





Cardiogenic Shock: Protocols, Teams, Centers, and Networks

Alex F Warren, MD, ^{1,2} Carolyn Rosner, NP,³ Raghav Gattani, MD, ³
Alex G Truesdell, MD, FSCAI, ^{3,4} and Alastair G Proudfoot, MD, PhD, ^{5,6,7,8}

1. South-East Scotland School of Anaesthesia, Edinburgh, UK; 2. Anaesthesia, Critical Care and Pain, University of Edinburgh, Edinburgh, UK; 3. Inova Heart and Vascular Institute, Falls Church, VA; 4. Virginia Heart, Falls Church, VA; 5. Department of Perioperative Medicine, Barts Heart Centre, London, UK; 6. Clinic for Anaesthesiology and Intensive Care, Charité-Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt Universität zu Berlin, Berlin, Germany; 7. Department of Anaesthesiology and Intensive Care, German Heart Centre Berlin, Berlin, Germany; 8. Queen Mary University of London, London, UK

Abstract

The mortality of cardiogenic shock (CS) remains unacceptably high. Delays in the recognition of CS and access to disease-modifying or hemodynamically stabilizing interventions likely contribute to poor outcomes. In parallel to successful initiatives in other disease states, such as acute ST-elevation MI and major trauma, institutions are increasingly advocating the use of a multidisciplinary ‘shock team’ approach to CS management. A volume–outcome relationship exists in CS, as with many other acute cardiovascular conditions, and the emergence of ‘shock hubs’ as experienced facilities with an interest in improving CS outcomes through a hub-and-spoke ‘shock network’ approach provides another opportunity to deliver improved CS care as widely and equitably as possible. This narrative review outlines improvements from a networked approach to care, discusses a team-based and protocolized approach to CS management, reviews the available evidence and discusses the potential benefits, challenges, and opportunities of such systems of care.

Keywords

Cardiogenic shock, shock teams, acute MI, percutaneous coronary intervention, shock networks

Disclosure: AGT is a consultant for Abiomed and serves on the speakers bureau for Abiomed. AGP declares an unrestricted educational grant from Abbott Vascular. AGT is a Guest Editor for *US Cardiology Review*; this did not influence peer review. All other authors have no conflicts of interest to declare.

Received: March 22, 2021 **Accepted:** June 14, 2021 **Citation:** *US Cardiology Review* 2021;15:e18. **DOI:** <https://doi.org/10.15420/usc.2021.10>

Correspondence: Alastair Proudfoot, Barts Heart Centre, St Bartholomew's Hospital, West Smithfield, London EC1A 7BE, UK. E: alastair.proudfoot1@nhs.net

Open Access: This work is open access under the CC-BY-NC 4.0 License which allows users to copy, redistribute and make derivative works for non-commercial purposes, provided the original work is cited correctly.

Cardiogenic shock (CS) can be defined as a syndrome of low cardiac output with resultant organ hypoperfusion and continues to have a high mortality.^{1–3} CS typically occurs in the setting of acute MI (AMI) or acute decompensated heart failure (ADHF), with or without prior cardiac arrest, and presently accounts for approximately 15% of all cardiac intensive care unit (CICU) admissions.^{4,5} Despite recent consensus efforts to standardize definitions, the complex hemodynamics and variable clinical phenotypes of the CS syndrome mean that the diagnosis and management of CS remain challenging and often require expertise across a range of specialties.^{1,6,7}

Depending on the clinical phenotype of CS, a wide array of interventions, from coronary revascularization, percutaneous or surgical correction of structural heart disease through to mechanical circulatory support (MCS) adjunctive to critical care management, may be required to maintain life-sustaining physiology. Delays in recognition of CS and access to disease-modifying or hemodynamically stabilizing interventions likely contribute to the significant lethality of CS. This may be compounded by heterogeneity of practice within and between hospitals, reflecting a limited evidence base, as well as logistical factors that can delay patient transfer to an experienced center for definitive intervention or hemodynamic assessment and support. These human factor elements are well recognized in other fields of acute care.⁸ The ideal service would deliver evidence-based or best-practice care efficiently, effectively, and reliably, with equity of access

for patients and referrers alike. Care would be multidisciplinary and ideally longitudinal, from resuscitation through to rehabilitation.

As a move towards this model, and in parallel with other time-critical clinical scenarios that have seen quantitative and qualitative improvements in care and process, regional networks of CS care are emerging.^{9–22} Referrers from regional hospitals are supported by a central shock hub staffed with a designated multiprofessional shock team and acute cardiac care specialists, with all the requisite technologies for diagnostics and patient management.^{12,14,15} The reliability of escalation to definitive care is ensured by locally developed protocols, with integration of consensus-guideline best practices to ensure timely and appropriate escalation and de-escalation of care, specifically relating to the use of MCS technologies, and mitigation of complications. In an era of increasing incidence of CS with mortality rates that remain between 30% and 40% in contemporary randomized trials and cohort studies, it is hoped that these systems of care will impact primarily on patient-centered outcomes, as well as on the quality and reliability of care and potentially cost-effectiveness.^{5,23–26}

This narrative review outlines improvements from a networked approach to care, discusses a team-based and protocolized approach to CS, reviews the available evidence and discusses the potential benefits, challenges, and opportunities of such systems of care.

Learning from Other Systems

CS patients form a heterogeneous cohort at the thin end of the wedge of those presenting with heart failure or MI. In other groups of critically ill patients, network-based care has led to improved outcomes.^{9–11} Coordination of ST-elevation MI (STEMI) care is perhaps the exemplar of network-based care. Emergency medical and ambulance services, community hospitals, and tertiary referral centers seamlessly interact to form standardized ‘hub-and-spoke’ STEMI networks to ensure timely reperfusion.⁹ These networks are supported in the US and UK by societal programs, such as the American Heart Association (AHA) and British Cardiac Intervention Society, to provide quality assurance metrics and mechanisms for quality improvement.

In major trauma, the Advanced Trauma Life Support (ATLS) paradigm emphasizes the need for all centers to be able to provide life-saving initial resuscitation and diagnostics, but also the requirement for the sickest patients to be triaged to tertiary ‘hub’ centers for definitive care. Similarly, the ATLS program incorporates research and injury prevention education. Transitioning to this model in major trauma has resulted in both qualitative service improvements and increased survival.¹⁰ Although these systems can result in improved patient outcomes, a key issue in translating these improvements to CS patients is their heterogeneity.^{9–11} Although STEMI and major trauma are relatively easy to classify and triage, the lack of clear consensus as to what constitutes CS and the difficulty in identifying the CS patient prior to manifestations of multiorgan failure provide particular challenges to introducing streamlined systems of care.

Cardiovascular procedural volumes have been consistently and positively associated with improved clinical outcomes, including survival.^{28–32} International practice guidelines recommend minimum procedural volumes for hospitals and operators for the maintenance of both accreditation and competency.^{33,34} In addition to procedural volumes, increased hospital volumes of CS patients are positively associated with improved outcomes in CS.^{35–38} An analysis of a US payer healthcare database including more than 500,000 CS patients demonstrated that hospitals treating <27 cases of CS each year had an absolute in-hospital mortality increase of 5%, compared with hospitals treating ≥107 cases/year.³⁵ A similar effect was seen in a large sample of AMI CS.³⁶ Mortality in centers with durable left ventricular assist device (LVAD) capability, a likely surrogate of existing experience and expertise in the treatment of CS, was lower than in non-LVAD centers, even after accounting for revascularization rates and the use of mechanical support devices.³⁷ Similarly, data from the greater Paris area showed a relative risk reduction in intensive care unit (ICU) mortality of 24% in CS patients managed in a university hospital compared with a non-university facility.³⁸

Although these volume–outcome relationships will be influenced by confounders, they may also reflect increased access to therapies that may improve outcomes in CS. In the US payer healthcare dataset, CS patients in high-volume centers received higher rates of early revascularization in AMI CS and more frequent escalation to MCS.³⁵ In CS patients undergoing percutaneous coronary intervention, intra-aortic balloon pump (IABP) or MCS use was more common in larger hospitals (>600 beds) and university and teaching hospitals than in community hospitals.³⁹ Similarly, the use of invasive hemodynamic monitoring, which may aid in the identification, management, and prognostication of CS, is almost three times more frequent in urban teaching hospitals than in smaller hospitals.^{35,40,41}

Despite this, 90% of AMI CS patients in a US registry were managed in community hospitals, with 43% treated in low-volume coronary

intervention and cardiac surgery centers.²⁴ Another likely contributor to the volume–outcome effect in CS is a ‘failure to rescue’ the sickest CS patients who present to resource-limited, lower-volume centers. Systems of care that foster collaboration between larger and smaller academic and community centers to facilitate the early identification, stabilization, and escalation of CS patients with expedited transfer for definitive management remain an unmet need.

Team-based Care in Cardiogenic Shock

The concept of team-based cardiovascular care is not novel, and heart teams currently support decision making in a range of elective cardiac interventions.^{34,42,43} A critical element of the management of CS is efficient and reliable alerting of a range of specialists to allow collaborative and streamlined decision making in highly complex and potentially high-resource-utilizing patients, particularly where there is a limited evidence base to drive practice.^{13–17} A core team of specialists, the shock team, is essential for time-critical decision making, supported by a wider team to ensure holistic follow-on care. The optimal composition of the shock team will depend on local resources, but contemporary shock teams typically comprise an interventional cardiologist, a cardiac critical care physician, cardiac critical care nurses, an advanced heart failure cardiologist, and a cardiac surgeon. Experience and knowledge in the management of CS is vital given the acuity and heterogeneity of presentation.

Although any given shock team may have leadership with overall responsibility for the patient, decisions should be made by consensus with due regard for the expertise and experience of the team members. Ideally the shock team should be capable of providing a response 24 hours a day, 365 days a year, regardless of patient location: emergency department, ICU, catheter laboratory, operating theatre, or off-site hospital. This reliability and resilience can be supported by technology solutions that allow real-time alerts and conference calling with first responders.⁴⁴ The role of the shock team is to facilitate specific interventions tailored to the etiology of CS and real-time patient physiology, provide expertise that supports locally approved escalation protocols for MCS, and efficiently triage patients to an appropriate care location. Although the evidence base for MCS in cardiogenic shock is incomplete, both European Society of Cardiology and American Heart Association guidelines recommend that patients with CS refractory to first-line therapies undergo evaluation for temporary MCS by a clinical team with experience in MCS technologies.^{45–47} Therefore, the shock team should have the capability to facilitate emergency institution of MCS where deemed appropriate. This underpins the need for the team to consist of clinicians from interventional cardiology, advanced heart failure cardiology, and cardiac surgery.

Finally, it must be remembered that CS is a condition with an exceptionally high mortality. Even when treatment is optimal and best practices are followed, patients may not survive and survivors may suffer complications and unacceptable functional limitation. The time-critical nature of CS requires rapid decision making, often with incomplete premonitory information and an incapacitated patient. As such, it is incumbent on the shock team to ensure that, even when decisions are time-critical, the ethical considerations of aggressive, often highly interventional treatments are borne in mind. Routine involvement of palliative care specialists in decision making has been advocated.⁴⁷ The inclusion of critical care nursing staff and early recourse to palliative care specialists where futility is likely or evident would seem advisable, and consideration of patient or family wishes should be at the forefront of all decision-making.

Table 1: Summary of Contemporary Studies of Cardiogenic Shock Teams and Protocols

Study	Location	Population	Composition	Methodology	No. Patients	Outcomes
Studies of Multidisciplinary CS Team						
Lee et al. ¹⁶	Ottawa, Canada	All CS etiologies	Smartphone-based team activation (ICU, IC, CTS, HF) with mobile MCS capability	Single-center before–after non-randomized study	64 (shock team), 36 (control)	8-month mortality: 67% versus 43%, control versus shock team
Tehrani et al. ¹⁵	Inova Heart and Vascular Institute, VA, US	All CS etiologies	Telephone-based ‘shock line’ (ICU, IC, CTS, HF) with mobile MCS capability	Single-center before–after non-randomized study	204 (shock team); no. for control not reported	30-day mortality: 53% versus 39%, control versus shock team
Taleb et al. ¹⁷	Salt Lake City, UT, US	All CS etiologies, MCS only	Shock team with mobile MCS capability (ICU, IC, CTS, HF)	Single-center before–after non-randomized study	123 (shock team), 121 (control)	In-hospital mortality: 52% versus 39%, control versus shock team
Mannino et al. ^{19*}	WellStar Health System, GA, US	AMI-CS, Impella only	Hub-and-spoke shock team with mobile MCS capability (ICU, IC)	Single-center before–after non-randomized study	37 (control), 156 (shock team + Impella)	In-hospital mortality: 46% versus 29%, control versus shock team
Studies of CS Protocols						
Basir et al. ¹⁸	National Cardiogenic Shock Initiative, 35 US centers	AMI-CS, Impella only	Defined cardiogenic shock protocol including Impella	Multicenter observational cohort study	172	In-hospital mortality: 28%
Studies of Mobile MCS Teams						
Jaroszewski et al. ²⁰	Mayo Clinic, AZ, US	All CS etiologies, MCS only	Mobile shock team (CTS/HF, perfusion, nursing)	Single-center observational cohort study	22 [†]	In-hospital mortality: 55%
Beurtheret et al. ²¹	Greater Paris area, France	All CS etiologies, VA-ECMO only [‡]	Mobile shock team (ICU, CTS, perfusion, nursing)	Single-center observational cohort study	87	In-hospital mortality: 63%
Ali et al. ²²	Royal Papworth Hospital, Cambridge, UK	All CS etiologies, VA-ECMO only	Mobile shock team (ICU, CTS, HF, perfusion, nursing)	Single-center observational cohort study	24	1-year mortality: 40%

*Non peer-reviewed study. †Cardiogenic shock (CS) patients only reported in this table. The original report contained five patients supported with mechanical cardiac support (MCS; here including intra-aortic balloon pump counterpulsation, veno-arterial extracorporeal membrane oxygenation [VA-ECMO] and the Impella microaxial left ventricular assist device [Abiomed]) for acute respiratory failure who are not included here. ‡Included patients with VA-ECMO instituted with ongoing cardiopulmonary resuscitation. ICU = intensive care; IC = interventional cardiology; CTS = cardiothoracic surgery; HF = heart failure cardiology.

Protocolized Care in Cardiogenic Shock

A number of healthcare systems in North America have described the development of shock teams and associated escalation protocols to streamline care and improve outcomes in patients with CS (Table 1). To date, there are no randomized studies on the use of CS teams, and comparisons are limited to historical controls from before–after studies.

The three largest reported studies to date included a total of 391 CS patients treated by multidisciplinary shock teams.^{15–17} The introduction of a telephone-activated multidisciplinary shock team at the Inova Heart and Vascular Institute in Virginia, accompanied by an institutional protocol for CS management, was associated with a reduction in 30-day mortality from 53% to 23%.^{14,15} A longer-term survival benefit was also reported from the introduction of a smartphone-activated shock team at the University of Ottawa, which was associated with a reduction in 8-month mortality from 67% to 43%.¹⁶ Both these studies introduced multidisciplinary shock teams comprising at least clinicians from critical care, heart failure cardiology, interventional cardiology, and cardiac surgery.

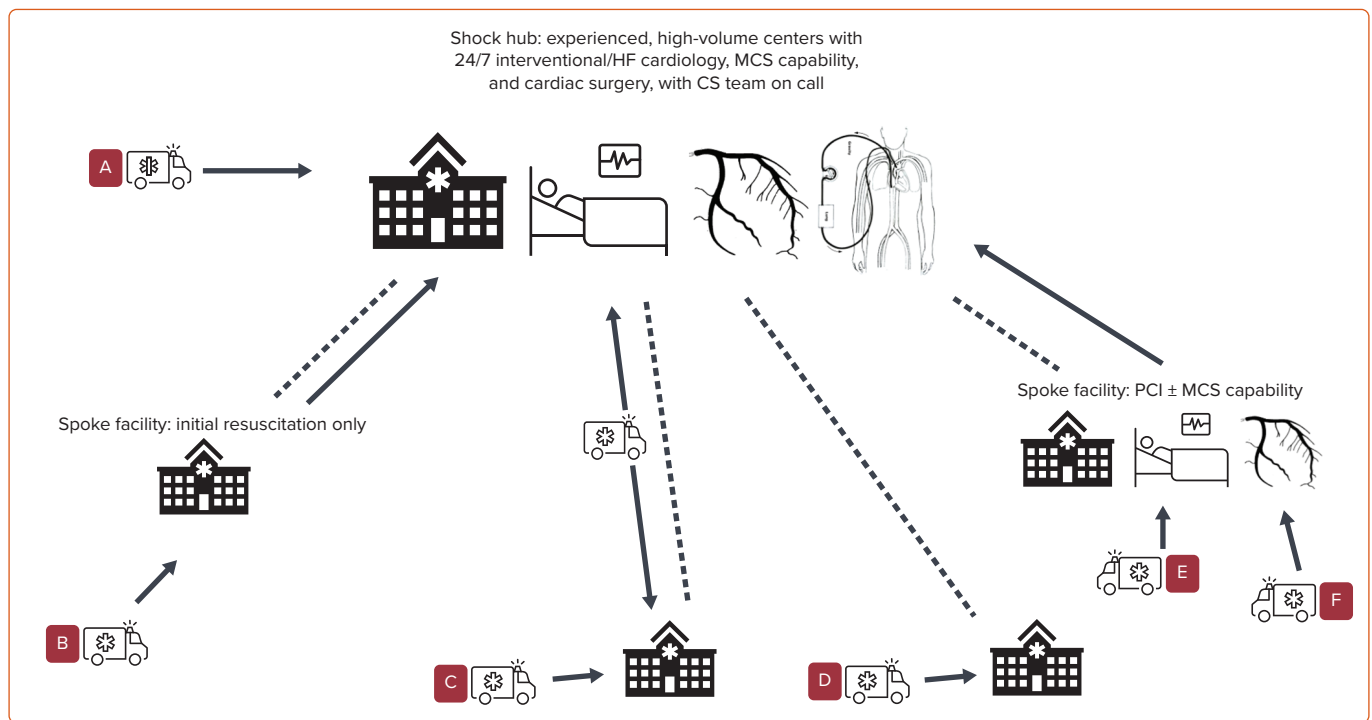
Although the majority of clinical decision making may be conducted by the core team, the involvement of the wider patient care team cannot be underestimated. Care is improved when bedside nursing staff and allied health professionals (including physiotherapy, occupational therapy, pharmacy, nutrition and dietetics, and perfusion staff) have experience of treating CS patients, including those on MCS. Because CS patients often develop multiorgan dysfunction and a systemic inflammatory response

syndrome, other available specialist physicians with an interest and experience in CS, including, but not limited to, nephrology, hematology, electrophysiology, anesthesia, and stroke medicine, also form part of the wider circle of individuals involved in the care of CS patients.

Other studies of shock teams have similarly reported the outcomes of CS patients treated with MCS as part of a multidisciplinary team approach. A study from the University of Utah compared 123 patients treated with short-term MCS by a shock team to a historical cohort of consecutive MCS patients without a team-based approach, reporting a reduction in in-hospital mortality from 52% to 39%.¹⁷ The National Cardiogenic Shock Initiative included 172 patients with AMI CS managed at 35 US centers with a protocol emphasizing early revascularization supported by pre-percutaneous coronary intervention (PCI) MCS, with a percutaneous microaxial flow left ventricular device (Impella, Abiomed) guided by hemodynamic data.¹⁸ This approach improved survival from 50% in a historical cohort to 72%, although the use of a shock team to support decision-making was not specified.¹⁶ A single-center study from the WellStar Health System in Georgia reported before and after hospital mortality of 46% and 29%, respectively, in a non-peer-reviewed study of a hub-and-spoke CS network in 156 patients treated with Impella.¹⁹

Although caution must be exercised in drawing conclusions from observational before–after studies, there is both a compelling rationale for the role of shock teams and a growing body of data to support patient-level benefit. Which specific aspects of shock protocols are likely to be

Figure 1: Example of a Hub-and-Spoke Cardiogenic Shock Network Showing Possible Patient Pathways Within the System



A: The patient is transferred directly to the shock hub as the nearest suitable hospital. B: The patient presents to a spoke hospital. CS is identified, the shock team is activated, and the patient is transferred to the shock hub for ongoing care. C: The patient presents to a spoke hospital. The shock team is activated and deploys a mobile mechanical circulatory support (MCS) team to retrieve the patient to the shock hub and provide on-site MCS at the local hospital if required. D: The patient presents to a spoke hospital. Discussions within the shock team lead to a consensus decision that advanced therapy is inappropriate. Palliative care is instituted at the local hospital. E: A patient is streamed by emergency medical services (EMS) to a percutaneous coronary intervention (PCI)-capable spoke hospital, receives revascularization but develops CS and is transferred to a shock hub for ongoing care. F: A patient develops CS at a PCI-capable spoke hospital. The patient is discussed with shock team, which advises on care, but transfer to a shock hub is not required. HF = heart failure; CS = cardiogenic shock; MCS = mechanical circulatory support.

Table 2: Definitions of Key Components of a Network-based Approach for Cardiogenic Shock

Shock Team

A core group of medical specialists collaborating in the multidisciplinary management of CS to include: rapid diagnosis; identification of specific CS phenotypes; recommendation and facilitation of definitive interventions, including MCS; recognition of futility and engagement of palliative care; triage of patients to the appropriate clinical care environment, including transfer to the network shock hub; and identification of patients suitable for clinical trial enrollment

Shock Hub

A facility with core service components that allow high-quality, reliable, and longitudinal care, with evidence-based interventions or locally established best practices. This includes an established shock team, the use of escalation algorithms and protocols, information technology solutions to support real-time communication between the shock team and referrers, infrastructure for data collection for quality and research purposes, and enrollment of patients in clinical trials. Typically, hubs will have a range of MCS options and would usually have access to durable MCS and the capability to evaluate and list for heart transplantation

Shock Network

A formal or informal community of hospitals within a geographic region committed to high-quality clinical care, education, uniform data collection, quality improvement, and evidence generation through clinical trials

CS = cardiogenic shock; MCS = mechanical circulatory support.

essential and affect mortality remains unclear. Protocols may standardize clinical approach within and across institutions. However, they may fail to address complex issues in real-world settings or allow individualization of patient care. Despite recent advances in classification, CS remains ill-defined and incorporates a range of phenotypes that cannot be

encapsulated by limited physiological and biochemical parameters alone.^{6,48,49} The role of early, pre-revascularization MCS in AMI CS remains unproven in randomized trials, as does the role of right heart catheter data to guide decision making and escalation to MCS, despite supportive observational data.^{45,50,51} Given the burden of complications of MCS and their effects on mortality, protocols pertaining to large-bore vascular access, anticoagulation, and MCS weaning and removal would seem prudent. Therefore, the role of shock teams may be to synthesize and analyze a locally (or regionally) defined minimum dataset of clinical, biochemical, imaging, and physiological parameters to guide the optimal timing of escalation to MCS, as well as device and patient selection.

Shock Hubs Within Networks of Cardiogenic Shock Care: Towards a 21st Century System of Care

The development and maturation of shock teams within high-volume cardiac centers is an intuitive first step. However, the extension of this expertise throughout a more formative network of CS care is required to deliver care equitably for both patients and referrers, and to improve patient-level outcomes at scale. This approach to CS care level has been advocated by societal guidelines and consensus statements.^{47,50,52} Proposed definitions of the requisite components of a network are outlined in Table 2. Given the prevalence of AMI CS within the cohort of CS patients as a whole, existing pathways to prioritize primary PCI in STEMI are a natural starting point, while also recognizing that non-AMI-related CS patients will have discrete needs, and may present through different pathways throughout the network. The outline of a potential regional shock network is shown in Figure 1, with key clinical logistical and organizational elements outlined in Table 3. Peripheral-spoke hospitals

Table 3: Criteria for the Ideal Cardiogenic Shock Network

Clinical
24/7 availability of multidisciplinary shock team comprising at least interventional cardiology (including structural heart interventions), advanced heart failure cardiology, cardiac critical care, and cardiac surgery to both discuss patient management and accept for rapid triage and transfer to a shock hub
Availability to provide MCS 24/7, with experience and expertise in the use of these devices (including medical, nursing, and perfusion staff)
Locally agreed escalation protocols based on clinical, hemodynamic, biochemical, and imaging data that are iterated as new evidence or data evolve
Inpatient acute care provided on a dedicated CICU with multidisciplinary expertise in acute cardiac care and MCS
Nurse:patient ratio of 1:1 for CS patients in the intensive care unit
Provision of, or ability to rapidly refer and transfer to, a durable LVAD and cardiac transplantation service
Logistical
A rapid and accessible call-out system to facilitate real-time discussion between the shock team and referring clinicians
Ability to safely and rapidly transfer CS patients from referring facilities to shock hubs, including the use of mobile MCS when required
Organizational
A commitment to leading and improving the management of CS patients, with dedicated time for key individuals
Incorporation of evidence-based practice and identification of best practices where limited high-quality evidence exists with protocolized escalation of care
Open culture of learning and a multifacility, multidisciplinary governance process including regular case reviews to ensure identification and discussion of quality improvement initiatives
Embedded routine collection of referral and outcome data with patient follow-up and patient-centered outcomes
Multidisciplinary education program with associated nursing and trainee education within acute cardiac critical care training programs
Research infrastructure and collaboration with other CS networks, and willingness to incorporate randomized and observational trials into clinical practice
<i>CICU = cardiac intensive care unit; CS = cardiogenic shock; LVAD = left ventricular assist device; MCS = mechanical cardiac support.</i>

may provide a range of services, including primary PCI and/or percutaneous MCS therapies, but many will only have the facility to provide initial assessment and resuscitation of patients. Because most CS patients will not present to a shock hub, the approach should be collaborative, with representatives from all types of facilities involved in all aspects of networked care delivery from inception.^{24,35}

For the sickest CS patients (Society for Cardiovascular Angiography and Interventions stage D or E⁶), survival may depend on rapid access to MCS to sustain physiology; when such patients present at spoke centers without the ability to institute MCS locally, they will often also be too unstable to safely transfer to definitive care. A number of single-center studies have described mobile MCS teams set up to retrieve patients from off-site hospitals after institution of MCS.^{20–22} These cohorts, although small, report higher mortality than studies of systems where patients are moved to an MCS center and escalated according to local protocols. Whether this reflects a selection bias, the benefit of care in an experienced center, or the role of local protocols in patient selection is unclear. Nonetheless, based on these data, mobile MCS is safe and feasible.^{20–22} The need for transport infrastructure within a CS network will depend on local geography and healthcare organization. The key standard is that the

Table 4: Key Performance Indicators for Shock Centers of Excellence

Door-to-balloon time for AMI CS
Door-to-shock team activation time
Full complement of multispecialty shock team on each alert
Shock team mustered and available within 5–10 min of activation
Access to coronary revascularization in all eligible patients
Adherence to locally agreed escalation protocols, including use of right heart catheterization
Comparable outcomes between patients presenting to a shock hub and those who are transferred in from an outlying ‘spoke’ center
Regular assessment and reassessment by the shock team on CICU
All eligible patients discussed with the regional advanced heart failure service to determine eligibility for durable MCS or heart transplantation
Engagement of palliative care services where futility is recognized and end-of-life care proposed
After action, review of all cases where concern regarding ‘failure to rescue’ and learning documented and implemented
Use of a nationalized and harmonized CS case report form for data collection
Registry data validity and quality control
Minimum quarterly clinical and governance meeting between hub and spoke clinicians to discuss outcomes, quality metrics, critical incidents, and research enrollment/ opportunities
<i>AMI = acute MI; CICU = cardiac intensive care unit; CS = cardiogenic shock; LVAD = left ventricular assist device; MCS = mechanical cardiac support.</i>

patients throughout a network have equitable and timely access to specialist support and associated interventions such as MCS.

Given the overlap between CS and cardiac arrest, and the emerging evidence base for extracorporeal membrane oxygenation in the treatment of refractory sudden cardiac arrest, extracorporeal cardiopulmonary resuscitation (eCPR) capability is likely to become a prerequisite for shock hubs.^{53,54} Although much of the infrastructure required for CS systems overlaps with that required for eCPR, eCPR demands 24/7 on-site expertise for patient selection and cannulation that may require the triage of patients to select geographical hubs or even mobilization of cannulation teams to the patient in the field. The resource implications of eCPR service provision are significant and should be balanced with the provision of optimal CS care at scale within shock hubs.

As CS systems of care evolve, it is vital to ensure continued stakeholder engagement, integration, and quality improvement inclusive across the entire patient journey. Clear pathways and protocols should be developed for referral, acceptance, transfer, and repatriation. Reimbursement will vary across healthcare systems, but an analysis of cost and the cost-effectiveness of the shock team and a networked approach have not been adequately described. Despite the challenges of clinical governance across different institutions, the limited evidence base to guide interventions and high complication rates with MCS should mandate an open culture of learning across the network to ensure that ‘failure to rescue’ scenarios are identified and mitigated and that protocols and best practices are iterated as local experience and published data evolve, complications are minimized, and outcomes are optimized.

These quality improvement efforts require routine and robust data collection. Networked data collection and integration would also facilitate longer-term follow-up data analysis, including post-discharge healthcare

utilization and quality of life metrics, and a shift towards a holistic model of CS care from resuscitation to recovery. Nonetheless, although local registries provide valuable information about participating network sites, simple comparisons between hospitals are not sufficiently reliable for reporting trends in demographics, access to interventions, and patient outcomes. Ultimately, data collection and analysis at scale could be achieved via a harmonized national case report form. This model has been adopted by the American Heart Association through the Get With the Guidelines initiative, which has led to transformation across several facets of acute cardiac care and could be a template for development of a nationalized CS registry given the overlap with existing programs in AMI and out-of-hospital cardiac arrest.^{55–57} This model may assist in validated designation of CS ‘centers of excellence’ using putative key performance metrics (Table 4).

Beyond quality improvement, research infrastructure and efficient approaches to informed consent should be a defining criterion of shock hubs. Given the historical challenges of patient recruitment to CS trials, it is imperative that with centralization of the sickest CS patients to shock hubs, the opportunity for clinical trial enrolment is leveraged.⁵⁸ Research activity is associated with better clinical outcomes in acute care and should form part of shock network activity.⁵⁹

Indeed, it should be remembered that with the exception of early revascularization in AMI CS, none of the interventions likely to be instituted by CS teams, systems, or shock hubs (e.g. MCS, invasive hemodynamic monitoring, or protocolized care) have been shown to improve outcomes in randomized trials.⁶⁰ Given the clear need to improve the evidence base for CS, the authors suggest that a key role of the shock team should be identification of eligible patients for future observational and randomized, intervention-based trials.

Conclusion

Mortality in cardiogenic shock remains unacceptably high. As has been demonstrated in other diseases, a multidisciplinary protocolized team-based approach with regional hub-and-spoke networks of care built around high-volume, experienced centers is likely to improve outcomes. The existing data, although incomplete, support this approach. The development of processes to ensure equitable access to CS care across geographical and institutional boundaries requires a consensus approach with a robust educational and governance structure alongside clinical pathways. As the clinical care of CS patients continues to improve, the creation of CS networks provides a unique opportunity to replicate the success of other acute cardiovascular care pathways and realize improved outcomes for this disease, as well as engagement in future clinical trials. □

1. Chioncel O, Parissis J, Mebazaa A, et al. Epidemiology, pathophysiology and contemporary management of cardiogenic shock – a position statement from the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail* 2020;22:1315–41. <https://doi.org/10.1002/ejhf.1922>; PMID: 32469155.
2. Stead EA Jr, Ebert RV. Shock syndrome produced by failure of the heart. *Arch Intern Med* 1942;69:369–83. <https://doi.org/10.1001/archinte.1942.00200150002001>.
3. Vahdatpour C, Collins D, Goldberg S. Cardiogenic shock. *J Am Heart Assoc* 2019;8:e011991. <https://doi.org/10.1161/JAHA.119.011991>; PMID: 30947630.
4. Bohula EA, Katz JN, van Diepen S, et al. Demographics, care patterns, and outcomes of patients admitted to cardiac intensive care units. *JAMA Cardiol* 2019;4:928–35. <https://doi.org/10.1001/jamacardio.2019.2467>; PMID: 31339509.
5. Berg DD, Bohula EA, van Diepen S, et al. Epidemiology of shock in contemporary cardiac intensive care units. *Circ Cardiovasc Qual Outcomes* 2019;12:e005618. <https://doi.org/10.1161/CIRCOUTCOMES.119.005618>; PMID: 30879324.
6. Baran DA, Grines CL, Bailey S, et al. SCAI clinical expert consensus statement on the classification of cardiogenic shock. *Catheter Cardiovasc Interv* 2019;94:29–37. <https://doi.org/10.1002/ccd.28329>; PMID: 31104355.
7. Samsky M, Krucoff M, Althouse AD, et al. Clinical and regulatory landscape for cardiogenic shock: a report from the Cardiac Safety Research Consortium ThinkTank on cardiogenic shock. *Am Heart J* 2020;219:1–8. <https://doi.org/10.1016/j.ahj.2019.10.006>; PMID: 31707323.
8. Edwards FH, Ferraris VA, Kurlansky PA, et al. Failure to rescue rates after coronary artery bypass grafting: an analysis from the Society of Thoracic Surgeons adult cardiac surgery database. *Ann Thorac Surg* 2016;102:458–64. <https://doi.org/10.1016/j.athoracsur.2016.04.051>; PMID: 27344280.
9. Huber K, Gersh BJ, Goldstein P, et al. The organization, function, and outcomes of ST-elevation myocardial infarction networks worldwide: current state, unmet needs and future directions. *Eur Heart J* 2014;35:1526–32. <https://doi.org/10.1093/eurheartj/ehu125>; PMID: 24742888.
10. Moran CG, Lecky F, Bouamra O, et al. Changing the system – major trauma patients and their outcomes in the NHS (England) 2008–17. *EJ Clin Med* 2018;2:3:13–21. <https://doi.org/10.1016/j.ejclinm.2018.07.001>; PMID: 31193723.
11. Warren A, Chiu Y-D, Villar SS, et al. Outcomes of the NHS England National Extracorporeal Membrane Oxygenation Service for adults with respiratory failure: a multicentre observational cohort study. *Br J Anaesth* 2020;125:259–66. <https://doi.org/10.1016/j.bja.2020.05.065>; PMID: 32736826.
12. Tchantchaleishvili V, Hallinan W, Massey HT. Call for organized statewide networks for management of acute myocardial infarction-related cardiogenic shock. *JAMA Surg* 2015;150:1025–6. <https://doi.org/10.1001/jamasurg.2015.2412>; PMID: 26375168.
13. Rab T, Ratanapo S, Kern KB, et al. Cardiac shock care centers: JACC Review Topic of the Week. *J Am Coll Cardiol* 2018;72:1972–80. <https://doi.org/10.1016/j.jacc.2018.07.074>; PMID: 30309475.
14. Truesdell AG, Tehrani B, Singh R, et al. ‘Combat’ approach to cardiogenic shock. *Interv Cardiol* 2018;13:81–6. <https://doi.org/10.15420/icr.2017.35:3>; PMID: 29928313.
15. Tehrani BN, Truesdell AG, Sherwood MW, et al. Standardized team-based care for cardiogenic shock. *J Am Coll Cardiol* 2019;73:1659–69. <https://doi.org/10.1016/j.jacc.2018.12.084>; PMID: 30947919.
16. Lee F, Hutson JH, Boodhwani M, et al. Multidisciplinary code shock team in cardiogenic shock: a Canadian centre experience. *CJC Open* 2020;2:249–57. <https://doi.org/10.1016/j.cjco.2020.03.009>; PMID: 32695976.
17. Taleb I, Koliopoulou AG, Tandar A, et al. Shock team approach in refractory cardiogenic shock requiring short-term mechanical circulatory support. *Circulation* 2019;140:98–100. <https://doi.org/10.1161/circulationaha.119.040654>; PMID: 31549877.
18. Basir MB, Kapur NK, Patel K, et al. Improved outcomes associated with the use of shock protocols: updates from the National Cardiogenic Shock Initiative. *Catheter Cardiovasc Interv* 2019;93:1173–83. <https://doi.org/10.1002/ccd.28307>; PMID: 31025538.
19. Tierney MC. Hub & spoke: improving cardiogenic shock outcomes at WellStar. *Cardiovascular Business* 2019;Sept–Oct:22–5. <https://www.cardiovascularbusiness.com/sponsored/1172/topics/practice-management/hub-spoke-improving-cardiogenic-shock-outcomes-wellstar> (accessed March 7, 2021).
20. Jaroszewski DE, Kleisli T, Staley L, et al. A traveling team concept to expedite the transfer and management of unstable patients in cardiopulmonary shock. *J Heart Lung Transplant* 2011;30:618–23. <https://doi.org/10.1016/j.healun.2010.11.018>; PMID: 21239189.
21. Beurtheret S, Mordant P, Paoletti X, et al. Emergency circulatory support in refractory cardiogenic shock patients in remote institutions: a pilot study (the Cardiac-RESCUE program). *Eur Heart J* 2013;34:112–20. <https://doi.org/10.1093/eurheartj/ehs081>; PMID: 22513777.
22. Ali JM, Vuylsteke A, Fowles JA, et al. Transfer of patients with cardiogenic shock using veno-arterial extracorporeal membrane oxygenation. *J Cardiothorac Vasc Anesth* 2020;34:374–82. <https://doi.org/10.1053/j.jvca.2019.05.012>; PMID: 31221511.
23. Thiele H, Zeymer U, Neumann FJ, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. *N Engl J Med* 2012;367:1287–96. <https://doi.org/10.1056/nejmoa1208410>; PMID: 22920912.
24. Wayankar SA, Bangalor S, McCoy LA, et al. Temporal trends and outcomes of patients undergoing percutaneous coronary interventions for cardiogenic shock in the setting of acute myocardial infarction: a report from the CathPCI registry. *JACC Cardiovasc Interv* 2016;9:341–51. <https://doi.org/10.1016/j.jcin.2015.10.039>; PMID: 26803418.
25. Thiele H, Akin I, Sandri M, et al. Strategies in patients with acute myocardial infarction and cardiogenic shock. *N Engl J Med* 2017;377:2419–32. <https://doi.org/10.1056/NEJMoa1710261>; PMID: 29083953.
26. Lauridsen MD, Rorth R, Lindholm MG, et al. P5012: Ten-year trends and outcomes in cardiogenic shock related to first-time acute myocardial infarction: a nationwide population-based cohort study. *Eur Heart J* 2019;40(Suppl 1):ehz746.0190. <https://doi.org/10.1093/eurheartj/ehz746.0190>.
27. American College of Surgeons (ACS) Committee on Trauma. *Advanced Trauma Life Support*. 10th ed. Chicago, IL: ACS, 2018.
28. Kumbhani DJ, Cannon CP, Fonarow GC, et al. Association of hospital primary angioplasty volume in ST-segment elevation myocardial infarction with quality and outcomes. *JAMA* 2009;302:2207–13. <https://doi.org/10.1001/jama.2009.1715>; PMID: 19934421.
29. Shah N, Chothani A, Agarwal V, et al. Impact of annual hospital volume on outcomes after left ventricular assist device (LVAD) implantation in the contemporary era. *J Card Fail* 2016;22:232–7. <https://doi.org/10.1016/j.cardfail.2015.10.016>; PMID: 26547012.
30. Pettit SJ, Jhund PS, Hawkins NM, et al. How small is too small? A systematic review of center volume and outcome after cardiac transplantation. *Circ Cardiovasc Qual Outcomes* 2018;5:783–90. <https://doi.org/10.1161/CIRCOUTCOMES.112.966630>; PMID: 23132331.
31. Alkhouli M, Alqahtani F, Cook CC. Association between surgical volume and clinical outcomes following coronary artery bypass grafting in contemporary practice. *J Card Surg* 2019;34:1049–54. <https://doi.org/10.1111/jocs.14205>; PMID: 31389634.
32. Becher PM, Goßling A, Schrage B, et al. Procedural volume and outcomes in patients undergoing VA-ECMO support. *Crit Care* 2020;24:291. <https://doi.org/10.1186/s13054-020-03016-z>; PMID: 32503646.
33. Banning AP, Baumbach A, Blackman D, et al. Percutaneous coronary intervention in the UK: recommendations for good practice 2015. *Heart* 2015;101:1–13. <https://doi.org/10.1136/heartjnl-2015-307821>; PMID: 23041756.
34. Wijns W, Kolh P, Danchin N, et al. Guidelines on myocardial revascularization. *Eur Heart J* 2010;31:2501–55. <https://doi.org/10.1093/eurheartj/ehq277>; PMID: 20802248.
35. Shaefi S, O’Gara B, Kociol RD, et al. Effect of cardiogenic shock hospital volume on mortality in patients with cardiogenic shock. *J Am Heart Assoc* 2015;4:e001462. <https://doi.org/10.1161/JAHA.114.001462>; PMID: 25559014.
36. Vallabhajosyula S, Dunlay SM, Barsness GW, et al. Hospital-level disparities in the outcomes of acute myocardial infarction with cardiogenic shock. *Am J Cardiol* 2019;124:491–8. <https://doi.org/10.1016/j.amjcard.2019.05.038>; PMID: 31221462.
37. Wang JI, Lu DY, Feldman DN, et al. Outcomes of hospitalizations for cardiogenic shock at left ventricular assist device versus non-left ventricular assist device

- centers. *J Am Heart Assoc* 2020;9:e017326. <https://doi.org/10.1161/JAHA.120.017326>; PMID: 33222608.
38. Puymirat E, Fagon JY, Aegerter P, et al. Cardiogenic shock in intensive care units: evolution of prevalence, patient profile, management and outcomes, 1997–2012. *Eur J Heart Fail* 2017;19:192–200. <https://doi.org/10.1002/ehf.646>; PMID: 27709722.
 39. Sandhu A, McCoy LA, Negi SI, et al. Use of mechanical circulatory support in patients undergoing percutaneous coronary intervention. *Circulation* 2015;132:1243–51. <https://doi.org/10.1161/circulationaha.114.014451>; PMID: 26286905.
 40. Osman M, Balla S, Patibandla S, et al. Regional variation in the adoption of invasive hemodynamic monitoring for cardiogenic shock in the United States. *Am J Cardiol* 2021;148:174–5. <https://doi.org/10.1016/j.amjcard.2021.02.028>; PMID: 33667450.
 41. Vallabhajosyula S, Shankar A, Patlolla SH, et al. Pulmonary artery catheter use in acute myocardial infarction-cardiogenic shock. *ESC Heart Fail* 2020;7:1234–45. <https://doi.org/10.1002/ehf2.12652>; PMID: 32239806.
 42. Fihn SD, Blankenship JC, Alexander KP, et al. 2014 ACC/AHA/AATS/PCNA/SCAI/STS focused update of the guideline for the diagnosis and management of patients with stable ischemic heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines, and the American Association for Thoracic Surgery, Preventive Cardiovascular Nurses Association, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. *J Thorac Cardiovasc Surg* 2015;149:e5–23. <https://doi.org/10.1016/j.jacc.2014.07.017>; PMID: 25827388.
 43. Gibbs D, Eusebio C, Sanders J, et al. Clinician perceptions of the impact of a shock team approach in the management of cardiogenic shock: a qualitative study. *Cardiovasc Revasc Med* 2021;22:78–83. <https://doi.org/10.1016/j.carrev.2020.06.011>; PMID: 32591309.
 44. The app that connects heart specialists to provide life-saving treatment. Barts Health NHS Trust. February 6, 2020. <https://www.bartshealth.nhs.uk/news/the-app-that-connects-heart-specialists-to-provide-lifesaving-treatment-7261> (accessed March 7, 2021).
 45. Combes A, Price S, Slutsky AS, Brodie D. Temporary circulatory support for cardiogenic shock. *Lancet* 2020;396:199–212. [https://doi.org/10.1016/S0140-6736\(20\)31047-3](https://doi.org/10.1016/S0140-6736(20)31047-3); PMID: 32682486.
 46. Ponikowski P, Voors AA, Anker SD, et al. 2016 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure: the Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure of the European Society of Cardiology (ESC). Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur Heart J* 2016;37:2129–200. <https://doi.org/10.1093/eurheartj/ehw128>; PMID: 27206819.
 47. Diepen S van, Katz JN, Albert NM, et al. Contemporary management of cardiogenic shock: a scientific statement from the American Heart Association. *Circulation* 2017;136:e232–68. <https://doi.org/10.1161/CIR.0000000000000525>; PMID: 28923988.
 48. Menon V, White H, LeJemtel T, et al. The clinical profile of patients with suspected cardiogenic shock due to predominant left ventricular failure: a report from the SHOCK Trial Registry. *J Am Coll Cardiol* 2000;36:1071–6. [https://doi.org/10.1016/s0735-1097\(00\)00874-3](https://doi.org/10.1016/s0735-1097(00)00874-3); PMID: 10985707.
 49. Kohsaka S, Menon V, Lowe AM, et al. Systemic inflammatory response syndrome after acute myocardial infarction complicated by cardiogenic shock. *Arch Intern Med* 2005;165:1643–50. <https://doi.org/10.1001/archinte.165.14.1643>; PMID: 16043684.
 50. Thiele H, Ohman EM, de Waha-Thiele S, et al. Management of cardiogenic shock complicating myocardial infarction: an update 2019. *Eur Heart J* 2019;40:2671–83. <https://doi.org/10.1093/eurheartj/ehz363>; PMID: 31274157.
 51. Thayer K, Zweck E, Hernandez-Montfort J, et al. Pulmonary artery catheter usage and mortality in cardiogenic shock. *J Heart Lung Transplant* 2020;39(Suppl):S54–5. <https://doi.org/10.1016/j.healun.2020.01.1240>; PMID: 32465974.
 52. Abrams D, Garan AR, Abdelbary A, et al. Position paper for the organization of ECMO programs for cardiac failure in adults. *Intensive Care Med* 2018;44:717–29. <https://doi.org/10.1007/s00134-018-5064-5>; PMID: 29450594.
 53. Yannopoulos D, Bartos J, Raveendran G, et al. Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial. *Lancet* 2020;396:1807–16. [https://doi.org/10.1016/S0140-6736\(20\)32338-2](https://doi.org/10.1016/S0140-6736(20)32338-2); PMID: 33197396.
 54. Bělohávek J. Hyperinvasive approach in refractory out-of-hospital cardiac arrest. Prague OHCA study. A randomized clinical trial. Presented at American College of Cardiology's 70th Annual Scientific Session, May 17, 2021. <https://www.ccronline.org/presentation-detail/hyperinvasive-approach-in-refractory-out-of-hospital> (accessed August 24, 2021).
 55. Ellrodt AG, Fonarow GC, Schwamm LH, et al. Synthesizing lessons learned from Get With The Guidelines. *Circulation* 2013;128:2447–60. <https://doi.org/10.1161/cir.0000435779.480075c>; PMID: 24166574.
 56. Lewis WR, Ellrodt AG, Peterson E, et al. Trends in the use of evidence-based treatments for coronary artery disease among women and the elderly. *Circ Cardiovasc Qual Outcomes* 2009;2:633–41. <https://doi.org/10.1161/CIRCOUTCOMES.108.824763>; PMID: 20031902.
 57. Starks MA, Dai D, Nichol G, et al. The association of duration of participation in Get With The Guidelines-resuscitation with quality of care for in-hospital cardiac arrest. *Am Heart J* 2018;204:156–62. <https://doi.org/10.1016/j.ahj.2018.04.018>; PMID: 30121017.
 58. Shaffer A, Sheikh O, Prasad A. Cardiogenic shock: a systemic review of clinical trials registered with ClinicalTrials.gov. *J Invasive Cardiol* 2020;32:e86–96. PMID: 32240097.
 59. Ozdemir BA, Karthikesalingam A, Sinha S, et al. Research activity and the association with mortality. *PLoS One* 2015;10:e0118253. <https://doi.org/10.1371/journal.pone.0118253>; PMID: 25719608.
 60. Hochman JS, Sleeper LA, Webb JG, et al. Early revascularization in acute myocardial infarction complicated by cardiogenic shock. *N Engl J Med* 1999;341:625–34. <https://doi.org/10.1056/nejm199908263410901>; PMID: 10460813.