CLINICAL AND HEMODYNAMIC CHARACTERISTICS OF CARDIOGENIC SHOCK COMPLICATING ACUTE MYOCARDIAL INFARCTION

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Among 84 patients with cardiogenic shock classified as Society for Cardiovascular Angiography and Interventions (SCAI) stage D–E, the in-hospital mortality rate was 29.8%. Mixed venous oxygen saturation (SvO_2) was associated with in-hospital mortality, with an optimal cutoff value of ≤55%. Patients with a cardiac power output (CPO) <0.535 W exhibited higher in-hospital mortality. These findings suggest that SvO_2 and CPO may provide additional value for early risk stratification among patients with cardiogenic shock complicating acute myocardial infarction, even within the same SCAI stage.

Keywords: Cardiogenic shock, cardiac power output, hemodynamics, microcirculation, mixed venous oxygen saturation.

I. INTRODUCTION

Cardiogenic shock complicating acute myocardial infarction is characterized by severe impairment of cardiac pumping function and inadequate systemic perfusion, leading to progressive organ dysfunction and a high mortality rate.[1,2] Although the SCAI shock classification has demonstrated a stepwise increase in mortality across stages A to E, differences in mortality still persist among patients within the same SCAI stage .[3] Pulmonary artery catheter (PAC)-derived oxygen transport variables may provide additional prognostic information beyond MAP, CO/CI, lactate, and SCAI stage. Therefore, this study aimed to evaluate the association between PAC-derived hemodynamic and oxygen transport indices and in-hospital mortality in patients with cardiogenic shock due to acute myocardial infarction.

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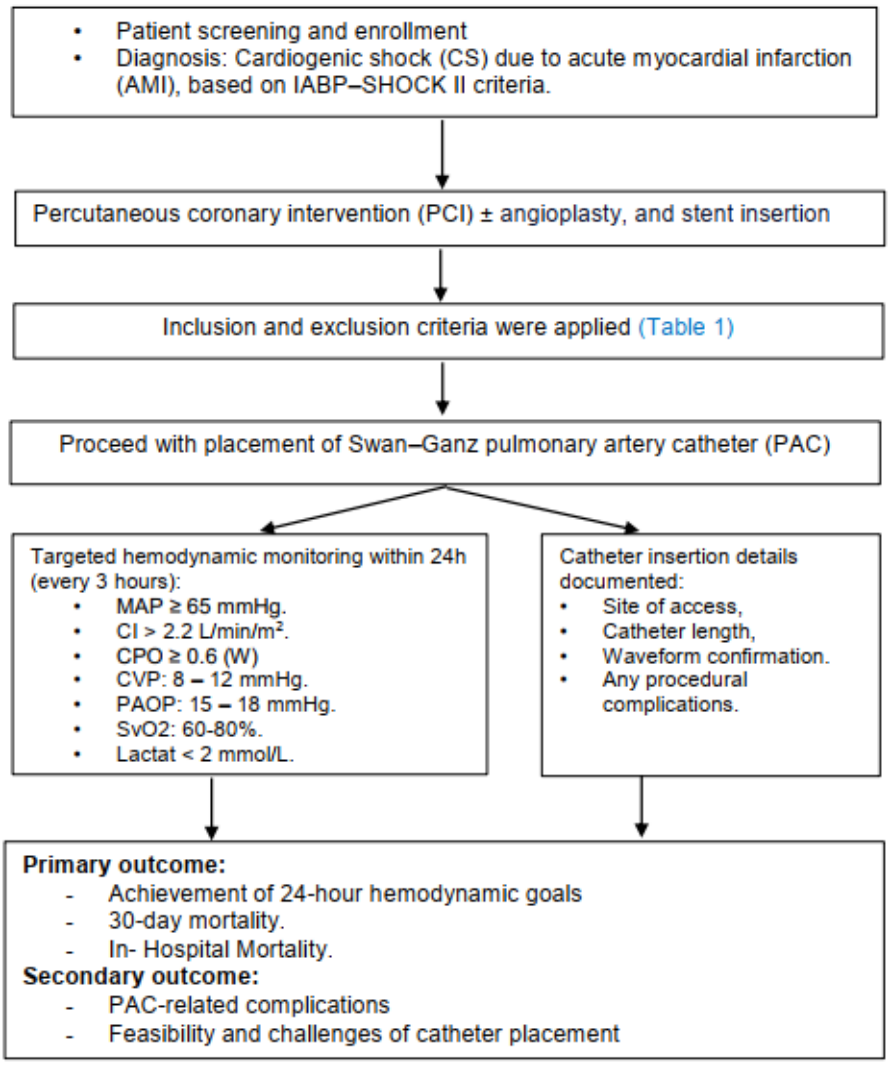
II. METHODS

1. Study design and trial registration

This was a prospective single-center observational cohort study involving invasive hemodynamic monitoring using pulmonary artery catheterization in patients with cardiogenic shock complicating acute myocardial infarction (ClinicalTrials.gov ID: NCT07062744).



Hemodynamic and oxygen transport variables were serially collected at time points after pulmonary artery catheter insertion (baseline time T0, T3h, T6h, T9h, T12h, T15h, T18h, T21h, and T24h). In the current analysis, we focused on baseline hemodynamic and oxygen transport parameters obtained immediately after pulmonary artery catheter placement (baseline time: T0) and evaluated their association with in-hospital mortality.

Hemodynamic calculations

Cardiac power output (CPO) and cardiac power index (CPI) were calculated using right atrial pressure-adjusted formulas to better reflect effective cardiac power output. CPO = (MAP - RAP)*CO/451; CPI = (MAP - RAP)*CI/451. Where MAP is mean arterial pressure, RAP is right atrial pressure, CO is cardiac output, and CI is cardiac index.

The vasoactive-inotropic score (VIS) was calculated according to previously published definitions: VIS = dopamine (μg/kg/min) + dobutamine (μg/kg/min) + 100 × epinephrine (μg/kg/min) + 100 × norepinephrine (μg/kg/min) + 10 × milrinone (μg/kg/min) + 10,000 × vasopressin (U/kg/min).

Population

Inclusion criteria:

- Age ≥18 years old.

- Written consent to participate in the study has been provided.

- Diagnosed with acute myocardial infarction (STEMI or NSTEMI) according to the ESC 2023 criteria [4].

- Diagnosed with cardiogenic shock due to acute myocardial infarction according to IABP-SHOCK II criteria (2012) [5]patients with acute MI and cardiogenic shock who were expected to undergo coronary revascularization were randomly assigned to receive or not to receive intraaortic balloon support. Balloon support had no effect on 30-day mortality. The rate of death among patients with cardiogenic shock complicating acute myocardial infarction is high even when the patients undergo early revascularization with percutaneous coronary intervention (PCI.

+ Systolic blood pressure (SBP) < 90 mmHg for at least 30 minutes, or requiring vasoconstrictor medication to maintain SBP > 90 mmHg.

+ Evidence of reduced blood flow to target organs, manifested by at least one of the following signs: altered mental status, urine output < 30 mL/hour, cold extremities, blood lactate > 2 mmol/L.

Exclusion criteria:

- There is evidence of cellulitis in the neck area.

- The anatomical structure of the neck region or the history of radiation therapy to the neck area could not be determined.

- Coagulation disorders (INR > 1.5 and/or platelet count < 50 G/L).

- End-stage chronic diseases, including: end-stage cancer, end-stage HIV, patients bedridden for more than 3 months, decompensated cirrhosis (Child-Pugh classification type C).

- Patients who experience cardiac arrest or mechanical complications such as myocardial rupture before Swan-Ganz catheter placement.

- Congenital heart defects or congenital cardiac catheterization.

- The patient or their legal representative refuses to participate.

Lead institution: Hanoi Medical University.

Study location: Bach Mai Hospital.

Research duration: April 2025 to December 2027. The present report represents a predefined interim analysis of baseline hemodynamic and oxygen transport characteristics in the first 84 enrolled patients.

2. Result

In-hospital mortality was identified as the primary outcome.

Statistical analysis

Statistical analyses: The study was performed using SPSS software, version 20 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation and compared between groups using Student's t-test or Mann-Whitney U-test, depending on the data distribution. Categorical variables were expressed as quantities and percentages and compared using the χ^2 test or Fisher's exact test. Receiver operating characteristic (ROC) curve analysis was used to assess the discriminant performance of baseline hemodynamic parameters. Optimal threshold values were determined using the Youden index. All tests were two-sided, and a p-value < 0.05 was considered statistically significant.

Sample size: We applied the sample size calculation formula to estimate a proportion with absolute error:

$$n = Z^2_{(1-\alpha/2)} \frac{p \,.\, (1 - p)}{d^2}$$

Where n is the required sample size, P is the mortality rate of cardiogenic shock patients whose hemodynamics were monitored using a Swan-Ganz catheter according to Hernandez et al. (P = 35%) [6], d is the absolute error (chosen d = 9%), the statistical significance level α = 0.05 and the Z value from the corresponding normal distribution is 1.96. Substituting these values into the formula, the expected sample size is calculated as n = 108. Within the scope of this paper, we analyzed 84 cases to serve the objective of analyzing the clinical and paraclinical characteristics of patients with cardiogenic shock due to acute myocardial infarction.

3. Research ethics

The study was approved by the Biomedical Research Ethics Committee of Bach Mai Hospital (Decision No. 33/BM-HĐĐĐ, dated May 21, 2025).

III. RESULTS

Table 1. Basic demographic and clinical characteristics

Variable	Overall (n=84)	Survivors (n=59)	Non-survivors (n=25)	p
Age (years)	70.01 ± 15.24	69.86 ± 16.41	70.40 ± 11.45	0.880
Weight (kg)	62.05 ± 10.31	62.07 ± 10.96	62.00 ± 8.85	0.980
Height (cm)	165 (154.75-168.25)	165 (153.5-169)	164 (158-168)	0.980
BMI (kg/m²)	23.4 (21.08-25.61)	23.6 (20.9-25.8)	23.4 (21.4-25.2)	0.820
IBW (kg)	61 (53-65.17)	60 (51-65.7)	61 (57-65)	0.800
LoS (days)	5 (3.75-7.25)	5 (4-8)	4 (2-7)	0.150
Dobutamine	10 (0-17.75)	10 (0-15)	15 (8-25)	**0.017**
Norepinephrine	0.40 (0.215-0.70)	0.30 (0.20-0.50)	0.60 (0.36-1.56)	**0.010**
Adrenaline	0	0	0 (0-0.20)	0.138
VIS	50 (30-92.75)	45 (30-70)	95 (50-210)	**0.008**

Abbreviations: *BMI, body mass index; IBW, ideal body weight; LoS, length of ICU stay; VIS, vasoactive-inotropic score.*

Demographic variables were generally comparable between survivors and non-survivors. However, non-survivors required significantly greater vasoactive support, including higher doses of dobutamine and norepinephrine, as well as higher vasoactive-inotropic score (VIS) values (***Table 1).***

Table 2. Comorbidities

Variable	Status	Survivors (n=59)	Non-survivors (n=25)	OR (95% CI)	p
Hypertension	Yes	37 (75.5%)	12 (24.5%)		0.211
	No	22 (62.9%)	13 (37.1%)		

Variable	Status	Survivors (n=59)	Non-survivors (n=25)	OR (95% CI)	p
Diabetes	Yes	28 (73.7%)	10 (26.3%)		0.530
	No	31 (67.4%)	15 (32.6%)		
Heart failure	Yes	18 (72.0%)	7 (28.0%)		0.818
	No	41 (69.5%)	18 (30.5%)		
CAD	Yes	13 (76.5%)	4 (23.5%)		0.529
	No	46 (68.7%)	21 (31.3%)		
COPD	Yes	9 (90.0%)	1 (10.0%)		0.268
	No	50 (67.6%)	24 (32.4%)		
CKD	Yes	3 (37.5%)	**5 (62.5%)**	**4.67 (1.02-21.3)**	**0.047**
	No	56 (73.7%)	**20 (26.3%)**		
Atrial fibrillation	Yes	1 (50.0%)	1 (50.0%)		0.509
	No	58 (70.7%)	24 (29.3%)		
Interstitial lung disease	Yes	1 (100%)	0		1.000
	No	58 (69.9%)	25 (30.1%)		
Malignancy	Yes	0	1 (100%)		0.298
	No	59 (71.1%)	24 (28.9%)		

Abbreviations: *CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease; OR, odds ratio; CI, confidence interval.*

Comorbidity profiles were generally similar between survivors and non-survivors. Chronic kidney disease was associated with higher in-hospital mortality (OR 4.67, 95% CI 1.02-21.3; p = 0.047). Whereas no significant associations were observed for hypertension, diabetes mellitus, heart failure, coronary artery disease, COPD, atrial fibrillation, interstitial lung disease, or malignancy ***(Table 2).***

Table 3. Arterial and pulmonary arterial blood gas variables

Variables related to arterial blood oxygen concentration, venous blood oxygen concentration, and systemic oxygen transport are summarized in Table 3.

Variable	Overall (n=84)	Survivors (n=59)	Non-survivors (n=25)	p
pH (Art)	7.34 ± 0.11	7.34 ± 0.09	7.32 ± 0.12	0.996
Lactate (Art)	3.5 ± 2.5	3.5 ± 2.5	3.6 ± 2.6	0.784

Variable	Overall (n=84)	Survivors (n=59)	Non-survivors (n=25)	p
PvO_2 (PAC)	37.1 ± 10.0	40.0 ± 11.2	31.4 ± 5.3	<0.001
SvO_2 (PAC)	59.3 ± 13.1	62.2 ± 12.4	52.4 ± 12.8	0.001
Lactate (PAC)	3.5 ± 2.4	3.5 ± 2.4	3.5 ± 2.6	0.924
PCO_2Gap	7.6 ± 3.8	7.6 ± 3.5	7.6 ± 4.4	0.994
CvO_2 (PAC)	10.1 ± 3.2	10.8 ± 3.1	8.8 ± 3.1	0.008
O_2ER (%)	38.1 ± 13.0	35.8 ± 12.5	43.4 ± 12.4	0.013

Abbreviations: *Art, arterial blood sample; PAC, pulmonary artery catheter; PvO_2, partial pressure of venous oxygen; SvO_2, mixed venous oxygen saturation; CvO_2, venous oxygen content; O_2ER, oxygen extraction ratio; PCO_2Gap, venous-to-arterial carbon dioxide partial pressure difference.*

Baseline arterial blood gas parameters were generally comparable between groups. In contrast, non-survivors demonstrated impaired systemic oxygen transport, characterized by lower PvO_2, SvO_2, and CvO_2 values together with a higher oxygen extraction ratio (O_2ER), whereas lactate and PCO_2Gap were not significantly different ***(Table 3).***

Hemodynamic parameters

Table 4.1. Hemodynamic parameters were measured using a pulmonary artery catheter

Variable	Overall (n=84)	Survivors (n=59)	Non-survivors (n=25)	p
HR (bpm)	117.1 ± 20.7	116.7 ± 21.3	117.9 ± 19.3	0.808
MAP (mmHg)	82.0 ± 14.8	83.8 ± 14.4	78.1 ± 15.3	0.108
CO (L/min)	3.97 ± 1.70	4.08 ± 1.88	3.71 ± 1.07	0.354
CI (L/min/m²)	2.42 ± 0.95	2.48 ± 1.04	2.27 ± 0.64	0.351
SVI (mL/m²)	22.2 ± 7.5	23.2 ± 8.3	19.9 ± 5.1	0.072
SVRI (dyn·s·cm^{-5}·m²)	2646.0 ± 1077.7	2686.0 ± 1095.6	2546.9 ± 1044.3	0.591
PAOP (mmHg)	18.6 ± 7.6	18.4 ± 7.7	19.2 ± 7.3	0.643
CPO (W)	0.77 ± 0.37	0.83 ± 0.41	0.63 ± 0.22	**0.026**
CPI (W/m²)	0.46 ± 0.21	0.50 ± 0.22	0.39 ± 0.14	**0.028**
SvO_2 (PAC)	61.6 ± 13.2	64.0 ± 12.4	55.9 ± 14.0	**0.010**

Abbreviations: *HR, heart rate; MAP, mean arterial pressure; CO, cardiac output; CI, cardiac index; SVI, stroke volume index; SVRI, systemic vascular resistance index; PAOP, pulmonary artery occlusion pressure; CPO, cardiac power output; CPI, cardiac power index; SvO_2, mixed venous oxygen saturation; PAC, pulmonary artery catheter.*

Non-survivors exhibited lower cardiac power output (CPO), cardiac power index (CPI), and SvO_2 values. Despite similar conventional macrocirculatory parameters such as MAP, CO, and CI ***(Table 4.1).***

Table 4.2. Multivariable logistic regression analysis for in-hospital mortality

Variable	Adjusted OR	95% CI	p-value
CPO < 0.535 (vs vs reference group)	2.64	0.93-7.53	0.07
Age (per year)	1.00	0.97-1.03	0.885
Lactate (per mmol/L)	1.01	0.83-1.23	0.929

Abbreviations: *Adjusted OR, adjusted odds ratio; CI, confidence interval; CPO, cardiac power output.*

Multivariable logistic regression analysis showed that lower CPO was associated with in-hospital mortality, although this association did not reach statistical significance after adjustment ***(Table 4.2).***

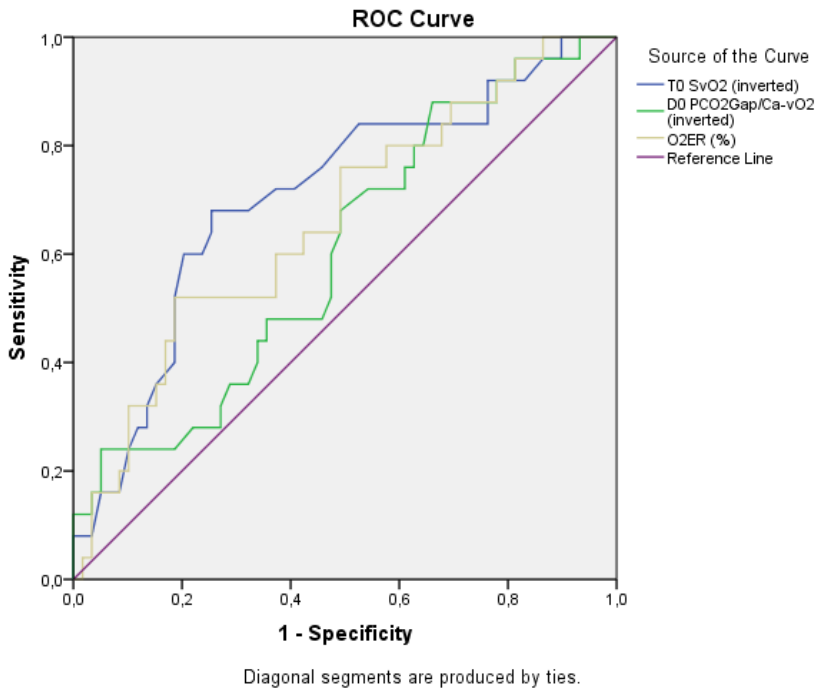


Figure 1. Optimal thresholds for predicting in-hospital mortality using SvO_2, O_2ER, PCO_2 Gap/Ca-vO_2

Receiver operating characteristic curve analysis evaluated the predictive performance of the selected oxygen transport variables ***(Figure 1).***

Abbreviations: SvO_2, mixed venous oxygen saturation; O_2ER, oxygen extraction ratio; PCO_2Gap/C(a-v)O_2, ratio of venous-to-arterial carbon dioxide partial pressure difference to arterial-venous oxygen content difference; ROC, receiver operating characteristic.

Variable	AUC	95%CI	p	Cut-off	Sensitivity	Specificity
SvO_2	0.707	0.584-0.831	0.003	≤ 55%	0.68	0.71
O_2ER	0.663	0.536-0.790	0.019	≥ 36%	0.76	0.49
$PCO_2Gap/C(a-v)O_2$	0.604	0.474-0.734	0.132	≥ 0.81	0.68	0.51

ROC analysis suggested that SvO_2 was associated with moderate discriminatory performance for in-hospital mortality. O_2ER also showed modest discriminatory ability, whereas $PCO_2Gap/C(a-v)O_2$ was not significantly associated with mortality in the present cohort ***(Figure 1).***

IV. DISCUSSION

Baseline characteristics, comorbidities, and mortality in severe cardiogenic shock

The mean age of the study group was 70 ± 15.24 years old, comparable to the age groups reported in the IABP-SHOCK II (2012) [5] and CULPRIT-SHOCK (2017).[7] The median ICU stay in the survivor group was 5 days (interquartile range 4-8 days) (Table 1). All 84 patients were classified as severe cardiogenic shock (SCAI stage D-E). Vasopressor-inotropic (VIS) scores and vasopressor doses were significantly higher in the non-survivors compared to the survivors. The in-hospital mortality rate in our study was 29.8%, consistent with recent studies evaluating Swan-Ganz catheter-guided hemodynamic monitoring in cardiogenic shock.[8,9]

Mixed venous oxygen saturation may help risk stratification within the same SCAI stage

ROC curve analysis showed that SvO_2 was associated with in-hospital mortality, with an optimal cutoff value of ≤55% (Figure 1). These results suggest that patients with the same SCAI stage but SvO_2 ≤55% may be at higher risk of in-hospital mortality and could require earlier hemodynamic optimization and mechanical circulatory support.[10] Mixed venous saturation may reflect severe hypoperfusion, even when macrocirculation targets such as SBP, DBP, and MAP are still in the stable phase.[11]

Lower CPO was observed in the non-survivor

Cardiac power output (CPO) was lower in the mortality group (Table 4.1). Although this difference was not statistically significant, it suggests a trend toward higher mortality rates in patients with lower CPO.

V. CONCLUSION

In patients with severe cardiogenic shock due to acute myocardial infarction, SvO_2 <55% was associated with in-hospital mortality. CPO <0.535 W was recorded in the non-survivors group, although this association did not reach statistical significance after adjustment. These parameters (CPO, SvO2) may help identify patients at higher risk of mortality within the same SCAI stage classification. Future studies should evaluate dynamic changes in SvO_2, lactate clearance, CPO, and O_2ER over time rather than relying only on a single baseline measurement.

LIMITATIONS

This study has several limitations. First, the relatively small sample size limited the use of multivariable adjustment. Therefore, the findings should be considered exploratory and hypothesis-generating. Residual confounding from clinically relevant variables could not be fully excluded (chronic kidney disease, hepatic injury markers, vasoactive drug dose). Second, this was a non-randomized observational study

without a control group, and selection bias could not be excluded. Third, the study was conducted at a single center with a structured hemodynamic monitoring protocol and a dedicated team experienced in pulmonary artery catheter management, which may limit the generalizability of the findings to other clinical settings. Future recommendations should emphasize serial assessment of SvO_2, lactate clearance, CPO, CPI, and O_2ER rather than reliance on a single baseline measurement.

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