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ORIGINAL RESEARCH

Consistency and Risk Stratification Performance of 4 Society for Cardiovascular Angiography and Interventions SHOCK Stage Definitions: A Retrospective Study

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BACKGROUND: Cardiogenic shock (CS) is a critical condition associated with high mortality rates, making prompt diagnosis essential for timely interventions that may improve patient outcomes. The Society for Cardiovascular Angiography and Interventions (SCAI) SHOCK Stage Classification is a validated tool for assessing CS and predicting patient outcomes. Here, we evaluated how different parameter definitions affect SCAI stage adjudication, hypothesizing that variations may influence stage determination and the overall assessment of CS.

METHODS: All patients diagnosed with CS or conditions leading to CS at the University Medical Center Mannheim, Germany, from January 2018 to June 2022 were included in the study. SCAI SHOCK stages were assigned retrospectively on the basis of 4 previously published studies. The distribution of SCAI SHOCK stages, outcomes, classification concordance, and predictive performance were assessed.

RESULTS: From January 2018 to June 2022, we identified 1303 patients on the basis of *International Classification of Diseases, Tenth Revision* (*ICD-10*) codes. Of these, 1281 patients (98.2%) were classified into SCAI SHOCK stages according to all 4 classification frameworks. While the assignment of SCAI SHOCK stages and associated mortality rates varied among the frameworks, Kendall's W indicated moderate to strong overall classification agreement (W=0.70). There was no significant difference in predictive performance for in-hospital death.

CONCLUSIONS: Our study demonstrates a moderate to strong concordance and comparable prognostic performance across different SCAI SHOCK Stage Classification frameworks in evaluating patients with CS. Despite differences in stage assignments, all frameworks effectively stratified patients by clinical severity. Comparable stage assignment in retrospective studies requires further standardization of the SCAI SHOCK Stage Classification system.

Key Words: cardiogenic shock ■ death ■ heart failure ■ myocardial infarction ■ prognosis ■ SCAI

Cardiogenic shock (CS) is a life-threatening condition associated with high mortality rates, ranging from 40% to 60% during hospitalization and up to 50% within 30 days of onset.[1,2] In recent decades, advances in our understanding of CS, particularly the development of innovative mechanical circulatory support (MCS) devices, have led to new therapeutic options that may improve patient outcomes.[3–5] To evaluate and

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CLINICAL PERSPECTIVE

What Is New?

- This study systematically compares 4 distinct SCAI SHOCK classification frameworks within a single real-world cohort and demonstrates comparable prognostic performance for in-hospital death across all frameworks.
- Despite overall consistency in risk stratification, notable differences in individual patient stage assignment between SCAI SHOCK classification frameworks were observed, emphasizing the need for further harmonization of classification criteria.

What Are the Clinical Implications?

- Awareness of differences in classification criteria is essential when applying different SCAI SHOCK classification frameworks in clinical practice and research, and standardized definitions may enhance comparability across studies and support structured patient management in cardiogenic shock.

Nonstandard Abbreviations and Acronyms

CS	cardiogenic shock
CZECH-Shock	Czech Registry of Cardiogenic Shock
DanGer-Shock	Danish–German Cardiogenic Shock
MCS	mechanical circulatory support
SCAI	Society for Cardiovascular Angiography and Interventions

compare patients with CS effectively across time and studies, it is essential to establish standardized and validated classification and prognostic frameworks. Reliable classification of CS depends on the consistent collection and interpretation of various parameters that contribute to the characterization of the condition. Discrepancies in these factors can result in variations in CS classification, ultimately affecting the accuracy of results and prognoses both within individual studies and across different studies. This issue is particularly critical when CS stages are assigned retrospectively, as only limited parameters and measurements are available for characterization, and no additional data can be collected prospectively.

The Society for Cardiovascular Angiography and Interventions (SCAI) SHOCK Stage Classification offers a structured approach for categorizing CS and predicting patient outcomes. This system integrates clinical, hemodynamic, and biochemical parameters, categorizing patients into 5 distinct stages: stage A (at risk, hemodynamically stable but at risk for developing CS) to stage E (extreme, with refractory shock or impending circulatory collapse).[6] Several independent clinical studies have validated this classification across diverse patient populations, confirming its utility in predicting outcomes for patients with CS.[7–10] In 2021, the SCAI SHOCK Stage Classification system was refined on the basis of insights from these studies.[11]

The prevalence of SCAI SHOCK stages has varied across validation studies, depending on study design, patient subpopulations, data collection time points, and the definitions used to assign stages.[7,9] For instance, there is significant variability in how hypoperfusion is defined and how patients are classified on the basis of vital sign abnormalities or vasopressor use.[7,12–14] The impact of these definitional differences on the predictive performance of the SCAI SHOCK Stage Classification remains unclear.

This study aims to assess whether variations in parameter collection, standardization, and interpretation influence the adjudication of the SCAI SHOCK stages. Using the SCAI SHOCK stage criteria applied in 4 frequently cited publications, we hypothesize that the distribution of SCAI SHOCK stages and the overall prognostic performance will depend on the specific SCAI SHOCK staging framework applied in studies with retrospectively collected data.

METHODS

General Methods

This study is a retrospective, observational cohort study that included all patients who underwent treatment at our intensive care unit from January 2018 to June 2022 at the University Medical Center Mannheim, Germany. This study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Guidelines.[15] The study was carried out according to the principles of the 1975 Declaration of Helsinki and was approved by the Medical Ethics Commission II of the Faculty of Medicine Mannheim, University of Heidelberg, Germany (institutional review board approval number: 2023–8990 -AF 11). The requirement for informed consent was waived due to the retrospective nature of the study. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Population

Patient inclusion criteria were based on the German modification of the *International Classification of*

Diseases, *Tenth Revision* (*ICD-10*) codes. We included all patients diagnosed with CS, identified by the *ICD-10* code R57.0, or with diagnoses that are frequently associated with the development of CS. This latter group comprised patients with acute coronary syndrome, defined by *ICD-10* codes I21.4, I21.0, and I21.1, as well as patients with acute heart failure (AHF), defined by *ICD-10* codes I50.13 and I50.14. All patients identified were included in a study population termed the *initial study cohort*. A flowchart illustrating the patient inclusion process is provided in Figure S1.

Data Extraction

All patient data collected during hospital stays were recorded in a patient data management system at the Data Integration Center of the University Medical Center Mannheim, Germany. The data included procedure codes, vital parameters, medication, laboratory parameters, and outcomes. *ICD-10* codes were assigned after a thorough review of all available data following discharge and were obtained from the Medical Controlling Department of the University Medical Center Mannheim. The data were then transferred to a relational database, and specific data points were retrieved using Structured Query Language.

Selected SCAI SHOCK Stage Classification Systems

SCAI SHOCK stages were determined on the basis of the adapted classification systems used in publications authored by Naidu et al (hereafter referred to as study 1 SCAI classification framework),[11] Lawler et al (referred to as study 2 SCAI classification framework),[13] Jentzer et al (referred to as study 3 SCAI classification framework)[12] and Thayer et al (referred to as study 4 SCAI classification framework).[14] These studies were selected to reflect variations in interpreting and implementing the SCAI SHOCK Stage Classification system, particularly regarding variable selection and timing of parameter recording. A detailed overview of the parameters used for each of the 4 adapted SCAI SHOCK Stage Classification systems is provided in Tables S1 through S4. Only data collected during the first 24 hours of each intensive care unit stay were used for subsequent SCAI SHOCK Stage Classification.

SCAI SHOCK Stage Classification Assignment

To assign SCAI SHOCK stages for the different classification frameworks provided in studies 1 through 4, we designed and implemented a web application using Node.js version 20.6.1 and primarily Express.js version 4.16.3. The code was versioned and stored in a GitHub repository. Given the retrospective nature of the study, minor adjustments were made to allow for the assignment of SCAI SHOCK stages as detailed in Table S5. As an example, clinical parameters that were not collected in a standardized format during treatment (eg, cool and mottled extremities) were excluded.

Cases in which all parameters required for an individual SCAI classification framework were missing were excluded from classification. In instances where only single parameters were missing, values were assumed to be within the respective normal range. In cases where a respective SCAI classification framework did not unanimously assign a patient to a definite SCAI SHOCK stage, final adjudication was performed by a physician on the basis of available data.

All patients who could be classified according to the four selected SCAI classification frameworks were included for subsequent analysis (termed the *final study cohort*). A summary of the parameters used to assign SCAI SHOCK stages across the 4 SCAI classification frameworks is provided in Table S6.

Study End Point

In-hospital death was selected as the study end point to assess predictive performance for each of the 4 SCAI classification frameworks.

Statistical Analysis

Statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC), Prism version 9.2.0 (GraphPad Software, La Jolla, CA), and R Statistical Software version 4.2.3 (R Core Team, 2024). Data for continuous variables are reported as median±interquartile range. Categorical variables are expressed as frequencies and percentages.

To evaluate the concordance of SCAI SHOCK stage assignment across the 4 SCAI classification frameworks, Kendall's W (coefficient of concordance) was calculated.[16] Predictive performance was evaluated using receiver operating characteristic curves, and comparisons of receiver operating characteristic curves within dependent samples were performed following the method published by DeLong et al.[17] Kaplan–Meier survival curves were generated to compare survival according to SCAI SHOCK stage, and differences in survival were assessed using the log-rank test. Multiple testing was adjusted using the Benjamini–Hochberg procedure to control the false discovery rate. Statistical significance for all tests was set at a 2-tailed P value of <0.05.

RESULTS

Patient Population and Study Population

Between January 2018 and June 2022, 1303 patients were identified on the basis of *ICD-10* codes and

Table. Patient Demographics, Medical History, ICU Stay, and Outcomes

	Initial study cohort (N=1303)	Final study cohort (N=1281)
Demographics and medical history		
Age, y, median (IQR)	69 (58–80)	69 (58–79)
Female sex, n (%)	401 (30.8)	392 (30.6)
Body mass index, kg/m^2, median (IQR)	26.6 (24.5–30.3)	26.6 (24.5–30.3)
Diabetes, n (%)	391 (30)	385 (30.1)
Hypercholesterolemia, n (%)	99 (7.6)	98 (7.6)
Arterial hypertension, n (%)	515 (39.5)	512 (40.0)
Chronic kidney disease (any stage), n (%)	194 (14.9)	193 (15.1)
Atrial fibrillation, n (%)	361 (27.7)	356 (27.8)
PCI and/or CABG, n (%)	170 (13)	169 (13.2)
Peripheral artery disease, n (%)	53 (4.1)	53 (4.1)
Out-of-hospital cardiac arrest, n (%)	66 (5.1)	63 (5.0)
Diagnosis		
CS[6]	85 (6.5)	80 (6.2)
Acute myocardial ischemia[7]	942 (72.3)	931 (72.7)
AHF[8]	276 (21.2)	270 (21.1)
Interventions		
Vasoactive or inotropic drugs, n (%)	315 (24.2)	291 (22.7)
Impella/ECMO, n (%)	28 (2.1)	28 (2.2)
Ventilation, n (%)	318 (24.4)	315 (24.6)
Dialysis, n (%)	106 (8.1)	105 (8.2)
ICU stay and outcomes		
In-hospital cardiac arrest, n (%)	8 (0.6)	8 (0.6)
ICU stay, median (IQR)	1.5 (0.8–2.6)	1.5 (0.8–2.6)
In-hospital stay (median IQR)	7 (4–14)	7 (4–14)
In-hospital death, n (%)	254 (19.5)	238 (18.6)

ACS indicates acute coronary syndrome; AHF, acute heart failure; CABG, coronary artery bypass grafting; CS, cardiogenic shock; ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit; IQR, interquartile range; and PCI, percutaneous coronary intervention.

compiled into the initial study cohort (Table). Of these, 85 (6.5%) had CS, 942 (72.3%) had acute coronary syndrome, and 276 (21.2%) were diagnosed with AHF.

The ability to retrospectively assign SCAI SHOCK stages varied across the 4 SCAI classification frameworks on the basis of the availability of data required to perform SCAI SHOCK stage adjudication. For the study 1 SCAI classification framework, 16 patients (1.2%) could not be assigned SCAI SHOCK stages. For the study 2 SCAI classification framework, 18 patients (1.4%) could not be retrospectively classified, while for the study 3 SCAI classification framework, 17 patients (1.3%) remained unclassified. All patients could be classified according to the study 4 SCAI classification framework (Table S7).

A total of 1281 patients (98.3%) could be classified into SCAI SHOCK stages according to all 4 study SCAI classification frameworks and were included in the study for analysis.

Consistent retrospective assignment of SCAI SHOCK stages across the different SCAI classification frameworks necessitated minor modifications to the previously published frameworks (Table S5). In cases where unanimous stage assignment was not achievable, physician adjudication was used. The frequency of cases requiring physician adjudication varied depending on the specific SCAI classification framework used (Table S8). All patients could be classified according to SCAI classification frameworks 3 and 4 by applying the original SCAI SHOCK classification framework with minor adjustments. In contrast, final SCAI SHOCK stage assignment required physician adjudication for 442 patients (34.3%) under SCAI classification framework 1 and for 384 patients (29.9%) under framework 2.

To evaluate the concordance between a CS diagnosis based on *ICD-10* codes and the SCAI SHOCK Stage Classification, we compared identification of CS using both primary and secondary *ICD-10* codes (R57.0) with classification according to SCAI stages C, D, and E. This analysis identified a total of 309 patients with either a primary or secondary *ICD-10* diagnosis of CS. Among these patients, 81% to 87% were classified as SCAI stage C, D, or E across the 4 SCAI classification frameworks, supporting the conclusion that CS

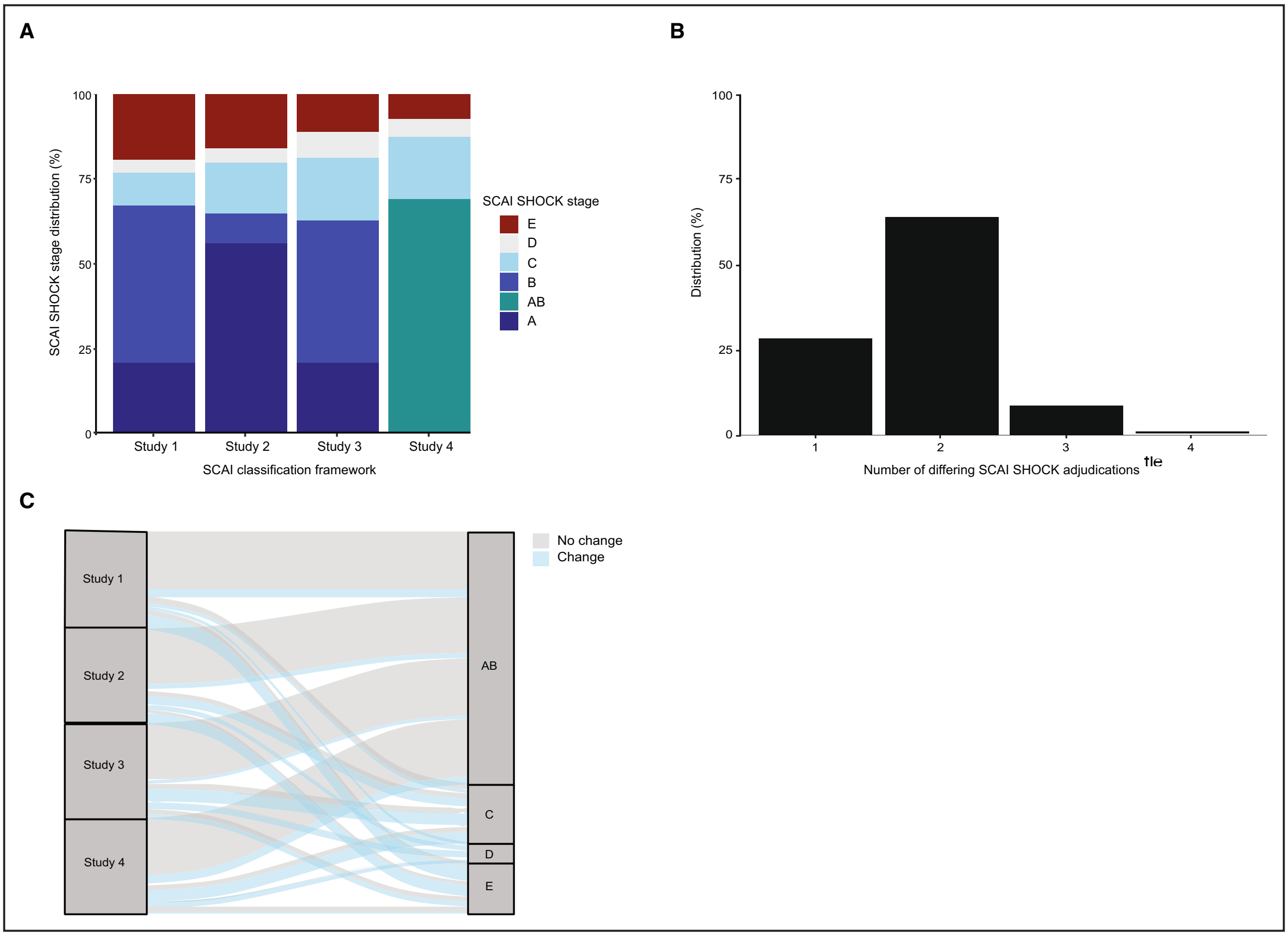

Figure 1. SCAI SHOCK Stage distribution and classification consistency across 4 frameworks.
A, SCAI SHOCK stage distribution across all 4 SCAI classification frameworks. **B**, Consistent and inconsistent SCAI SHOCK stage classifications across all 4 SCAI classification frameworks. **C**, Sankey diagram illustration consistent and inconsistent SCAI SHOCK stage classifications across all 4 SCAI classification frameworks. SCAI indicates Society for Cardiovascular Angiography and Interventions.

diagnoses based on *ICD-10* coding generally correspond to the SCAI SHOCK Stage Classification.

However, 35% to 45% of patients who met the SCAI criteria for shock (stages C/D/E) did not have a corresponding *ICD-10* code for CS, indicating that administrative coding may fail to capture a substantial proportion of clinically identified shock cases and thus underestimate the true prevalence of CS (Tables S9 and S10).

In the final study cohort, the median age was 69 (interquartile range, 58–79) years, and 392 (30.6%) of patients were women. Eighty (6.2%) patients had CS as their primary diagnosis, while 931 (72.7%) were diagnosed with acute coronary syndrome and 270 (21.1%) had AHF. The in-hospital mortality rate was 18.6%. The low use of temporary MCS in our final cohort (2.2%) is primarily explained by limited extracorporeal membrane oxygenation availability during the COVID-19 pandemic and the absence of on-site cardiac surgery, which restricted the use of advanced support modalities. Additionally, intra-aortic balloon pumps are no longer used in our institution, reflecting national practice trends. All patient characteristics for the final study cohort are presented in the Table.

SCAI SHOCK Stage Distribution According to SCAI Classification Frameworks

The classification of SCAI SHOCK stages for the 1281 patients included in this study varied according to the SCAI classification framework (Figure 1A and Table S11). In the context of Study 1's SCAI classification framework, 268 patients (20.9%) were categorized as stage A, 592 (46.2%) as stage B, 122 (9.5%) as stage C, 50 (3.9%) as stage D, and 249 (19.4%) as stage E. Conversely, under the study 2 SCAI classification framework, 716 patients (55.9%) were classified as stage A, 113 (8.8%) as stage B, 194 (15.1%) as stage C, 205 (16.0%) as stage D, and 199 (26.5%) as stage

E. For study 3, the classification included 267 patients (20.8%) in stage A, 539 (42.1%) in stage B, 238 (18.6%) in stage C, 97 (7.6%) in stage D, and 140 (11.0%) in stage E. Finally, within the study 4 framework, 888 patients (69.3%) were classified as stage AB, while 234 (18.3%) were assigned to stage C, 66 (5.5%) to stage D, and 93 (7.3%) to stage E.

The distribution of patients at risk or with early signs of shock (defined as SCAI SHOCK stages A and B) compared with those exhibiting classic shock, deteriorating shock, or shock at extremis (defined as SCAI SHOCK stages C, D, and E) revealed differences across the various SCAI classification frameworks: study 1 SCAI classification framework, 860 patients (67.1%) versus 421 patients (32.9%); study 2 SCAI classification framework, 829 patients (64.7%) versus 452 patients (35.3%); study 3 SCAI classification framework, 806 patients (62.9%) versus 475 patients (37.1%); and study 4 SCAI classification framework 888 patients (69.3%) versus 393 patients (30.7%) (Figure S2). These differences were statistically significant when comparing the 2 groups (P=0.0039), indicating variation in classification across frameworks. In addition, notable discrepancies were observed for specific SCAI SHOCK stages. For instance, while study 1 SCAI classification framework classified 249 patients (19.4%) as SCAI SHOCK stage E, only 93 patients (7.3%) were assigned to this stage according to the Study 4 SCAI classification framework.

Concordance Across SCAI Classification Frameworks

We subsequently evaluated the consistency of SCAI SHOCK stage assignments across the 4 SCAI classification frameworks. For 358 patients (27.9%), a consistent classification into the same shock stage was observed across all 4 frameworks. In contrast, 808 patients (63.1%) were assigned to different SCAI SHOCK stages in 2 of the 4 frameworks, while 109 patients (8.5%) differed in 3 frameworks, and 6 patients (0.5%) were classified differently across all 4 classification systems (Figure 1B). For the purpose of this comparison, patients classified in SCAI SHOCK stage AB according to the study 4 SCAI classification framework were included in concordance analysis for stages A and B. The distribution of SCAI SHOCK stage assignments is further illustrated in a Sankey diagram (Figure 1C), where gray flows represent patients consistently classified across SCAI classification frameworks and blue flows indicate differing classifications. The width of these flows reflects the proportion of patients in each stage, highlighting the variability in classification systems, particularly at the higher SCAI SHOCK stages (ie, SCAI SHOCK stages C, D, and E).

To evaluate the overall consistency of the classification systems across the 4 studies, we calculated Kendall's W. The resulting coefficient indicated a moderate to strong agreement (W=0.70) demonstrating a generally high level of consistency in patient classification across SCAI stages among the 4 SCAI classification frameworks.

Mortality Rates Across SCAI Classification Frameworks

Next, we evaluated the differences in mortality rates associated with individual SCAI SHOCK stages across all 4 SCAI classification frameworks, considering the observed variability in stage assignment. For each of the 4 SCAI classification frameworks, we observed a stepwise increase in mortality rates corresponding to each SCAI SHOCK stage (Figure 2A and Table S12). The most pronounced absolute differences in mortality rates among the SCAI classification frameworks were evident for SCAI SHOCK stages D and E, while the differences for stages A, B, and C were comparatively smaller (Table S12). For instance, the mortality rate for SCAI SHOCK stage E was recorded at 56.6% for the study 1 SCAI classification framework, whereas it was 76.3% when categorized under the study 4 SCAI classification framework.

To determine whether the observed differences in mortality rates for individual SCAI SHOCK stages across the 4 SCAI classification frameworks yielded statistical significance, we constructed Kaplan–Meier curves and conducted log-rank tests comparing pairs of frameworks, adjusting for multiple comparisons (Figure 2B and 2F). Statistically significant differences were identified for SCAI stage B (between study 2 and studies 3 and 4; adjusted P=0.0003 and 0.00002), SCAI stage D (between study 3 and study 4; adjusted P=0.005) and for SCAI stage E (between study 1 and studies 3 and 4; adjusted P=0.002 and 0.004, respectively). To provide a comprehensive visual overview of these statistical comparisons, heatmaps of adjusted P values were generated for each SCAI SHOCK stage. The heatmaps illustrate the pairwise differences in mortality rates between the 4 classification frameworks, with color gradients indicating the magnitude and significance of the P values (Figure 3). Particularly for stages B, D, and E, the heatmaps highlight consistent and significant discrepancies between specific study comparisons, further supporting the observed stage-dependent variability in outcome classification.

Predictive Performance of the 4 Different SCAI Classification Frameworks

Finally, we evaluated the predictive performance of the 4 SCAI classification frameworks for in-hospital death.

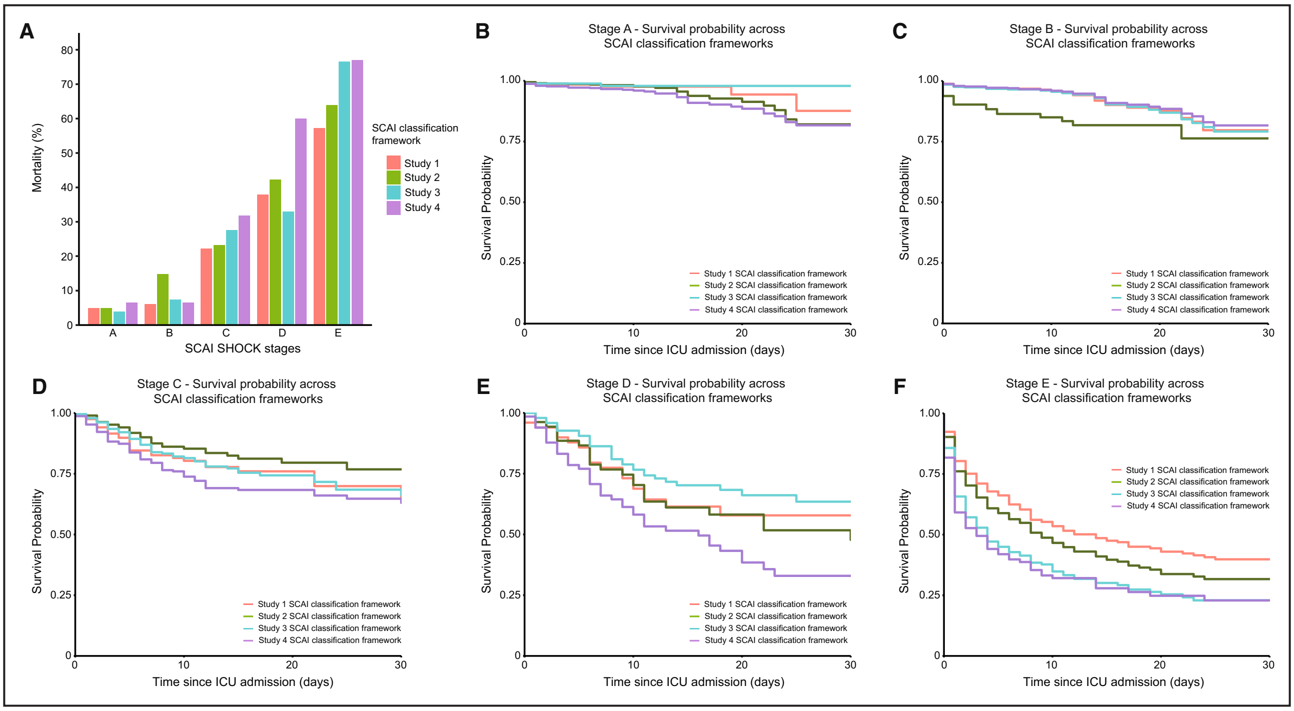

Figure 2. In-hospital mortality and survival probabilities across SCAI SHOCK stages and classification frameworks.
A, In-hospital mortality rates across SCAI SHOCK stages for all 4 SCAI classification frameworks. **B**, Kaplan–Meier curves illustrating survival probabilities for all 4 SCAI classification frameworks for patients classified in SCAI SHOCK stage A. **C**, Kaplan–Meier curves illustrating survival probabilities for all 4 SCAI classification frameworks for patients classified in SCAI SHOCK stage B. **D**, Kaplan–Meier curves illustrating survival probabilities for all 4 SCAI classification frameworks for patients classified in SCAI SHOCK stage C. **E**, Kaplan–Meier curves illustrating survival probabilities for all 4 SCAI classification frameworks for patients classified in SCAI SHOCK stage D. **F**, Kaplan–Meier curves illustrating survival probabilities for all 4 SCAI classification frameworks for patients classified in SCAI SHOCK stage E. SCAI indicates Society for Cardiovascular Angiography and Interventions.

Overall, mortality rates exhibited a progressive increase with advancing SCAI SHOCK stages from A to E across all 4 frameworks (Table S12). For in-hospital death, the area under the receiver operating characteristic curve values were as follows: 0.83 (95% CI, 0.80–0.86) for the study 1 SCAI classification framework, 0.84 (95% CI, 0.81–0.86) for the study 2 SCAI classification framework, 0.84 (95% CI, 0.81–0.87) for the study 3 SCAI classification framework, and 0.82 (95% CI, 0.79–0.85) for the study 4 SCAI classification framework (Figure 4). Pairwise comparisons of the areas under the curve using the DeLong test indicated no statistically significant differences in in-hospital death across the studies (Figure S3).

These findings suggest that all 4 SCAI classification frameworks exhibit comparable predictive performance for in-hospital death without statistically significant differences.

When analyzed according to the underlying shock pathogenesis, all SCAI classification frameworks demonstrated greater prognostic performance in the acute myocardial infarction subgroup (area under the curve, 0.81–0.84) compared with the AHF subgroup (area under the curve, 0.71–0.76) (see Tables S13 through S15 and Figures S4 through S5).

DISCUSSION

To effectively evaluate and compare patients with CS across studies, standardized and validated classification and prognostic frameworks are essential. Reliable CS classification depends on the consistent collection and interpretation of parameters. Discrepancies can lead to variations that affect results and prognostic accuracy, both within and between studies.

Applying the SCAI SHOCK Stage Classification relies on 2 fundamental data collection approaches: retrospective analysis of existing records and prospective assessment. Retrospective classification often faces limitations due to incomplete clinical context, inconsistent data collection, and missing key hemodynamic or laboratory parameters, particularly in patients at lower risk of CS. In contrast, prospective studies, such as those by Baran et al,[18] the CZECH-Shock (Czech Registry of Cardiogenic Shock) registry,[19] and Morici et al[20] -demonstrate the advantages of prospective SCAI staging, providing more complete data, clinical context, and greater consistency. However, while prospective classification benefits from enhanced data quality, it is more resource intensive and may be

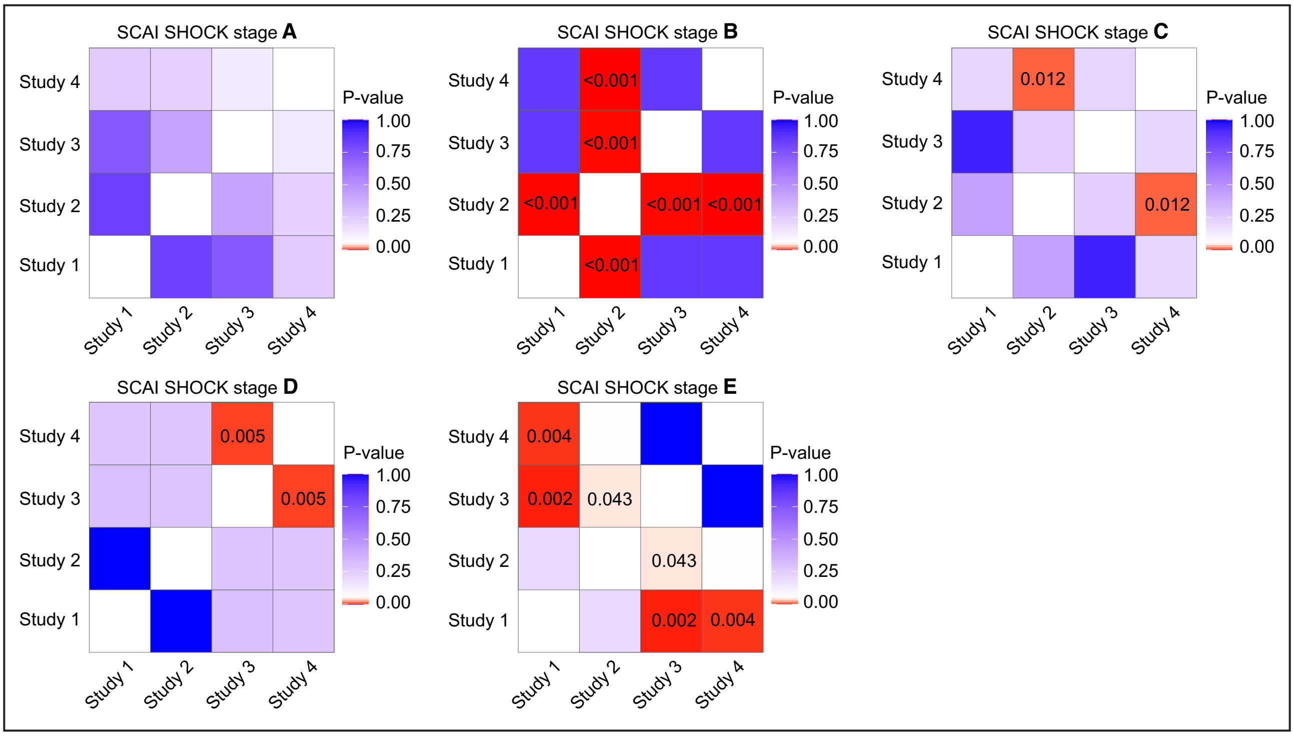

Figure 3. Adjusted, pairwise multiple comparisons of log-rank tests comparing mortality estimates for different SCAI SHOCK stages across all 4 different SCAI classification frameworks.
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subject to interpretation bias during real-time evaluation. Despite these differences, both retrospective and prospective SCAI SHOCK Stage assignments can effectively distinguish patients at risk for or with manifest CS on the basis of prognosis.

The 2021 SCAI SHOCK Stage Classification Expert Consensus summarized the results of multiple validation studies that were conducted since the initial publication of the SCAI SHOCK Stage Classification framework.[11] As of now, there has not been any published research that directly evaluates and compares the effectiveness of various SCAI SHOCK Stage Classification frameworks within a single patient population.

In this study, we evaluated 4 distinct adaptations of the SCAI SHOCK Stage Classification system to determine whether the distribution of SCAI stages and their overall prognostic performance vary on the basis of the specific framework applied, using data from a retrospective analysis in 1 patient cohort. Our findings demonstrate a moderate to strong classification concordance across all 4 SCAI classification frameworks, along with similar prognostic performance for in-hospital death. There are, however, differences when comparing the assignment of individual SCAI SHOCK stages and mortality rates associated with individual SCAI SHOCK stages across the assessed SCAI classification frameworks.

Concordance Across Classification Frameworks

Our analysis revealed variability in the ability to retrospectively assign patients to SCAI SHOCK stages. While overall moderate to strong agreement was observed across the 4 classification frameworks, differences in criteria led to discrepancies in individual classifications. These variations were particularly evident in the higher SCAI SHOCK stages. A key factor contributing to classification consistency is the use of shared physiological parameters. For instance, all frameworks require lactate levels <2 mmol/L for classification into lower shock stages, ensuring a common baseline for early-stage patients. However, differences in the weighting of additional hemodynamic and biochemical markers likely account for the observed discrepancies, particularly in advanced stages.[12]

The differences in the assignment of individual SCAI SHOCK stages described in our study highlight the need to standardize key classification criteria to allow for consistent classification across studies.

Overall Predictive Performance Is Independent of Selected Parameters

Despite variations in the conditions and criteria used by the 4 SCAI classification frameworks, our results demonstrate that their predictive performance for in-hospital

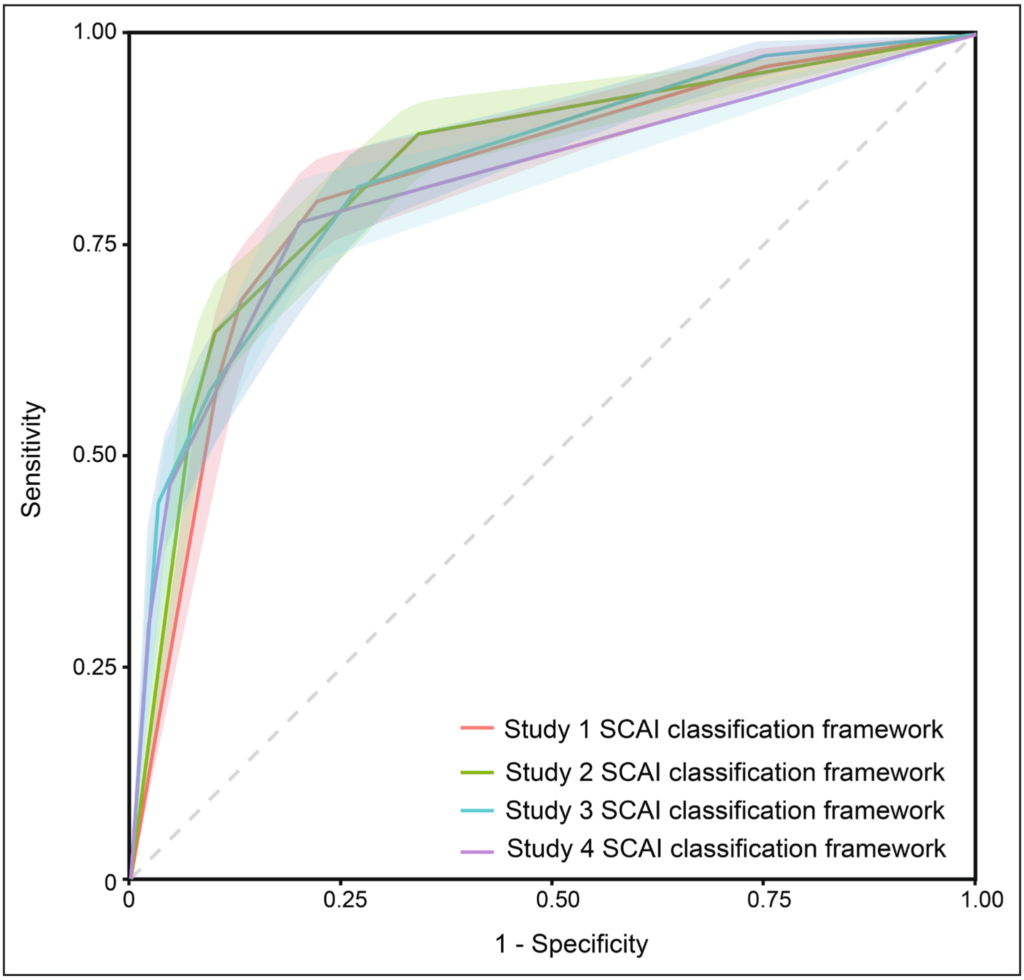

Figure 4. Area under the receiver operating characteristics curves illustrating the predictive performance for in-hospital death for all four SCAI classification frameworks. Shaded area denotes 95% CIs.
SCAI indicates Society for Cardiovascular Angiography and Interventions.

death is largely independent of the specific parameters selected. All frameworks consistently showed a stepwise increase in mortality rates with advancing SCAI SHOCK stages, highlighting their ability to stratify patients on the basis of clinical severity. Importantly, receiver operating characteristic values for in-hospital death were comparable across all 4 frameworks, with no statistically significant differences observed in predictive accuracy.

Our findings align with and build upon previous studies focusing on the SCAI SHOCK Stage classification. Similar to our results, studies applying individual SCAI SHOCK Stage Classification frameworks have consistently demonstrated the ability to stratify outcomes on the basis of shock severity in patients with CS, out-of-hospital cardiac arrest, and patients treated in cardiac intensive care units.[13,21,22] The stepwise increase in mortality rates observed across all SCAI SHOCK stages in our study reflects the robustness of the overall classification system.

The underlying pathogenesis of cardiogenic shock—acute myocardial infarction versus AHF—appears to influence the predictive performance of the SCAI SHOCK Stage Classification. In our cohort, which included a higher proportion of patients with acute myocardial infarction, the SCAI stages demonstrated greater accuracy in predicting death for acute myocardial infarction compared with acute decompensated heart failure consistently across all frameworks. This observation aligns with findings by Jentzer et al,[12] who reported similar differences in areas under the curve between acute coronary syndrome and heart failure patients. In both studies, admission diagnoses were determined on the basis of *ICD-10* codes. We hypothesize that these disparities reflect differences in pathophysiology, hemodynamics, comorbidities, and treatment responses between the 2 groups, which may have affected the classification's prognostic utility independent of the applied SCAI classification framework.

Differences When Comparing the Assignment of Individual SCAI SHOCK Stages and Mortality Rates Associated With Individual SCAI SHOCK Stages

Despite the strong overall agreement among the 4 SCAI SHOCK Stage Classification frameworks and their similar prognostic performance, there were notable differences in how individual patients were assigned to specific SCAI SHOCK Stages. Nevertheless, all 4 frameworks effectively distinguished between patients at risk of or in early CS and those in classic or advanced CS stages. Approximately 70% of patients were classified in either stage A or B across all 4 frameworks. However, the distribution between these 2 stages varied widely among the frameworks. Significant differences were also observed in the assignment of patients to stages C, D, and E. In the framework applied by Naidu et al, almost 19.4% of patients were assigned to stage E, whereas the framework used by Thayer et al classified only 7.3% of patients into stage E.[11,14] These differences are also reflected by the differing mortality rates of 56.6% and 76.3%, respectively, when applying the 2 SCAI SHOCK Stage Classification frameworks mentioned above.

This observation can be largely attributed to the differing criteria and definitions of SCAI SHOCK stages across the various frameworks. In general, at-risk patients and those in the early stages of CS are defined by normal lactate levels and the absence of vasoactive drugs or MCS devices. The distinctions between stages A and B arise from additional criteria related to laboratory values, blood pressure, and heart rate. In contrast, the criteria for assigning classic and advanced forms of shock vary more significantly in terms of both criteria and cutoff values. For instance, the framework developed by Lawler et al requires not only lactate levels but also laboratory values that reflect kidney and liver function, as well as the use of vasoactive and inotropic drugs and MCS devices to classify a patient as stage D.[13] In comparison, the framework applied by Jentzer et al considers lactate levels and the use of vasoactive and inotropic drugs for the same classification.[12]

These differences in stage assignment may not only result from the varying criteria applied across frameworks but also from the way in which SCAI stages were determined in each study setting.[18–20]

Finally, the 4 selected SCAI SHOCK Stage Classification frameworks were developed and applied to different patient cohorts, including those with acute coronary syndrome, myocardial infarction, and AHF, as well as all patients in the cardiac intensive care unit and those with CS. We assume that these varying study settings may have influenced the individual adaptations of the SCAI SHOCK Stage Classification system.

The principal finding of this study is that the SCAI SHOCK Stage Classification remains valid irrespective of methodological nuances, indicating that it captures fundamental biological processes in CS. This underscores the need for further investigation into the mechanisms driving shock progression. The absence of such mechanistic insight may have contributed to the negative outcomes of prior clinical trials, highlighting an important area for future research.

The SCAI SHOCK Stage Classification is gaining recognition and is increasingly integrated into clinical research; however, its fully prospective application for patient selection and treatment monitoring in randomized trials remains in development. A recent example is the DanGer-Shock (Danish–German Cardiogenic Shock) trial,[23] which used the SCAI classification as defined by Kapur et al[24] in a prespecified subgroup analysis, this study demonstrated that adding a microaxial flow pump to standard care in patients with ST-segment–elevation myocardial infarction complicated by cardiogenic shock improved 180-day all-cause death, regardless of whether patients were classified as SCAI stage C or D/E. These findings underscore the promise of the SCAI classification but also highlight the need for further research to clarify its clinical utility in guiding patient selection, treatment decisions, and evaluation of therapeutic response.

Limitations

Our study has several limitations that should be considered when interpreting the data, results, and conclusions. First, the retrospective assignment of SCAI SHOCK stages relied heavily on the applied SCAI SHOCK framework, which varied in its feasibility. Additionally, we did not assess all previously published adaptations of the SCAI SHOCK classification frameworks. Notably, the 2021 SCAI SHOCK Stage Classification Expert Consensus identifies 2 additional adapted versions by Schrage et al[7] and Pareek et al.[9] The inclusion of these frameworks might have yielded different results and conclusions. All 4 SCAI classification frameworks required further adaptations for consistent application in our study. In cases where a respective SCAI classification framework did not unanimously assign a patient to a definite SCAI SHOCK stage, physician adjudication was used. The need for and extent of adaptations and the necessity for physician adjudication varied with the complexity of each framework, which may affect results and their interpretation. These modifications may have altered the original classification framework and could have introduced additional bias. Another limitation of our study is the reliance on *ICD-10* coding to identify cardiogenic shock cases. While we included both primary and secondary *ICD-10* diagnoses (R57.0) and compared these with SCAI SHOCK stage classifications (stages C, D, and E), discrepancies remain. Although 81% to 87% of patients with *ICD-10*–coded CS were classified within SCAI stages C through E, a substantial proportion (35%–45%) of patients meeting clinical SCAI criteria lacked a corresponding *ICD-10* code. This suggests that administrative coding may underrepresent the true prevalence of CS, potentially missing patients identified through clinical classification. Another limitation of this study is the limited use of temporary MCS devices, such as extracorporeal membrane oxygenation and Impella, due to capacity constraints during the COVID-19 pandemic and the lack of an affiliated cardiac surgery department at University Hospital Mannheim. Additionally, intra-aortic balloon pumps are no longer used at our institution, reflecting national trends. These factors may have influenced treatment patterns and should be considered when interpreting the severity distribution across SCAI stages.

CONCLUSIONS

In conclusion, our study highlights a moderate to strong concordance and similar prognostic performance of 4 distinct SCAI SHOCK Stage Classification frameworks in retrospectively assessing patients with CS. Despite notable differences in individual stage assignments and the criteria used, all frameworks effectively stratified patients on the basis of clinical severity and demonstrated a consistent increase in mortality rates with advancing SCAI stages. These findings underscore the importance of standardized classification systems for improving patient stratification. Future research should aim to further refine these frameworks and explore additional adaptations to enhance their applicability across diverse patient populations.

ARTICLE INFORMATION

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Supplemental Material

Tables S1–S15
Figures S1–S5

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