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ORIGINAL RESEARCH

# Using a Cardiogenic Shock Classification System for Predicting Postcardiotomy Shock Mortality

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## ABSTRACT

**BACKGROUND** Cardiogenic shock (CS) is a life-threatening hemodynamic state. Patients with differing shock severity show varying responsiveness to clinical interventions. CS also occurs in patients who have undergone cardiac surgery. A few evaluation systems have been developed for postcardiotomy patients. The Society for Cardiovascular Angiography and Intervention (SCAI) has developed a new classification scheme for CS.

**OBJECTIVES** This study aimed to assess the parameters that define the stages of CS and the diagnostic utility of an SCAI-based CS classification system for patients undergoing cardiac surgery to inform the prediction of outcomes.

**METHODS** This single-center, retrospective, observational study included 8,335 consecutive adult patients undergoing cardiac surgery from January to December 2022. This cohort was divided into 5 groups based on lactate and types of intervention received, including vasopressors and mechanical circulatory support systems. The primary outcome was in-hospital mortality.

**RESULTS** CS occurred in 970 (11.1%) patients of this cohort. The frequencies of distribution of various postcardiotomy shock stages differed significantly: stage A = 4,747 (57.0%), stage B = 2,658 (31.9%), stage C = 779 (9.3%), stage D = 64 (0.8%), and stage E = 87 (1.0%) ($P < 0.001$) patients. In-hospital mortality was 1.1% (94 of 8,335). A progressive increase in the stage of the disease led to a clear stepwise increase in in-hospital mortality: Stage A = 0.4% (19 of 4747), Stage B = 0.8% (21 of 2658), Stage C = 2.8% (22 of 779), Stage D = 7.8% (5 of 64), and Stage E = 31.0% (27 of 87) ($P < 0.001$). The area under the receiver-operating curve of this classification for postcardiotomy CS was 0.781 (95% CI: 0.746-0.815).

**CONCLUSIONS** In this single-center postcardiotomy population, CS occurred in 11.1% of patients. Postcardiotomy SCAI-derived criteria for CS severity suggested a good correlation with in-hospital mortality. (JACC Asia. 2025;5:663–676)


Cardiogenic shock (CS) is a life-threatening hemodynamic state,[1] and the all-cause mortality rate remains close to 50%.[2] Patients with diverse shock severity show distinctly different responsiveness to clinical interventions.[3,4] Therefore, severity assessment of CS is a critical step in the management of patients with CS and often influences subsequent treatment decisions.

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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**ABBREVIATIONS AND ACRONYMS**

**CABG** = coronary artery bypass grafting

**MCS** = mechanical circulatory support

**PCS** = postcardiotomy cardiogenic shock

**SCAI** = Society for Cardiovascular Angiography and Intervention

**VA-ECMO** = venoarterial extracorporeal membrane oxygenation

Among patients who underwent cardiac surgery, 2% to 6% developed postcardiotomy cardiogenic shock (PCS),[5,6] which is associated with elevated mortality rates.[7] Compared with cardiology, cardiac surgery has the following characteristics: 1) a broader spectrum of diseases; 2) improvement of cardiac structure and function by repairing diseased tissues, resulting in more injury and a more intense postoperative stress response; and 3) the use of general anesthesia during surgery, with some patients requiring cardioplegia and relying on extracorporeal circulation to maintain systemic perfusion, which also induces hemodynamic changes.[8] Therefore, the criteria for inclusion in this cohort should differ from those used in cardiology. However, there is a lack of scoring systems for assessing the severity of CS in postcardiotomy patients.[9-11]

In 2019, the Society for Cardiovascular Angiography and Intervention (SCAI) developed a new CS classification scheme.[12] Based on the degree of hemodynamic disorder, this SCAI-derived scheme groups patients at risk of developing CS into 5 stages of severity (A-E), ranging from "at risk" to "extreme" CS (**Central Illustration A**). Nevertheless, there have been few studies that have evaluated the efficacy of the SCAI-based CS classification system in postcardiotomy patients. This study aimed to assess the parameters that define the stages of CS and the diagnostic utility of an SCAI-based CS classification system for patients undergoing cardiac surgery to inform the prediction of outcomes in this cohort.

## METHODS

**STUDY DESIGN AND ETHICS.** This single-center, retrospective, observational study was carried out in the Center for Cardiac Intensive Care (CCIC), Beijing Anzhen Hospital, Capital Medical University, China, which is an 80-bed unit designed for perioperative observation and treatment of postcardiotomy patients. This study was approved by the Research Ethics Committee of Beijing Anzhen Hospital (Ethical Approval Number: 2024166x). The requirement for individual patient consent was waived because the study was based on anonymized data obtained from routine care.

**POPULATION.** This study included the consecutive adult patients who received cardiac surgery and then were admitted to CCIC at Beijing Anzhen Hospital from January 2022 to December 2022. In our research, cardiac surgery was regarded as a transthoracic procedure. Patients undergoing only percutaneous surgeries or missing key data were excluded (**Figure 1**).

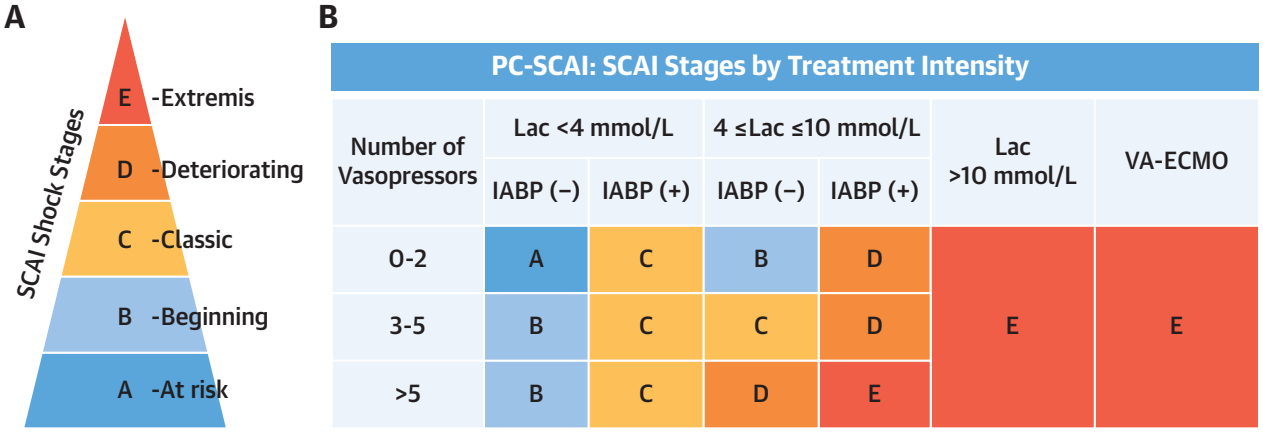
**DATA COLLECTION.** Patient demographics, admission diagnoses based on the International Classification of Diseases-10th Revision, medical history, clinical data, surgery, and interventions information were extracted from the electronic patient data management system. Each patient may have had more than 1 diagnosis. The EuroSCORE (European System for Cardiovascular Operational Risk Evaluation) II and IABP-SHOCK (Intra-aortic Balloon Pump in Cardiogenic Shock) II scores were calculated retrospectively.[9,13]

Procedural data were analyzed for the first surgical procedure preceding the initial CCIC admission. If the patient had multiple CCIC admissions, the data on the first admission related to cardiac surgery were selected. Surgery types encompassed the main surgery type of the index procedure as specified by the operating surgeon, including coronary artery bypass grafting (CABG), valve surgery, aortic surgery, and congenital heart surgery. Combined surgery was defined as receiving more than 1 main surgery type.

**OUTCOMES AND DEFINITIONS.** The primary outcome was in-hospital mortality that was defined as death from any cause occurring during hospitalization. A manual chart review was conducted for each transferred patient, and patients who were transferred because of abandonment of treatment for critical conditions were regarded as in-hospital deaths. Secondary outcomes included intensive care unit (ICU) mortality, final use of mechanical circulatory support (MCS) device (during the whole hospital stay), postoperative complications, invasive mechanical ventilation duration, and hospital length of stay.

The postcardiotomy (PC)-SCAI-based CS severity stages after CCIC admission used in this analysis were assigned retrospectively using a modification of the classification proposed by the original SCAI-based CS severity stage classification[12,14] and the CSWG, based on serum lactate levels, number of vasopressors, intra-aortic balloon pump (IABP), and venoarterial extracorporeal membrane oxygenation (VA-ECMO). Vasopressors were defined as drugs with vasoconstrictive properties (with or without inotropic properties), and the specific types of drugs have been described in the Supplemental Appendix. Similar to the original SCAI CS severity classification, PC-SCAI-based CS severity criteria also divided the population into 5 stages in increasing order from mild to severe: A, B, C, D, and E. Patients with PC-SCAI stages

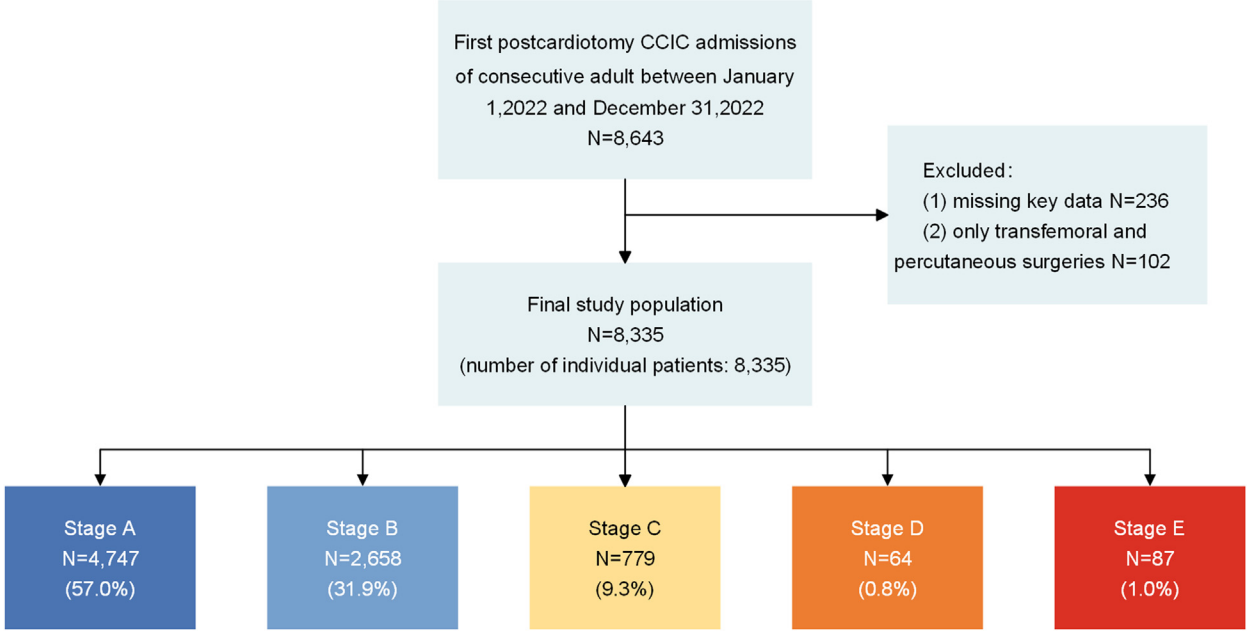
**CENTRAL ILLUSTRATION** **The SCAI CS Classification for Predicting Postcardiotomy Shock Mortality**




**Wang Y, et al. JACC Asia. 2025;5(5):663-676.**

(A) The original Society for Cardiovascular Angiography and Intervention (SCAI) shock classification stratified patients into 5 stages A to E. (B) Select parameters of number of vasopressors, lactate level, and usage of temporary machinal circulation support device. IABP = intra-aortic balloon pump; Lac = lactate; PC = postcardiotomy; VA-ECMO = venous-arterial extracorporeal membrane oxygenation.

**FIGURE 1** **Flow Chart**




A total of 8,643 adult patients underwent cardiac surgery and were admitted to the ICU. In all, 236 patients were excluded for missing key data and 102 for only percutaneous surgery. Finally, 8,335 patients were included in the analysis. The arrows represent the filtering process. CCIC = center for cardiac intensive care.

C, D, or E were deemed to have developed PCS. Detailed grading criteria are shown in **Central Illustration B**.

**STATISTICAL ANALYSIS.** Patient characteristics were reported as proportions for categorical variables and as mean ± SD or median (Q1-Q3) for continuous variables. Categorical variables were compared using chi-square or Fisher's exact tests, and continuous variables were compared using the Student's *t*-test, Mann-Whitney *U* test, or 1-way analysis of variance, as appropriate. Univariate and multivariate logistic regressions were used to analyze the predictors of in-hospital mortality. Trends across the SCAI-based CS severity stages were determined using linear regression for continuous variables and the Cochran-Armitage test for binary categorical variables. Independent risk factors were reported as OR. The area under the receiver-operating characteristic curve (AUROC), as well as its 95% CI, was computed and used to help determine the discrimination of the selected scales in the predictions of in-hospital mortality. Two-tailed *P* values <0.05 were considered statistically significant. All statistical analysis was performed using SPSS Statistics software (version 27.0, IBM Corp) and MedCalc software (version 19, MedCalc Software Ltd).

## RESULTS

**STUDY POPULATION.** Between January and December 2022, 8,643 adult patients underwent cardiac surgery and were subsequently admitted to the ICU. A total of 236 patients were excluded for missing key data, and 102 were excluded for having undergone only percutaneous surgery. Ultimately, 8,335 patients were included in the final analysis (**Figure 1**). The patient population had a mean age of 59.08 ± 11.58 years, and 30.1% were women. Among them, 582 (7.0%) had experienced MI; 990 (11.9%) had received percutaneous coronary intervention treatment, and 314 (3.8%) had undergone cardiac surgery before admission. The major admission diagnoses included coronary heart disease in 5,385 (64.6%, 491 of whom were diagnosed with acute myocardial infarction [AMI]) patients, aortic diseases in 1,519 (18.2%), and valvular heart disease in 3,441 (41.3%) patients. The mean LVEF was 57.6% ± 9.0%. The median EuroSCORE II value was 4 (Q1-Q3: 3-6). Details including patient characteristics and evaluation upon admission are summarized in **Table 1**.

Among the study population, the major surgeries included CABG (61.7%), aortic surgery (15.7%), valve surgery (29.5%), and congenital surgery (4.6%). A total of 4,373 (52.5%) patients received on-pump surgery, and 1,709 (20.5%) underwent combined procedures. After surgery, 169 (2.0%) patients required reoperation, 243 (2.9%) patients received continuous renal replacement therapy, and 9 (0.1%) patients underwent endoscopy for gastrointestinal hemorrhage. During the first 24 hours of ICU admission, the mean serum lactate level was 2.59 mmol/L. IABP and VA-ECMO were implanted in 74 (0.9%) and 28 (0.3%) patients, respectively. More details of surgery and postcardiotomy information are provided in **Table 2**.

**INCIDENCE AND RISK FACTORS OF PCS.** Among the study population, PCS occurred in 970 (11.1%) postcardiotomy patients. The distribution frequency of PC-SCAI CS stages was as follows: Stage A = 4,747 (57.0%), Stage B = 2,658 (31.9%), Stage C = 779 (9.3%), Stage D = 64 (0.8%), and Stage E = 87 (1.0%) (**Figure 1**). The proportions of PC-SCAI CS severity stages among subgroups (surgical types) suggested significant differences (**Figure 2**). In the PCS cohort, 80.3% (779 of 970), 6.6% (64 of 970), and 9.0% (87 of 970) of patients were at PC-SCAI-based CS severity stages C, D, and E, respectively.

In our cohort, cardiac surgery history (OR: 2.34; 95% CI: 1.78-3.09; $P < 0.001$), admission serum creatinine level ≥353.6 μmol/L (OR: 2.17; 95% CI: 1.07-4.37; $P = 0.031$), admission LVEF <50% (OR: 2.44; 95% CI: 2.07-2.87; $P < 0.001$), EuroSCORE II (OR: 1.16; 95% CI: 1.13-1.19; $P < 0.001$), combined surgery (OR: 4.23; 95% CI: 3.67-4.88; $P < 0.001$), and on-pump surgery (OR: 8.94; 95% CI: 7.24-11.05; $P < 0.001$) were observed to be significant predictors of PCS in the unadjusted model. After multivariate regression analysis, it was found that cardiac surgery history (OR: 1.58; 95% CI: 1.19-2.11; $P = 0.002$), admission serum creatinine level ≥353.6 μmol/L (OR: 3.1; 95% CI: 1.42-6.74; $P = 0.004$), admission LVEF <50% (OR: 2.41; 95% CI: 2.03-2.87; $P < 0.001$), and having had on-pump surgery (OR: 6.49; 95% CI: 5.18-8.13; $P = 0.036$) were independent risk factors for PCS occurrence (Supplemental Table 1).

**OUTCOMES.** The overall in-hospital mortality in this cohort was 1.1% (95% CI: 0.901%-1.355%). There was a clear stepwise increase in in-hospital mortality with increasing PC-SCAI-based CS severity stage: stage A = 0.4% (95% CI: 0.22%-0.58%), stage B = 0.8% (95% CI: 0.05%-1.13%), stage C = 2.8% (95% CI: 1.66%%-4.00%), stage D = 7.8% (95% CI: 1.06%-14.57%), and stage E = 31.0% (95% CI: 21.12%-40.95%) ($P < 0.001$). Patients with PCS had a higher in-hospital mortality rate than those without PCS (0.5% vs 5.8%, respectively; $P < 0.001$). The detailed outcomes are shown in **Table 3**. The in-hospital mortality rate

**TABLE 1 Characteristics of Patients Receiving Cardiac Surgery**

| | With Data, % | All (n = 8,335, 100.0%) | SCAI A (n = 4,747, 57.0%) | SCAI B (n = 2,658, 31.9%) | SCAI C (n = 779, 9.3%) | SCAI D (n = 64, 0.8%) | SCAI E (n = 87, 1.0%) | *P* Value |
|---|---|---|---|---|---|---|---|---|
| Age, y | 100 | 59.08 ± 11.58 | 58.84 ± 11.67 | 59.40 ± 11.37 | 59.14 ± 11.57 | 62.00 ± 11.61 | 60.33 ± 12.08 | 0.057 |
| Female | 100 | 2,513 (30.1) | 1,313 (27.7) | 865 (32.5) | 285 (36.6) | 22 (34.4) | 28 (32.2) | <0.001 |
| BMI, kg/m$^2$ | 95.9 | 25.34 ± 3.53 | 25.63 ± 3.47 | 25.04 ± 3.61 | 24.63 ± 3.55 | 25.03 ± 2.71 | 24.84 ± 3.58 | <0.001 |
| Tobacco use | 100 | 3,432 (41.2) | 2,067 (43.5) | 1,035 (38.9) | 267 (34.3) | 29 (45.3) | 34 (39.1) | <0.001 |
| Prior history of | 100 | | | | | | | |
| PCI | | 990 (11.9) | 630 (13.3) | 262 (9.9) | 68 (8.7) | 10 (15.6) | 20 (23.0) | <0.001 |
| Cardiac surgery | | 314 (3.8) | 137 (2.9) | 108 (4.1) | 58 (7.4) | 4 (6.30) | 7 (8.0) | <0.001 |
| Myocardial infraction | | 582 (7.0) | 333 (7.0) | 180 (6.8) | 56 (7.2) | 8 (12.5) | 5 (5.7) | 0.486 |
| Major cardiotomy etiology | 100 | | | | | | | |
| Aortic disease | | 1,519 (18.2) | 862 (18.2) | 472 (17.8) | 154 (19.8) | 13 (20.3) | 18 (20.7) | 0.701 |
| Coronary heart disease | | 5,385 (64.6) | 3,076 (64.8) | 1,720 (64.7) | 493 (63.3) | 37 (57.8) | 59 (67.8) | 0.669 |
| AMI | | 491 (5.9) | 285 (6.0) | 142 (5.3) | 49 (6.3) | 5 (7.8) | 10 (11.5) | 0.129 |
| Congenital heart disease | | 413 (5.0) | 231 (4.9) | 128 (4.8) | 46 (5.9) | 4 (6.3) | 4 (4.6) | 0.748 |
| Valvular heart disease | | 3,441 (41.3) | 1,928 (40.6) | 1,097 (41.3) | 362 (46.5) | 24 (37.5) | 30 (34.5) | 0.021 |
| Pulmonary embolism | | 24 (0.3) | 16 (0.3) | 4 (0.2) | 3 (0.4) | 1 (1.6) | 0 (0.0) | 0.179 |
| Arrhythmia | | 1,325 (15.9) | 753 (15.9) | 409 (15.4) | 137 (17.6) | 11 (17.2) | 15 (17.2) | 0.666 |
| Comorbidities | 100 | | | | | | | |
| Hypertension | | 4,203 (50.4) | 2,377 (50.1) | 1,358 (51.1) | 397 (51.0) | 29 (45.3) | 42 (48.3) | 0.804 |
| Hyperlipidemia | | 3,222 (38.6) | 1,864 (39.2) | 1,015 (38.2) | 297 (38.1) | 15 (23.4) | 31 (35.6) | 0.106 |
| Diabetes | | 2,079 (24.9) | 1,199 (25.3) | 672 (25.3) | 170 (21.8) | 17 (26.6) | 21 (24.1) | 0.333 |
| Cerebrovascular disease | | 75 (0.9) | 35 (0.7) | 30 (1.1) | 8 (1.0) | 1 (1.6) | 1 (1.1) | 0.480 |
| COPD | | 64 (0.8) | 36 (0.8) | 19 (0.7) | 8 (1.0) | 1 (1.6) | 0 (0.0) | 0.737 |
| Chronic kidney disease | | 5 (0.1) | 3 (0.1) | 1 (0.0) | 1 (0.1) | 0 (0.0) | 0 (0.0) | 0.222 |
| Laboratory/imaging data when admission | | | | | | | | |
| Hb, g/L | 99.9 | 124.14 ± 24.01 | 125.36 ± 23.03 | 122.84 ± 24.47 | 122.99 ± 26.53 | 114.13 ± 26.40 | 115.36 ± 30.32 | <0.001 |
| WBC, × 10$^9$/L | 99.9 | 8.35 ± 3.89 | 8.23 ± 3.46 | 8.35 ± 4.03 | 8.74 ± 4.81 | 9.83 ± 5.90 | 10.21 ± 7.76 | <0.001 |
| PLT, × 10$^9$/L | 99.9 | 187.61 ± 70.58 | 194.91 ± 67.39 | 182.60 ± 71.14 | 166.58 ± 77.14 | 154.33 ± 73.02 | 154.93 ± 91.44 | <0.001 |
| Scr, μmol/L | 99.9 | 85.72 ± 61.15 | 84.36 ± 62.25 | 84.39 ± 47.59 | 93.23 ± 75.68 | 115.89 ± 159.44 | 111.47 ± 78.61 | <0.001 |
| ALT, U/L | 99.9 | 26.72 ± 75.49 | 24.74 ± 30.85 | 28.19 ± 114.56 | 28.73 ± 78.46 | 51.39 ± 177.48 | 53.494 ± 118.19 | <0.001 |
| $PaO_2$, mm Hg | 99.9 | 121.99 ± 73.81 | 122.18 ± 73.26 | 120.93 ± 73.03 | 121.74 ± 75.52 | 120.55 ± 77.15 | 147.271 ± 101.57 | 0.029 |
| EF, % | 98.6 | 57.63 ± 8.97 | 58.72 ± 7.83 | 57.02 ± 9.50 | 54.63 ± 10.70 | 51.66 ± 11.36 | 49.07 ± 15.48 | <0.001 |
| LVEDD, mm | 98.6 | 47.86 ± 7.40 | 47.51 ± 6.73 | 48.33 ± 7.98 | 48.57 ± 8.78 | 45.66 ± 7.79 | 47.37 ± 8.55 | <0.001 |
| EuroSCORE II | 100 | 4 (3-6) | 4 (1-7) | 4 (1-7) | 5 (1-9) | 6 (2-10) | 7 (2-12) | <0.001 |

Values are mean ± SD, n (%), or median (Q1-Q3).

ALT = alanine aminotransferase; BMI = body mass index; EuroSCORE = European System for Cardiac Operative Risk Evaluation; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fractions; PCI = percutaneous coronary intervention; SCAI = Society for Cardiovascular Angiography and Intervention; Scr = serum creatinine; WBC = white blood cell.

trends in 2 subgroups (on-pump vs off-pump, and single vs combined surgery), measured by PC-SCAI-based CS severity stage, were similar to those in the whole cohort (Figure 3).

A total of 32 (0.4%) patients died in ICU with significance differences in each PC-SCAI CS stage ($P < 0.001$). As the PC-SCAI stage increased, the cohort experienced an increased incidence of complications, including final MCS device use ($P < 0.001$), gastrointestinal hemorrhage ($P < 0.001$), stroke ($P < 0.001$), hyperbilirubinemia ($P < 0.001$), AKI ($P < 0.001$), and LV dysfunction ($P < 0.001$). With the PC-SCAI CS stage increasing, the patients had longer hospital stays ($P < 0.001$), ICU stays ($P < 0.001$), and invasive mechanical ventilation duration ($P < 0.001$) (Table 3, Figure 4).

**PC-SCAI-BASED CS SEVERITY IN MORTALITY RISK STRATIFICATION.** Overall, each increase in the PC-SCAI-based CS severity stage was associated with a significantly elevated in-hospital mortality rate compared with PC-SCAI-based CS severity stage A in univariate and multivariate logistic regression models (Table 4). Moreover, cardiac surgery history (OR: 2.76; 95% CI: 1.37-5.53; $P = 0.003$), admission serum creatinine level ≥353.6 μmol/L (OR: 10.97; 95% CI: 4.24-28.37; $P < 0.001$), admission LVEF <50% (OR: 3.9; 95% CI: 2.57-5.95; $P < 0.001$), having combined surgery (OR: 2.55; 95% CI: 1.68-3.87; $P < 0.001$),

**TABLE 2 Surgery and Postoperative Information**

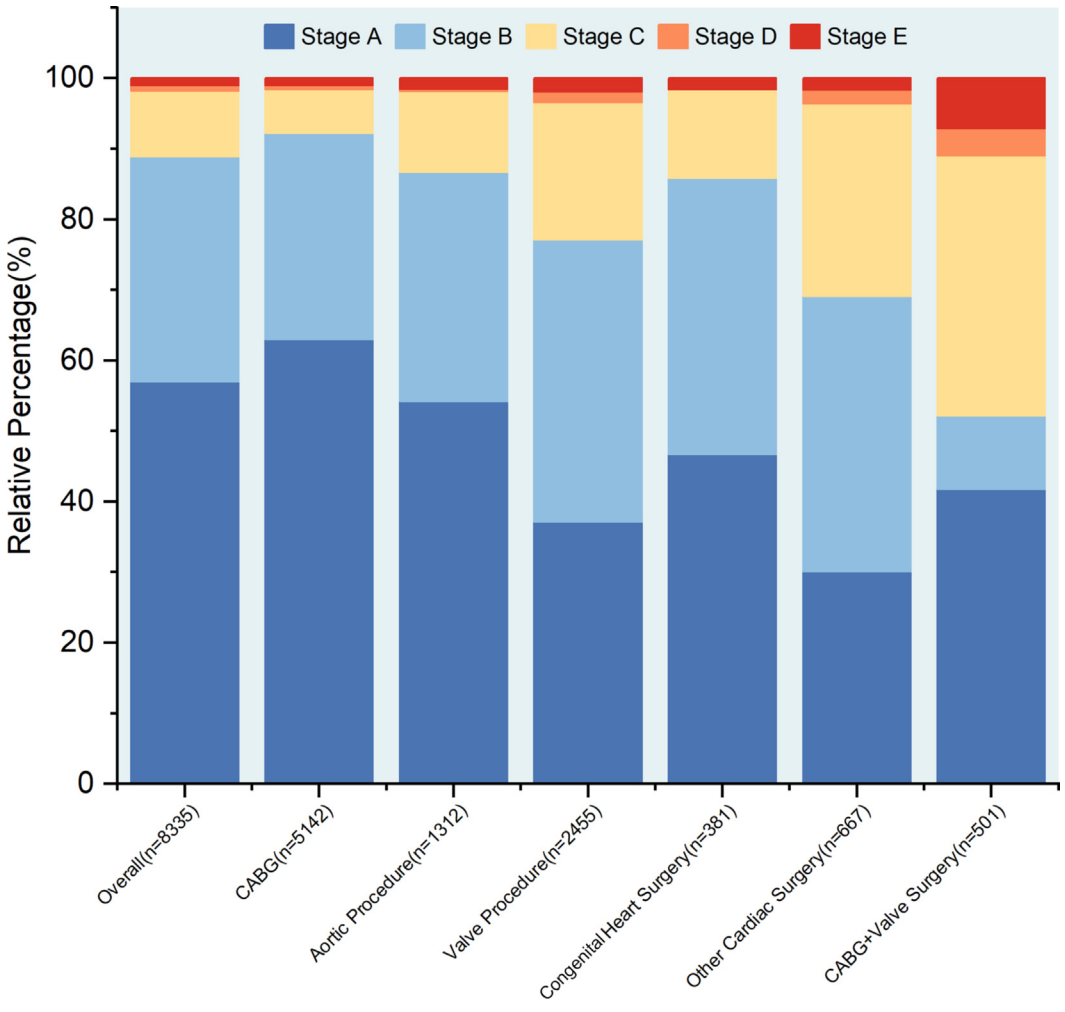
| | With Data, % | All (n = 8,335) | SCAI A (n = 4,747) | SCAI B (n = 2,658) | SCAI C (n = 779) | SCAI D (n = 64) | SCAI E (n = 87) | *P* Value |
|---|---|---|---|---|---|---|---|---|
| Major cardiac surgical type | 100 | | | | | | | |
| CABG | | 5,142 (61.7) | 3,241 (68.3) | 1,500 (56.4) | 317 (40.7) | 33 (51.6) | 51 (58.6) | <0.001 |
| Valve surgery | | 2,455 (29.5) | 910 (19.2) | 981 (36.9) | 479 (61.5) | 38 (59.4) | 47 (54.0) | <0.001 |
| Aortic surgery | | 1,312 (15.7) | 725 (15.3) | 408 (15.3) | 154 (19.8) | 4 (6.3) | 21 (24.1) | 0.001 |
| Congenital heart surgery | | 381 (4.6) | 178 (3.7) | 149 (5.6) | 48 (6.2) | 0 (0.0) | 6 (6.9) | <0.001 |
| Other cardiac surgery | | 667 (8.0) | 201 (4.2) | 260 (9.8) | 182 (23.4) | 13 (20.3) | 11 (12.6) | <0.001 |
| Combined surgery | | 1,709 (20.5) | 626 (13.2) | 648 (24.4) | 368 (47.2) | 25 (39.1) | 42 (48.3) | <0.001 |
| CABG+ Valve surgery | | 501 (6.0) | 141 (3.0) | 199 (7.5) | 124 (15.9) | 13 (20.3) | 24 (27.6) | <0.001 |
| On pump | | 4,373 (52.5) | 1,960 (41.3) | 1,584 (59.6) | 691 (88.7) | 55 (85.9) | 83 (95.4) | <0.001 |
| First 24 h ICU admission | 100 | | | | | | | |
| Lactate, mmol/L | | 2.59 ± 1.84 | 1.88 ± 0.75 | 2.61 ± 1.36 | 5.61 ± 1.57 | 6.03 ± 1.31 | 11.45 ± 4.37 | <0.001 |
| <4 | | 7,807 (85.0) | 4,747 (100.0) | 2,296 (86.4) | 39 (5.0) | 0 (0.0) | 5 (5.7) | <0.001 |
| 4-10 | | 1,182 (14.2) | 0 (0.0) | 362 (13.6) | 740 (95.0) | 64 (100) | 16 (18.4) | <0.001 |
| >10 | | 66 (0.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 66 (75.9) | <0.001 |
| MCS | | | | | | | | |
| IABP | | 74 (0.9) | 0 (0.0) | 0 (0.0) | 39 (5.0) | 22 (34.4) | 13 (14.9) | <0.001 |
| ECMO | | 28 (0.3) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 28 (32.2) | <0.001 |
| Number of vasopressors | | | | | | | | |
| 0-2 | | 5,130 (61.6) | 4,747 (100.0) | 362 (13.6) | 9 (1.2) | 3 (4.7) | 9 (11.5) | <0.001 |
| 3-5 | | 3,103 (37.3) | 0 (0.0) | 2,257 (84.9) | 767 (98.5) | 19 (29.7) | 60 (76.9) | <0.001 |
| >5 | | 93 (1.1) | 0 (0.0) | 39 (1.5) | 3 (0.4) | 42 (65.6) | 9 (11.5) | <0.001 |
| IABP-SHOCK II | | 0.83 ± 1.13 | 0.63 ± 0.94 | 0.79 ± 1.10 | 1.86 ± 1.39 | 2.41 ± 1.35 | 2.89 ± 1.28 | <0.001 |
| Postoperative procedure | 100 | | | | | | | |
| Re-open | | 169 (2.0) | 28 (0.6) | 54 (2.0) | 49 (6.3) | 12 (18.8) | 26 (29.9) | <0.001 |
| Pericardiocentesis | | 10 (0.1) | 7 (0.1) | 3 (0.1) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0.839 |
| Right/left heart catheterization | | 38 (0.5) | 7 (0.1) | 20 (0.8) | 11 (1.4) | 0 (0.0) | 0 (0.0) | <0.001 |
| Tracheotomy | | 27 (0.3) | 3 (0.1) | 7 (0.3) | 12 (1.5) | 1 (1.6) | 4 (4.6) | <0.001 |
| Thoracentesis | | 45 (0.5) | 21 (0.4) | 16 (0.6) | 7 (0.9) | 1 (1.6) | 0 (0.0) | 0.329 |
| CRRT | | 243 (2.9) | 64 (1.3) | 62 (2.3) | 68 (8.7) | 11 (17.2) | 38 (43.7) | <0.001 |
| Endoscopy for gastrointestinal hemorrhage | | 9 (0.1) | 3 (0.1) | 5 (0.2) | 1 (0.1) | 0 (0.0) | 0 (0.0) | 0.617 |
| CAG | | 5 (0.1) | 1 (0.0) | 0 (0.0) | 3 (0.4) | 0 (0.0) | 1 (1.1) | <0.001 |
| Decompressive craniectomy | | 9 (0.1) | 5 (0.1) | 2 (0.1) | 1 (0.1) | 1 (1.6) | 0 (0.0) | 0.012 |
| Permanent pacemaker implantation | | 7 (0.1) | 2 (0.0) | 3 (0.1) | 2 (0.3) | 0 (0.0) | 0 (0.0) | 0.386 |
| Debridement | | 27 (0.3) | 13 (0.3) | 8 (0.3) | 6 (0.8) | 0 (0.0) | 0 (0.0) | 0.222 |

Values are n (%) or mean ± SD.

CABG = coronary angioplasty bypass grafting; CAG = coronary arteriography; CRRT = continuous renal replacement therapy; IABP-SHOCK = Intra-Aortic Balloon Pump In Cardiogenic Shock; ICU = intensive care unit; LVAD = left ventricular assist device.

having on-pump surgery (OR: 4.48; 95% CI: 2.61-7.68; $P < 0.001$), EuroSCORE II (OR: 1.37; 95% CI: 1.29-1.46; $P < 0.001$), IABP-SHOCK II (OR: 1.86; 95% CI: 1.62-2.13; $P < 0.001$), reopening surgery (OR: 17.96; 95% CI: 10.92-29.55; $P < 0.001$), and postcardiotomy continuous renal replacement therapy (OR: 66.72; 95% CI: 43.03-103.44; $P < 0.001$) were observed to be significant predictors of in-hospital mortality in the unadjusted model. After multivariate regression analysis, it was found that admission serum creatinine levels ≥353.6 μmol/L (OR: 8.61; 95% CI: 2.66-27.85; $P < 0.001$), admission LVEF <50% (OR: 2.48; 95% CI: 1.56-3.94; $P < 0.001$), on-pump surgery (OR: 1.96; 95% CI: 1.05-3.67; $P = 0.003$), and PC-SCAI-based CS severity stages (C: OR: 4.58; 95% CI: 2.35-8.93; $P < 0.001$; D: OR: 11.01; 95% CI: 3.80-31.88; $P < 0.001$; and E: OR: 61.32; 95% CI: 30.28-124.17; $P < 0.001$) were independent risk factors for in-hospital mortality. The AUROC value for the PC-SCAI-based CS severity stage was 0.781 (95% CI: 0.746-0.815), which was better than those for EuroSCORE II (0.741; 95% CI: 0.696-0.786), IABP-SHOCK II (AUROC = 0.739; 95% CI: 0.690-0.789), and number of vasopressors (AUROC = 0.731; 95% CI: 0.682-0.779) (**Figure 5**), as well as in subgroup comparisons (Supplemental Figure 1). After sensitivity analysis, we found the same trend (Supplemental Figure 2). When comparing the AUROC of these 3 evaluation methods, we found

**FIGURE 2** **Distribution of Postcardiotomy Society for Cardiovascular Angiography and Intervention Shock Stages Across Surgery Types**




Relative distributions of Postcardiotomy Society for Cardiovascular Angiography and Intervention shock stages were displayed for the overall cohort and every surgery type. Postcardiotomy Society for Cardiovascular Angiography and Intervention shock stages were distributed heterogeneously among different surgery types ($P < 0.001$). CABG = coronary angioplasty bypass grafting.

that there was no significant statistical difference between each pair (EuroSCORE II vs IABP-SHOCK II; $P = 0.9597$; EuroSCORE II vs PC-SCAI; $P = 0.2683$; IABP-SHOCK II vs PC-SCAI; $P = 0.0974$). The details are shown in Supplemental Table 2.

## DISCUSSION

In this retrospective analysis of a single-center cohort, CS occurred in 11.1% (970 of 8,335)of post-cardiotomy patients. For the first time, the SCAI CS criteria were integrated into a simplified mortality risk stratification model for postcardiotomy patients, revealing a strong correlation with in-hospital mortality. This study reports a new approach to defining CS severity for postcardiotomy patients using simple, specific, and accessible parameters available upon admission and throughout hospitalization.

CS often occurs in cases of AMI, acute exacerbation of chronic heart failure, valve diseases, arrhythmia, myocarditis, and postcardiotomy status, leading to hypoperfusion of the terminal organs.[1,15-17] Although therapeutic interventions for CS, particularly early percutaneous coronary intervention in patients with AMI, have developed rapidly in recent years because of global medical efforts, the all-cause mortality rate remains high.[2] Early identification of the presence and severity of CS can help physicians make timely

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**TABLE 3 Clinical Outcomes and Complications**

| | With data, % | All (n = 8,335) | SCAI A (n = 4,747) | SCAI B (n = 2,658) | SCAI C (n = 779) | SCAI D (n = 64) | SCAI E (n = 87) | *P* Value |
|---|---|---|---|---|---|---|---|---|
| In-hospital mortality | 100 | 94 (1.1) | 19 (0.4) | 21 (0.8) | 22 (2.8) | 5 (7.8) | 27 (31.0) | <0.001 |
| ICU mortality | 100 | 32 (0.4) | 6 (0.1) | 7 (0.3) | 9 (1.2) | 1 (1.6) | 9 (10.3) | <0.001 |
| Final MCS | 100 | 207 (2.5) | 27 (0.6) | 51 (1.9) | 62 (8.0) | 25 (39.1) | 42 (48.3) | <0.001 |
| IABP | | 162 (1.9) | 23 (0.5) | 43 (1.6) | 56 (7.2) | 24 (37.5) | 16 (18.4) | <0.001 |
| VA-ECMO | | 65 (0.8) | 6 (0.1) | 11 (0.4) | 9 (1.2) | 3 (4.7) | 36 (41.4) | <0.001 |
| Complications | 100 | | | | | | | |
| Gastrointestinal hemorrhage | | 204 (2.4) | 95 (2.0) | 64 (2.4) | 31 (4.0) | 3 (4.7) | 11 (12.6) | <0.001 |
| Ischemic or hemorrhagic stroke | | 163 (2.0) | 79 (1.7) | 45 (1.7) | 23 (3.0) | 6 (9.4) | 10 (11.5) | <0.001 |
| Nosocomial infection | | 224 (2.7) | 63 (1.3) | 72 (2.7) | 62 (8.0) | 6 (9.5) | 21 (24.1) | <0.001 |
| Hyperbilirubinemia | | 251 (3.0) | 111 (2.3) | 79 (3.0) | 43 (5.5) | 4 (6.3) | 14 (16.1) | <0.001 |
| AKI | | 395 (4.7) | 128 (2.7) | 138 (5.2) | 83 (10.7) | 13 (20.3) | 33 (37.9) | <0.001 |
| LV dysfunction | | 1,629 (19.5) | 732 (15.4) | 565 (21.3) | 260 (33.4) | 27 (42.2) | 45 (51.7) | <0.001 |
| Total MV duration, h | 99.4 | 20 (15.5-27) | 18.5 (14.5-22) | 21 (17.5-39) | 40.5 (20.5-75.5) | 72 (47-116) | 94.5 (29.9-196.8) | <0.001 |
| ICU length of stay, h | 100 | 110.58 (25.42-240.03) | 20.28 (16.03-26.17) | 24.18 (19.57-47.28) | 46.35 (22.52-96.78) | 92.91 (55.16-161.20) | 110.58 (25.42-240.03) | <0.001 |
| Hospital length of stay, d | 100 | 14 (11-18) | 13 (10-16) | 14 (11-19) | 16 (13-22) | 19.5 (14-27.8) | 18 (12-24) | <0.001 |

Values are n (%) or median (Q1-Q3).

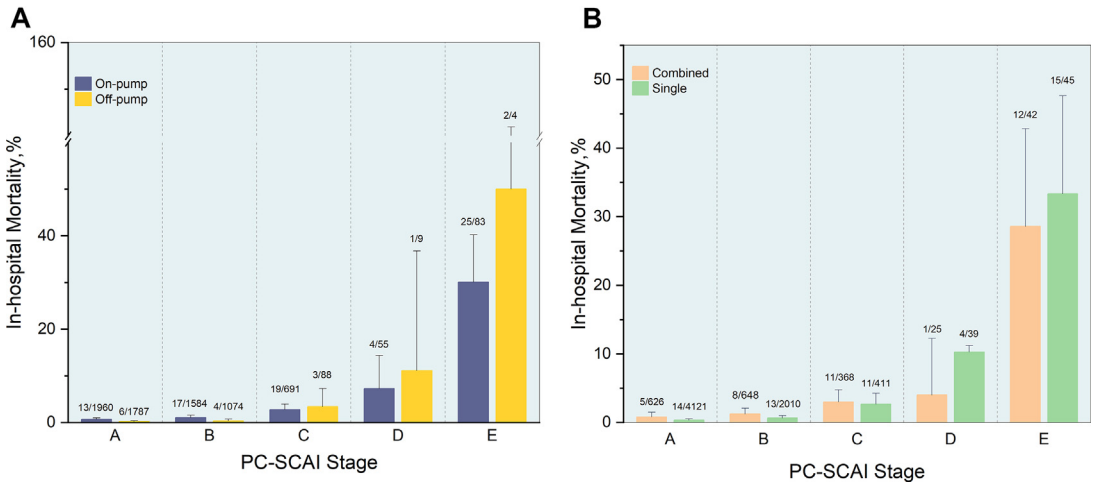
AKI = acute kidney injury; IABP = intra-aortic balloon pump; LV = left ventricular; ICU = intensive care unit; MCS = mechanical circulation support; VA-ECMO = venoarterial extracorporeal membrane oxygenation.

treatment decisions, such as the use of extracorporeal life support equipment.[18,19] However, after reviewing the literature, we found that most risk-scoring methods for CS severity are based on AMI, and the requirement for multiple clinical data reduces their clinical applicability, making clinical decision-making more challenging.[20,21]

PCS is a form of CS arising from various factors after cardiac surgery, with treatment typically involving the use of first-line inotropic drugs and vasoconstrictors, followed by short-term mechanical circulatory support devices in refractory cases.[22] However, similar to the broader definition of CS,[17] the conventional concept of PCS does not effectively guide the classification of shock severity, making it less useful in determining the severity of the condition.[18] However, despite growing global evidence and experience with extracorporeal life support, mortality remains high, with approximately 42% of patients surviving up to the time of hospital discharge, according to a recent Extracorporeal Life Support Organization registry analysis of the postcardiotomy cohort.[23] In critically ill patients with PCS, decision-making is urgent and complex, and the outcomes are often unpredictable.[7] Apart from the EuroSCORE II, a tool used before cardiac surgery to predict mortality during hospitalization in patients with cardiac diseases, there is no other specialized method of assessing the severity of CS in patients undergoing cardiac surgery.[11] The classical SCAI CS criteria categorized our study cohort into 5 classes: 1) at risk for CS (A); 2) beginning CS (B); 3) classical CS (C); 4) deteriorating CS (D); and 5) extreme CS (E), primarily discriminated by using the bedside description of hypotension, tachycardia, hypoperfusion, deterioration, and refractory shock.[15] The confidence and validity of the SCAI-based CS classification system has been well-received in published literature, with reports showing that an increase in the degree of risk predicts worse outcomes.[17,24,25] Due to the complexity and subjectivity of the judging criteria, the CSWG proposed a classification based on the number of vasopressors and short-term MCS devices that showed a good association with in-hospital mortality among patients with heart failure and AMI.[14]

We modified the CSWG scheme by including current clinical management, containing 3 parameters: serum lactate levels, the number of vasopressors, and short-term MCS usage. Lactate plays a critical role in our criteria because of its demonstrated efficacy in other studies when diagnosing CS.[26,27] The complex cardiac surgery process increases lactate production in the body while reducing the lactate clearance rate.[28] Elevated lactate levels have been commonly observed in postcardiotomy patients and were typically higher than those in the general critically ill population.[29] In comparison to the CSWG classification,[14] we defined a lactate level of 4 mmol/L as the threshold marking the onset of classic CS. Several researchers have also suggested that an arterial lactate cutoff level of 10 mmol/L or greater is associated with significantly worse outcome.[29,30] Thus, we defined the cutoff value for extreme CS as a lactate

**FIGURE 3** **In-Hospital Mortality of PC-SCAI Shock Stage in Relevant Subgroups**



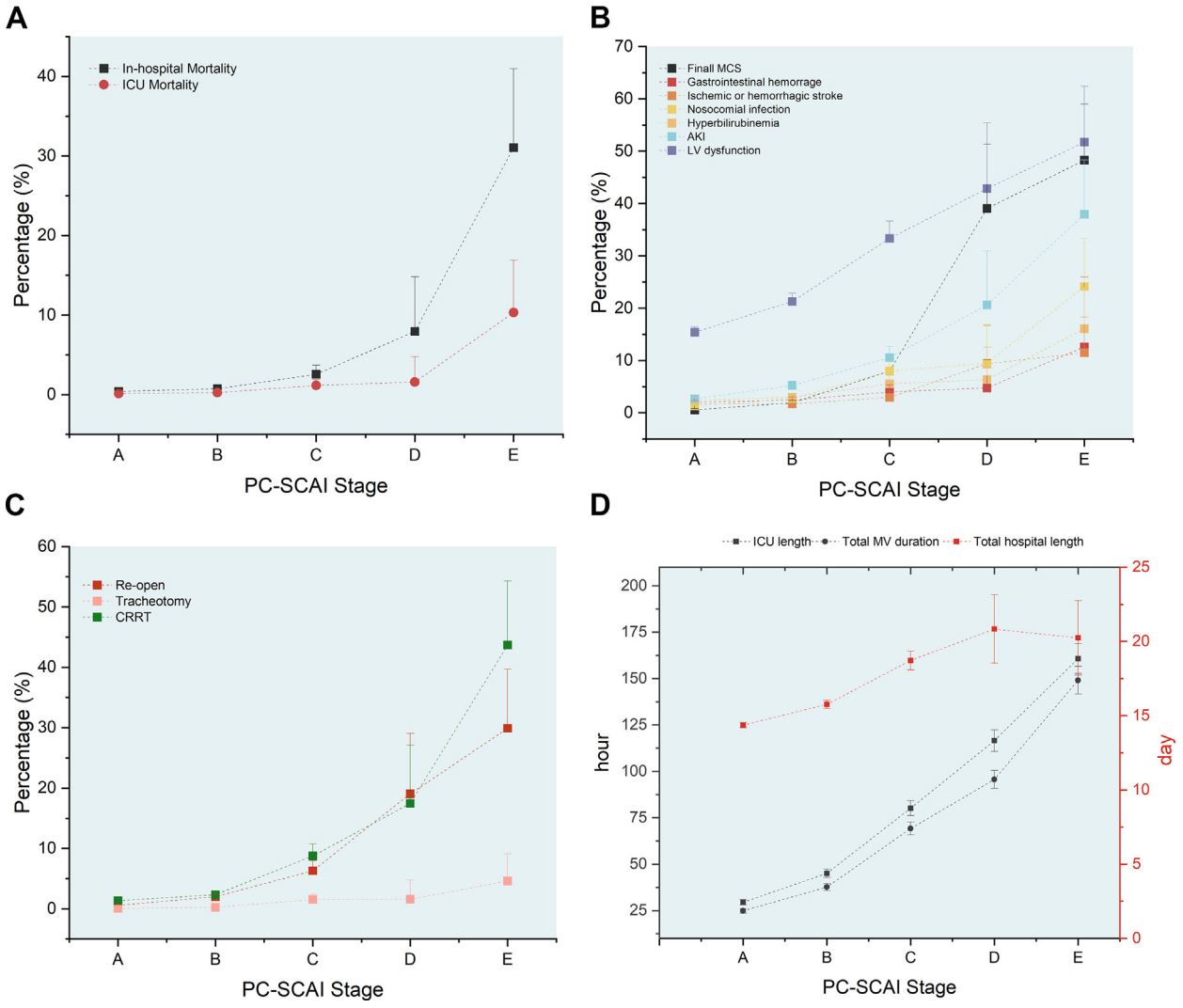

Mean (with 95% CI) in-hospital mortality as a function of Postcardiotomy Society for Cardiovascular Angiography and Intervention (PC-SCAI) shock stage and on-pump vs off-pump (A), and combined surgery vs single surgery (B). Both subgroups analysis was statistically different (*$P < 0.001$).

level of 10 mmol/L. Compared with a previously reported postcardiotomy cohort,[29] our population had a comparable overall mean lactate level during 24 hours after cardiac surgery (2.59 mmol/L vs 3.6 mmol/L, respectively). However, even when lactate levels were below 4 mmol/L, patients receiving IABP assistance were still classified as PC-SCAI stage C, because the hemodynamic support provided by IABP helps maintain systemic perfusion.[13]

The occurrence of any stage of PCS (PC-SCAI stage C to E) in our cohort was 11.1% (970 of 8,335) according to our PC-SCAI-based CS severity classification. In contrast, PCS was observed in 56.8% (15,226 of 26,792) of patients in another mixed postcardiotomy cohort.[29] In the original SCAI CS study, the rate of CS was 24.0% (2,404 of 10,004), higher than our study. The probable cause was the heterogeneity of the study cohort.[20] This discrepancy may be attributed to our adjusted lactate threshold, which resulted in fewer patients being classified into PC-SCAI stage C. Nevertheless, patients without CS (PC-SCAI stages A and B) in our cohort had a comparable mortality rate (0.54%; 40 of 7,405) to that reported in the previously reported cohort (0.51%). Additionally, the overall in-hospital mortality in our study population was 1.1% (94 of 8,335), which is a lower value than the 6.2% (1,651 of 10,004) observed in the referenced cohort.[29] This difference may be caused by the improvement of methods in surgical and perioperative management quality between the 2 study periods (January 2022 to December 2022 vs November 2012 to June 2022). With the advances, combined with new surgical techniques, there was safe repair of many malformations early in life and an improved long-term functional result.[31] The time span of the study cohort is limited to 1 year; thus, it is minimally affected by technology heterogeneity. Additionally, another reason for lower in-hospital mortality in PCS patients may be that, in our center, we have already mastered mature technology and implemented well-developed management system of IABP and ECMO before 2022.

After univariate and multivariate analysis, we found that patients with a cardiac surgery history ($P < 0.001$), admission LVEF <50% ($P < 0.001$), combined surgery ($P < 0.001$), and on-pump surgery ($P < 0.001$) were more prone to PCS. The structure and function of the heart are closely interrelated.[32] An abnormal cardiac structure can cause a decline in cardiac function, and patients with chronic heart failure often experience ventricular remodeling. Compared with a normal heart, a heart with myocardial fibrosis[32] or a heart bearing scar tissue from a previous cardiac surgery may have a reduced affordability for various invasive procedures.[33] Such hearts, with decreased function, are less capable of handling hemodynamic stress and fluid load fluctuations.[34] Based on the reasons enumerated above, involving

**FIGURE 4 Outcomes in PC-SCAI Shock Stages**




This figure shows primary and secondary outcome distributions in relation to Postcardiotomy Society for Cardiovascular Angiography and Intervention (PC-SCAI) shock stages. The purpose is to illustrate how these outcomes vary with increasing shock severity. We observed in-hospital and intensive care unit (ICU) mortality (A), postcardiotomy procedures (B), complications (C), and lengths of stay (D) all change significantly (all $P < 0.001$). AKI = acute kidney injury; CRRT = continuous renal replacement therapy; LV = left ventricular; MCS = mechanical circulation support; MV = machinal ventilation.

the etiology and severity of primary disease, surgeons may opt to perform on-pump or combined surgery caused by concerns about potential risk.[35]

IABP can increase coronary blood flow and decrease the cardiac afterload.[13] VA-ECMO provides both circulatory and respiratory support, rapid access, and nearly full cardiac output.[2] In our present study, the application proportion of IABP and VA-ECMO during the first 24 hours of CCIC admission was 0.9% (74 of 8,335) and 0.3% (28 of 8,335), respectively (details are shown in **Table 2**). The patient who received VA-ECMO was considered PC-SCAI-based CS severity stage E for actual or impending circulatory collapse (details are shown in the **Central Illustration**).

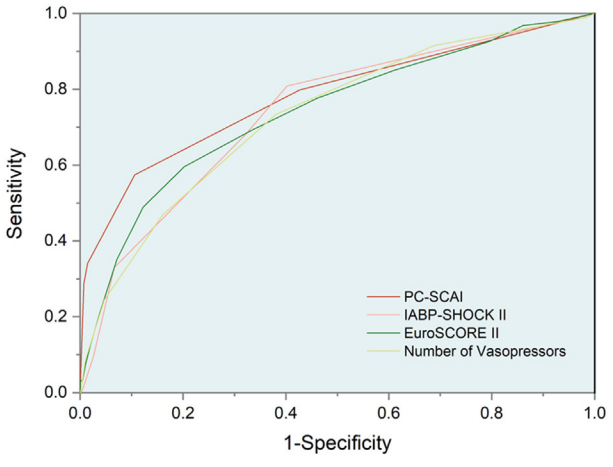
The severity assessment of PCS affects and leads to clinical treatment decisions. Nevertheless, because of a lack of analysis of severity, the traditional definition of CS supports less postoperative management. The in-hospital mortality rate of the PCS population was 5.8%. Compared with expectations based on the literature, stages A and B were associated with below-

**TABLE 4 Factors Associated With In-Hospital Mortality**

| | Univariate Analysis | | | Adjusted: Multivariate | | |
|---|---|---|---|---|---|---|
| **Predictor Variables** | **OR** | **95% CI** | ***P* Value** | **OR** | **95% CI** | ***P* Value** |
| PC-SCAI stage | | | <0.001 | | | <0.001 |
| A | | Ref. | | | Ref. | |
| B | 1.99 | 1.06-3.69 | 0.028 | 1.65 | 0.87-3.10 | 0.124 |
| C | 7.24 | 3.90-13.42 | <0.001 | 4.58 | 2.35-8.93 | <0.001 |
| D | 21.09 | 7.62-58.37 | <0.001 | 11.01 | 3.80-31.88 | <0.001 |
| E | 111.98 | 59.06-212.32 | <0.001 | 61.32 | 30.28-124.17 | <0.001 |
| Cardiac surgery history | 2.76 | 1.37-5.53 | 0.003 | 1.93 | 0.90-4.13 | 0.089 |
| Admission | | | | | | |
| Scr ≥353.6 μmol/L | 10.97 | 4.24-28.37 | <0.001 | 8.61 | 2.66-27.85 | <0.001 |
| LVEF <50% | 3.91 | 2.57-5.95 | <0.001 | 2.48 | 1.56-3.94 | <0.001 |
| Combined surgery | 2.55 | 1.68-3.87 | <0.001 | 1.04 | 0.64-1.69 | 0.863 |
| On-pump surgery | 4.48 | 2.61-7.68 | <0.001 | 1.96 | 1.05-3.67 | 0.036 |
| EuroSCORE II | 1.37 | 1.29-1.46 | <0.001 | | | |
| First 24 h in ICU | | | | | | |
| Adrenaline | 8.87 | 5.68-13.84 | <0.001 | | | |
| Norepinephrine | 3.61 | 2.30-5.69 | <0.001 | | | |
| Isoproterenol | 1.68 | 1.00-2.82 | 0.047 | | | |
| Vasopressin | 4.73 | 3.12-7.18 | <0.001 | | | |
| IABP-SHOCK II | 1.86 | 1.62-2.13 | <0.001 | | | |
| Re-open | 17.96 | 10.92-29.55 | <0.001 | | | |
| Postcardiotomy CRRT | 66.72 | 43.03-103.44 | <0.001 | | | |

CRRT = continuous renal replacement therapy; EuroSCORE = European System for Cardiac Operative Risk Evaluation; LVEF = left ventricular ejection fraction; IABP-SHOCK = Intra-Aortic Balloon Pump in Cardiogenic Shock; PC-SCAI = Postcardiotomy Society for Cardiovascular Angiography and Intervention; Scr = serum creatinine.

**FIGURE 5 AUROC of PC-SCAI in the Whole Population**




Area Under the Curve

| | Area | Standard Error | Asymptotic Significance | 95% Confidence Interval Low | Up |
|---|---|---|---|---|---|
| PC-SCAI | 0.781 | 0.018 | <0.001 | 0.746 | 0.815 |
| IABP-SHOCK II | 0.739 | 0.025 | <0.001 | 0.690 | 0.789 |
| EuroSCORE II | 0.741 | 0.023 | <0.001 | 0.696 | 0.786 |
| Number of Vasopressors | 0.731 | 0.025 | <0.001 | 0.682 | 0.779 |

The area under the receiver-operating characteristic curves (AUROC) for predicting in-hospital mortality. AUROC are reported with 95% CIs. Discriminatory performance of Postcardiotomy Society for Cardiovascular Angiography and Intervention (PC-SCAI) shock stage was greater than other scales. EuroSCORE = European System for Cardiac Operative Risk Evaluation; IABP-SHOCK = Intra-Aortic Balloon Pump in Cardiogenic Shock.

average in-hospital mortality rates in our study.[24] The observed all-cause in-hospital mortality rate values of each PC-SCAI stage were roughly similar to the rates in the study by Roeschl et al[29]: stage A = 0.4% vs 0.4%, stage B = 0.8% vs 0.6%, stage C = 2.8% vs 3.3%, stage D = 7.8% vs 4.1%, and stage E = 31.0% vs 29.1%, respectively. In the present study, a clear stepwise increase in in-hospital mortality rates can be observed with increasing PC-SCAI stage, ranging from 0.4% in PC-SCAI stage A to 31.0% in PC-SCAI stage E (trends $P < 0.05$). The observed OR: values suggested a similar trend, progressing from stage B = 1.99 to stage E = 111.98.

Moreover, complications have been associated with poor prognosis.[25] As the PC-SCAI stage increases, the occurrence of various complications is elevated with statistically significant differences (**Figure 4**). In general, it is logical to regard PC-SCAI criteria as a useful layering tool when predicting outcomes and making treatment plans.

Few scoring systems have been developed and used to predict survival in patients undergoing cardiac surgery. Several scoring methods have been applied to patients with CS to predict outcomes, such as SOFA (Sequential Organ Failure Assessment) score, APACHE (Acute Physiology and Chronic Health Evaluation) II score, and VIS (Vasoactive-Inotropic Score). However, the application of these scoring methods is often targeted to comprehensive ICU populations or management methodologies. The approach we have described here is more suitable for a patient cohort undergoing a variety of cardiac surgeries across a wide spectrum and when the objective is to stratify mortality risk.

We adopted the EuroSCORE II and IABP-SHOCK II scoring methods to compare the accuracy of predicting in-hospital mortality using the PC-SCAI classification system. The AUROC value of PC-SCAI criteria was 0.781 (95% CI: 0.724-0.838), suggesting a robust diagnostic performance in predicting hospital mortality that was superior to EuroSCORE II (AUROC = 0.741; 95% CI: 0.696-0.786) and IABP-SHOCK II (AUROC = 0.739; 95% CI: 0.690-0.789) values, as well as in subgroup comparisons (Supplemental Figure 1). The EuroSCORE II scoring method, highlighting an underlying diagnosis prompting prognosis,[11] demonstrated a reasonable association with outcomes, underscoring the importance of precardiotomy prediction to enhance patient selection. The mean EuroSCORE II value in a separate cohort undergoing isolated off-pump CABG was 0.852, which was higher than that for our cohort, likely caused by differences in disease homogeneity and surgery type.[36] Although the number of vasopressors (AUROC = 0.731; 95% CI: 0.682-0.779) showed a weaker relationship with outcomes, vasopressor usage remains a crucial component of PC-SCAI classification. The timely identification and accurate assessment of PCS is essential, and our study offers a valuable risk stratification tool for early use following cardiac surgery.

**STUDY LIMITATIONS.** First, the potentially unmeasured confounding variables affected infer a causal relationship between CS severity and mortality, because this was a retrospective study of a single-center data set. Second, this cohort excluded those patients who underwent transfemoral or percutaneous surgery alone, which impaired the extrapolation of conclusions. Missing data and several unmeasured confounders may influence the representativeness of the data set. Further external validation of our results is needed. Third, IABP and ECMO were the only percutaneous MCS devices available in mainland China. Thus, only IABP and ECMO were included in our PC-SCAI CS criteria. In addition, the accuracy of predicting in-hospital mortality was not compared among SOFA, APACHE-IV, and PC-SCAI classifications, because some hemodynamic monitoring data were not uniformly available in retrospective analysis.

## CONCLUSIONS

In this single-center postcardiotomy population, PCS occurred in 11.1% of patients. PC-SCAI-based CS severity stage was observed to provide a robust correlation with in-hospital mortality. Further external validation of our results is warranted.

## FUNDING SUPPORT AND AUTHOR DISCLOSURES

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**KEY WORDS** cardiac surgery, cardiogenic shock, coronary artery bypass grafting, mortality, outcome, postcardiotomy

**APPENDIX** For an expanded Methods section and supplemental tables and figures, please see the online version of this paper.