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Mechanical Circulatory Support in Patients With COVID-19 Presenting With Myocardial Infarction

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ST-segment elevation myocardial infarction (STEMI) complicating COVID-19 is associated with an increased risk of cardiogenic shock and mortality. However, little is known about the frequency of use and clinical impact of mechanical circulatory support (MCS) in these patients. We sought to define patterns of MCS utilization, patient characteristics, and outcomes in patients with COVID-19 with STEMI. The NACMI (North American COVID-19 Myocardial Infarction) is an ongoing prospective, observational registry of patients with COVID-19 positive (COVID-19+) with STEMI with a contemporary control group of persons under investigation who subsequently tested negative for COVID-19 (COVID-19−). We compared the baseline characteristics and in-hospital outcomes of COVID-19+ and patients with COVID-19− according to the use of MCS. The primary outcome was a composite of in-hospital mortality, stroke, recurrent MI, and repeat unplanned revascularization. A total of 1,379 patients (586 COVID-19+ and 793 COVID-19−) enrolled in the NACMI registry between January 2020 and November 2021 were included in this analysis; overall, MCS use was 12.3% (12.1% [n = 71] COVID-19+/MCS positive [MCS+] vs 12.4% [n = 98] COVID-19−/MCS+). Baseline characteristics were similar between the 2 groups. The use of percutaneous coronary intervention was similar between the groups (84% vs 78%; p = 0.404). Intra-aortic balloon pump was the most frequently used MCS device in both groups (53% in COVID-19+/MCS+ and 75% in COVID-19−/MCS+). The primary outcome was significantly higher in COVID-19+/MCS+ patients (60% vs 30%; p = 0.001) because of very high in-hospital mortality (59% vs 28%; p = 0.001). In conclusion, patients with COVID-19+ with STEMI requiring MCS have very high in-hospital mortality, likely related to the significantly higher pulmonary involvement compared with patients with COVID-19− with STEMI requiring MCS.

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COVID-19 continues to have a drastic impact on all aspects of acute myocardial infarction (MI) care.1,2 Myocardial injury is present in 8% to 62% of patients hospitalized with COVID-19 infection and is associated with poor clinical outcomes.3–6 Patients with ST-segment elevation myocardial infarction (STEMI) and COVID-19 infection have unique demographic and adverse clinical characteristics, including frequent in-hospital presentation,
extra-cardiac manifestations such as lung infiltrates, and cardiogenic shock. STEMI patients with COVID-19 represent a high-risk group with greater odds of in-hospital mortality, stroke, recurrent MI, and repeat unplanned revascularization than those without COVID-19. In addition, patients with COVID-19 and STEMI are less likely to receive invasive angiography and reperfusion therapy, all of which may contribute to increased adverse outcomes. Mechanical circulatory support (MCS) is being used with increasing frequency for the management of patients with acute MI and cardiogenic shock, and clinical outcomes of MCS use have been previously reported. However, little is known about the use of MCS in patients with COVID-19 presenting with STEMI. Although data on the use of veno-venous extracorporeal membrane oxygenation (VV-ECMO) in patients with COVID-19 with severe acute respiratory failure has been reported previously, no study to date has reported on the use of MCS for cardiogenic shock in these patients. In this study, we assessed patterns of MCS utilization in patients with COVID-19 presenting with STEMI and its association with in-hospital outcomes compared with patients who are COVID-19 negative (COVID-19−).

Methods

The NACMI (North American COVID-19 Myocardial Infarction) registry is a prospective, investigator-initiated, multicenter, observational registry of hospitalized patients with STEMI with COVID-19 infection (confirmed or suspected) created in collaboration with the Society for Cardiovascular Angiography and Interventions (SCAI) and the Canadian Association of Interventional Cardiology in conjunction with the American College of Cardiology Interventional Council. A detailed description of the study rationale and design has previously been published. Standardized data collection forms modeled after the American College of Cardiology National Cardiovascular Data Registry definitions were used with a secure web-based application (REDCap [Research Electronic Data Capture]) to manage the dataset.

In this sub-study, all patients with COVID-19+ enrolled in the NACMI registry between January 1, 2020, and November 22, 2021, were included and compared with persons under investigation for COVID-19 subsequently confirmed to be negative. Cardiogenic shock was defined as systolic blood pressure ≤90 mm Hg and cardiac index <2.2 L/min/m² and/or need for vasopressors or inotropes for hemodynamic stabilization. The type of temporary MCS devices (intra-aortic balloon pump, Impella, tandem heart, or extracorporeal membrane oxygenation) used to treat hemodynamically unstable patients was left to the discretion of the operator performing the procedure. The study cohort was divided in 4 groups according to COVID-19 and MCS status (1) COVID-19 positive (COVID-19+)/MCS positive (MCS+), (2) COVID-19+/MCS negative (MCS−), (3) COVID-19−/MCS+, and (4) COVID-19−/MCS−. Baseline characteristics, clinical presentation, angiographic findings, and in-hospital outcomes were compared between the groups.

The primary outcome of interest was a composite of in-hospital death, stroke, recurrent MI, and unplanned revascularization. The secondary outcomes included individual components of the primary end point. The study protocol was approved by the Institutional Review Boards at each of the respective hospitals.

Statistical analysis was performed at the data coordinating center at the Minneapolis Heart Institute Foundation. Continuous variables are reported as mean ± SD if normally distributed or as median (interquartile range) if skewed and were analyzed using Student’s t test or Wilcoxon rank-sum test depending on the distribution. Discrete variables are reported as counts and percentages and were analyzed using chi-square or Fisher’s exact test, where appropriate. All analyses were performed using Stata version 15.1 (StataCorp, College Station, Texas).

Results

A total of 1,379 patients (COVID-19+/MCS+ [n = 71], COVID-19+/MCS− [n = 515], COVID-19−/MCS+ [n = 98] and COVID-19−/MCS− [n = 695]) were enrolled in the NACMI registry during the study period and were included in the present analysis. Patients with COVID-19+ (n = 586) commonly had minority ethnicity (51% [African-American 14%, Asian 7%, Hispanic 17%, Other 9%]), a high prevalence of diabetes mellitus (40%), and presented with respiratory symptoms such as dyspnea with infiltrates on chest-x-ray. In patients with COVID-19+, those who received MCS were predominantly Caucasian (58%). The baseline clinical characteristics are listed in Table 1. Of the 1,379 patients with STEMI, MCS was used in 169 patients (12.3%) with no difference between patients with COVID-19+ (12.1%) and COVID-19− (12.4%) (Figure 1).

A summary of clinical and angiographic characteristics is listed in Table 2. Patients with COVID-19+ more frequently presented with dyspnea and infiltrates on chest-x-ray. Cardiogenic shock pre-percutaneous coronary intervention (pre-PCI) was present in 42.6% of patients requiring MCS compared with 7.7% in those not needing MCS (p <0.001). Similarly, 27.8% of patients in the MCS group had cardiac arrest pre-PCI compared with 8.4% in the non-MCS group (p <0.001). Although all patients in the COVID-19−/MCS+ group underwent coronary angiography, 3% of patients with COVID-19+/MCS+ with STEMI did not undergo angiography. In patients who underwent coronary angiography and PCI, median door-to-balloon times were similar between patients with COVID-19+ /MCS+ and COVID-19−/MCS+, and overall PCI rates (primary and rescue) were not different between the 2 groups (77% vs 76.5%, p = 0.1). Coronary artery bypass grafting was performed more frequently in patients with COVID-19−/MCS+ than patients with COVID-19+/MCS+ (13% vs 3%, p = 0.031). The distribution of the culprit vessel was similar between patients with COVID-19+/MCS+ and COVID-19−/MCS+

Right-sided cardiac catheterization was performed in about 39% of patients with COVID-19+/MCS+ compared with <25% in patients with COVID-19−/MCS+ (Table 3). All the patients that received MCS were classified as either
SCAI class D shock (62% of patients with COVID-19+/MCS+ vs 51% of patients with COVID-19−/MCS+) or class E SCAI shock classification (38% in COVID-19+/MCS+ group vs 49% in COVID-19−/MCS+ group).

Intra-aortic balloon pump (IABP) was the most common type of MCS used in both groups (74% and 62% in COVID-19−/MCS+ and COVID-19+/MCS+, respectively; Figure 2). Although Impella use was comparable between the 2 groups (21% in COVID-19−/MCS+ and 28% in COVID-19+/MCS+), the use of ECMO was numerically higher in the COVID-19+/MCS+ group (COVID-19+ 7% vs COVID-19− 3%, p = 0.11).

The primary outcome occurred in 58% of patients with COVID-19+/MCS+ and 28% of patients with COVID-19−/MCS+ (p < 0.001). The difference was driven by higher in-hospital mortality (55% in the COVID-19+/MCS+ group vs 27% in the COVID-19−/MCS+ group; p = 0.001) with no difference in stroke, recurrent MI, or unplanned revascularization. Length of intensive care unit and total length of hospital stay were not significantly different between COVID-19+/MCS+ and COVID-19−/MCS+ groups, although significantly longer when compared with patients with COVID-19+/MCS− and COVID-19−/MCS− (Figure 3).

Left ventricular ejection fraction was significantly lower in the COVID-19+/MCS+ group compared with patients with COVID-19+MCS− (30 ± 13% vs 46 ± 13%, p < 0.001; Supplementary Tables 1 and 2). Coronary angiography was not performed in 2.9% and 14% of patients with COVID-19+/MCS− and COVID-19−/MCS−, respectively (p = 0.009). In contrast, PCI (both primary and rescue) was performed in 82% of patients in the COVID-19+/MCS+ group compared with 70.8% in the patients with COVID-19+/MCS− (p = 0.10). Left anterior descending coronary artery was the predominant culprit vessel in patients with COVID-19+/MCS+, whereas the right coronary artery was the major culprit vessel in patients with COVID-19+/MCS−.
The primary end point occurred in 25% of patients with COVID-19+/MCS+ in comparison with 58% in patients with COVID-19+/MCS (p <0.001) (Figure 3, Supplementary Table 3).

Table 2
Clinical presentation and angiographic findings

|                  | COVID+ (n = 71) | COVID+ (n = 98) | p Value | COVID+ (n = 515) | COVID+ (n = 695) | p Value |
|------------------|-----------------|-----------------|---------|------------------|------------------|---------|
| Dyspnea          | 37 (52%)        | 32 (33%)        | 0.011   | 241 (47%)        | 223 (32%)        | <0.001  |
| Chest pain       | 36 (51%)        | 72 (73%)        | 0.002   | 291 (57%)        | 566 (81%)        | <0.001  |
| Syncope          | 7 (9.9%)        | 4 (4.1%)        | 0.2     | 15 (2.9%)        | 34 (4.9%)        | 0.084   |
| Infiltrates      | 31 (44%)        | 22 (22%)        | 0.003   | 195 (38%)        | 84 (12%)         | <0.001  |
| Pleural effusion | 9 (13%)         | 13 (13%)        | >0.9    | 42 (8.2%)        | 41 (5.9%)        | 0.12    |
| Cardiomegaly     | 6 (8.5%)        | 4 (4.1%)        | 0.3     | 45 (8.7%)        | 42 (6.0%)        | 0.073   |
| Arrest pre-PCI   | 13 (21%)        | 34 (35%)        | 0.056   | 34 (7.6%)        | 68 (10%)         | 0.13    |
| Shock pre-PCI    | 33 (52%)        | 39 (41%)        | 0.2     | 42 (9.7%)        | 51 (7.8%)        | 0.3     |
| In-house presentation | 6 (8.6%)  | 1 (1.0%)        | 0.021   | 33 (6.5%)        | 10 (1.5%)        | <0.001  |
| Ejection fraction | 30±13           | 32±14           | 0.4     | 46±13            | 45±12            | 0.3     |
| D2B, median (IQR)| 82 (56, 122)    | 77 (48, 137)    | 0.8     | 73 (50, 109)     | 73 (51, 102)     | 0.9     |
| D2B (primary PCI only) | 94 (59, 124) | 78 (52, 120)    | 0.5     | 71 (48, 106)     | 73 (52, 100)     | 0.6     |
| D2B <90         | 17 (49%)        | 33 (61%)        | 0.2     | 120 (64%)        | 317 (68%)        | 0.3     |
| No angiography   | 2 (2.9%)        | 0 (0%)          | 0.2     | 68 (14%)         | 25 (3.7%)        | <0.001  |
| Reperfusion strategy | 0.10           | 0.10            |         | 5 (0.8%)         | 5 (0.8%)         | <0.001  |
| Thrombolitics    | 0 (0%)          | 0 (0%)          |         | 16 (3.8%)        | 5 (0.8%)         |         |
| Primary PCI      | 53 (79%)        | 72 (76%)        |         | 278 (67%)        | 526 (80%)        |         |
| Facilitated/rescue PCI | 2 (3.0%)   | 3 (3.2%)        |         | 16 (3.8%)        | 18 (2.7%)        |         |
| Medical therapy  | 10 (15%)        | 8 (8.4%)        |         | 102 (24%)        | 93 (14%)         |         |
| CABG             | 2 (3.0%)        | 12 (13%)        |         | 6 (1.4%)         | 15 (2.3%)        |         |
| Any PCI          | 55 (82%)        | 75 (79%)        | 0.6     | 294 (70%)        | 544 (83%)        | <0.001  |
| Normal coronaries (no culprit) | 7 (10%) | 4 (4.2%)        | 0.2     | 99 (24%)         | 74 (11%)         | <0.001  |
| Culprit artery*  | 0.2             | 0.2             |         | 0.2              | 0.2              | <0.001  |

CABG = coronary artery bypass grafting; COVID = coronavirus disease; D2B = door-to-balloon; IQR = interquartile range; LAD = left anterior descending artery; LCx = left circumflex artery; LMCA = left main coronary artery; MCS = mechanical circulatory support; PCI = percutaneous coronary intervention; PDA = posterior descending artery; RCA = right coronary artery; SD = standard deviation.

* In patients who underwent coronary angiography.

Discussion

We used the NACMI registry to describe clinical and angiographic characteristics, patterns of MCS utilization, and in-hospital outcomes of patients with STEMI and
concomitant COVID-19 infection. Several important findings are noted. First, MCS was used in 12.3% of patients with COVID-19+ presenting with STEMI, which is comparable with patients with STEMI without COVID-19. Second, in patients treated with MCS, ECMO use was significantly higher in patients with COVID-19+/MCS+ compared with COVID-19−/MCS+. Third, despite use of patients with MCS, COVID-19+ had significantly higher in-hospital mortality rates than patients with COVID-19−/MCS+. Fourth, when compared with a control group composed of patients with COVID-19 needing MCS devices, patients with COVID-19+ had a similar proportion of high-risk pre-PCI conditions (cardiogenic shock and cardiac arrest). Fifth, although most patients with STEMI and COVID-19+ were treated with MCS, 22.3% of patients in the COVID-19+ group were treated with ECMO, which is significantly higher than in the COVID-19−/MCS+ group (3.0%). Table 3: Hemodynamic data

|                      | COVID+/MCS+ (n = 71) | COVID−/MCS+ (n = 98) | p Value | COVID+/MCS− (n = 515) | COVID−/MCS− (n = 695) | p Value |
|----------------------|----------------------|----------------------|---------|-----------------------|-----------------------|---------|
| LVEDP, mm Hg         | 26 (20, 36)          | 23 (15, 34)          | 0.4     | 17 (12, 24)           | 18 (12, 24)           | 0.4     |
| Swan-Ganz inserted, n (%) | 22 (39%)          | 17 (22%)             | 0.035   | 16 (5.0%)             | 18 (3.3%)             | 0.2     |
| RA (mean), mm Hg     | 13 (10, 19)          | 15 (12, 19)          | 0.5     | 12.0 (7.8, 15.0)      | 15.0 (10.0, 20.5)     | 0.2     |
| RV (systolic), mm Hg | 39 (32, 55)          | 36 (30, 42)          | 0.6     | 41 (33, 47)           | 47 (37, 50)           | 0.3     |
| Mean PAP mm Hg       | 30 (25, 33)          | 30 (22, 41)          | >0.9    | 26 (21, 35)           | 30 (28, 45)           | 0.12    |
| Wedge (mean) mm Hg   | 22 (17, 24)          | 19 (16, 28)          | 0.5     | 15 (9, 24)            | 23 (17, 29)           | 0.051   |
| Cardiac output, L/min |3.15 (2.35, 3.94)   | 3.90 (3.14, 6.16)    | 0.068   | 4.20 (3.49, 5.44)     | 4.09 (3.40, 5.79)     | 0.7     |
| Cardiac index, L/min/m² | 1.94 (1.59, 2.56)  | 1.90 (1.30, 2.62)    | 0.7     | 2.04 (1.75, 2.82)     | 2.25 (1.89, 3.12)     | 0.4     |
| Intubated, n (%)     | 45 (74%)             | 50 (55%)             | 0.019   | 102 (23%)             | 79 (12%)              | <0.001  |

SCAI cardiogenic class, n (%)*

- A: 0 (0%)
- B: 0 (0%)
- C: 0 (0%)
- D: 0 (0%)
- E: 40 (62%) 50 (51%)
- 25 (38%) 48 (49%)

| COVID = coronavirus disease; IQR = interquartile range; LAD = left anterior descending artery; LVEDP = left ventricular end-diastolic pressure; MCS = mechanical circulatory support; PAP = pulmonary artery pressure; RA = right atrium; RV = right ventricle; SCAI = Society of Cardiovascular Angiography and Intervention. * SCAI cardiogenic shock classification data were available for all patients in the COVID-19−/MCS+ group and 65 patients in the COVID-19+/MCS+ group.

Figure 2: Bar graph demonstrating frequency of use of various MCS devices stratified by COVID-19 status.
COVID-19+ infection in the NACMI registry were from ethnic minorities,2 those who received MCS were predominantly Caucasian. Patients with COVID-19+ had significantly higher rates of the composite primary end point driven primarily by very high rates of in-hospital mortality and abnormal lung findings (infiltrates), which suggest that extra-cardiac (i.e., pulmonary) involvement may account for these differential outcomes. Currently, there is no data on MCS use in patients with COVID-19 presenting with STEMI, and this is the first study to address this challenging yet crucial aspect of STEMI management in these high-risk patients.

COVID-19 has had a drastic impact on the overall management of STEMI. Globally, there was a decrease in the number of STEMI activations and primary PCI, an increase in door-to-balloon times, total ischemic times, and higher in-hospital mortality because of multiple reasons, including fear of contracting the disease in the hospital, delayed presentations, and a switch to pharmacological reperfusion.2,12−14

Cardiogenic shock complicates about 5% to 10% of STEMI cases and is associated with an in-hospital mortality rate of 23% if isolated, but as high as 44% when combined with pre-PCI cardiac arrest.15 The rationale for temporary MCS use in cardiogenic shock complicating acute MI includes maintaining organ perfusion, thereby preventing systemic shock syndrome, and reducing left ventricular filling pressures and wall stress, all of which reduce myocardial oxygen consumption, thereby limiting ischemia and infarct size.16,17 In patients presenting with acute MI and cardiogenic shock, MCS initiated before PCI, coupled with hemodynamic assessment, has shown to improve outcomes, including survival in observational studies, although randomized controlled trials employing this strategy are lacking.9,10,18,19

At the beginning of the pandemic, MCS, in the form of VV-ECMO, was primarily used in the setting of severe acute respiratory distress syndrome caused by COVID-19 infection.20 However, in patients with cardiovascular compromise, MCS may also be required for hemodynamic stabilization. Prepandemic data from the National Cardiovascular Disease Registry demonstrated that MCS devices were used in about 45% of patients presenting with cardiogenic shock and MI.21,22 Although the overall trend in the use of MCS remained stable over the past several years, IABP use has seen a significant decrease, whereas Impella use has more than doubled.21 In our study, most patients received IABP (62% and 74% in patients with COVID-19+ and COVID-19−, respectively). Not surprisingly, the frequency of ECMO use in patients with COVID-19+/MCS+ was numerically higher than that in the COVID-19−/MCS− group (7% vs 3%), and most of them were VV-ECMO. Data from the National Cardiovascular Disease Registry CathPCI and Chest Pain-MI registries showed that between 2015 and 2017, the frequency of ECMO use in patients with acute MI complicated by cardiogenic shock who underwent PCI was about 2.6%.21

Patients who received MCS were predominantly Caucasian, representing 58% and 67% of COVID-19+ and COVID-19−, respectively, although 51% of patients in NACMI had minority ethnicity. On the contrary, data from the NACMI registry showed that patients with COVID-19 and STEMI were predominantly ethnic minorities.2 Previous reports have indicated that women and ethnic minorities are less likely to receive MCS and have high mortality.23 Differences in socioeconomic or education status and...
timely access to care are some of the factors associated with disparities in healthcare. It is currently unclear from our study whether Caucasian patients had more unstable presentations compared with other ethnicities or if there was any implicit bias toward the management approach in this high-risk patient population because of the previously mentioned factors. Future studies addressing this key question might shed some light on whether racial and ethnic disparities exist in COVID-19 and STEMI care.

The most striking finding of this study is the very high in-hospital mortality of patients with STEMI with COVID-19 infection who require MCS support, with nearly 2 of 3 patients dying in the hospital. In-hospital mortality rate in patients with STEMI with cardiogenic shock has trended higher in hospitals with COVID-19 requiring MCS and PCI in our registry. 24 Despite similar rates of revascularization and hemodynamic profile, patients with COVID-19+/MCS+ with STEMI had significantly higher rates of in-hospital mortality of 55% compared with 27% in patients with COVID-19−/MCS+. It is likely that COVID-19 infection confers additional risk of mortality to patients with STEMI through concomitant pulmonary involvement, as evidenced by abnormal findings on chest x-rays and more mechanical ventilation in this group, and systemic hypercoagulable state. 25−27

There are important limitations to our study. First, the NACMI registry is a prospective registry that includes only patients with STEMI. Patients with cardiogenic shock requiring MCS from etiologies other than STEMI are not represented in our study. Second, only in-hospital outcomes are reported in the present study. Long-term follow-up data on patients who survived to hospital discharge is ongoing. Third, although the type of MCS device was known, the decision to implant a particular device was left to individual operator discretion and not randomized. Therefore, we are unable to compare different MCS devices. The type of ECMO support was not recorded in the NACMI registry. In addition, the duration of MCS support in these patients was not available. Fourth, whereas a sizable number of patients in the COVID-19+/MCS+ and COVID-19−/MCS+ groups presented with cardiac arrest or had shock pre-PCI, we speculate hemodynamic compromise as a potential indication for MCS used in the rest of the patients and that decision was left to the operator discretion. Finally, we do not have data on the relation between the timing of initiation of MCS and PCI in our registry.

In conclusion, patients with STEMI with COVID-19 infection requiring MCS support have very high in-hospital mortality compared with patients with STEMI without COVID-19 requiring MCS.

Disclosures
The authors have no conflicts of interest to declare.

Supplementary materials
Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2022.09.030.

1. Garcia S, Albaghdadi MS, Meraj PM, Schmidt C, Garberich R, Jaffer FA, Dixon S, Rade JJ, Tannenbaum M, Chambers J, Huang PP, Henry TD. Reduction in ST-segment elevation cardiac catheterization laboratory activations in the United States during COVID-19 pandemic. J Am Coll Cardiol 2020;75:2871–2872.

2. Garcia S, Dehghani P, Grines C, Davidson L, Nayak KR, Saw J, Waksman R, Blair J, Akshay B, Garberich R, Schmidt C, Ly HQ, Sharkey S, Mercado N, Alfonso CE, Misumida N, Acharya D, Madan M, Hafiz AM, Javed N, Shavadiya J, Stone J, Alraies MC, Huhn W, Downey W, Bergmark BA, Ebinger J, Aloysette F, Khalili H, Hwang CW, Purrow J, Llanos A, McGrath B, Tannenbaum M, Resar J, Bagur R, Cox-Alamor P, Stefanesco Schmidt AC, Cilia LA, Jaffer FA, Gharacholou M, Salinger M, Case B, Kabour A, Dai X, Elkhateeb O, Kobayashi T, Kim HH, Roumia A, Aguirre FV, Rade J, Chong AY, Hall HM, Amlani S, Bagherli A, Patel RAG, Wood DA, Welt FG, Giri J, Mahmud E, Henry TD. Society for Cardiac Angiography and Interventions, the Canadian Association of Interventional Cardiology, and the American College of Cardiology Interventional Council. Initial findings from the North American COVID-19 Myocardial Infarction registry. J Am Coll Cardiol 2021;77:1994–2003.

3. Franks CE, Scott MG, Farnsworth CW. Elevated cardiac troponin I is associated with poor outcomes in COVID-19 patients at an Academic Medical Center in Midwestern USA. J Appl Lab Med 2020;5:1137–1139.

4. Shi S, Qiu M, Shen B, Cai Y, Liu T, Yang F, Gong W, Liu X, Liang J, Zhou Q, Huang H, Yang B, Huang C. Association of cardiac injury with mortality in hospitalized patients with COVID-19 in Wuhan, China. JAMA Cardiol 2020;5:802–810.

5. Guo T, Fan Y, Chen M, Wu X, Zhang L, He T, Wang H, Wan J, Wang X, Lu Z. Cardiovascular implications of fatal outcomes of patients with coronavirus disease 2019 (COVID-19). JAMA Cardiol 2020;5:811–818.

6. Merkus TS, Sokoll LJ, Barth AS, Czarny MJ, Hays AG, Lowenstein CJ, Michos ED, Nolley EP, Post WS, Resar JR, Thiemann DR, Trost JC, Hasan RK. Myocardial injury in severe COVID-19 compared with non-COVID-19 acute respiratory distress syndrome. Circulation 2021;143:553–565.

7. Kite TA, Ludman PF, Gale CP, Wu J, Caixeta A, Mansourati J, Sabate M, Jimenez-Quevedo P, Candilio L, Sadeghipour P, Iniesta AM, Hoole SP, Palmer N, Ariza-Sole A, Namitokov A, Escuita-Cuevas HH, Vincent F, Tica O, Ngunga M, Meray A, Morrow A, Arefin MM, Lindsay S, Kazamel G, Sharma V, Saad A, Sinagra G, Sanchez FA, Roik M, Savonitto S, Vavlvukis M, Sangaraju S, Malik IS, Kean S, Curzen N, Berry C, Stone GW, Gersh BJ, Gershlick AH. International COVID-ACS Registry Investigators, International prospective registry of acute coronary syndromes in patients with COVID-19. J Am Coll Cardiol 2021;77:2466–2476.

8. Shah M, Patha S, Patel B, Ram P, Garg L, Agarwal M, Agrawal S, Arora S, Patel N, Wald J, Jorde UP. Trends in mechanical circulatory support use and hospital mortality among patients with acute myocardial infarction and non-infarction related cardiogenic shock in the United States. Clin Res Cardiol 2018;107:287–303.

9. Basir MB, Kapur NK, Patel K, Salam MA, Schreiber T, Kaki A, Hanson I, Almany S, Timmis S, Dixon S, Kolski B, Todd J, Senter M, Marso S, Lasorda D, Wilkins C, Lalonde T, Attallah A, Larkin T, Dupont A, Marshall J, Patel N, Overly T, Green M, Tehrani B, Truesdell AG, Sharma R, Akhtar Y, McRae T, 3rd, O’Neill B, Finley J, Rahman A, Foster M, Askari R, Goldsweig A, Martin S, Bharadwaj A, Khuddus M, Caputo C, Korpas D, Cawich I, McAllister D, Blank N, Alraies MC, Fisher R, Khandelwal A, Alaswad K, Lenmor A, Johnson T, Hakala M, O’Neill WW. National Cardiogenic Shock Initiative Investigators. Improved outcomes associated with the use of shock protocols: updates from the National cardiogenic shock initiative. Catheter Cardiovasc Interv 2019;93:1173–1183.

10. Basir MB, Schreiber T, Dixon S, Alaswad K, Patel K, Almany S, Khandelwal A, Hanson I, George A, Ashbrook M, Blank N, Abdelsalam M, Sareen N, Timmis SBH, O’Neill Md WW. Feasibility of early mechanical circulatory support in acute myocardial infarction complicated by cardiogenic shock: the Detroit cardiogenic shock initiative. Catheter Cardiovasc Interv 2018;91:454–461.

11. Dehghani P, Davidson L, Grines CL, Nayak K, Saw J, Kaul P, Bagai A, Garberich R, Schmidt C, Ly HQ, Giri J, Meraj P, Shah B, Garcia S, Sharkey S, Wood DA, Welt FG, Mahmud E, Henry TD. North American COVID-19 ST-segment-elevation myocardial infarction (NACMI)
infarction complicated by cardiogenic shock: a scientific statement from the American Heart Association. Circulation 2021;143:e815–e829.

19. O’Neill WW, Schreiber T, Wohns DH, Rihal C, Naidu SS, Civitello AB, Dixon SR, Massaro JM, Maini B, Ohman EM. The current use of Impella 2.5 in acute myocardial infarction complicated by cardiogenic shock: results from the USpell Registry. J Interv Cardiol 2014;27:1–11.

20. Barbaro RP, MacLaren G, Boonstra PS, Iwashyna TJ, Slutsy AS, Fan E, Blettelt RH, Tonna JE, Hyslop R, Fanning JJ, Rycus PT, Hyer SJ, Anders MM, Agerstrand CL, Hryniewicz K, Diaz R, Lorusso R, Combes A, Brodie D. Extracorporeal Life Support Organization. Extracorporeal membrane oxygenation support in COVID-19: an international cohort study of the Extracorporeal Life Support Organization registry. Lancet 2020;396:1071–1078.

21. Dhruva SS, Ross JS, Mortazavi BJ, Hurley NC, Krumholz HM, Curtis JP, Berkowitz AP, Masoudi FA, Messenger JC, Parzynski CS, Ngufor CG, Girotta S, Amin AP, Shah ND, Desai NR. Use of mechanical circulatory support devices among patients with acute myocardial infarction complicated by cardiogenic shock. JAMA Netw Open 2021;4:e2037748.

22. Sandhu A, McCoy LA, Negi SI, Hameed I, Atri P, Al’Aref SJ, Curtis J, McNulty E, Anderson HV, Shroff A, Menegus M, Swaninnath RV, Gurum H, Messenger J, Wang T, Bradley SM. Use of mechanical circulatory support in patients undergoing percutaneous coronary intervention: insights from the National Cardiovascular Data Registry. Circulation 2015;132:1243–1251.

23. Ya’qoub L, Lemor A, Dabbagh M, O’Neill W, Khandelwal A, Martinec SC, Ibrahim NE, Grines C, Voeltz M, Basir MB. Racial, ethnic, and sex disparities in patients with STEMI and cardiogenic shock. JACC Cardiovasc Interv 2021;14:653–660.

24. Kolte D, Khera S, Aronow WS, Mujib M, Palaniswamy C, Sule S, Jain D, Gotsis W, Ahmed A, Frishman WH, Fonarow GC, Trends in incidence, management, and outcomes of cardiogenic shock complicating ST-elevation myocardial infarction in the United States. J Am Heart Assoc 2014;3:e000590.

25. Guzik TJ, Mohiddin SA, Dimarco A, Patel V, Savvatis K, Marelli-Berg FM, Madhur MS, Tomaszewski M, Maffia P, D’Acquisto F, Nicklin SA, Marian AJ, Nosalski R, Murray EC, Guzik B, Berry C, Touyz RM, Kreutz R, Wang DW, Bhella D, Sagliocco O, Crea F, Thomson EC, McInnes IB. COVID-19 and the cardiovascular system: implications for risk assessment, diagnosis, and treatment options. Circ Cardiovasc Res 2020;116:1666–1687.

26. Woolf SH, Chapman DA, Sabo RT, Weinberger DM, Hill L, Taylor DDH. Excess deaths from COVID-19 and other causes, March–July 2020. JAMA 2020;324:1562–1564.

27. Dehghani P, Schmidt CW, Garcia S, Okeson B, Grines CL, Singh A, Patel RAG, Wiley J, Hunn WW, Nayak KR, Alraies MC, Ghasezmdeh N, Davidson LJ, Acharya D, Stone J, Aylousf T, Case BC, Dai H, Hazir AM, Madan M, Jaffer FA, Shavadi JS, Garberich R, Bagai A, Singh J, Aronow HD, Mercado N, Henry TD. North American COVID-19 Myocardial Infarction (NACMI) risk score for prediction of in-hospital mortality. J Soc CardioVasc Angiogr Interv 2022;1:100404.