Timely reperfusion for patients with an ST-elevation myocardial infarction (STEMI) reduces myocardial cell loss resulting in preserved LV performance, a reduced incidence of congestive heart failure, and significantly lower early and late mortality,\(^1\) while conversely, any delay in reperfusion has a deleterious effect on morbidity and mortality.\(^2\) Originally, the recommended time-to-treatment targets focused on hospital arrival to treatment metrics, e.g., \(\leq 30\) min from hospital arrival to fibrinolytic drug administration.\(^3\) Subsequent research established primary percutaneous coronary intervention (PCI) to be the more effective reperfusion strategy with an initial goal of hospital door-to-balloon (updated to door-to-device) time \(\leq 90\) min.\(^4\) Recent ACC/AHA STEMI treatment guidelines recommended primary PCI as the preferred reperfusion strategy, if a first medical contact-to-device (FMC-D) time \(\leq 90\) min could be achieved for patients directly transported by emergency medical systems (EMS) to a PCI-hospital or \(\leq 120\) min for those who are initially transported to a STEMI referral (non-PCI) hospital.\(^5\) Establishment of regional systems of STEMI care was strongly recommended in order to facilitate the achievement of these time-to-treatment goals.\(^5,6\) These STEMI care systems have evolved over the last 10 years from relatively simple hub and spoke designs, encompassing one or at most a few non-PCI hospitals and EMS services referring to a single PCI-hospital, to more complex systems serving large metropolitan areas or entire states.\(^7\) Outside of the United States, where national health care systems exist, STEMI systems may encompass entire countries, but with varying degrees of penetration.\(^12\) While tailored to the particular needs and conditions of their communities, they are all designed to facilitate the achievement of guideline-recommended time-to-treatment goals by incorporating a number of common components (Table 1).\(^5,12\)

The improvements achieved in STEMI system performance metrics due to implementation of the ACC/AHA guidelines were recently reported. The American Heart Association Mission: Lifeline STEMI Systems Accelerator regional systems of care demonstration project\(^15\) reported that implementation of regional STEMI care systems increased the proportion of patients meeting guideline FMC–D times who either presented directly via EMS to a PCI-hospital (50%–55%; \(P < 0.001\)) or were transferred from a STEMI referral hospital (44%–48%; \(P = 0.002\)). While significant variability occurred among regional

| Table 1. Performance indicators for a regional STEMI system.\(^5,12\) |
|-----------------------------------------------------------|
| Rapid recognition of myocardial ischemic symptoms and initiation of EMS contact |
| Timely on-scene arrival of EMS |
| System integration that includes the following: |
| Cooperative agreements among the EMS services and hospitals |
| Pre-hospital ECG performance with identification of STEMI and suitability for primary PCI |
| Pre-hospital catheterization laboratory activation |
| Transport directly to a PCI-hospital or expeditious inter-hospital transfer |
| Emergency department bypass |
| Coordinated treatment protocols |
| A robust CQI process that includes complete regional data collection and reporting. |

CQI: continuous quality improvement; EMS: emergency medical systems; PCI: percutaneous coronary intervention; STEMI: ST-elevation myocardial infarction.
system performances, the greatest improvement in the percentage of patients achieving the FMC-D time goal occurred in five regions, increasing from 45% to 57% for direct EMS transport and from 38% to 50% for transferred patients (both \( P < 0.001 \)). These gains were achieved by focusing on the FMC-D time, implementation of coordinated treatment protocols, and regional data collection and reporting.

STEMI patients residing in rural areas with low population density and where the nearest PCI-hospital may be located far from the patient’s home, e.g., in a city center, can experience several technical and logistical barriers to timely PCI-based reperfusion (Table 2). However, these barriers have led to the design of STEMI care systems that have successfully integrated rural-based EMS systems and STEMI-receiving hospitals (lacking PCI capability) with primary-PCI hospitals, often located in metropolitan areas. Some of these systems employ a hybrid a model that incorporates ground and air transport, especially for inter-hospital transfer or over long distances, with rapid turn-around at the STEMI-receiving hospital to achieve the guideline-recommended door-in-door-out time of 30 min. Using this approach, a number of investigators report that the median time from STEMI-receiving hospital arrival to coronary reperfusion device insertion could be reduced to < 90 min, accompanied by a reduction in STEMI mortality.\(^{16,17}\) However, Terkelsen, Fosbol and co-authors reported that patients who were sent directly to a PCI-hospital, bypassing a STEMI receiving hospital had significantly shorter times to reperfusion.\(^{18,19}\) Additional time savings can be achieved by bypassing the Emergency Department,\(^{20,21}\) as Emergency Department dwell time is an established cause of increased door-to-device times and in-hospital mortality.\(^{22,23}\) This approach was recommended in the 2012 European Society of Cardiology STEMI guidelines.\(^{24}\)

The systems recently reported by Yan, et al.\(^{25,27}\) and Bennin, et al.\(^{26}\) in the Journal of Geriatric Cardiology incorporate a regional cooperative model. However, each is tailored to its unique geography, hospital locations, and medical systems in order to achieve FMC-D goals. The system reported by Yan, et al.\(^{25,27}\) is based in Zhenjiang, China, a prefecture-level city of 3847 km\(^2\) and a population of over 3 million inhabitants. A prefecture-level city is a Chinese administrative division that is characterized by an urban core surrounded by smaller cities, and suburban and rural areas.\(^{26}\) The PCI-hospital was located on the campus of the medical school of Jiangsu University in the Jingkou District (population of approximately 600,000), one of two districts that comprise the urban core.\(^{29}\) The system consists of six primary (STEMI-referral) hospitals and a PCI-capable receiving hospital, with a maximal distance between the hospitals of 105 km. In contrast to many Western systems, patients self-transport to the primary hospital. The unique features of this system were: (1) yearly physician education for STEMI identification in the non-PCI hospitals; (2) Real-time transmission of the ECG performed at the primary hospital to a tablet computer at the PCI-hospital via a Bluetooth communication protocol which could then be relayed to multiple devices at the hospital; (3) Pre-activation of the cardiac catheterization laboratory; (4) Transferring ambulances equipped with GPS positioning and real-time traffic tracking query systems to optimize inter-hospital transit times; and (5) direct admission to the cardiac catheterization laboratory. Compared to patients transferred from those six primary hospitals to the PCI-hospital before activation of the regional STEMI system, mean FMC-D \((211 \pm 97 \pm 20 \text{ min})\) and door-to-device \((105 \pm 14 \pm 22 \pm 8 \text{ min})\) times were markedly reduced. Importantly, greater improvement in FMC-D times was observed in older patients after implementation of the STEMI system. Major adverse cardiac events (MACE), defined as cardiac death, recurrent nonfatal myocardial infarction or unplanned revascularization, occurring in-hospital and at one and six months post-discharge decreased significantly. The reduction in MACE rates was associated with improvement in LV remodeling and performance, but also in reduced hospital length of stay and costs. While not specifically stated, it appears that a majority of patients achieved a FMC-D time \(\leq 120 \text{ min}\), and a significant number of those under 60 years of age achieved a FMC-D \(\leq 90 \text{ min}\). The performance of this STEMI system would be more comparable to other

### Table 2. Barriers to timely reperfusion for rural STEMI patients.

| Low population density |
|------------------------|
| Widely dispersed EMS paramedics and ambulances |
| Fewer available PCI-hospitals with 24/7 staffing |
| Lack of physician and medical staff education |
| Longer transportation distances over poorer quality roads |
| Greater difficulties with EMS to hospital communication due to gaps in cell phone networks, especially important for pre-hospital ECG transmission |
| Traffic patterns: diurnal and weekly |
| Climate, especially in winter, that can affect both ground and air transportation |
| Geography |
| Local practice patterns |
| Other deficiencies creating barriers based on financial status, age, education level, and gender |
| Lack of insurance coverage |

EMS: emergency medical systems; PCI: percutaneous coronary intervention; STEMI: ST-elevation myocardial infarction.

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systems had the authors reported the percent of those patients who achieved door-to-device times ≤ 30 min and FMC-D times of ≤ 90 and ≤ 120 min.

Bennin, et al.\[26\] evaluated the performance of a regional STEMI system encompassing 3 rural counties in northeast Florida and southeast Georgia and the University of Florida Health-Jacksonville (UFHJ), Florida. In contrast to the system in Zhenjiang, the Florida-Georgia system employed direct transport of STEMI patients within a 50-mile radius by ground EMS to UFHJ for primary PCI. Non-PCI-capable hospitals were bypassed. EMS paramedics were trained to employ a protocol for rapid identification and triage of STEMI patients that incorporated three elements: (1) A cooperative agreement between each of the rural EMS agencies and UF Health-Jacksonville; (2) performance of a validated algorithm consisting of performance of a pre-hospital ECG with paramedic validation to avoid significant artifacts or obvious computer interpretation error and accompanied by use of a clinical checklist to screen for common confounders or contra-indications to primary PCI;\[30\] and (3) direct transfer by ground transportation to the cardiac catheterization laboratory at UF Health-Jacksonville. Despite differences in triage and protocol, the clinical results were comparable to those in Zhenjiang. Mean FMC-D time was shorter at 83.4 ± 17.8 min, while the mean door-to-device time of 38.1 ± 19.3 min was longer than that reported by Yan, et al.\[25\]. Overall, Bennin et al.\[26\] achieved a FMC-D ≤ 90 min in 69.2% of patients, while all but one patient achieved a FMC-D time ≤ 120 min. Importantly, those two studies reported shorter door-to-device times than those reported by Le May, et al.\[31\] for both direct EMS transport to a PCI-hospital (median 66 min) and when inter-hospital transfer from STEMI-referral to a PCI-hospital (median 117 min) was employed. While they reported that direct EMS transport to a PCI-hospital significantly reduced the average 180 day mortality by 6.5% to 3.0% compared to inter-hospital transfer,\[31\] the latter was similar to the six-month cardiac mortality rate of 3.4% reported by Yan, et al.\[25\].

These studies illustrate the importance of utilizing modern technology combined with systems engineering principles to optimize the design of a STEMI system to account for regional factors, e.g., population density, geography, climate, distribution of STEMI-referral and PCI-capable hospitals, transportation facilities, and available resources. Importantly, ECG performance and STEMI identification by EMS,\[30,32\] can reduce the delay caused by ECG transmission failures, a problem in rural areas, especially in those regions with unfavorable geography. In addition, local practice patterns and customs need to be considered, e.g., self-transport to a STEMI-referral hospital. While these factors may contain impediments to optimal system performance, they should not prevent the development of and optimization of a robust collaborative system of care. For example, the use of modern data communication combined with Emergency Department bypass in Zhenjiang may have contributed to their short door-to-device times. Also, FMC to either a STEMI-referral hospital or to a PCI-hospital, and inter-hospital transport times can be predicted by use of computer-based modeling and with GPS positioning and real-time tracking query systems.\[33,34\]

Irrespective of their limitations and potential biases, these two studies illustrate challenges and benefits incurred in designing and implementing an effective and efficient rural STEMI care system. They both incorporated formal cooperative agreements among EMS and hospitals, the use of advanced pre-hospital ECG recording, analysis, and transmission equipment; the use of computer-based transportation systems, and the importance of robust system performance data. However, both were retrospective in design; the study by Bennin, et al.\[26\] contained small numbers of patients, while in the Yan, et al.\[25\] study the control and model cohorts were enrolled sequentially, not randomly. Also, while Yan, et al.\[25\] reported no statistical differences for age, gender, number of diseased coronary arteries, distribution of myocardial infarctions, and co-morbidities, the troponin I levels were lower in the STEMI system patients which could represent either a smaller infarct or earlier presentation; either could affect the reported difference in clinical outcomes.

System design and performance improvements should be data-driven and implemented using an iterative approach. The design of a STEMI system should involve formal collaborative agreements among all participants. However, despite the reported success in reduction of reperfusion times achieved by this approach in North Carolina (RACE), many states, including Florida, continue to be resistant to formally organized and regulated state-wide systems. In spite of that resistance, a self-organizing system based on ACC/AHA guidelines developed in Florida that resulted in almost 90% of EMS-transported STEMI patients going directly to high volume PCI-centers by the first half of 2009.\[35\] The recent acceptance by the AHA/ACC/SCAI\[36\] of primary PCI centers that lack on-site cardiac surgery promises to improve primary PCI access while achieving clinical and quality benchmarks. However, the additional number of PCI-hospitals could complicate the design and performance of STEMI care systems.

A key requirement for the success of any system is a robust continuous quality improvement (CQI) process, requiring data to be prospectively collected, verified as to
accuracy, and shared among all of the system stakeholders (EMS agencies and hospitals). Use of registry data, while useful to obtain large sample sizes, contains significant limitations that degrade its reliability for use by regional STEMI systems.\(^{[57]}\) Despite these recommendations in the ACC/AHA guidelines, failure of collaboration among stakeholders is a major impediment to the success of regional STEMI care systems. Reasons articulated for lack of collaboration, including competition for patients, distrust among stakeholders, concerns about security of performance and outcome data, and financial issues due to potential loss of non-STEMI patients,\(^{[38]}\) etc. These concerns must be addressed by regular meetings of all of the system participants where system performance data is presented and discussed in order to develop trust for the success of a robust CQI process. In summary, while the design operation of rural STEMI care systems contains unique challenges, most of the components can be derived from already existent systems.

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