (20/237)	0.3 (5/1,464)	26.9 (10.8-81.5)	0.84	<0.0001
≥2 previous sternotomies	6.3 (15/237)	1.0 (16/1,545)	6.5 (3.1-13.3)	0.68	<0.0001
eGFR <60 mL/min/1.73 m^2	10.3 (10/97)	1.3 (20/1,532)	8.7 (3.8-18.7)	0.64	<0.0001
Urgent surgery	7.6 (11/145)	1.2 (19/1,573)	6.7 (3-14.2)	0.64	<0.0001
Impaired systemic ventricular function	5.6 (7/125)	1.2 (16/1,308)	4.8 (1.8-11.5)	0.61	0.0007
≥1 previous sternotomy	2.5 (22/897)	1.0 (9/885)	2.5 (1.2-5.6)	0.60	0.02
Hemoglobin level <10 or >20 g/L	14.3 (6/42)	1.4 (22/1,525)	11.4 (4-28.3)	0.60	<0.0001
Female	2.5 (20/802)	1.1 (11/980)	2.3 (1.1-4.9)	0.60	0.03
Severely raised sPAP (>55 mm Hg)	7.8 (4/51)	1.4 (18/1,293)	6 (1.7-16.9)	0.57	0.002
Critical preoperative state	25.0 (3/12)	1.6 (28/1,762)	20.6 (4.4-73.6)	0.55	<0.0001
Active endocarditis	7.6 (4/53)	1.6 (27/1,729)	5.2 (1.5-13.8)	0.55	0.003
High ACHS score (1.6-3.0)	11.1 (3/27)	1.6 (28/1,742)	7.7 (1.8-23.6)	0.54	0.002
Previous neurological insult	7.9 (3/38)	1.6 (28/1,744)	5.3 (1.2-15.8)	0.54	0.009

Values are % (n/N) unless otherwise indicated. Univariate regression analysis identifying univariate predictors of in-hospital mortality in the development cohort. Only predictors which were significant on univariate analysis are presented. Additional parameters included in this analysis, but not presented as not significant were: age, previous thoracotomy, anatomic complexity, body mass index, and surgery on the thoracic aorta.

Abbreviations as in Table 1.

analysis and testing model calibration (Hosmer-Lemeshow chi-square goodness-of-fit). The predicted in-hospital mortality for each PEACH score bracket was calculated from the fitted univariable logistic regression model of the final PEACH score in both development and validation cohorts. The predicted mortality was then plotted against the observed risk in each series.

RESULTS

PATIENT CHARACTERISTICS AND OUTCOMES. During the study period, 1,782 adult congenital cardiac surgeries were performed at the Royal Brompton Hospital and formed the development cohort. Their baseline characteristics are shown in Table 1. Mean age at the time of surgery was 35.6 ± 14.4 years, and 980 (55%) were men. CHD complexity was classified as "moderate" in 1,040 (59.7%) and "great" in 163 (9.4%) patients, including 23 (1.3%) patients with a systemic right ventricle. The majority (60.6%) of patients were in NYHA functional class II, with 25.5% in functional class I (no exertional breathlessness). A total of 926 (52%) were "redo" procedures: 897 (50.3%) patients had a previous sternotomy and 52 (2.9%) a thoracotomy. Most (n = 1,573, 91.6%) procedures were nonurgent. Procedures are listed in Supplemental Table 1. The procedure-specific risk estimated using the ACHS mortality score could be calculated in 1,769 (99.3%) of procedures and was high (>1.5) in 27 (1.5%) patients, including Fontan conversion/revision or coronary artery bypass grafting. Survival status at discharge was available for all patients. There were 31 (1.7%) in-hospital deaths.

COMPARISON TO EuroSCORE II AND RISK FACTORS FOR THE NEW MODEL. Univariate regression analysis demonstrated a number of clinical characteristics associated with in-hospital mortality (Table 2). These included variables from the EuroSCORE II mortality score: female sex, NYHA functional class >II, systemic ventricular dysfunction, renal dysfunction, active endocarditis, a critical preoperative state, greater procedural urgency, neurological dysfunction, and a higher procedure-specific risk score (used in place of "weight of procedure"). There were no recent myocardial infarctions prior to surgery, and angina was extremely rare in this population (n = 6; 0.3%); hence, these variables were not included in the analysis. In our population, increasing age at surgery was not associated with increased in-hospital mortality (OR: 2.34; 95% CI: 0.86-7.39; P = 0.11). The number of previous sternotomies was predictive of mortality (OR: 2.1; 95% CI: 1.55-2.82; P < 0.0001), whereas the number of thoracotomies was not. The following variables not included in the EuroSCORE II were found to be associated with a higher perioperative mortality in our population on univariate analysis: presence of severe pulmonary hypertension (defined as a systolic pulmonary arterial pressure >55 mm Hg) (OR: 6.03; 95% CI: 1.69-16.92; P = 0.002), and a hemoglobin level of <100 g/L (anemia) or >200 g/L (secondary erythrocytosis) (OR: 11.39; 95% CI: 4.00-28.27; P < 0.0001).

Critical preoperative state was present in <1% of patients and was no longer predictive of in-hospital mortality when combined with NYHA functional class in a bivariate model; therefore, it was removed from the final score. Pulmonary hypertension status did not significantly improve the Akaike Information Criterion of the final score; hence, it was also removed.

The final PEACH score consisted of the following variables: NYHA functional class III or IV, urgent surgery, renal dysfunction (eGFR <60 mL/min/1.73 m^2), active endocarditis, ≥2 previous sternotomies, a high ACHS score (>1.5), and an abnormal hemoglobin level (<100 or >200 g/L). A risk score was calculated for each patient by adding 1 point for each risk variable present (**Table 3**). The distribution of PEACH score was as follows: 0 points in 1,223 (68.6%) patients, 1 point in 384 (21.5%), 2 points in 111 (6.2%), 3 points in 34 (1.9%), and ≥4 points in 30 (1.7%) (**Central Illustration**). This modified, unweighted risk model performed well in predicting in-hospital mortality (**Figure 1A**) (AUC: 0.88; 95% CI: 0.822-0.937). A risk score weighted by the ORs from the univariate regression analysis did not significantly improve its performance and was not used (Supplemental Figure 1) (AUC: 0.88; 95% CI: 0.822-0.938). The new model compared favorably against the ACHS score and was significantly better in terms of discrimination compared with ACHS (**Figure 1B**) (AUC: 0.69; 95% CI: 0.60-0.78; $P = 0.0003$). Patients were then divided into 3 different risk groups: a low-risk group (0 points, mortality 0.2%), an intermediate-risk group (1-2 points, mortality 3.6%), and a high-risk group (≥3 points, mortality 17.2%) (**Central Illustration**).

CHARACTERISTICS OF THE VALIDATION COHORT. A total of 975 ACHD patients underwent cardiac surgery in the validation cohort during the study period. The clinical characteristics of the validation cohort are shown in Supplemental Table 2. There were differences in baseline characteristics of ACHD patients between the development and validation cohorts. The mean age of patients in the validation cohort was higher than in the development cohort (42.8 ± 17.9 years vs 35.6 ± 14.4 years; $P < 0.0001$). Compared with the development cohort, an even greater proportion of patients had undergone nonurgent surgery (97.9% vs 91.6%; $P < 0.0001$) and more complex procedures (ACHS score >1.5 in 7.8% vs 1.5%; $P < 0.0001$). By contrast, preoperative renal dysfunction (eGFR <60 mL/min/1.73 m^2) was less common in the validation compared with the development cohort (6% vs. 10.9%; $P < 0.0001$). In-hospital death did not differ between the 2 cohorts (2.6% in the validation cohort; $P = 0.18$).

VALIDATION OF THE RISK SCORE. The PEACH score was calculated for each patient in the validation cohort, with an AUC of 0.75 (95% CI: 0.72-0.77) (Supplemental Figure 2). The low-risk group in the validation cohort (0 points) had a mortality of 1.0%, the intermediate-risk group (1-2 points) had a mortality of 4.7%, and the high-risk group (≥3 points) had a mortality of 22.7% (**Central Illustration**). The model was well-calibrated in the validation cohort (Hosmer-Lemeshow chi-square goodness-of-fit $P = 0.55$).

TABLE 3 Factors for Calculation of the PEACH Score

	Score
NYHA functional class	
I/II	0
III/IV	1
Procedural urgency	
Nonurgent	0
Urgent	1
Renal function (eGFR), mL/min/1.73 m^2	
≥60	0
<60	1
Active endocarditis	
No	0
Yes	1
Multiple previous sternotomies	
<2	0
≥2	1
ACHS score	
0.1-1.5	0
1.6-3.0	1
Hemoglobin level, g/L	
100-200	0
<100 or >200	1

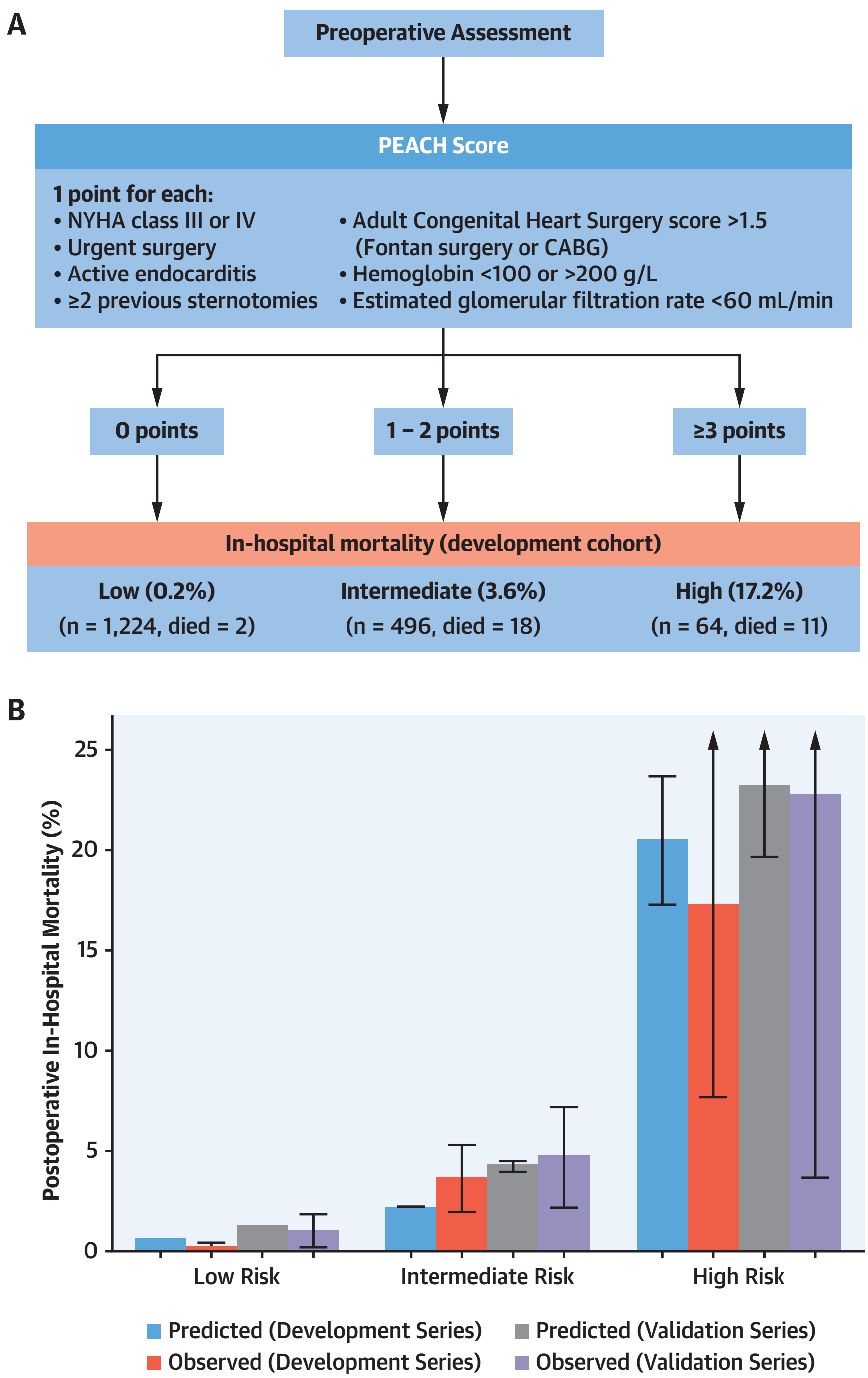
Abbreviations as in **Table 1**.

DISCUSSION

In this study, we have developed and validated a novel prognostic score that is reliable in predicting mortality around congenital cardiac surgery in ACHD patients. For this purpose, we have used components of the EuroSCORE II that were predictive of outcome in this population and added clinical parameters that are relevant to congenital cohorts and were associated with perioperative outcome. The PEACH score was validated externally in an ACHD population undergoing surgery in a different European tertiary center. Therefore, we submit that this validated score should be considered when assessing ACHD patients undergoing cardiac surgery to inform the consent process and ensure that adequate measures are taken to reduce perioperative risk.

The EuroSCORE II is a robust, validated risk score in cardiac surgery. We found that several parameters of the EuroSCORE II were also predictive of periprocedural mortality in the ACHD population, but others did not apply. This was in part because this

CENTRAL ILLUSTRATION The PEACH Score: Risk Score Calculation, Predicted and Observed In-Hospital Mortality



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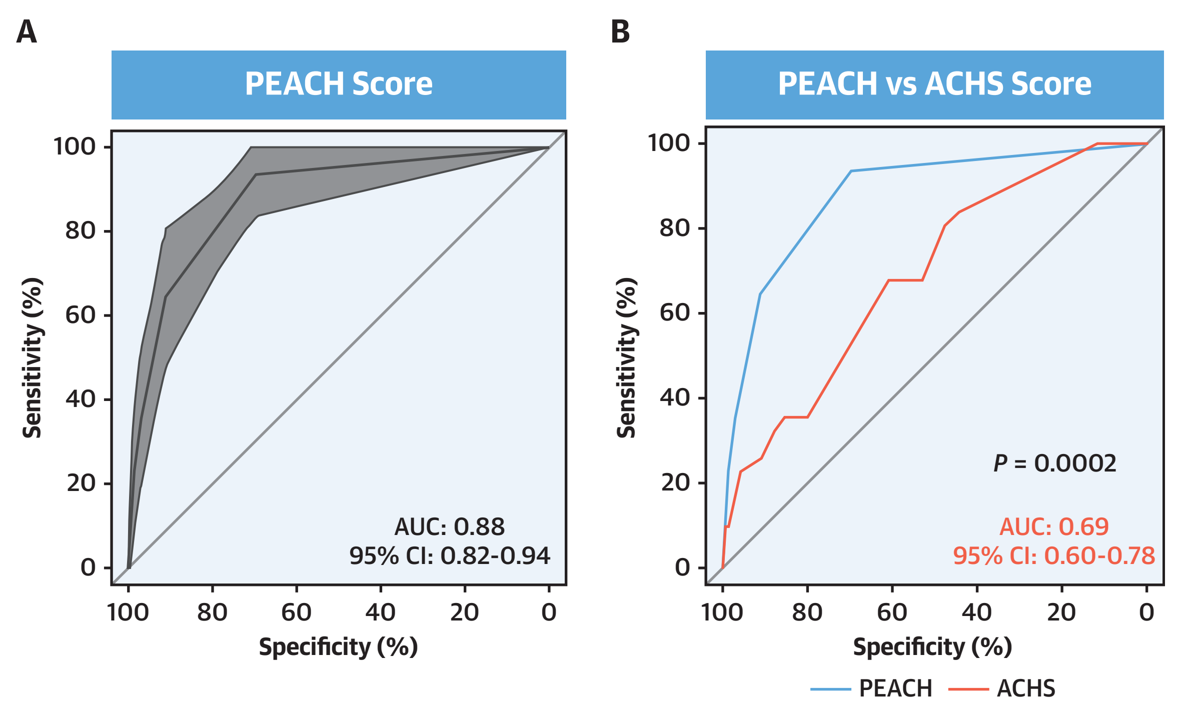
(A) The PErioperative ACHd (PEACH) score is calculated from the risk factors shown, the presence of each of these contributing 1 point to the final score. Low-, intermediate-, and high-risk groups relate to different postoperative in-hospital mortality. **(B)** Predicted versus actual mortality in the development and validation cohorts is shown. CABG = coronary artery bypass grafting; NYHA = New York Heart Association.

FIGURE 1 **PEACH Score Performance**



(A) Receiver-operating characteristic (ROC) curves for the PErioperative ACHd (PEACH) scoring system in predicting in-hospital mortality. **(B)** Performance of the PEACH score versus the ACHS score for in-hospital mortality. ACHS = Adult Congenital Heart Surgery; AUC = area under the curve.

was a young population, and thus, myocardial infarction and diabetes mellitus, 2 important variables of the EuroSCORE II, were present in very small numbers, and also because of the types of operations performed. Indeed, this score was derived from a cohort of patients of whom the vast majority had surgery for acquired heart disease (coronary artery bypass grafting in 48%, aortic valve replacement in 30%). Moreover, the spectrum of cardiac surgical procedures performed in ACHD patients differs significantly from that in acquired cardiac patients, and includes a significantly larger proportion of operations involving right-sided structures, shunt lesions, and revisions of previous surgery (50% of cases in our cohort) (2). Hence, predictors of perioperative mortality in ACHD surgery cannot be assumed to be equivalent in these 2 cohorts. The ACHS score, an ACHD-specific score for perioperative mortality, has performed variably well in previous studies, but did not perform well in our cohort, perhaps because it is based purely on the procedure undertaken and ignores several established prognostic markers in congenital cardiac surgery (6,17). Procedural difficulty alone is not sufficient to capture risk in an ACHD surgical population and should be integrated with clinical features to achieve a stronger risk stratification tool. The GUCH mortality score, which combined existing pediatric risk models including information on comorbidities, outperformed existing risk tools, but is complex to derive and requires external validation (6). Nonetheless, existing scores, especially the EuroSCORE II and the ACHS score, provided a valuable basis for the development of the PEACH score.

The PEACH score was developed from variables relevant to the adult population. Other perioperative risk scores derived from the pediatric population have been assessed in ACHD (6) but lack discriminative power when externally validated (18). Indeed, risk variables identified in the pediatric CHD population may not be applicable or relevant to adults, who are likely to have had previous palliative or reparative congenital heart surgery and more frequently exhibit long-standing residual hemodynamic lesions or sequelae such as arrhythmias, heart failure, and pulmonary hypertension. Hence, an ACHD-specific score is needed to guide the clinical and perioperative assessment in these patients.

Age was not a significant predictor of mortality in our population even though it has been included in other surgical scores. Indeed, this was in an entirely adult population, which excluded neonatal and pediatric patients in whom surgery may carry greater risks. Moreover, the majority of patients in our population underwent surgery between the third and fourth decades of life; hence, age may not have had as significant an impact as it would have in older cohorts.

External validation is an essential part of verifying risk scores before they can enter clinical practice. We externally validated the PEACH score in a second ACHD cohort from a tertiary center in another European country, with different practices and surgical pathways. Despite differences in the characteristics of the 2 populations, the PEACH score retained its discriminative power in identifying patients who were at increased risk of perioperative mortality. Although further validation would be desirable, the current study identifies the PEACH score as a useful tool for clinical practice.

The PEACH score is simple to calculate and can support surgical planning and the consent process. The vast majority of patients in our cohorts had a low PEACH score indicative of a low perioperative mortality, which reflects current tertiary ACHD practice and surgical outcomes. However, higher PEACH scores are associated with moderate or severely increased risk of perioperative mortality and should trigger further evaluation and perioperative management of potentially modifiable risks, eg, optimization of heart failure therapy, improvement of renal function, iron replacement, or blood transfusion for pre-operative anemia. Moreover, careful surgical planning for high-risk patients should include multidisciplinary discussions, seeking alternatives to surgery (eg, percutaneous interventions or transplantation), and planning perioperative support, including extracorporeal membrane oxygenation and other short-term mechanical circulatory support. Last, but not least, our data beg the question as to whether earlier surgical intervention timed to dynamic risk factors, such as lower NYHA functional class and absence of renal dysfunction, would have had merits; however, these are intention to treat series and, therefore, this point remains speculative (19).

STUDY LIMITATIONS. The main limitation of our study was its retrospective design, with data collected from clinical databases. Bivariable rather than higher-order multivariable analysis was performed given the limited number of events in the development cohort. Moreover, a weighted score based on the findings of the univariable analysis was attempted but did not improve the performance of the PEACH score. Continuous variables were transformed into binomial; hence, a linear relationship between these parameters and the risk of death was not assumed. This strategy may not utilize the full depth of information contained in the data, but simplifies its use in clinical practice. Finally, the relatively small number of events did not allow internal validation by splitting our population into a training and validation cohort, which would significantly limit power. Instead, we externally validated the model using a cohort from a second tertiary center in a different country. We opted for the most robust external validation of our score using an ACHD cohort with differences in clinical characteristics to the development cohort. Despite this, the PEACH score was able to identify patients at increased risk of in-hospital mortality.

CONCLUSIONS

The proposed perioperative score is able to predict mortality around ACHD surgery and should be considered in clinical practice when assessing perioperative risk and planning perioperative and postoperative management.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL SKILLS: A risk score based on functional impairment, type of surgical procedure (ACHS score), urgency of surgery, previous sternotomies, active infective endocarditis, renal dysfunction, and abnormal hemoglobin content accurately predicts perioperative mortality in adults with CHD undergoing cardiac surgery.

TRANSLATIONAL OUTLOOK: Future research should assess whether specific interventions that target each component of the risk model can reduce the risk of perioperative mortality in patients with ACHD undergoing cardiac surgery.

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KEY WORDS clinical risk tool, congenital heart disease, perioperative risk, risk score

APPENDIX For supplemental tables and figures, please see the online version of this paper.