



Article

Invasive Phenotyping of Acute-Myocardial-Infarction-Related Cardiogenic Shock

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Abstract: Background: Studies had previously identified three cardiogenic shock (CS) phenotypes (cardiac-only, cardiorenal, and cardiometabolic). Therefore, we aimed to understand better the hemodynamic profiles of these phenotypes in acute myocardial infarction-CS (AMI-CS) using pulmonary artery catheter (PAC) data to better understand the AMI-CS heterogeneity. Methods: We analyzed the PAC data of 309 patients with AMI-CS. The patients were classified by SCAI shock stage, congestion profile, and phenotype. In addition, 24 h hemodynamic PAC data were obtained. Results: We identified three AMI-CS phenotypes: cardiac-only (43.7%), cardiorenal (32.0%), and cardiometabolic (24.3%). The cardiometabolic phenotype had the highest mortality rate (70.7%), followed by the cardiorenal (52.5%) and cardiac-only (33.3%) phenotypes, with significant differences ($p < 0.001$). Right atrial pressure ($p = 0.001$) and pulmonary capillary wedge pressure ($p = 0.01$) were higher in the cardiometabolic and cardiorenal phenotypes. Cardiac output, index, power, power index, and cardiac power index normalized by right atrial pressure and left-ventricular stroke work index were lower in the cardiorenal and cardiometabolic than in the cardiac-only phenotypes. We found a hazard ratio (HR) of 2.1 for the cardiorenal and 3.3 for cardiometabolic versus the cardiac-only phenotypes ($p < 0.001$). Also, multi-organ failure, acute kidney injury, and ventricular tachycardia/fibrillation had a significant HR. Multivariate analysis revealed that CS phenotypes retained significance ($p < 0.001$) when adjusted for the Society for Cardiovascular Angiography & Interventions score ($p = 0.011$) and Δ congestion ($p = 0.028$). These scores independently predicted mortality. Conclusions: Accurate patient prognosis and treatment strategies are crucial, and phenotyping in AMI-CS can aid in this effort. PAC profiling can provide valuable prognostic information and help design new trials involving AMI-CS.

Keywords: acute myocardial infarction; cardiogenic shock; pulmonary artery catheter; hemodynamic profiles; CS phenotypes; congestion profiling

1. Introduction

Acute myocardial infarction complicated by cardiogenic shock (AMI-CS) has a looming prognosis. Recently, the Society for Cardiovascular Angiography & Interventions (SCAI)

classification offered new terms that clinicians and researchers can use to communicate the severity of the CS [1].

While the severity of CS can be assessed using the SCAI system, there is still a need for more comprehensive phenotyping of CS to understand its underlying mechanisms and improve patient outcomes. Recently, a phenotypification of CS into three clusters was provided by Zweck et al. [2,3]. Although SCAI 2022 provides an abstract form of measuring severity, the presence of organ involvement in the phenotyping process must be included. Also, dynamic congestion is paramount in AMI-CS outcomes [4]. Furthermore, hemodynamic trajectories must be studied because much of the information used to classify patients is single-point data, rather than with repeated measures [2,5,6].

We propose an analysis of the hemodynamic “signature” of AMI-CS using repeated measures data from pulmonary artery catheter (PAC) studies that could provide a more precise and individualized prognostication [7]. Furthermore, by identifying distinct hemodynamic patterns and their associations with CS phenotypes, we can improve our current understanding of AMI-CS heterogeneity and its potential complications.

2. Materials and Methods

We analyzed retrospective PAC data from 309 AMI-CS patients from January 2006 to July 2021 at the National Institute of Cardiology in Mexico City. CS was defined as a systolic pressure of ≤ 90 mmHg, the need for vasoactive or mechanical support (MCS), lactate ≥ 2 mmol/L, and/or a cardiac index of ≤ 2.2 L/min/m² [8]. Our institution’s Research and Ethics Committee approved the study protocol, and patient consent was not required. All procedures were conducted in accordance with the Declaration of Helsinki and local regulations.

2.1. Classifications and Definitions

We classified the patients according to the 2022 SCAI stage, with the worst stage at 24 h after a PAC was installed [1]. We created a congestion profile for all patients using the standardized cut-off values [6] of pulmonary capillary wedge pressure (PCWP, ≥ 18 mmHg) and right atrial pressure (RAP, ≥ 12 mmHg), and we used the changes in these congestion profiles to categorize the patients into 3 groups: decongestive, neutral, or congestive within the first 24 h [1,2,4] (See Full Description in the Supplementary Data).

2.2. Cardiometabolic Phenotype

Three phenotypes were created based on parameters described by Zweck et al. [2] at the initial CS presentation: cardiac-only (no organ involvement), cardiorenal (estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73 m²), and cardiometabolic (renal + hepatic (alanine transaminase (ALT)) 150 U/L, >3 upper normal limit) (For a full description, see the Supplementary Data).

2.3. Complications

Complications included ventricular tachycardia/fibrillation; acute kidney injury (AKI), defined by the KDIGO AKI guidelines (“KDIGO Clinical Practice Guideline for Acute Kidney Injury,” 2012) [9]; and multi-organ failure (MOF), defined by the Multiple Organ Dysfunction score (MODS) [10] for in-hospital 30-day follow-up (For a full description, see the Supplementary Data).

3. Statistical Analysis

The demographic data for qualitative variables were presented as frequencies and percentages, and the Chi-squared or exact Fisher tests were used as appropriate to assess the differences. For continuous variables, median and interquartile ranges and comparisons were performed using the Kruskal–Wallis or Mann–Whitney *U* tests for group comparisons. Bonferroni correction was used when the comparison involved multiple groups.

We used the ANOVA for repeated measures to evaluate the changes over time, and the Mauchly test was performed for the sphericity test. Finally, the Greenhouse–Geisser test was used to correct the degrees of freedom and to compare each group's hemodynamic variables.

Kaplan–Meier curves were constructed, a 30-day restricted mean survival time (RMST) was obtained, and differences were assessed using the log-rank test. The phenotypes were compared to the SCAI score and congestion changes to evaluate the value of using the triple-scoring system to predict mortality. Furthermore, the phenotypes and outcomes were compared against in-hospital mortality in multivariate analyses against age, sex, DM, HTN, type of myocardial infarction (MI), primary reperfusion, and SCAI score. Finally, hazard ratios and their 95% confidence intervals were reported.

All statistical tests were 2-tailed, and significance was assumed if a p -value < 0.05 was obtained. Statistical analyses were performed using IBM SPSS Statistics, MedCalc for Windows (v19.4; MedCalc Software, Ostend, Belgium), and SAS on Demand for Academics (SAS Institute, Cary, NC, USA).

4. Results

The phenotypes were cardiac (43.7%), cardiorenal (32%), and cardiometabolic (24.3%). The cardiac group was the youngest compared with the cardiorenal and cardiometabolic groups ($p < 0.001$). The prevalence of hypertension was higher in the cardiorenal and cardiometabolic compared with the cardiac group (59.6% and 58.7% vs. 42.2%; $p = 0.026$ and 0.012 , respectively). The incidence of previous chronic kidney disease was also higher in the cardiorenal and cardiometabolic compared with the cardiac group. The proportion of patients with diabetes mellitus was also higher but not significantly different in the cardiorenal group ($p = 0.115$).

Previous MI, percutaneous coronary intervention (PCI), and coronary artery bypass graft (CABG) were not significantly different among the three groups. There was a significant difference in the type of AMI ($p = 0.022$), with a higher percentage of STEMI in the cardiometabolic group (93.3%) compared with the other groups. The out-hospital cardiac arrest was not different ($p = 0.92$). The Killip–Kimball classification showed significant differences ($p < 0.001$), with a higher proportion of class IV in the cardiometabolic group.

The results show that the cardiometabolic group had the lowest left-ventricular ejection fraction (LVEF) of 30% compared with 35% in the cardiac and 32% in the cardiorenal group; however, this was not statistically significant ($p = 0.073$).

White blood cell counts were higher, and platelets were lower, in the cardiometabolic group compared to the cardiorenal and cardiac groups. Glucose levels were significantly higher in the cardiometabolic compared with the cardiac ($p = 0.02$) and the cardiorenal groups ($p = 0.034$). BUN and creatinine levels were significantly higher in the cardiorenal group ($p < 0.001$). The eGFR was considerably lower in the cardiorenal and cardiometabolic groups ($p < 0.001$).

Values of aspartate transaminase (AST), ALT, lactate dehydrogenase (LDH), maximum creatinine, maximum AST, maximum ALT, bilirubin, and lactate significantly differed in the groups, with the highest values found in the cardiometabolic group. The cardiometabolic group had lower base excess and pH values ($p < 0.001$).

In primary reperfusion cases, the rate of thrombolysis was 20.1% (27) in the cardiac, 17.2% (17) in the cardiorenal, and 6.7% (5) in the cardiometabolic groups. The rate of primary percutaneous coronary intervention (pPCI) was 34.3% (46) in the cardiac, 27.3% (27) in the cardiorenal, and 21.3% (16) in the cardiometabolic group. In comparison, the rate of non-primary reperfused cases was 45.5% (61) in the cardiac, 55.6% (55) in the cardiorenal, and 72% (54) in the cardiometabolic groups ($p = 0.005$). (For specific coronary artery distribution in different cardiogenic shock profiles, refer to Table S4).

Likewise, the rate of mechanical ventilation was 60.7% in the cardiac, 72.7% in the cardiorenal, and 80% in the cardiometabolic groups, and the difference was statistically

significant ($p = 0.01$). Finally, the rate of hemodialysis was 4.4% (6) in the cardiac, 17.2% (17) in the cardiorenal, and 28% (21) in the cardiometabolic groups ($p < 0.001$).

Norepinephrine was used in 74.1% of the cardiac, 82.8% of the cardiorenal, and 88% of the cardiometabolic groups ($p = 0.039$). Vasopressin was used in 45.9% of the cardiac, 56.6% of the cardiorenal, and 73.3% of the cardiometabolic groups ($p = 0.001$). Levosimendan was used in 25.9%, 27.3%, and 48% of the cardiac, cardiorenal, and cardiometabolic groups, respectively ($p = 0.002$). Dobutamine use was lower in 76.3% of the cardiac group compared with 83.8% and 97.3% of the cardiorenal and cardiometabolic groups, respectively. Considering the number of vasoactive drugs, a higher proportion of the cardiometabolic group had four drugs compared with the cardiac and cardiorenal groups ($p < 0.001$).

No differences were seen regarding mechanical circulatory support (MCS), with the majority being intra-aortic balloon pumps, with only two patients with a cardiorenal phenotype receiving extracorporeal membrane oxygenation and only two patients receiving Impella-CP (one each in the cardiorenal and cardiometabolic groups, respectively).

The incidence of AKI was higher in the cardiorenal (82.8%) and cardiometabolic (92%) groups compared with the cardiac group (43%) ($p < 0.001$). Furthermore, the severity of AKI was higher in the cardiometabolic and cardiorenal compared with the cardiac group ($p < 0.001$).

Significant differences existed in the number of organ failures and the presence of MOF. A higher percentage of patients with cardiometabolic comorbidities had MOF than in the other groups (80% vs. 62.6% in the cardiorenal and 41.5% in the cardiac group; $p < 0.001$). In addition, a higher percentage of patients with the cardiometabolic phenotype had ≥ 4 more organ failures than in the other groups (33.3% vs. 18.2% in the cardiorenal and 6.7% in the cardiac groups; $p < 0.001$).

The cardiometabolic group had higher MODS scores, indicating higher organ dysfunction levels than in the other groups ($p < 0.001$). The same pattern was seen with the SCAI score, with patients in the cardiometabolic and cardiorenal groups having higher scores ($p < 0.001$).

Finally, the highest mortality rate was seen in the cardiometabolic (70.7%), followed by the cardiorenal (52.5%) and cardiac groups (33.3%), with significant differences ($p < 0.001$; see Table 1 and full pairwise comparison in Supplementary Table S1).

Table 1. Characteristics of patients with acute myocardial infarction cardiogenic shock phenotypes.

| Variables | | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value |
|--------------------------|--------|---------------------------|-------------------------|-----------------------------|---------|
| Gender | Male | 115 (85.2%) | 78 (78.8) | 61 (81.3) | 0.439 |
| | Female | 20 (14.8%) | 21 (21.2) | 14 (18.7) | |
| Age (years) | | 57 (50–64) | 64 (58–69) | 62 (56–69) | <0.001 |
| Weight (kg) | | 76 (68–85) | 75 (65–85) | 75 (68–80) | 0.534 |
| Height (m) | | 1.68 (1.61–1.7) | 1.67 (1.6–1.71) | 1.68 (1.6–1.7) | 0.516 |
| BMI (kg/m ²) | | 27.49 (24.51–29.39) | 26.86 (24.2–29.05) | 26.64 (24.49–29.41) | 0.683 |
| BSA (m ²) | | 1.8 (1.7–1.9) | 1.8 (1.68–1.92) | 1.77 (1.67–1.9) | 0.129 |
| Smoking history (%) | | 88 (65.2) | 59 (59.6) | 42 (56) | 0.394 |
| Hypertension (%) | | 57 (42.2) | 59 (59.6) | 44 (58.7) | 0.012 |
| COPD (%) | | 2 (1.5) | 5 (5.1) | 2 (2.7) | 0.286 |
| Previous HF episodes (%) | | 9 (6.7) | 5 (5.1) | 8 (10.7) | 0.348 |
| Previous CKD (%) | | 0 | 12 (12.1) | 5 (6.7) | <0.001 |
| Diabetes mellitus (%) | | 58 (43) | 56 (56.6) | 35 (46.7) | 0.115 |
| Previous MI (%) | | 25 (18.5) | 13 (13.1) | 11 (14.7) | 0.51 |
| Previous PCI (%) | | 8 (5.9) | 8 (8.1) | 6 (8) | 0.772 |
| Previous CABG (%) | | 2 (1.5) | 1 (1) | 3 (4) | 0.494 |

Table 1. Cont.

| Variables | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value | |
|--|---------------------------|--------------------------|-----------------------------|---------|-----------|
| Type of AMI (%) | NSTEMI | 28 (20.7) | 20 (20.2) | 0.022 | |
| | STEMI | 107 (79.3) | 79 (79.8) | | 70 (93.3) |
| Out-of-hospital cardiac arrest (%) | 4 (3) | 3 (3) | 3 (4) | 0.92 | |
| Killip–Kimball (%) | I | 31 (23) | 10 (10.1) | <0.001 | |
| | II | 55 (40.7) | 21 (21.2) | | 13 (17.3) |
| | III | 33 (24.4) | 30 (30.3) | | 13 (17.3) |
| | IV | 16 (11.9) | 38 (38.4) | | 44 (58.7) |
| LVEF (%) | 35 (30–43) | 32 (26–40) | 30 (20–45) | 0.073 | |
| Heart rate (bpm) | 96 (85–110) | 97 (84–110) | 101 (81–117) | 0.552 | |
| SBP (mmHg) | 108 (97–119) | 106 (95–119) | 103 (89–115) | 0.143 | |
| DBP (mmHg) | 65 (56–74) | 60 (52–72) | 65 (54–75) | 0.25 | |
| Hemoglobin (g/dL) | 14.5 (12.6–16.3) | 14 (12.1–16) | 14.2 (12.8–16.3) | 0.756 | |
| WBC (cell/mm ³) | 12 (9.4–15.4) | 13.6 (10.5–17.5) | 14.7 (11.8–18.5) | <0.001 | |
| Neutrophils (%) | 79.35 (71.5–85.1) | 82.75 (78–86.6) | 82 (76.6–86) | 0.024 | |
| Lymphocytes (%) | 13.25 (8.6–17.1) | 10.5 (7.2–15) | 11 (7–16.5) | 0.024 | |
| Platelets (cell/mm ³) | 224 (179–287) | 241 (194–285) | 195 (144–274) | 0.005 | |
| PT (sec) | 13.5 (12.1–15) | 14 (12.4–16.1) | 13.9 (12–18) | 0.154 | |
| PTT (sec) | 33.6 (29.8–39) | 35.25 (30.1–45) | 34.2 (30.1–43) | 0.37 | |
| Glucose (mg/dL) | 153 (128–248) | 213 (130–324) | 217 (146–308) | 0.007 | |
| BUN (mg/dL) | 18 (13–24) | 30 (23–40.8) | 35.21 (24–50) | <0.001 | |
| Creatinine (mg/dL) | 1 (0.9–1.1) | 1.8 (1.5–2.5) | 2 (1.5–2.61) | <0.001 | |
| eGFR by CKD-EPI (mL/min/m ²) | 81.78 (69.59–95.14) | 39.18 (26.59–49.5) | 32.1 (24.38–47.84) | <0.001 | |
| Chloride (mEq/L) | 104 (101–107) | 104 (100–108) | 102 (98–105) | 0.04 | |
| Sodium (mEq/L) | 136 (133–138) | 136 (132–140) | 136 (133–139.1) | 0.859 | |
| Potassium (mEq/L) | 4.1 (3.8–4.4) | 4.6 (4.2–5.2) | 4.4 (4.09–5.2) | <0.001 | |
| Magnesium (mg/dL) | 2.28 (2–2.5) | 2.3 (2.04–2.5) | 2.1 (2–2.33) | 0.131 | |
| Albumin (g/dL) | 3.4 (2.99–3.88) | 3.27 (2.9–3.7) | 3.3 (2.9–3.6) | 0.159 | |
| AST (U/L) | 76.5 (41–249) | 83.35 (40–229) | 700 (325–992) | <0.001 | |
| ALT (U/L) | 61.5 (34.8–103.5) | 51.3 (36.2–84.5) | 450 (204.4–1257) | <0.001 | |
| LDH (U/L) | 635 (330–1248) | 545 (324–1244) | 1290 (715–2250) | <0.001 | |
| Hs-C-reactive protein (mg/L) | 63.25 (21.2–130.5) | 56.8 (20.2–153) | 102.3 (35.4–150.8) | 0.353 | |
| Maximum creatinine (mg/dL) | 1.1 (0.99–1.48) | 2.3 (1.7–3.19) | 2.94 (1.93–3.74) | <0.001 | |
| Maximum AST (U/L) | 129 (56.9–406) | 128 (54–424) | 832 (465–1951) | <0.001 | |
| Maximum ALT (U/L) | 68.75 (37.95–111.85) | 54.85 (36.4–84.7) | 468.3 (210–1257) | <0.001 | |
| Bilirubin (mg/dL) | 0.96 (0.66–1.61) | 0.99 (0.54–1.58) | 1.46 (0.96–2.37) | 0.006 | |
| Minimum PaO ₂ /FiO ₂ ratio | 247.62 (146–304.76) | 200 (120–300) | 152.8 (100–257) | 0.004 | |
| Lactate | 2.1 (1.45–3.3) | 2.95 (1.7–6) | 4.35 (2.8–6) | <0.001 | |
| Base excess | −5.19 (−8.21; −3.12) | −8.78 (−13.23; −5.51) | −10.66 (−14.87; −7.59) | <0.001 | |
| pH | 7.37 (7.32–7.42) | 7.29 (7.23–7.37) | 7.28 (7.22–7.35) | <0.001 | |
| Minimum 24 h MAP | 72 (65.33–78.33) | 67.67 (61.57–74) | 68 (60–72) | 0.003 | |
| Minimum 24 h SBP | 98 (90–104) | 96 (86–101) | 91 (81–102) | 0.01 | |
| Time of delay symptom to ER (hr:min) | 12:16 (5:05–60:39) | 16:21 (7:00–58:37) | 28:42 (11:50–47:00) | 0.253 | |

Table 1. *Cont.*

| Variables | | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value |
|--------------------------------|------|---------------------------|-------------------------|-----------------------------|---------|
| Primary reperfusion (<12 h, %) | PI | 27 (20.1) | 17 (17.2) | 5 (6.7) | 0.005 |
| | PCI | 47 (34.8) | 27 (27.3) | 16 (21.3) | |
| | NR | 61 (45.5) | 55 (55.6) | 54 (72) | |
| Angiography (%) | | 126 (93.3) | 78 (78.8) | 67 (89.3) | 0.003 |
| Total PCI (%) | | 103 (76.3) | 59 (59.6) | 53 (70.7) | 0.023 |
| Mechanical ventilation (%) | | 82 (60.7) | 72 (72.7) | 60 (80) | 0.01 |
| Hemodialysis (%) | | 6 (4.4) | 17 (17.2) | 21 (28) | <0.001 |
| Norepinephrine (%) | | 100 (74.1) | 82 (82.8) | 66 (88) | 0.039 |
| Vasopressin (%) | | 62 (45.9) | 56 (56.6) | 55 (73.3) | 0.001 |
| Dobutamine (%) | | 103 (76.3) | 83 (83.8) | 73 (97.3) | <0.001 |
| Levosimendan (%) | | 35 (25.9) | 27 (27.3) | 36 (48) | 0.002 |
| Number of vasoactive drugs (%) | None | 17 (12.6) | 4 (4) | 1 (1.3) | <0.001 |
| | 1 | 17 (12.6) | 15 (15.2) | 3 (4) | |
| | 2 | 39 (28.9) | 24 (24.2) | 13 (17.3) | |
| | 3 | 43 (31.9) | 39 (39.4) | 31 (41.3) | |
| | 4 | 19 (14.1) | 17 (17.2) | 27 (36) | |
| Mechanical support (%) | | 72 (53.3) | 57 (57.6) | 48 (64) | 0.325 |
| Acute kidney injury (%) | | 58 (43) | 82 (82.8) | 69 (92) | <0.001 |
| AKIN stage (%) | None | 77 (57) | 17 (17.2) | 6 (8) | <0.001 |
| | 1 | 32 (23.7) | 33 (33.3) | 24 (32) | |
| | 2 | 13 (9.6) | 18 (18.2) | 12 (16) | |
| | 3 | 13 (9.6) | 31 (31.3) | 33 (44) | |
| VT/VF (%) | | 44 (32.6) | 27 (27.3) | 30 (40) | 0.208 |
| Multi-organ failure (%) | | 56 (41.5) | 62 (62.6) | 60 (80) | <0.001 |
| Number of organ failures (%) | 0–1 | 79 (58.5) | 37 (37.4) | 15 (20) | <0.001 |
| | 2–3 | 47 (34.8) | 44 (44.4) | 35 (46.7) | |
| | 4–5 | 9 (6.7) | 18 (18.2) | 25 (33.3) | |
| MODS score | 0–4 | 66 (48.9) | 31 (31.3) | 10 (13.3) | <0.001 |
| | 5–10 | 49 (36.3) | 36 (36.4) | 26 (34.7) | |
| | ≥11 | 20 (14.8) | 32 (32.3) | 39 (52) | |
| SCAI score | C | 31 (23) | 10 (10.1) | 0 | <0.001 |
| | D | 76 (56.3) | 45 (45.5) | 31 (41.3) | |
| | E | 28 (20.7) | 44 (44.4) | 44 (58.7) | |
| Mortality (%) | | 45 (33.3) | 52 (52.5) | 53 (70.7) | <0.001 |

AKI: Acute Kidney Injury; ALT: Alanine Transaminase; AMI: Acute Myocardial Infarction; AST: Aspartate Transaminase; BMI: Body Mass Index; BSA: Body Surface Area; BUN: Blood Urea Nitrogen; CABG: Coronary Artery Bypass Grafting; CKD: Chronic Kidney Disease; COPD: Chronic Obstructive Pulmonary Disease; DBP: Diastolic Blood Pressure; eGFR: Estimated Glomerular Filtration Rate; HF: Heart Failure; Hs-CRP: High-sensitivity C-reactive Protein; LVEF: Left-Ventricular Ejection Fraction; LDH: Lactate Dehydrogenase; MAP: Mean Arterial Pressure; MI: Myocardial Infarction; MODS: Multiple Organ Dysfunction Syndrome; NSTEMI: Non-ST-Elevation Myocardial Infarction; NR: Non-primary Reperfusion; PCI: Percutaneous Coronary Intervention; PI: Pharmacoinvasive Strategy; PaO₂/FiO₂: Ratio of Arterial Oxygen Partial Pressure to Fraction of Inspired Oxygen; PT: Prothrombin Time; PTT: Partial Thromboplastin Time; SBP: Systolic Blood Pressure; SCAI: Society for Cardiovascular Angiography & Interventions; sec: seconds; STEMI: ST-Elevation Myocardial Infarction; VT/VF: Ventricular Tachycardia/Fibrillation; WBC: White Blood Cell Count.

4.1. Hemodynamic Variables and CS phenotypes

Heart rate did not show any significant differences in the three groups as a whole and at any time point ($F = 0.44$; $p = 0.644$), nor was any interaction seen in the within-subjects' effects.

However, SBP showed significant differences between subjects, where the effects were lower in the cardiometabolic and higher in the cardiac groups at all time points ($F = 3.78$; $p = 0.024$). In the point comparison, only at 24 h do we see a difference in the multiple comparison adjustment ($p = 0.008$), with lower SBP in the cardiometabolic compared with the cardiac group ($p = 0.007$) but not the cardiorenal group ($p = 0.067$). Significant differences in mean arterial pressure (MAP), similar to SBP, were seen between groups ($F = 3.52$; $p = 0.031$), but only at 24 h did we see differences in the time-point analysis. Considering DBP, no differences were observed in the between- or within-subjects effects, but only at 24 h did the cardiac group show a higher DBP ($p = 0.007$). In addition, a difference in comparison with the cardiometabolic group was seen in the multiple comparisons ($p = 0.01$).

Perfusion pressure (MAP-RAP) showed significant group differences and higher F values than its derived components ($F = 8.17$; $p < 0.001$), with lower values in the cardiorenal and cardiometabolic groups in the multiple comparisons. However, all time points showed a difference after 6 h. In the pairwise comparison, we saw differences between the cardiac vs. the cardiometabolic group and at 24 h vs. the cardiorenal group.

RAP showed significant differences among the groups ($F = 6.64$; $p = 0.001$), with higher values in the cardiometabolic and cardiorenal groups for all time points. Significant differences were seen at all time points in the point data analysis. When corrected by multiple comparisons at 12 and 24 h, differences were seen between the cardiac and cardiorenal groups and at all time points for the cardiometabolic group. PCWP showed significant differences between groups ($F = 4.71$; $p = 0.01$), with the lowest values in the cardiac group. This was only significant in the time-point analysis at the 24 h mark.

Considering pulmonary artery systolic pressure (PASP), no difference was initially seen in the analyses of variance (ANOVAs) between subjects, but the values decreased over time, and lower values were seen in the cardiac group at the 24 h time-point analysis. However, the significance was not retained in the pairwise analysis. PA diastolic pressure (PADP) had differences in the group \cdot time interaction, with lower values in the cardiac group and a tendency to decrease compared with the increasing levels in the cardiorenal and cardiometabolic profiles. The point analysis showed differences only at 24 h, with the lowest values in the cardiac group, which, in the pairwise comparisons, only significantly differed from the cardiometabolic group. Considering the mean PA pressure (mPAP), no differences between subjects were seen in the ANOVA results. In the time-point analysis, differences were seen at 6 h, with the highest values in the cardiometabolic profile. At 24 h, the cardiac group had the lowest values, although no differences were seen in the pairwise analysis. Considering the pulmonary artery pressure index (PAPi), no differences were seen between the groups in ANOVA or time-point analyses.

Cardiac output, index, power, power index, and $CPI_{(RAP)}$ showed similar behavior when using ANOVA, and differences arose in the between-group comparison ($p < 0.05$), with the lowest cardiac output and derived indexes in the cardiometabolic group and the highest levels in the cardiac group. In the time-point analysis, all times showed differences, with a pairwise comparison showing lower levels in cardiometabolic patients vs. cardiac patients; only at 6 h did the cardiorenal group show higher levels of cardiac output, index, power, and $CPI_{(RAP)}$ than the cardiometabolic group. (Table 2, Figures 1 and 2, and Supplementary Tables S2 and S3)

Table 2. Hemodynamic parameters in AMI-CS phenotypes.

| Hemodynamic Parameter | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value |
|--|--------------------------|---------------------------|---------------------------|---------|
| Time 0 h | | | | |
| Heart rate (bpm) | 96 (85–110) | 97 (84–110) | 101 (81–117) | 0.552 |
| SBP (mmHg) | 108 (97–119) | 106 (95–119) | 103 (89–115) | 0.143 |
| DBP (mmHg) | 65 (56–74) | 60 (52–72) | 65 (54–75) | 0.25 |
| MAP (mmHg) | 80 (70–88) | 76.67 (66.3–86.33) | 76.33 (68–88) | 0.247 |
| RAP (mmHg) | 12 (8–17) | 14 (10–18) | 15 (11–19) | 0.02 |
| PCWP (mmHg) | 18 (14–22) | 19 (16–24) | 19 (14–25) | 0.068 |
| PASP (mmHg) | 36 (29–43) | 37 (30–46) | 37 (28–45) | 0.71 |
| PADP (mmHg) | 21 (18–26) | 22 (18–28) | 21 (16–29) | 0.611 |
| mPAP (mmHg) | 26 (21–31) | 29 (22–34) | 27 (21–35) | 0.199 |
| Cardiac output (L/min) | 4.3 (3.6–5.6) | 3.9 (3.1–5) | 3.5 (2.8–4.5) | <0.001 |
| Cardiac index (L/min/m ²) | 2.41 (1.93–3.02) | 2.21 (1.82–2.81) | 1.95 (1.56–2.67) | 0.002 |
| Cardiac power (W) | 0.78 (0.59–0.99) | 0.66 (0.48–0.98) | 0.57 (0.43–0.83) | <0.001 |
| Cardiac power index (W/m ²) | 0.44 (0.32–0.51) | 0.37 (0.29–0.54) | 0.34 (0.25–0.47) | 0.002 |
| CPI _(RAP) (W) | 0.38 (0.26–0.44) | 0.3 (0.21–0.45) | 0.27 (0.19–0.39) | 0.001 |
| Perfusion pressure (mmHg) | 67.67 (57.33–75.33) | 61 (49–72.67) | 62 (50.33–72.33) | 0.035 |
| PAPi | 1.13 (0.67–1.77) | 0.93 (0.61–1.5) | 0.89 (0.65–1.48) | 0.114 |
| Stroke volume (mL) | 46.44 (34.67–57.74) | 42.42 (32.95–55.95) | 35.9 (28.1–46.43) | 0.001 |
| Stroke volume index (mL/m ²) | 25.32 (18.72–32.58) | 23.33 (18.75–30.12) | 21.49 (15.76–27.31) | 0.003 |
| SVR (dynes/sec/cm ⁻⁵) | 1224.69 (907.26–1476.92) | 1221.18 (935.38–1529.95) | 1363.81 (1059.36–1752.38) | 0.078 |
| PVR (dynes/sec/cm ⁻⁵) | 160 (86.25–247.42) | 163.64 (66.67–293.88) | 185.71 (107.46–311.69) | 0.243 |
| SVRi (dynes/sec·m ² /cm ⁻⁵) | 2163.09 (1699.2–2784.83) | 2266.67 (1666.42–2741.78) | 2372.83 (1792–2979.24) | 0.187 |
| PVRi (dynes/sec·m ² /cm ⁻⁵) | 274.07 (166.39–421.05) | 302.22 (115.2–495.16) | 335.19 (185.14–529.87) | 0.35 |
| LVSWi (gm-m/m ² /beat) | 22.24 (14.49–27.77) | 18.74 (11.74–28.05) | 15.2 (10.65–22.09) | 0.001 |
| RVSWi (gm-m/m ² /beat) | 4.41 (2.29–7.53) | 4.15 (2.04–7.32) | 3.16 (1.6–5.61) | 0.048 |
| Time 6 h | | | | |
| Heart rate (bpm) | 98 (90–107) | 98.25 (86.22–112) | 100 (81–115) | 0.971 |
| SBP (mmHg) | 109 (98–118) | 106 (96–121) | 104 (93–114) | 0.117 |
| DBP (mmHg) | 66 (57–73) | 62 (52.84–71) | 62 (54–72) | 0.175 |
| MAP (mmHg) | 79.67 (73.67–86) | 77.33 (69.33–84.67) | 77.67 (68.33–84) | 0.134 |
| RAP (mmHg) | 12 (9–16) | 14 (11–17) | 16 (12–19) | <0.001 |
| PCWP (mmHg) | 16 (12–20) | 18 (13–21) | 18 (15–21) | 0.089 |
| PASP (mmHg) | 34 (29–39) | 35 (30–44) | 36 (29–44) | 0.132 |
| PADP (mmHg) | 20 (16–24) | 21 (17–26) | 22 (18–28) | 0.074 |
| mPAP (mmHg) | 25 (20–28) | 26 (22–31) | 27 (22–34) | 0.038 |
| Cardiac output (L/min) | 4.7 (4–5.9) | 4.51 (3.62–5.6) | 3.8 (3.18–4.6) | <0.001 |

Table 2. Cont.

| Hemodynamic Parameter | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value |
|--|------------------------------|------------------------------|-----------------------------|---------|
| Cardiac index (L/min/m ²) | 2.65 (2.16–3.21) | 2.56 (2.05–3.05) | 2.13 (1.78–2.66) | <0.001 |
| Cardiac power (W) | 0.84 (0.69–1.07) | 0.78 (0.6–0.99) | 0.68 (0.53–0.84) | <0.001 |
| Cardiac power index (W/m ²) | 0.46 (0.39–0.58) | 0.45 (0.34–0.56) | 0.39 (0.3–0.49) | <0.001 |
| CPI _(RAP) (W) | 0.39 (0.32–0.48) | 0.37 (0.27–0.48) | 0.3 (0.23–0.41) | <0.001 |
| Perfusion pressure (mmHg) | 67.33 (58.67–74.33) | 63 (54.67–71) | 61 (51.33–71.33) | 0.003 |
| PAPi | 1.13 (0.63–1.86) | 1.15 (0.69–1.5) | 0.92 (0.48–1.53) | 0.09 |
| Stroke volume (mL) | 48.05 (39.26–61.96) | 45.87 (35.63–58.97) | 38.67 (30.94–50.62) | <0.001 |
| Stroke volume index (mL/m ²) | 26.49 (22.07–34.97) | 24.59 (19.08–33.82) | 21.97 (18.46–28.22) | 0.001 |
| SVR (dynes/sec/cm ⁻⁵) | 1130.98 (869.57–1377.78) | 1160.78 (897.35–1412.14) | 1276.19 (1000–1630.48) | 0.011 |
| PVR (dynes/sec/cm ⁻⁵) | 138.27 (86.49–196.49) | 150.94 (88.08–266.67) | 172.97 (106.67–316.28) | 0.017 |
| SVRi (dynes/sec·m ² /cm ⁻⁵) | 2008.33 (1613.54–2431.73) | 2059.71 (1596.27–2470.83) | 2284.8 (1739.15–2763.24) | 0.041 |
| PVRi (dynes/sec·m ² /cm ⁻⁵) | 251.45 (160–328.21) | 271.7 (162.16–427.33) | 310.4 (182.86–560) | 0.028 |
| LVSWi (gm·m/m ² /beat) | 22.6 (17.54–30.54) | 20.5 (14.93–29.11) | 16.63 (12.51–25.56) | 0.001 |
| RVSWi (gm·m/m ² /beat) | 4.18 (2.49–6.15) | 4.23 (2.15–6.81) | 3.47 (1.37–5.89) | 0.149 |
| Time 12 h | | | | |
| Heart rate (bpm) | 96 (87–106) | 99 (88–112) | 98 (86–114) | 0.543 |
| SBP (mmHg) | 108 (100–115) | 105 (97–115) | 100 (94–114) | 0.155 |
| DBP (mmHg) | 66 (57–73) | 62 (56–70) | 62 (55–74) | 0.147 |
| MAP (mmHg) | 80 (73–85.67) | 76.67 (70.67–85.33) | 74.96 (68.67–86.67) | 0.118 |
| RAP (mmHg) | 12 (9–16) | 14 (11–17) | 14 (11–18) | 0.006 |
| PCWP (mmHg) | 17 (13–20) | 18 (14–21) | 17 (14–22) | 0.278 |
| PASP (mmHg) | 36 (28–41) | 37 (31–48) | 39 (29–48) | 0.117 |
| PADP (mmHg) | 20 (17–24) | 22 (18–26) | 22 (17–30) | 0.088 |
| mPAP (mmHg) | 25 (20–30) | 27 (22–32) | 27 (21–35) | 0.092 |
| Cardiac output (L/min) | 5 (4.1–6.2) | 4.6 (3.81–5.6) | 4.25 (3.5–5.2) | 0.002 |
| Cardiac index (L/min/m ²) | 2.82 (2.25–3.24) | 2.53 (2.24–3.07) | 2.37 (1.95–2.93) | 0.003 |
| Cardiac power (W) | 0.86 (0.71–1.09) | 0.82 (0.63–0.99) | 0.73 (0.56–0.94) | 0.003 |
| Cardiac power index (W/m ²) | 0.49 (0.39–0.6) | 0.46 (0.38–0.56) | 0.4 (0.32–0.53) | 0.007 |
| CPI _(RAP) (W) | 0.41 (0.31–0.5) | 0.38 (0.31–0.46) | 0.32 (0.25–0.44) | 0.002 |
| Perfusion pressure (mmHg) | 67.33 (59–73.67) | 62.33 (54.67–72.33) | 60.51 (52.67–70.33) | 0.009 |
| PAPi | 1.16 (0.76–1.7) | 1.17 (0.8–1.89) | 1 (0.67–1.86) | 0.517 |
| Stroke volume (mL) | 50.57 (40.2–64.58) | 47.22 (36.39–58.54) | 44.92 (36.07–52.17) | 0.003 |
| Stroke volume index (mL/m ²) | 29.55 (23.68–34.54) | 26.54 (20.34–34.2) | 24.8 (20.27–30.69) | 0.008 |
| SVR (dynes/sec/cm ⁻⁵) | 1021.14 (885.19–1341.14) | 1078.79 (880–1377.39) | 1139.39 (915.94–1474.51) | 0.319 |
| PVR (dynes/sec/cm ⁻⁵) | 136.36 (80–202.81) | 150.94 (84.75–233.11) | 183.61 (105.26–266.67) | 0.05 |

Table 2. Cont.

| Hemodynamic Parameter | Cardiac-Only (n = 135) | Cardiorenal (n = 99) | Cardiometabolic (n = 75) | p-Value |
|--|------------------------------|------------------------------|------------------------------|---------|
| SVRi (dynes/sec·m ² /cm ⁻⁵) | 1860.55 (1629.4–2311.95) | 1993.85 (1543.11–2426.67) | 1928.91 (1665.23–2580.39) | 0.521 |
| PVRi (dynes/sec·m ² /cm ⁻⁵) | 247.27 (152–379.23) | 273.68 (147.69–417.28) | 317.29 (184.32–466.67) | 0.101 |
| LVSWi (gm·m/m ² /beat) | 24.37 (17.93–31.18) | 22.9 (15.24–27.7) | 19.15 (15.28–26.19) | 0.003 |
| RVSWi (gm·m/m ² /beat) | 4.85 (3.2–6.75) | 4.33 (2.32–7.6) | 4.02 (2.04–7.14) | 0.381 |
| Time 24 h | | | | |
| Heart rate (bpm) | 96 (86–109) | 97 (87–111) | 99 (80–115) | 0.867 |
| SBP (mmHg) | 107 (100–116) | 105 (97–118) | 100 (91–109) | 0.008 |
| DBP (mmHg) | 65 (58–71) | 61 (55–69) | 59 (53–69) | 0.007 |
| MAP (mmHg) | 80.37 (72.6–85.91) | 76.07 (69.81–85.33) | 71.67 (67.33–81.33) | 0.002 |
| RAP (mmHg) | 12 (10–16) | 15 (12–17) | 14 (11–18) | 0.006 |
| PCWP (mmHg) | 16 (13–20) | 19 (15–20) | 19 (16–24) | 0.001 |
| PASP (mmHg) | 35 (29–42) | 38 (31–50) | 40 (30–50) | 0.03 |
| PADP (mmHg) | 20 (16–25) | 22 (18–26) | 23 (18–30) | 0.001 |
| mPAP (mmHg) | 25 (21–30) | 28 (23–33) | 27 (23–34) | 0.025 |
| Cardiac output (L/min) | 5.09 (4.2–6.3) | 4.8 (3.89–5.9) | 4.4 (3.65–5.5) | 0.021 |
| Cardiac index (L/min/m ²) | 2.83 (2.29–3.33) | 2.6 (2.27–3.18) | 2.5 (2.05–3.14) | 0.045 |
| Cardiac power (W) | 0.89 (0.72–1.15) | 0.82 (0.67–1.04) | 0.76 (0.58–0.97) | 0.001 |
| Cardiac power index (W/m ²) | 0.5 (0.4–0.64) | 0.44 (0.38–0.57) | 0.43 (0.31–0.53) | 0.003 |
| CPI _(RAP) (W) | 0.41 (0.33–0.52) | 0.36 (0.3–0.46) | 0.33 (0.25–0.43) | 0.001 |
| Perfusion pressure (mmHg) | 67.33 (57.34–72.67) | 60.95 (54.33–69.67) | 57 (52–67.67) | <0.001 |
| PAPi | 1.25 (0.85–1.79) | 1.2 (0.73–1.81) | 1.05 (0.64–1.62) | 0.129 |
| Stroke volume (mL) | 53.68 (41.18–65.79) | 49.47 (40.43–61.06) | 45.45 (37.63–57.27) | 0.047 |
| Stroke volume index (mL/m ²) | 29.35 (23.65–36.11) | 27.82 (23.09–35.28) | 25.81 (21.37–32.58) | 0.081 |
| SVR (dynes/sec/cm ⁻⁵) | 1041.86 (813.05–1365.99) | 1056.74 (834.57–1360) | 1066.67 (871.79–1310.64) | 0.825 |
| PVR (dynes/sec/cm ⁻⁵) | 136.17 (84.21–209.84) | 148.15 (92.41–216.75) | 163.64 (103.63–215.38) | 0.246 |
| SVRi (dynes/sec·m ² /cm ⁻⁵) | 1875.17 (1541.33–2380.26) | 1946.06 (1491.67–2317.73) | 1942.86 (1525.33–2261.35) | 0.995 |
| PVRi (dynes/sec·m ² /cm ⁻⁵) | 253.33 (150.77–374) | 267.52 (172.73–372.13) | 278.98 (179.73–409.23) | 0.42 |
| LVSWi (gm·m/m ² /beat) | 25.04 (18.92–31.43) | 21.94 (16.85–28.51) | 19.54 (14.53–25.61) | 0.002 |
| RVSWi (gm·m/m ² /beat) | 4.95 (3.02–6.88) | 4.8 (2.92–7.75) | 4.34 (2.73–6.54) | 0.63 |

Bpm: Beats per minute; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; RAP: Right atrial pressure; PCWP: Pulmonary capillary wedge pressure; PASP: Pulmonary artery systolic pressure; PADP: Pulmonary artery diastolic pressure; mPAP: Mean pulmonary artery pressure; CPI: Cardiac power index; CPI_(RAP): Cardiac power index normalized by right atrial pressure; PAPi: Pulmonary artery pulsatility index; sec: seconds; SV: Stroke volume; SVi: Stroke volume index; SVR: Systemic vascular resistance; PVR: Pulmonary vascular resistance; SVRi: Systemic vascular resistance index; PVRi: Pulmonary vascular resistance index; LVSWi: Left-ventricular stroke work index; and RVSWi: Right-ventricular stroke work index.

Stroke volume (SV) and stroke volume index (SVi) data show differences in both SV and SVI ($F = 6.91$, $p = 0.001$ and $F = 4.63$, $p = 0.01$, respectively). In the time-point analysis, the cardiometabolic group had far worse hemodynamic parameters at baseline in

the pairwise comparison with the cardiac and cardiorenal groups. However, differences were only seen in contrast with the cardiac group at 6 and 12 h.

Systemic vascular resistance (SVR) but not the SVR index (SVRi) had significant group differences in the ANOVA results ($F = 3.1, p = 0.046$). These differences were further enhanced in the time-point analysis, and only at 6 h did SVR and SVRi show some higher differences in the cardiometabolic group. However, neither pulmonary vascular resistance (PVR) nor PVR index (PVRi) did not achieve statistical differences among the groups. In the time-point analysis, only at 6 and 12 h did PVR have significant differences, with the lowest values in the cardiac group, and PVRi only achieved this at 6 h.

The left-ventricular stroke work index (LVSWi) showed differences ($F = 7.18, p = 0.001$), with the lowest values seen in the cardiometabolic group along the four-time points compared with the cardiac group. However, the right-ventricular stroke work index (RVSWi) did not show these differences. Only at the baseline were significant differences between the cardiometabolic and cardiac groups.

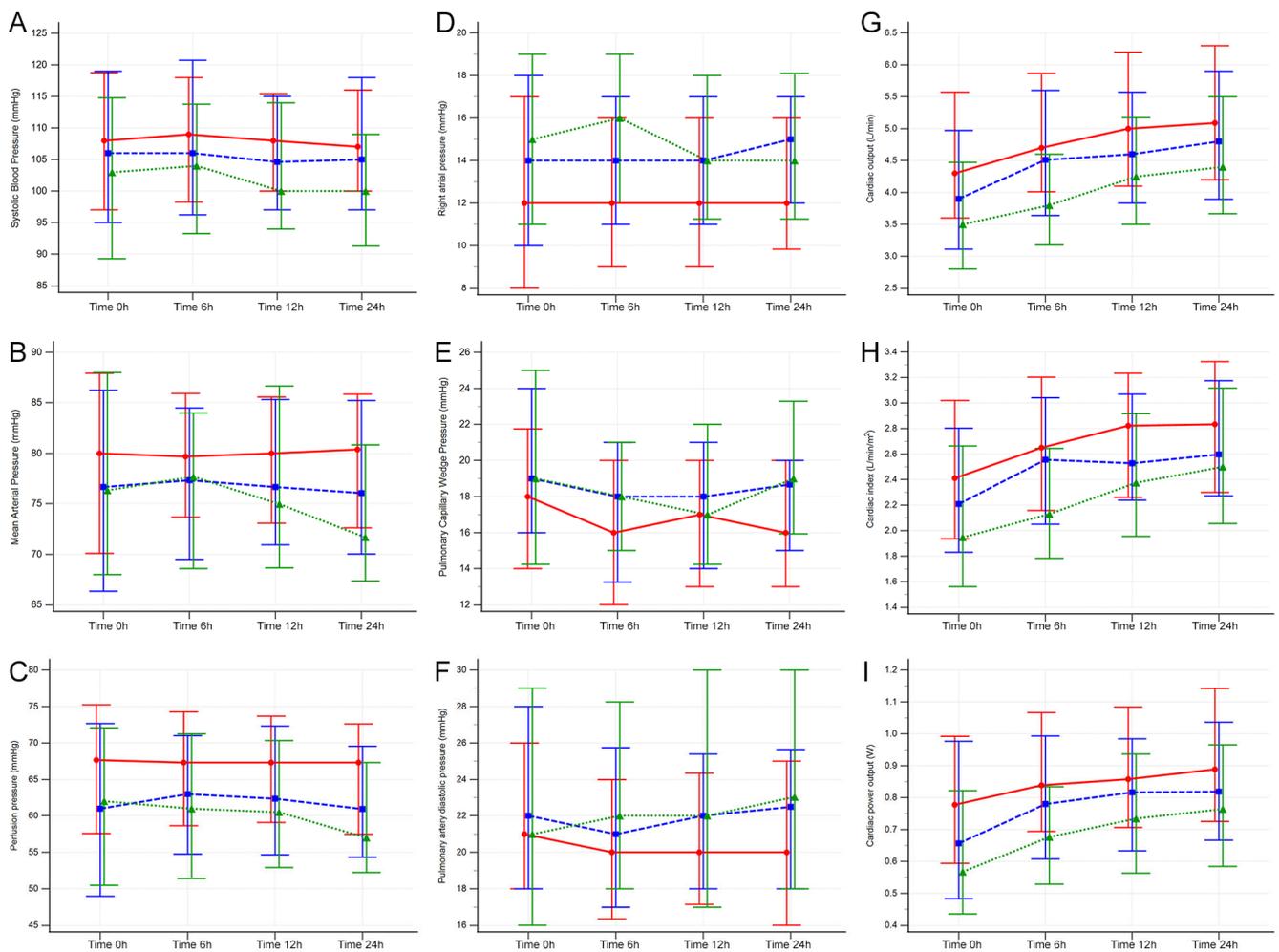


Figure 1. ANOVA repeated measures in CS-AMI phenotypes. Red—cardiac-only; blue—cardiorenal; and green—cardiometabolic; with median and interquartile ranges represented for systolic blood pressure (A), mean blood pressure (B), perfusion pressure (C), right atrial pressure (D), pulmonary capillary wedge pressure (E), pulmonary artery diastolic pressure (F), cardiac output (G), cardiac index (H), and cardiac power output (I). (Key in Figure 2).

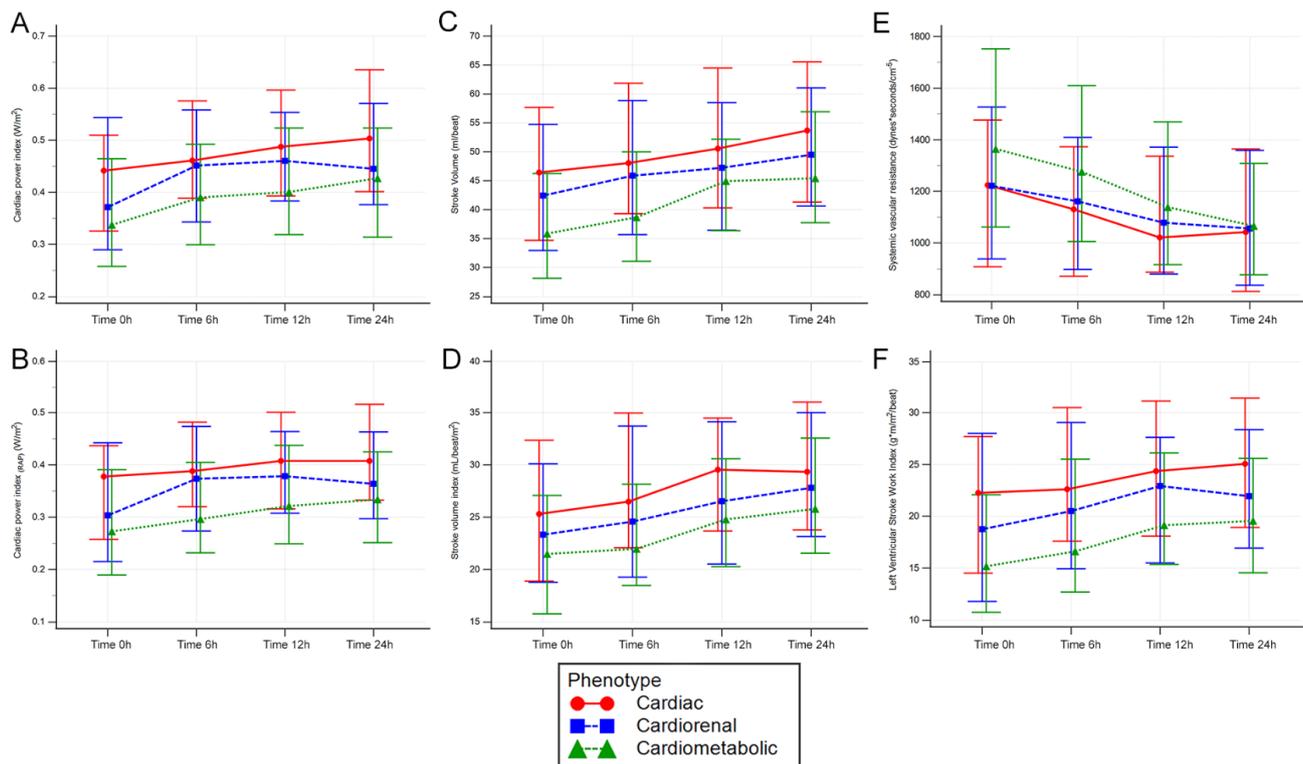


Figure 2. ANOVA repeated measures in CS-AMI phenotypes. Red—cardiac-only; blue—cardiorenal; and green—cardiometabolic; with median and interquartile ranges represented for cardiac power index (A), cardiac power index_(RAP) (B), stroke volume (C), stroke volume index (D), systemic vascular resistance (E), and left ventricular stroke work index (F). The key is shown at the bottom.

4.2. Hemodynamic Variables and Multi-Organ Failure, AKI, and Ventricular Arrhythmias

Multi-organ failure: Regarding $CPI_{(RAP)}$, lower values with statistical significance were seen in the MOF group. In the time-point analysis at baseline, 6, 12, and 24 h, lower perfusion pressure was seen in MOF. LVSWi had differences more marked in this group, with all these hemodynamic parameters significantly different at all time points (Figure S1A–C).

AKI: $CPI_{(RAP)}$ had significant differences overall lower in patients with AKI at all time points. SBP, MAP, and perfusion pressure were significant in the ANOVA, with lower values in patients with AKI. PCWP had substantial differences ($F = 4.42$, $p = 0.036$) with higher values in AKI, which was seen at 6 and 24 h in the time-point analysis. LVSWi had differences with lower values in AKI, but in the time-point analysis, this was seen from 6 to 24 h (Figure S1D–F).

Ventricular tachycardia or fibrillation: Low $CPI_{(RAP)}$, perfusion pressure, and LVSWi were seen in the ventricular tachycardia/fibrillation (VT/VF) in the first 24 h of active hemodynamic monitoring (Figure S1G–I). (Table 3, for Detailed Description, See the Supplementary Text, Table S3, Figure S1).

4.3. Survival Analysis

Group differences were significant in the Cox and log regression tests (Cox = 34.85, log-rank = 35.62; both $p < 0.001$). Considering the RMST, the cardiac group had more survival days than the cardiorenal and cardiometabolic groups at 6.04 (2.93–9.15; $p < 0.001$) and 10.63 (7.59–13.57; $p < 0.001$), respectively. When these last two groups were compared, the cardiorenal group had an advantage of 4.59 days (1.08–8.1; $p = 0.01$). The Cox regression showed an HR = 2.1 (1.4–3.14; $p < 0.001$) in the cardiorenal phenotype and 3.28 (2.19–4.92) in the cardiometabolic phenotype compared with the cardiac phenotype, with an AUC of 0.661 (0.606–0.714) for prediction power (Figure 3A,E).

Table 3. Hemodynamics parameters in AMI-CS complications.

| Hemodynamic Parameter | No MOF (n = 131) | MOF (n = 178) | p-Value | No AKI (n = 100) | AKI (n = 209) | p-Value | No VT/VF (n = 208) | VT/VF (n = 101) | p-Value |
|--|---------------------------|---------------------------|---------|---------------------------|------------------------|---------|--------------------------|---------------------------|---------|
| Time 0 h | | | | | | | | | |
| Heart rate (bpm) | 93 (84–109) | 99 (84–113) | 0.088 | 99 (86–113) | 97 (82–110) | 0.278 | 97 (82–110) | 98 (88–113) | 0.173 |
| SBP (mmHg) | 109 (99–124) | 102 (90–115) | 0.001 | 108 (96–121) | 104 (93–116) | 0.16 | 108 (95–119) | 102 (90–115) | 0.093 |
| DBP (mmHg) | 66 (57–73) | 61 (52–74) | 0.108 | 66 (56–74) | 62 (53–74) | 0.228 | 64 (55–75) | 60 (50–71) | 0.109 |
| MAP (mmHg) | 80 (71.33–88) | 75.67 (65.67–86) | 0.005 | 78.83 (70.33–88.17) | 76.67 (68–86.67) | 0.193 | 78.67 (70–88.17) | 76.67 (66.67–84.33) | 0.083 |
| RAP (mmHg) | 13 (9–17) | 15 (10–18) | 0.093 | 14 (10–18) | 14 (10–18) | 0.788 | 13 (10–18) | 15 (10–18) | 0.764 |
| PCWP (mmHg) | 17 (13–22) | 19 (16–23) | 0.035 | 18 (13–23) | 19 (15–23) | 0.082 | 18 (14–22) | 19 (15–24) | 0.071 |
| PASP (mmHg) | 36 (30–45) | 37 (29–45) | 0.477 | 36 (29–44) | 37 (30–45) | 0.611 | 36 (29–44) | 38 (30–46) | 0.532 |
| PADP (mmHg) | 21 (17–28) | 22 (18–27) | 0.966 | 20 (17–28) | 22 (18–28) | 0.593 | 21 (17–27) | 23 (18–29) | 0.433 |
| mPAP (mmHg) | 26.1 (21–34) | 27 (22–33) | 0.963 | 25.5 (21–32.5) | 27 (22–34) | 0.248 | 27 (21–33) | 28 (22–35) | 0.261 |
| Cardiac output (L/min) | 4.3 (3.54–5.6) | 3.83 (3–4.8) | 0.001 | 4.35 (3.5–5.55) | 3.9 (3.1–5) | 0.024 | 4.2 (3.28–5.45) | 3.81 (3–4.48) | 0.012 |
| Cardiac index (L/min/m ²) | 2.47 (1.94–3.11) | 2.15 (1.69–2.72) | 0.001 | 2.49 (1.93–3.11) | 2.21 (1.78–2.76) | 0.02 | 2.4 (1.86–3.11) | 2.14 (1.73–2.52) | 0.004 |
| Cardiac power (W) | 0.79 (0.62–0.99) | 0.61 (0.47–0.9) | <0.001 | 0.79 (0.54–1) | 0.66 (0.48–0.9) | 0.025 | 0.73 (0.52–1) | 0.64 (0.48–0.84) | 0.003 |
| Cardiac power index (W/m ²) | 0.45 (0.34–0.53) | 0.35 (0.27–0.49) | <0.001 | 0.45 (0.31–0.53) | 0.38 (0.28–0.49) | 0.021 | 0.43 (0.3–0.53) | 0.36 (0.27–0.45) | 0.001 |
| CPI _(RAP) (W) | 0.38 (0.27–0.45) | 0.28 (0.21–0.41) | <0.001 | 0.38 (0.23–0.44) | 0.3 (0.22–0.41) | 0.049 | 0.36 (0.23–0.46) | 0.27 (0.21–0.38) | 0.001 |
| Perfusion pressure (mmHg) | 68 (58–75.67) | 62 (50–72.33) | 0.002 | 65 (53.83–74) | 64.33 (52.67–73.67) | 0.37 | 65.33 (53.33–75.33) | 64.33 (51–71.33) | 0.17 |
| PAPi | 1.08 (0.67–1.75) | 0.94 (0.63–1.58) | 0.109 | 1 (0.64–1.74) | 1 (0.65–1.6) | 0.925 | 1 (0.65–1.7) | 1 (0.67–1.5) | 0.854 |
| Stroke volume (mL) | 46.43 (36.82–58.1) | 38 (29.19–51.22) | 0.001 | 44.81 (33.14–56.41) | 41.12 (31.06–54.62) | 0.255 | 45.08 (32.95–57.51) | 37.47 (29.39–47.63) | 0.002 |
| Stroke volume index (mL/m ²) | 25.36 (20.57–32.77) | 22.44 (16.77–28.79) | <0.001 | 24.41 (18.18–30.67) | 23.21 (17.26–30.13) | 0.293 | 24.71 (18.74–31.7) | 21.03 (16.33–27.49) | 0.001 |
| SVR (dynes/sec/cm ⁻⁵) | 1224.24 (904.76–1575.38) | 1276.61 (1026.67–1535.63) | 0.413 | 1205.86 (900.25–1476.92) | 1300 (1019.05–1574.6) | 0.08 | 1249.95 (933.46–1519.69) | 1236.3 (1052.99–1608.89) | 0.297 |
| PVR (dynes/sec/cm ⁻⁵) | 163.64 (88.89–266.67) | 167.45 (102.86–260.16) | 0.816 | 166.67 (78.13–254.83) | 166.67 (102.86–266.67) | 0.757 | 162.99 (88.96–253.66) | 175 (96–293.88) | 0.213 |
| SVR _i (dynes/sec-m ² /cm ⁻⁵) | 2215.38 (1662.22–2818.33) | 2260.34 (1813.33–2845.33) | 0.404 | 2106.44 (1646.41–2602.21) | 2278.6 (1792–2871.11) | 0.058 | 2224.9 (1673.51–2801.78) | 2270.12 (1851.71–2948.41) | 0.207 |
| PVR _i (dynes/sec-m ² /cm ⁻⁵) | 294.85 (160–493.71) | 304.79 (180.4–453.33) | 0.903 | 304.79 (159.22–441.35) | 298.54 (178.18–493.71) | 0.793 | 300.38 (175.11–454.56) | 310.48 (170.67–528.81) | 0.214 |
| LVSWi (gm-m/m ² /beat) | 22.91 (15.47–28.38) | 15.84 (11.45–24.53) | <0.001 | 21.11 (13.38–28.28) | 17.8 (12.6–26.18) | 0.117 | 21.47 (13.86–28.22) | 14.61 (11.21–23.85) | <0.001 |
| RVSWi (gm-m/m ² /beat) | 4.52 (2.01–7.72) | 3.69 (2.15–6.01) | 0.026 | 3.92 (1.72–7.23) | 4.11 (2.29–6.91) | 0.762 | 4.28 (2.03–7.23) | 3.83 (2.29–6.88) | 0.742 |

Table 3. *Cont.*

| Hemodynamic Parameter | No MOF (n = 131) | MOF (n = 178) | p-Value | No AKI (n = 100) | AKI (n = 209) | p-Value | No VT/VF (n = 208) | VT/VF (n = 101) | p-Value |
|--|--------------------------|--------------------------|---------|--------------------------|---------------------------|---------|---------------------------|---------------------------|---------|
| Time 6 h | | | | | | | | | |
| Heart rate (bpm) | 98 (88–110) | 98.85 (88–111) | 0.817 | 100 (90.9–111.5) | 98 (86–110) | 0.099 | 98 (88–110) | 99 (88–110) | 0.581 |
| SBP (mmHg) | 109 (100–120.73) | 105 (95–116) | 0.012 | 108.96 (99.5–120.37) | 105 (95–117) | 0.075 | 107.49 (99–119.91) | 104 (95–117) | 0.079 |
| DBP (mmHg) | 66 (57–73) | 61 (54–71) | 0.058 | 66 (56.77–71) | 62 (55–71) | 0.342 | 65.5 (56.77–73.5) | 60 (53–70) | 0.018 |
| MAP (mmHg) | 80 (73.67–86.67) | 77.17 (69.33–84) | 0.007 | 80.5 (71.81–86.46) | 77.67 (70–84.33) | 0.081 | 79.33 (71.15–85.83) | 76 (69.33–84) | 0.014 |
| RAP (mmHg) | 13 (10–17) | 14 (10–18) | 0.167 | 13 (10–16) | 14 (10–18) | 0.026 | 14 (10–18) | 14 (10–17) | 0.731 |
| PCWP (mmHg) | 17 (12–22) | 18 (14–20) | 0.135 | 16 (12–20) | 18 (14–21) | 0.007 | 17 (13–21) | 17 (15–21) | 0.618 |
| PASP (mmHg) | 34 (28–42) | 35 (30–42) | 0.562 | 33 (28–40) | 36 (30–43) | 0.012 | 35 (29–42) | 35 (30–42) | 0.707 |
| PADP (mmHg) | 20 (16–24) | 21 (17–26) | 0.08 | 20 (16–24) | 21 (17–26) | 0.033 | 20 (17–25) | 21 (17–25) | 0.233 |
| mPAP (mmHg) | 25 (21–30) | 26 (22–30) | 0.386 | 24 (20–28) | 26 (22–31) | 0.004 | 25 (21–30) | 36 (22–31) | 0.117 |
| Cardiac output (L/min) | 4.7 (3.91–5.77) | 4.14 (3.6–5.2) | 0.002 | 4.8 (3.89–5.9) | 4.24 (3.6–5.3) | 0.005 | 4.56 (3.7–5.7) | 4.1 (3.6–5.1) | 0.063 |
| Cardiac index (L/min/m ²) | 2.71 (2.28–3.15) | 2.34 (1.96–2.91) | 0.001 | 2.71 (2.2–3.26) | 2.4 (2.03–2.94) | 0.004 | 2.58 (2.07–3.17) | 2.37 (1.96–2.76) | 0.023 |
| Cardiac power (W) | 0.84 (0.68–1.06) | 0.74 (0.56–0.93) | 0.001 | 0.85 (0.69–1.1) | 0.76 (0.59–0.93) | 0.003 | 0.82 (0.64–1.05) | 0.73 (0.59–0.9) | 0.01 |
| Cardiac power index (W/m ²) | 0.48 (0.39–0.58) | 0.4 (0.32–0.53) | <0.001 | 0.5 (0.37–0.59) | 0.41 (0.33–0.53) | 0.003 | 0.46 (0.36–0.58) | 0.4 (0.32–0.5) | 0.003 |
| CPI _(RAP) (W) | 0.4 (0.32–0.49) | 0.33 (0.26–0.44) | <0.001 | 0.41 (0.31–0.52) | 0.35 (0.27–0.44) | 0.001 | 0.39 (0.28–0.49) | 0.33 (0.26–0.41) | 0.001 |
| Perfusion pressure (mmHg) | 67 (58.33–75.67) | 61.88 (55.33–71) | 0.002 | 67.65 (58.17–75.33) | 62 (55.33–72) | 0.009 | 66.5 (57–74) | 61.33 (54–69.67) | 0.007 |
| PAPi | 1.18 (0.6–1.91) | 1.07 (0.63–1.41) | 0.114 | 1.08 (0.62–1.65) | 1.12 (0.63–1.6) | 0.846 | 1.11 (0.64–1.72) | 1.1 (0.58–1.54) | 0.312 |
| Stroke volume (mL) | 48.75 (38.91–61.26) | 42.54 (34.56–57.14) | 0.008 | 47.65 (38.95–61.88) | 43.75 (35.66–57.66) | 0.085 | 47.1 (35.97–61.76) | 43.41 (36.13–53.54) | 0.062 |
| Stroke volume index (mL/m ²) | 27.24 (21.79–34.29) | 23.28 (18.83–32.19) | 0.006 | 26.55 (21.06–34.73) | 23.53 (19.57–32.79) | 0.113 | 25.73 (20.3–34.07) | 22.85 (19.76–30.07) | 0.021 |
| SVR (dynes/secs/cm ⁻⁵) | 1125.93 (869.57–1377.78) | 1200.23 (913.68–1500.95) | 0.118 | 1131.34 (859.82–1394.2) | 1190.7 (945.74–1468.64) | 0.145 | 1168.51 (901.64–1458.96) | 1171.93 (916.36–1422.22) | 0.902 |
| PVR (dynes/sec/cm ⁻⁵) | 145.45 (88.08–222.22) | 156.67 (97.56–239.81) | 0.296 | 131.8 (80.27–204.76) | 158.84 (95.52–240) | 0.096 | 139.36 (82.69–209.11) | 172.55 (102.56–266.67) | 0.017 |
| SVR _i (dynes/sec-m ² /cm ⁻⁵) | 2000 (1627.69–2423.19) | 2122.67 (1761.82–2581.9) | 0.132 | 1980.2 (1567.28–2432.84) | 2117.87 (1761.82–2544.57) | 0.111 | 2057.57 (1625.84–2512.94) | 2117.87 (1741.22–2470.83) | 0.653 |
| PVR _i (dynes/sec-m ² /cm ⁻⁵) | 256.6 (160–406.76) | 273.12 (171.94–443.48) | 0.31 | 239.75 (157.42–360.72) | 274.54 (174.55–438.3) | 0.114 | 252.11 (151.3–362.51) | 304 (193.85–469.24) | 0.012 |
| LVSWi (gm-m/m ² /beat) | 24.26 (17.18–30.54) | 18.97 (14.42–26.06) | <0.001 | 23.85 (16.17–31.06) | 20.38 (14.99–27.38) | 0.017 | 22.35 (15.83–30.95) | 19.34 (14.37–24.38) | 0.004 |
| RVSWi (gm-m/m ² /beat) | 4.66 (2.49–6.52) | 3.74 (2.03–5.47) | 0.054 | 3.9 (2.42–5.92) | 4.24 (2.15–6.13) | 0.841 | 4.13 (2.04–6.77) | 4.01 (2.44–5.27) | 0.867 |

Table 3. Cont.

| Hemodynamic Parameter | No MOF (n = 131) | MOF (n = 178) | p-Value | No AKI (n = 100) | AKI (n = 209) | p-Value | No VT/VF (n = 208) | VT/VF (n = 101) | p-Value |
|--|--------------------------|---------------------------|---------|--------------------------|--------------------------|---------|--------------------------|---------------------------|---------|
| Time 12 h | | | | | | | | | |
| Heart rate (bpm) | 98 (86–110) | 96 (87–112) | 0.942 | 98 (87–111) | 96 (88–111) | 0.832 | 96 (88–111) | 98 (87–113) | 0.807 |
| SBP (mmHg) | 108 (100–119) | 104 (95–114) | 0.025 | 108 (100–116) | 104 (96–115) | 0.102 | 108 (99–120) | 102 (94–110) | 0.001 |
| DBP (mmHg) | 66 (58–74) | 63 (56–71) | 0.109 | 66 (55–72) | 63 (56–72) | 0.335 | 64 (57–74) | 63 (55–69) | 0.025 |
| MAP (mmHg) | 80 (73.33–87) | 76.83 (70.33–85) | 0.024 | 80 (72.67–86.83) | 77 (70.67–85.33) | 0.135 | 80 (72.67–87) | 75 (69.33–82) | 0.002 |
| RAP (mmHg) | 13 (9–16) | 14 (11–18) | 0.007 | 12.15 (10–16) | 14 (10–17) | 0.042 | 13 (10–17) | 13 (10–16) | 0.982 |
| PCWP (mmHg) | 17 (13–21) | 17 (14–21) | 0.411 | 17 (13–20) | 17 (14–21) | 0.139 | 17 (14–21) | 18 (14–21) | 0.437 |
| PASP (mmHg) | 36 (29–45) | 37 (30–44) | 0.811 | 35 (29–43) | 37 (29–46) | 0.177 | 37 (29–44) | 36 (29–46) | 0.863 |
| PADP (mmHg) | 21 (17–25) | 22 (18–27) | 0.716 | 21 (18–25) | 22 (17–27) | 0.38 | 22 (18–26) | 21 (17–25) | 0.848 |
| mPAP (mmHg) | 27 (21–31) | 26 (21–32) | 0.834 | 25 (20–30) | 27 (22–32) | 0.069 | 26 (21–32) | 27 (20–32) | 0.75 |
| Cardiac output (L/min) | 5 (4.17–6.08) | 4.55 (3.6–5.5) | 0.004 | 5.07 (4.13–6.2) | 4.6 (3.8–5.4) | 0.004 | 4.8 (3.9–5.9) | 4.55 (3.7–5.38) | 0.158 |
| Cardiac index (L/min/m ²) | 2.84 (2.35–3.24) | 2.47 (2.03–2.94) | 0.001 | 2.9 (2.4–3.25) | 2.52 (2.14–2.97) | 0.001 | 2.72 (2.22–3.19) | 2.52 (2.14–2.95) | 0.081 |
| Cardiac power (W) | 0.89 (0.71–1.06) | 0.78 (0.6–0.95) | 0.002 | 0.86 (0.72–1.11) | 0.79 (0.63–0.98) | 0.007 | 0.85 (0.66–1.06) | 0.78 (0.59–0.92) | 0.005 |
| Cardiac power index (W/m ²) | 0.49 (0.4–0.59) | 0.43 (0.34–0.53) | 0.001 | 0.49 (0.4–0.6) | 0.44 (0.35–0.54) | 0.004 | 0.49 (0.39–0.58) | 0.41 (0.35–0.5) | 0.002 |
| CPI _(RAP) (W) | 0.42 (0.32–0.5) | 0.35 (0.27–0.44) | <0.001 | 0.42 (0.34–0.5) | 0.36 (0.28–0.45) | 0.002 | 0.41 (0.31–0.5) | 0.34 (0.28–0.42) | 0.001 |
| Perfusion pressure (mmHg) | 67.67 (60–75) | 62.52 (54.33–71) | 0.001 | 67 (59.41–75) | 62.67 (55–72) | 0.03 | 66.83 (57.83–74.33) | 61.33 (54.33–69) | 0.002 |
| PAPi | 1.23 (0.8–2) | 1.06 (0.73–1.62) | 0.058 | 1.17 (0.77–1.73) | 1.13 (0.74–1.8) | 0.653 | 1.14 (0.74–1.87) | 1.14 (0.78–1.62) | 0.81 |
| Stroke volume (mL) | 49.59 (41.01–62.2) | 45.85 (36.07–58.33) | 0.012 | 51.33 (38.64–65.1) | 46.51 (38.02–57.97) | 0.019 | 48.54 (38.76–61.59) | 45.92 (37.78–56.96) | 0.167 |
| Stroke volume index (mL/m ²) | 29.22 (23.92–34.31) | 25.39 (20.27–31.45) | 0.005 | 29.63 (23.37–35.92) | 25.96 (21.08–31.48) | 0.011 | 27.21 (22.14–34.39) | 25.45 (20.15–31.71) | 0.116 |
| SVR (dynes/sec/cm ⁻⁵) | 1075.71 (894.62–1320.07) | 1080.89 (882.05–1422.22) | 0.514 | 1020.91 (836.98–1310.45) | 1106.67 (896.97–1410.97) | 0.142 | 1074.89 (879.58–1388.89) | 1079.07 (905.78–1320.07) | 0.989 |
| PVR (dynes/sec/cm ⁻⁵) | 145.45 (84.21–222.12) | 162.36 (95.93–233.04) | 0.368 | 138.59 (79.7–198.51) | 160 (93.33–241.86) | 0.088 | 145.45 (90.44–218.33) | 163.64 (88.89–233.33) | 0.54 |
| SVR _i (dynes/sec-m ² /cm ⁻⁵) | 1860.55 (1629.4–2348.82) | 1956.65 (1633.75–2442.22) | 0.41 | 1851.3 (1569.23–2227.65) | 1955.56 (1644–2464) | 0.105 | 1882.14 (1641.49–2432.2) | 1987.11 (1604.27–2365.71) | 0.924 |
| PVR _i (dynes/sec-m ² /cm ⁻⁵) | 257.14 (147–411.67) | 294.64 (163.33–409.66) | 0.353 | 255.32 (133.32–362.1) | 288.26 (163.02–435.35) | 0.098 | 259.71 (161.96–403.14) | 292.17 (161.68–417.28) | 0.557 |
| LVSW _i (gm-m/m ² /beat) | 23.7 (19.05–30.97) | 20.66 (15.54–26.72) | 0.002 | 25.27 (17.91–31.75) | 21.63 (16.26–26.72) | 0.006 | 23.47 (17.31–30.83) | 20.57 (15.8–25.63) | 0.002 |
| RVSW _i (gm-m/m ² /beat) | 5.08 (3.3–7.6) | 4.03 (2.04–6.59) | 0.003 | 4.84 (3.22–6.57) | 4.34 (2.42–7.16) | 0.435 | 4.81 (2.44–7.11) | 4.33 (2.94–6.76) | 0.699 |

Table 3. Cont.

| Hemodynamic Parameter | No MOF (n = 131) | MOF (n = 178) | p-Value | No AKI (n = 100) | AKI (n = 209) | p-Value | No VT/VF (n = 208) | VT/VF (n = 101) | p-Value |
|--|-------------------------|---------------------------|---------|---------------------------|---------------------------|---------|---------------------------|--------------------------|---------|
| Time 24 h | | | | | | | | | |
| Heart rate (bpm) | 96 (85–110) | 98 (87–114) | 0.219 | 97 (86–111) | 97 (85–110) | 0.645 | 96 (87–110) | 98 (85–111) | 0.849 |
| SBP (mmHg) | 108 (98–121) | 103 (92–113) | 0.008 | 108 (100–118) | 103 (93–114) | 0.012 | 107 (98–116) | 101 (91–114) | 0.014 |
| DBP (mmHg) | 65 (58–71) | 60 (55–69) | 0.038 | 66 (58–72) | 60 (55–69) | 0.006 | 65 (57–70) | 59 (54–67) | 0.002 |
| MAP (mmHg) | 80.33 (72.33–87) | 74.68 (68.97–83.33) | 0.006 | 80.73 (72.67–87.67) | 75.67 (68.77–83.67) | 0.003 | 79.83 (71.33–86.33) | 72.67 (67.09–81.33) | 0.001 |
| RAP (mmHg) | 13 (10–16) | 14 (11–17) | 0.037 | 13 (10–16) | 14 (11–17) | 0.307 | 13 (10–17) | 14 (10–17) | 0.777 |
| PCWP (mmHg) | 16 (14–20) | 18 (15–22) | 0.006 | 16 (14–20) | 18 (14–22) | 0.04 | 17 (14–20) | 18 (15–22) | 0.151 |
| PASP (mmHg) | 36 (29–45) | 38 (30–47) | 0.464 | 35 (29–42) | 38 (30–47) | 0.218 | 36 (29–46) | 38 (32–47) | 0.119 |
| PADP (mmHg) | 20 (17–25) | 22 (18–27) | 0.078 | 20 (17–26) | 22 (18–27) | 0.243 | 20 (16–26) | 23 (18–28) | 0.054 |
| mPAP (mmHg) | 26 (22–31) | 27 (22–33) | 0.266 | 25 (22–30) | 27 (23–33) | 0.134 | 25 (22–32) | 27 (24–32) | 0.075 |
| Cardiac output (L/min) | 5.1 (4–6.28) | 4.68 (3.8–5.65) | 0.024 | 5.15 (4.2–6.3) | 4.7 (3.84–5.86) | 0.02 | 4.9 (4–6.15) | 4.7 (3.9–5.6) | 0.098 |
| Cardiac index (L/min/m ²) | 2.89 (2.29–3.4) | 2.54 (2.17–3.08) | 0.01 | 2.84 (2.44–3.39) | 2.55 (2.16–3.16) | 0.012 | 2.77 (2.25–3.3) | 2.54 (2.2–3.02) | 0.073 |
| Cardiac power (W) | 0.89 (0.71–1.16) | 0.8 (0.63–0.98) | 0.002 | 0.88 (0.73–1.15) | 0.8 (0.63–0.99) | 0.002 | 0.86 (0.67–1.13) | 0.77 (0.62–0.93) | 0.011 |
| Cardiac power index (W/m ²) | 0.5 (0.4–0.64) | 0.44 (0.34–0.54) | 0.002 | 0.49 (0.41–0.64) | 0.44 (0.34–0.56) | 0.002 | 0.48 (0.38–0.63) | 0.44 (0.35–0.51) | 0.006 |
| CPI _(RAP) (W) | 0.41 (0.34–0.53) | 0.36 (0.28–0.46) | <0.001 | 0.41 (0.33–0.55) | 0.37 (0.28–0.46) | 0.002 | 0.4 (0.31–0.51) | 0.36 (0.28–0.42) | 0.002 |
| Perfusion pressure (mmHg) | 66.33 (57.34–74) | 59.67 (54–69.67) | <0.001 | 66.71 (58.33–74.46) | 60.67 (54–70.33) | 0.002 | 65 (56.5–72.93) | 58.33 (53.33–67.33) | 0.001 |
| PAPi | 1.31 (0.86–1.82) | 1.09 (0.71–1.67) | 0.071 | 1.3 (0.85–1.72) | 1.15 (0.75–1.76) | 0.71 | 1.21 (0.77–1.76) | 1.15 (0.75–1.76) | 0.932 |
| Stroke volume (mL) | 53.75 (40.48–65.88) | 46.87 (39.26–60.19) | 0.021 | 52.14 (41.39–67.71) | 48.6 (39.26–61.58) | 0.112 | 51.35 (40.33–64.69) | 47.73 (38.78–59.76) | 0.191 |
| Stroke volume index (mL/m ²) | 29.87 (23.65–36.11) | 26.34 (22.49–33.22) | 0.012 | 29.19 (23.57–36.57) | 27 (22.65–33.54) | 0.107 | 28.59 (22.8–35.73) | 26.08 (23.4–32.52) | 0.125 |
| SVR (dynes/sec/cm ⁻⁵) | 1048.89 (826.8–1270.78) | 1040.75 (835.9–1365.99) | 0.86 | 1046.18 (821.08–1271.05) | 1044.44 (838.1–1360) | 0.813 | 1060.22 (821.08–1358.66) | 1028.57 (851.74–1290.32) | 0.793 |
| PVR (dynes/sec/cm ⁻⁵) | 141.18 (91.43–220) | 150.77 (92.41–212.68) | 0.789 | 132.34 (78.84–216.47) | 153.76 (101.59–213.33) | 0.137 | 147.97 (87.67–212.98) | 152.38 (105.66–213.9) | 0.321 |
| SVRi (dynes/sec-m ² /cm ⁻⁵) | 1880 (1537.85–2288.9) | 1948.51 (1522.58–2379.75) | 0.681 | 1849.85 (1554.09–2316.28) | 1946.06 (1491.67–2330.22) | 0.779 | 1917.26 (1543.83–2359.52) | 1885.4 (1525.33–2322.04) | 0.852 |
| PVRi (dynes/sec-m ² /cm ⁻⁵) | 259.05 (159.3–394.28) | 272 (170.31–366.31) | 0.829 | 247.62 (149.93–391.8) | 273.78 (177.82–374) | 0.217 | 258.52 (155.43–385) | 268 (197–371.59) | 0.249 |
| LVSWi (gm-m/m ² /beat) | 25.49 (19.17–32.47) | 20.57 (15.92–27.83) | <0.001 | 25.2 (18.71–32.78) | 21.35 (15.99–27.91) | 0.005 | 24.29 (17.2–31.55) | 20.24 (17.15–25.4) | 0.004 |
| RVSWi (gm-m/m ² /beat) | 5.14 (3.49–7.75) | 4.6 (2.34–6.18) | 0.02 | 4.99 (3.04–7.12) | 4.8 (2.79–6.54) | 0.433 | 4.83 (2.64–7.36) | 4.91 (3.59–6.25) | 0.948 |

AKI: Acute kidney injury, MOF: Multi-organ failure, VT/VF: Ventricular tachycardia/fibrillation, bpm: Beats per minute, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial pressure, RAP: Right atrial pressure, PCWP: Pulmonary capillary wedge pressure, PASP: Pulmonary artery systolic pressure, PADP: Pulmonary artery diastolic pressure, mPAP: Mean pulmonary artery pressure, CPI: Cardiac power index, CPI_(RAP): Cardiac power index normalized by right atrial pressure, PAPI: Pulmonary artery pulsatility index, sec: seconds, SV: Stroke volume, SVi: Stroke volume index, SVR: Systemic vascular resistance, PVR: Pulmonary vascular resistance, SVRi: Systemic vascular resistance index, PVRi: Pulmonary vascular resistance index, LVSWi: Left ventricular stroke work index; RVSWi: Right ventricular stroke work index.

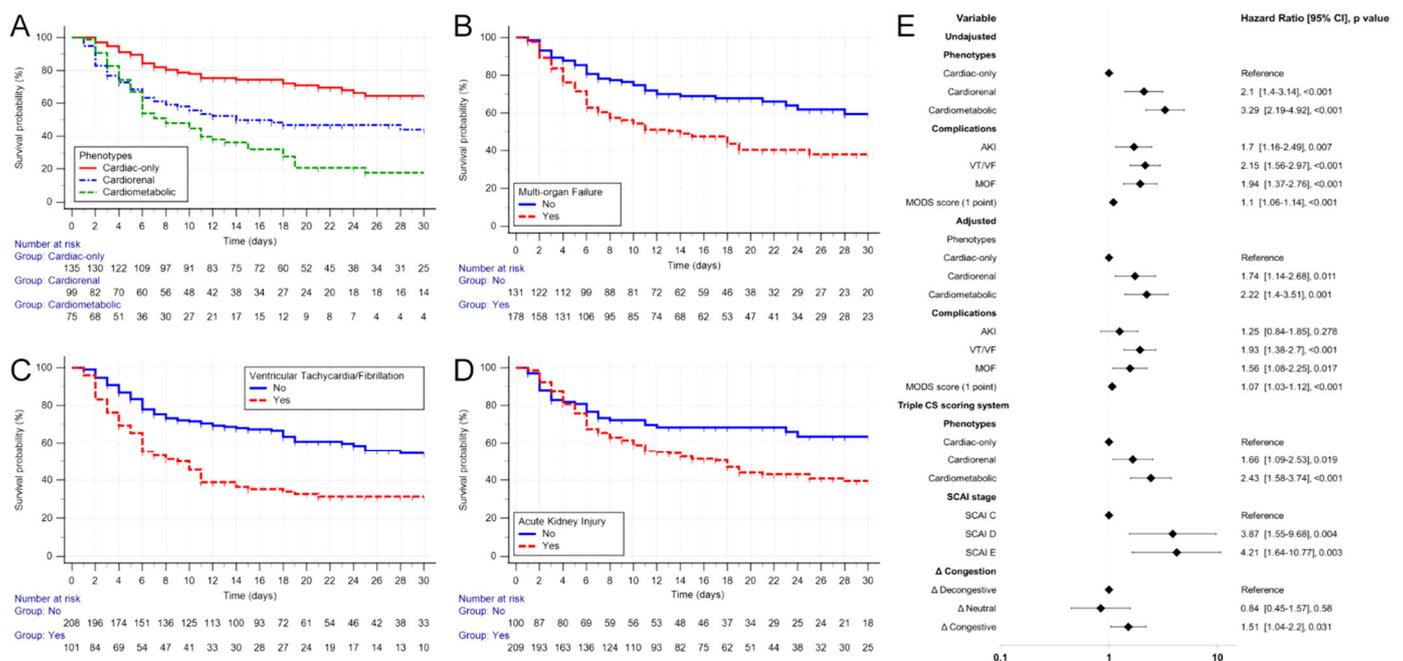


Figure 3. Kaplan–Meier curves according to phenotypes (A), multi-organ failure (B), ventricular tachycardia/fibrillation (C), and acute kidney injury (D). Forest plot for Cox regression (E).

In the case of complications, the presence of MOF showed differences ($p < 0.001$), with an HR = 1.94 (1.37–2.76; $p < 0.001$) and an RMST of 5.63 (2.95–8.31; $p < 0.001$) days less in the presence of MOF. Patients with AKI had an HR = 1.7 (1.16–2.49; $p = 0.007$). Furthermore, these patients had a survival disadvantage of 4.34 (1.44–7.24; $p = 0.003$) days, while patients with VT/VF had an HR = 2.15 (1.56–2.97; $p < 0.001$) and patients who did not present this complication had a survival advantage of 7.17 (4.35–9.99; $p < 0.001$) days. An increase of one point in the MODS score gave an HR = 1.1 (1.06–1.14; $p < 0.001$; Figure 3B–E).

4.4. Multivariate Analysis

When adjusted for SCAI and Δ congestion, the phenotyping retained its significance ($p < 0.001$); furthermore, SCAI and Δ congestion also appeared to have an independent value for mortality prediction ($p = 0.011$ and 0.028, respectively), with an AUC of 0.72 (0.67–0.77; Figure 3E).

When adjusted for the clinically relevant variables, CS phenotypes had a significant difference in the Cox regression ($p = 0.002$), with a cardiorenal HR = 1.74 (1.14–2.68; $p = 0.011$) and a cardiometabolic HR = 2.22 (1.4–3.51; $p = 0.001$). MOF had an adjusted HR = 1.56 (1.08–2.25; $p = 0.017$); for VT/VF, the HR = 1.93 (1.38–2.7; $p < 0.001$); in the case of AKI, a loss of statistical significance was seen, with an HR = 1.25 (0.84–1.85; $p = 0.278$). Finally, for MODS, significant differences were found, with an HR = 1.07 (1.03–1.12; $p < 0.001$) per point (Figure 3E).

5. Discussion

Herein, we describe the full invasive hemodynamic profiling of AMI-CS. To our knowledge, this is the first attempt to define a three-axis model of CS profiling (phenotype + SCAI + congestion). Previously, the proposed phenotypes by Zweck et al. [2] correctly classified specific higher mortality groups; we aimed to allocate the patient groups into specific phenotypes by utilizing alanine aminotransferase (ALT) and estimated glomerular filtration rate (eGFR) as straightforward indicators. Moreover, the independent mortality estimated by SCAI or change in congestion could help to allocate high-intensity therapies, such as MCS, or other resourceful interventions. We also demonstrated that complications, such as MOF, AKI, and VT/VF, increased mortality in AMI-CS.

CS phenotypes exhibit a distinct hemodynamic signature, with the cardiometabolic group demonstrating the worst hemodynamic parameters. Regarding congestion, previous studies have shown that patients in the cardiorenal and cardiometabolic groups have higher RAP and PCWP levels, indicating that they have trouble achieving decongestion compared with the cardiac group [2,3]. As expected, patients in the cardiac group had the highest cardiac output and power and their derived measures in our study, while patients in the cardiometabolic group had the lowest levels.

The best hemodynamic parameters to distinguish between the groups were cardiac power followed by $CPI_{(RAP)}$. Baldetti et al. suggests that a cut-off of 0.28 W/m^2 indicates an increased risk of mortality in a time-fixed manner [11]. We saw that the cardiometabolic group had more trouble achieving higher values than the other two groups. These findings, derived from perfusion pressure, suggest that increased congestion is observed in the cardiorenal and cardiometabolic groups, and they can identify more splanchnic damage (renal and liver) [11]. PADP showed a particular response based on the group type. Patients in the cardiac group had lower levels of PADP, while patients in the cardiorenal and cardiometabolic groups had increased levels as the first 24 h progressed. LVSWi also showed good discriminative power; previous studies suggested that it can better discriminate mortality risk than LVEF and improve mortality risk stratification [12]. This could aid in characterizing phenotypes, as a step up in LVSWi is observed in cardiorenal and cardiac groups in contrast to the cardiometabolic group.

Interestingly, the vasoactive analysis reveals intriguing association differences in usage among the different CS phenotypes. Vasopressin and dobutamine showed more pronounced disparities, with cardiometabolic patients often requiring higher percentages. Also, levosimendan showed a higher use in cardiorenal and cardiometabolic groups. These associations suggest that CS phenotypes may have varying hemodynamic needs, possibly linked to their underlying phenotype-related pathophysiology and the severity of organ involvement, which is usually more pronounced in the cardiometabolic group. Further research is needed to uncover the mechanisms behind these differences and their implications in CS management, as these associations probably underlie the higher MOF seen in the cardiorenal and cardiometabolic phenotypes.

MOF development could be discerned from the first 24 h hemodynamics. As suggested by previous studies, $CPI_{(RAP)}$ had the best discriminative power, followed by perfusion pressure. An inadequate pressure–flow state, which is globally measured by $CPI_{(RAP)}$ and impaired in MOF, compromises tissular metabolic demands, which leads to end-organ failure. In the CardShock study [13], variables such as confusion, elevated blood lactate, and eGFR were predictors of in-hospital mortality, as in the MODS system [10]. Thus, it is important to underscore the usefulness of $CPI_{(RAP)}$ and also LVSWi as a hemodynamic goal and a discriminative power to identify patients who develop MOF [11,13,14]. Lower PAPI levels in MOF suggest that these patients had an overall worse RV function, which is also supported by the fact that these patients had more RV congestion, as seen by higher RAP levels [15]. Therefore, as proposed previously [4], an effective rapid decongestion is paramount to avoiding MOF.

The development of AKI has been associated with higher overall mortality. Unlike previous studies on the cardiorenal syndrome that have mainly focused on heart failure and that failed to find an association between cardiac index and AKI development [16,17], our study revealed that lower levels of cardiac power and output, as well as their derived measurements, had an impact on the development of AKI. In addition, $CPI_{(RAP)}$ was found to have the best discriminative power, possibly because of the different hemodynamic responses in the acute setting of AMI-CS [11,14]. Finally, there were substantial differences in PCWP and RAP, with the latter observed not between groups but as an interaction with time. High LV congestion and ineffective RV/LV decongestion led to AKI development.

Few studies have investigated the relationship between hemodynamics and arrhythmogenesis in cases of electrical instability. Typically, the underlying mechanism is an ischemia-induced insult resulting in low pressures. The most useful parameter for pre-

dicting arrhythmogenesis, as with previous complications, is $CPI_{(RAP)}$. While VT/FV has been extensively studied in advanced HF [18], there is a lack of research in patients with AMI-CS, highlighting the importance of predicting this complication. Our cohort shows low pressure–flow parameters among patients who develop these arrhythmias. Thus, achieving an adequate pressure–flow state is crucial, and the optimization by MCS or pharmacological treatment could potentially prevent arrhythmia development.

The cardiogenic shock profiling aids to provide a more granular classification of the classic types of shock (cardiac, hypovolemic, septic, etc.). In our study’s three-axis model for subsets of AMI-CS, profiling offers clinicians a tool to personalize treatments, optimizing resource allocation and ultimately improving patient outcomes. Also, axis phenotyping could help us design appropriate granular data to study patients that might benefit from MCS [3], especially VA-ECMO, since trials showed no reduction in 30-day outcomes in AMI-CS all-comers [19,20].

The current study’s limitations are its single-center retrospective data, the lack of a specific time for complications, and the lack of records of the particular vasoactive drug dose, the timing of MCS, and the response to PAC-derived hemodynamic data, which prevents the calculation of other scores, such as SOFA. In addition, as the cohort has inherent mortality or PAC withdrawal losses, the expectation–maximization algorithm’s intrinsic limitations impact the current data. Nevertheless, this method helps us to understand the hemodynamic trajectories and is more informative and statistically rigorous [21,22]. The strengths of the present study are the large cohort and the full record of the hemodynamic profiling in an academic center, which kept all specific primary PAC-derived data, which contrasts with the scarce complete PAC profiling for AMI-CS in a previous registry [5]. The longitudinal PAC measures described here, and the dynamic nature of AMI-CS could help improve our understanding of this high mortality entity, develop prevention strategies, and allocate resources more effectively.

6. Conclusions

Comprehensive phenotyping in AMI-CS can provide valuable patient-level prognostic information. The phenotyping of cardiogenic shock reveals varying mortality rates and complications. In addition, specific hemodynamic behaviors can signal potentially high-risk complications, such as MOF, AKI, and/or ventricular arrhythmias. Therefore, complete phenotyping in patients with AMI-CS is crucial for providing accurate prognosis and for the design of new trials.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/jcm12185818/s1>, Figure S1: ANOVA repeated measures of representative hemodynamic parameters in CS-AMI complications. In multi-organ failure, cardiac power index(RAP) (A), perfusion pressure (B), and left ventricular stroke work index (C). In acute kidney injury, cardiac power index(RAP) (D), left ventricular stroke work index (E), and perfusion pressure (F). For VT/VF (ventricular tachycardia/fibrillation), cardiac power index (RAP) (G), left ventricular stroke work index (C), and mean arterial pressure (I).; Table S1. Pairwise comparison with Bonferroni correction of the characteristics of patients with acute myocardial infarction cardiogenic shock phenotype. Table S2. Pairwise comparison of hemodynamics parameters in AMI-CS phenotypes. Table S3. ANOVA analysis of the phenotypes and complications in acute myocardial infarction complicated by cardiogenic shock. Table S4. Coronary Artery Distribution in Different Cardiogenic Shock Profiles. References [1,8–10,23,24] are cited in Supplementary Materials.

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