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The Oral–Systemic Inflammation Axis: Integrating Dental Assisting, Hematological Biomarkers, Laboratory Diagnostics, Pharmacological Interventions, and Physical Rehabilitation.

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Abstract

Background: Out-of-hospital cardiac arrest (OHCA) remains a major public health challenge. Survival depends on timely recognition, cardiopulmonary resuscitation (CPR), defibrillation, emergency response, and coordinated post-arrest care. Outcomes vary across populations and healthcare systems.

Aim: This review examines evidence on OHCA epidemiology, recognition, prehospital management, individualized resuscitation, in-hospital treatment, and long-term recovery.

Methods: Published evidence on cardiac arrest registries, sex-related disparities, dispatcher-assisted CPR, first-responder networks, public education, resuscitation strategies, and post-arrest management was synthesized. System-level barriers and emerging approaches to strengthen the chain of survival were also considered.

Results: Registry data demonstrates variation in OHCA incidence, bystander CPR, AED use, and survival between regions. Dispatcher-assisted CPR, trained community responders, accessible AEDs, and public education can strengthen early links in the chain of survival. Women may receive bystander intervention less often, highlighting social and recognition barriers. For refractory ventricular fibrillation, vector-change and double-sequential external defibrillation show potential benefits, although further evidence is needed. In hospitals, temperature control and coronary assessment should reflect clinical presentation. Survivors with non-ischemic causes may require targeted evaluation, including cardiac imaging and genetic assessment. Fatigue, cognitive impairment, and psychological symptoms remain important determinants of functional recovery and quality of life.

Conclusion: Improving OHCA outcomes requires an integrated approach linking community action, emergency medical services, individualized resuscitation, evidence-based hospital care, and rehabilitation. Standardized registries, equitable access, and continued research are essential. The review also identifies priorities for equitable implementation and future research.

Keywords: out-of-hospital cardiac arrest; cardiopulmonary resuscitation; automated external defibrillator; emergency response; post-cardiac arrest care; quality of life.

Introduction

Cardiac arrest represents a major global public health challenge and remains one of the leading causes of sudden death, particularly in developed countries [1]. It occurs when the heart abruptly loses its ability to maintain effective circulation, resulting in an immediate interruption of blood flow to vital organs, including the brain and lungs. Cardiac arrest may occur as the first clinical manifestation of previously undiagnosed cardiovascular disease, making early recognition and immediate intervention essential for preventing irreversible organ damage and death [2]. Despite substantial advances in cardiovascular medicine, emergency response systems, and resuscitation techniques, survival following cardiac arrest remains relatively low. In particular, survival to hospital discharge after out-of-hospital cardiac arrest (OHCA) frequently remains below 10% in several populations, highlighting the continuing challenges associated with timely recognition, emergency response, and effective resuscitation [3]. The management of cardiac arrest has evolved considerably through the development of structured emergency response strategies. One of the most influential contributions was the introduction of the chain of survival concept by Cummins and colleagues in 1991 [4]. This framework emphasized that successful resuscitation depends on a coordinated sequence of interventions rather than a single medical procedure. These interventions include early recognition of cardiac arrest, activation of emergency medical services,

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immediate initiation of cardiopulmonary resuscitation (CPR), rapid defibrillation when indicated, advanced life support, and appropriate post-resuscitation care. The chain of survival established the importance of integrating community responses with professional emergency medical services to improve patient outcomes.

Subsequent research has further demonstrated that the initial stages of the chain of survival have a substantial influence on survival and neurological outcomes. Early recognition of cardiac arrest, prompt activation of emergency services, and immediate CPR performed by bystanders can maintain partial blood circulation and oxygen delivery to vital organs until advanced medical assistance becomes available [5]. Early defibrillation is particularly important in patients presenting with shockable cardiac rhythms, such as ventricular fibrillation and pulseless ventricular tachycardia. Delays in initiating these interventions progressively reduce the likelihood of successful resuscitation and increase the risk of permanent neurological injury. Cardiopulmonary resuscitation is therefore a fundamental component of first aid and emergency response. Its effectiveness depends on the quality of chest compressions, appropriate ventilation when indicated, minimal interruptions, and timely access to an automated external defibrillator (AED). However, several barriers continue to limit the effectiveness of community-based resuscitation, including inadequate public awareness, insufficient CPR training, fear of causing injury, delayed emergency calls, and limited availability of AEDs in public locations. Furthermore, improving cardiac arrest outcomes requires continuous development of emergency response systems, standardized resuscitation protocols, healthcare professional training, and public education initiatives. Strengthening cooperation between bystanders, emergency dispatchers, first responders, and hospital-based resuscitation teams is essential for improving the continuity and effectiveness of care. Accordingly, this review aims to examine the contemporary principles and challenges of cardiac arrest management, with particular emphasis on its epidemiology, early recognition, first aid interventions, cardiopulmonary resuscitation, defibrillation, and advanced emergency management. It also highlights the importance of the chain of survival as an integrated framework for reducing cardiac arrest mortality and improving survival and neurological outcomes.

The Epidemiological Challenges of Cardiac Arrest

Understanding the epidemiology of cardiac arrest is essential for identifying its underlying causes, evaluating the effectiveness of emergency response systems, and developing strategies to improve survival and patient outcomes [6]. Accurate epidemiological assessment requires more than recording the number of cardiac arrest cases. It involves collecting comprehensive clinical, demographic, organizational, and socioeconomic information to identify variations in incidence, treatment, and survival across different populations. Important variables include patient age, sex, medical history, location of arrest, initial cardiac rhythm, presumed etiology, emergency response intervals, resuscitation interventions, and neurological outcomes. These factors provide a comprehensive understanding of the burden of cardiac arrest and help identify opportunities for improving prevention and emergency management. Since the early 1990s, the Utstein style has served as an internationally recognized standardized framework for collecting, defining, and reporting cardiac arrest data. Its primary objective is to improve consistency in epidemiological reporting and facilitate comparisons between countries, healthcare systems, and emergency medical services (EMS). The 2024 Utstein update introduced several refinements to improve data quality and reporting accuracy. These included clearer definitions of attempted resuscitation, improvements in the documentation of emergency dispatch processes, more precise descriptions of time intervals, and structured flowcharts for evaluating the performance of resuscitation systems [7]. Such developments emphasize the importance of standardized registries in monitoring healthcare performance, identifying weaknesses in emergency response pathways, and supporting evidence-based quality improvement initiatives.

Estimating the actual incidence of cardiac arrest remains a significant epidemiological challenge. Many national registries primarily document cases of out-of-hospital cardiac arrest (OHCA) in which EMS personnel attempt resuscitation. Consequently, cases in which resuscitation is not initiated, deaths occurring before emergency services arrive, and other unrecorded events may be excluded from official statistics. This limitation can result in an underestimation of the actual population burden. Data from the European Registry of Cardiac Arrest (EuReCa) studies demonstrated considerable geographical variation in EMS-treated OHCA incidence, ranging from 17 to 104 cases per 100,000 population, with an average incidence of approximately 55 cases per 100,000 population [8]. These differences may reflect variations in population age structures, cardiovascular disease prevalence, comorbidities, healthcare accessibility, cultural attitudes toward providing first aid, and the ability of emergency dispatchers to recognize cardiac arrest promptly. The epidemiological characteristics of cardiac arrest also differ according to patient demographics, arrest location, initial cardiac rhythm, and underlying etiology. Shockable rhythms, particularly ventricular fibrillation and pulseless ventricular tachycardia,

account for approximately 20% of EMS-treated OHCA cases, although reported proportions vary considerably between countries, ranging from 11% to 37%. These differences are clinically important because patients presenting with shockable rhythms generally have greater potential to benefit from early defibrillation than those presenting with non-shockable rhythms.

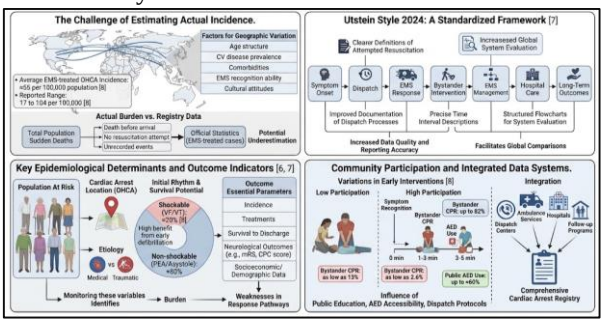


Figure-1: Epidemiological Challenges of Cardiac Arrest.

Community participation represents another major determinant of cardiac arrest outcomes. Bystander CPR rates vary substantially across healthcare systems, ranging from approximately 13% to 82%. Similarly, the reported use of publicly accessible automated external defibrillators (AEDs) ranges from 2.6% to nearly 60% [8]. These variations highlight the influence of public awareness, CPR training programs, AED accessibility, emergency telephone dispatch protocols, and organized first-responder networks. Communities with established public education initiatives and accessible defibrillation programs may achieve higher rates of early intervention before the arrival of professional medical assistance. Furthermore, accurate epidemiological evaluation requires the integration of information from multiple healthcare sources. Emergency dispatch centers, ambulance services, hospitals, and long-term follow-up programs should contribute to comprehensive cardiac arrest registries. Linking these datasets allows researchers to evaluate the entire resuscitation pathway, from initial recognition and emergency activation to hospital admission, survival to discharge, and neurological recovery. The 2024 Utstein update reinforces this approach by emphasizing the integration of dispatch, EMS, hospital, and long-term outcome information [7]. Accordingly, improving cardiac arrest epidemiology requires standardized reporting systems, complete case registration, consistent outcome definitions, and international collaboration. These measures are necessary to establish reliable estimates of disease burden, identify inequalities in emergency care, evaluate the performance of resuscitation systems, and guide public health policies. More importantly, accurate epidemiological information provides the foundation for developing targeted interventions that strengthen the chain of survival and improve outcomes following cardiac arrest.

Sex-Related Disparities in Cardiac Arrest Recognition and Management

Sex-related disparities represent an important challenge in the early recognition and management of cardiac arrest. Increasing evidence indicates that women and men do not always receive equivalent emergency interventions, particularly during the initial stages of the chain of survival. These differences are evident in cardiac arrest recognition, the provision of bystander cardiopulmonary resuscitation (CPR), access to automated external defibrillators (AEDs), and subsequent survival outcomes. Although CPR and defibrillation are essential interventions for all individuals experiencing cardiac arrest, social perceptions and differences in bystander responses may influence whether women receive immediate assistance [9]. One of the most frequently reported disparities concerns the lower likelihood of women receiving bystander CPR compared with men. Research suggests that individuals witnessing a cardiac arrest may hesitate to perform chest compressions on women because of concerns about physical contact, removing or exposing clothing, and potential accusations of inappropriate touching. These concerns can delay or prevent the initiation of life-saving interventions. Similarly, women experiencing cardiac arrest in public locations may be less likely to receive AED application because bystanders feel uncertain about exposing the chest or positioning defibrillation pads. Such hesitation is particularly concerning because every minute without effective CPR and, when indicated, defibrillation reduces the probability of successful resuscitation. Differences in the circumstances surrounding cardiac arrest may further contribute to the observed disparities. Women experiencing cardiac arrest are often older than men, and their arrests are more frequently associated with non-shockable initial rhythms, including pulseless electrical activity and asystole. In contrast, men may be more likely to present with shockable rhythms, such as ventricular fibrillation, which can respond effectively to early defibrillation. The lower prevalence of shockable rhythms among women may partly reflect differences in underlying cardiovascular conditions, clinical presentation, and delays in recognizing cardiac arrest or initiating resuscitation. Furthermore, cardiac arrest in women occurs more frequently in private residences, whereas men may have a greater proportion of arrests in public locations. The location of the event influences the availability of bystanders, access to AEDs, and the likelihood of receiving immediate assistance.

These clinical and contextual differences may contribute to persistent sex-related variations in return of spontaneous circulation (ROSC), survival to hospital discharge, and 30-day survival. Studies have

demonstrated that women may experience lower survival rates than men even after accounting for several characteristics of cardiac arrest [10]. However, these differences should not automatically be attributed to biological characteristics. Age, initial cardiac rhythm, underlying disease, arrest location, emergency response intervals, and the likelihood of receiving bystander interventions are important factors that may explain part of the observed survival gap. Evidence from the Swiss out-of-hospital cardiac arrest registry provides further insight into these disparities. The findings indicate that nationwide interventions and improvements in emergency response systems can reduce differences in survival between women and men. Importantly, strengthening organized resuscitation strategies has the potential to improve outcomes across both sexes, suggesting that healthcare system performance and access to timely interventions play substantial roles in determining survival [11]. Addressing these inequalities requires a systematic approach involving public education, emergency dispatcher training, and improvements in first-responder protocols. Public CPR campaigns should explicitly emphasize that cardiac arrest requires immediate intervention regardless of the patient's sex, age, or physical appearance. Training programs should demonstrate appropriate chest exposure and AED pad placement on female patients to reduce uncertainty and hesitation among bystanders. In addition, emergency dispatchers should provide clear, standardized instructions to callers and encourage immediate CPR without unnecessary delays.

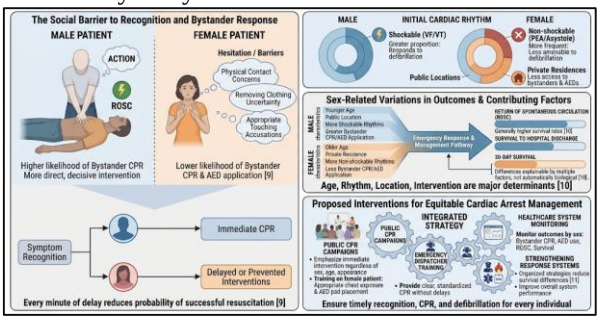


Figure-2: Sex-Related Disparities in Cardiac Arrest Recognition.

Healthcare authorities should also monitor cardiac arrest outcomes according to sex, including rates of bystander CPR, AED application, ROSC, hospital admission, and survival to discharge. Such monitoring can help identify inequalities and evaluate the effectiveness of targeted interventions. Ultimately, equitable cardiac arrest management requires ensuring that every individual receives timely recognition, CPR, and defibrillation when indicated. Reducing social barriers, improving public confidence, and strengthening emergency response systems are essential steps toward eliminating preventable sex-related disparities and improving survival following cardiac arrest.

Cardiac Arrest Registries: The Importance of Broad Geographical Coverage

Cardiac arrest registries play a fundamental role in understanding the epidemiological burden of cardiac arrest, evaluating emergency medical services (EMS) performance, and identifying opportunities to improve patient outcomes. Their effectiveness, however, depends considerably on the extent of geographical coverage, the completeness of collected information, and the consistency of data reporting. Although local registries provide valuable information about specific hospitals or communities, their limited geographical scope may prevent researchers from identifying broader epidemiological patterns and healthcare inequalities. In contrast, regional and national registries offer a more comprehensive understanding of cardiac arrest incidence, treatment practices, and survival outcomes across different populations. Expanding registry coverage is therefore essential for developing effective public health strategies and improving the quality of emergency cardiovascular care. Considerable geographical inequalities exist in the incidence, management, and outcomes of cardiac arrest. Differences in population characteristics, socioeconomic conditions, environmental factors, healthcare infrastructure, and emergency response organization may contribute to variations between regions. These differences are particularly evident in survival outcomes following out-of-hospital cardiac arrest (OHCA). According to the European Resuscitation Council (ERC) 2025 report, survival to hospital discharge varies substantially across European countries, ranging from 3.1% to 35%, despite the adoption of standardized epidemiological definitions and reporting approaches [8]. This variation indicates that the availability of standardized guidelines alone does not guarantee equivalent outcomes across healthcare systems. Differences in bystander CPR, emergency response intervals, defibrillation accessibility, and hospital-based resuscitation services may substantially influence survival.

Similar geographical inequalities have been documented in the United States. Data from the Cardiac Arrest Registry to Enhance Survival (CARES) demonstrate considerable differences in bystander CPR rates and survival outcomes between geographical jurisdictions. Notably, neighbouring areas may experience differences of up to twofold in survival, reflecting variations in community preparedness, emergency medical response, and access to appropriate resuscitation interventions [5]. These findings demonstrate the importance of examining cardiac arrest outcomes at both local and national levels to identify underserved communities and determine which components of emergency response systems require improvement. Australian registry data provide further evidence of geographical

variation in cardiac arrest outcomes. According to the Australian and New Zealand Out-of-Hospital Cardiac Arrest Registry (Aus-ROC), survival to hospital discharge or 30-day survival among resuscitated patients reached approximately 10.4% nationally in 2022. However, survival approached 30% among patients with bystander-witnessed cardiac arrest and an initially shockable rhythm. Considerable differences were also reported between state-based EMS systems, suggesting that regional organization and the effectiveness of early resuscitation interventions influence patient outcomes [12].

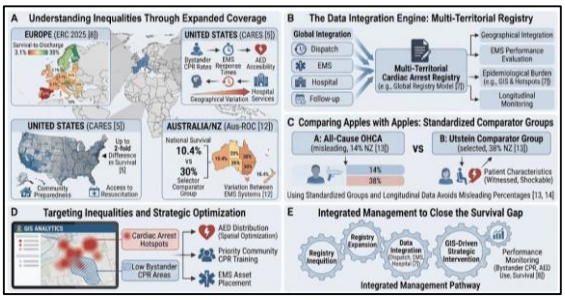


Figure-3: Cardiac Arrest Registries.

Evidence from New Zealand further supports the importance of geographical coverage in cardiac arrest surveillance. During 2023/2024, the Wellington Free Ambulance service reported approximately 14% survival at 30 days among patients experiencing all-cause OHCA. This proportion increased to 38% among patients included in the Utstein Comparator Group, which represents a selected population with characteristics associated with greater resuscitation potential. This finding demonstrates how survival estimates differ according to patient characteristics and emphasizes the importance of using standardized comparison groups when evaluating EMS performance across different regions [13]. These observations are consistent with findings from a systematic review examining global inequalities in cardiac arrest outcomes. Overall survival following cardiac arrest remains below 10% in many settings, with considerable differences between countries and healthcare systems. Variations in EMS organization, bystander CPR participation, dispatcher-assisted resuscitation, AED availability, and regional healthcare capacity contribute to these differences [14]. Consequently, comparisons based exclusively on overall survival percentages may be misleading unless differences in population characteristics and clinical circumstances are considered. Broad geographical coverage also provides opportunities for advanced epidemiological investigations. Multi-regional and national registries allow researchers to perform geographical information system (GIS) analyses, identify cardiac arrest hotspots, examine regional differences in emergency response times, and detect populations with limited access to resuscitation services. These analyses can support the strategic distribution of AEDs, the development of community CPR training programs, and the optimization of ambulance station locations. For example, identifying areas with high cardiac arrest incidence but low bystander CPR rates can help healthcare authorities prioritize public education and first-responder interventions.

The 2024 Utstein update emphasizes the importance of integrating geographical characteristics, emergency dispatch information, and sociodemographic variables into cardiac arrest registries [7]. Combining these data with clinical information and long-term patient outcomes enables a more comprehensive evaluation of the entire resuscitation pathway. Furthermore, longitudinal registries allow healthcare systems to monitor changes over time, assess the impact of new interventions, and determine whether improvements in emergency response translate into better survival and neurological recovery. Therefore, cardiac arrest registries should prioritize the widest feasible geographical coverage, standardized data collection, and continuous longitudinal monitoring. Collaboration between EMS organizations, hospitals, public health authorities, and research institutions is necessary to establish comprehensive and reliable databases. Multi-territorial registries based on Utstein reporting principles provide an essential foundation for identifying regional inequalities, improving emergency response strategies, supporting evidence-based healthcare policies, and reducing preventable deaths associated with cardiac arrest.

Dispatcher-Assisted Cardiopulmonary Resuscitation

Dispatcher-assisted cardiopulmonary resuscitation (DA-CPR) represents a fundamental component of modern out-of-hospital cardiac arrest (OHCA) management. It aims to reduce delays in initiating resuscitation by providing real-time guidance to individuals witnessing a cardiac arrest. According to the 2025 European Resuscitation Council (ERC) guidelines, the chain of survival consists of four interconnected stages: early recognition of cardiac arrest and activation of emergency services, early CPR and defibrillation, advanced life support and post-resuscitation care, and survival and recovery [15]. Each stage contributes to successful resuscitation; however, the initial interventions are particularly important because they determine how quickly the patient receives life-saving assistance. Early recognition of cardiac arrest and immediate initiation of CPR are among the most important determinants of survival. When cardiac arrest occurs, the sudden cessation of effective cardiac output interrupts oxygen delivery to the brain and other vital organs. Without immediate intervention, irreversible neurological injury may develop within minutes. Although EMS systems are designed to provide rapid emergency assistance, ambulance response times rarely allow medical personnel to prevent the initial consequences of

prolonged circulatory interruption without intervention from bystanders [16]. Therefore, individuals witnessing cardiac arrest play an essential role in maintaining circulation until professional medical assistance arrives.

Evidence increasingly demonstrates that the early components of the chain of survival, particularly rapid recognition and bystander CPR, have a substantial influence on survival compared with interventions delivered during later stages of advanced life support [5]. Immediate chest compressions help maintain partial blood flow to the heart and brain, increasing the likelihood of successful resuscitation and improving the potential for neurological recovery. Conversely, delays in recognizing cardiac arrest or initiating CPR can reduce the effectiveness of subsequent medical interventions. Emergency medical dispatchers serve as an important link between bystanders and professional emergency response teams. When an individual contacts emergency services, dispatchers use structured questioning protocols to determine whether the patient is experiencing cardiac arrest. Recognition generally relies on identifying unresponsiveness and abnormal or absent breathing. However, this process can be challenging because callers may be unfamiliar with cardiac arrest symptoms, may provide incomplete information, or may misinterpret abnormal respiratory patterns. Agonal breathing, characterized by occasional gasping or irregular respiratory movements, is particularly problematic because bystanders may mistakenly interpret it as normal breathing [5]. Such misunderstandings can delay emergency activation and the initiation of CPR.

Once cardiac arrest is suspected, dispatchers should immediately guide the caller through the initiation of CPR. This intervention is particularly important for individuals without previous resuscitation training or those who lack confidence in performing chest compressions. Studies indicate that immediate bystander CPR can double or even triple the probability of survival following cardiac arrest [17]. Nevertheless, several barriers may prevent bystanders from initiating resuscitation, including insufficient knowledge, fear of causing physical injury, uncertainty about the correct technique, and concerns regarding personal responsibility [18]. DA-CPR addresses these barriers by providing step-by-step instructions through telephone communication. Dispatchers explain how to position the patient, identify the appropriate location for chest compressions, place the hands correctly, and maintain an appropriate compression rate and depth. This approach enables individuals without formal CPR training to participate in emergency resuscitation. Evidence indicates that dispatcher-assisted interventions increase bystander CPR rates and contribute to improved survival following OHCA [5,19]. Compression-only CPR is generally recommended for dispatcher instructions when an adult experiences sudden cardiac arrest and the bystander is untrained or unable to provide rescue breaths. This technique involves continuous chest compressions without mouth-to-mouth ventilation. Its relative simplicity reduces the complexity of instructions, minimizes hesitation, and encourages more individuals to initiate resuscitation. Several studies have demonstrated that dispatcher-guided compression-only CPR can improve bystander participation and facilitate earlier intervention [20–22]. However, conventional CPR involving chest compressions and rescue breaths remains important in specific circumstances, particularly cardiac arrest associated with respiratory causes, drowning, and pediatric emergencies.

Traditionally, DA-CPR has relied primarily on verbal instructions delivered through telephone communication. Recent technological developments have introduced video-assisted dispatcher CPR, allowing emergency dispatchers to observe the patient's condition and provide visual guidance through smartphones. This approach may improve CPR quality by helping dispatchers assess hand positioning, compression depth, chest recoil, and compression rate. Visual communication may also help identify incorrect techniques and provide immediate corrective instructions. Despite these potential advantages, video-assisted DA-CPR presents certain limitations. Establishing a video connection, positioning the smartphone, and adjusting the camera may delay the initiation of chest compressions. Recent meta-analyses have therefore highlighted the possibility that improvements in compression quality may be offset by longer times to the first compression [23]. This issue emphasizes the importance of balancing CPR quality with the need for immediate intervention. Verbal instructions should remain a priority when video communication is likely to delay the start of resuscitation. The effectiveness of DA-CPR ultimately depends on dispatcher training, standardized recognition algorithms, clear communication, and efficient coordination with EMS teams. Emergency dispatch centers should continuously evaluate recognition accuracy, call-processing intervals, time to first compression, and the proportion of eligible patients receiving dispatcher-assisted CPR. Furthermore, integrating AED guidance into dispatcher protocols can facilitate early defibrillation when an automated external defibrillator is available. In summary, dispatcher-assisted CPR is an essential strategy for strengthening the early stages of the chain of survival. By reducing hesitation, improving cardiac arrest recognition, and guiding bystanders through immediate resuscitation, DA-CPR can bridge the gap between cardiac arrest occurrence and professional medical intervention. Continued improvements in

dispatcher training, communication technologies, and standardized protocols are necessary to increase bystander participation, improve CPR quality, and enhance survival and neurological outcomes following OHCA.

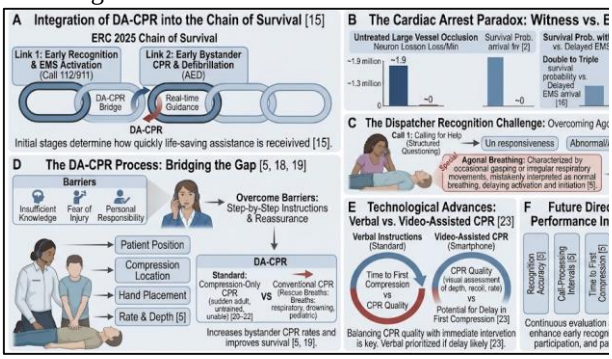


Figure-4: Dispatcher-Assisted Cardiopulmonary Resuscitation.

First Responder Networks

Over the past decade, first responder (FR) networks have become an important component of community-based emergency cardiac arrest management. These systems aim to shorten the time between the occurrence of out-of-hospital cardiac arrest (OHCA) and the initiation of cardiopulmonary resuscitation (CPR) and defibrillation. They typically involve trained volunteers, known as community first responders, as well as on-duty personnel such as police officers and firefighters. Once an emergency call identifies a suspected cardiac arrest, nearby responders receive alerts through mobile applications or other communication systems. These applications provide information about the patient's location and may direct responders to the nearest available automated external defibrillator (AED) [24]. The primary objective of FR networks is to ensure that trained individuals can reach patients before the arrival of emergency medical services (EMS). This is particularly important in areas where ambulance response times are prolonged because of traffic congestion, geographical distance, or limited emergency service resources. Early CPR can maintain a degree of blood circulation to the brain and other vital organs, while early defibrillation can restore an effective cardiac rhythm in patients with shockable rhythms. Integrating FR networks with established EMS systems therefore creates an additional layer of early intervention and may improve the overall effectiveness of the chain of survival [25]. Evidence from systematic reviews and meta-analyses indicates that activation of FR networks is associated with higher rates of bystander CPR, increased AED use before EMS arrival, and improved survival following OHCA. These benefits are particularly relevant when the first responder can reach the patient within a short period and provide effective chest compressions or early defibrillation. However, the effectiveness of these systems depends on several operational factors. These include reliable communication between emergency dispatch centers and responders, accurate GPS-based identification of nearby volunteers, appropriate responder training, and clear instructions regarding the actions expected at the scene. In addition, AED accessibility is essential. Digital AED registries should provide accurate information about device locations, availability, and accessibility outside normal working hours. Integrating these registries into responder applications enables rapid identification and retrieval of the nearest available device [26].

Despite their potential benefits, FR networks remain inconsistently implemented across European countries. Differences exist in geographical coverage, financial resources, legal arrangements, volunteer recruitment, and the extent to which these systems are integrated into national emergency dispatch services. Some countries have established coordinated national programs, whereas others depend on regional or local initiatives. Legal frameworks also influence whether volunteers can be activated through emergency dispatch centers and what responsibilities they may assume when providing assistance. Sustainable implementation therefore requires clear operational protocols, appropriate insurance and liability arrangements, continuous training, public engagement, and long-term funding [8]. Denmark provides an example of successful nationwide implementation. Its approach combines several complementary interventions, including mandatory CPR training for individuals applying for a driving licence, introduced in 2006, dispatcher-assisted CPR, a national AED registry integrated with EMS dispatch centers, and a mobile application-based volunteer responder network. This coordinated strategy has contributed to bystander CPR rates exceeding 75% and 30-day survival rates of approximately 16% among patients experiencing OHCA [27]. The Danish experience demonstrates the value of combining public CPR education, accessible defibrillation, effective emergency dispatch, and organized community participation rather than relying on isolated interventions. In line with this evidence, the 2025 European Resuscitation Council (ERC) Guidelines recommend implementing FR systems within healthcare systems to strengthen the community response to cardiac arrest [17]. Successful implementation should involve coordination between EMS providers, emergency dispatch centers, public authorities, volunteer organizations, and AED program administrators. Regular monitoring of activation rates, responder arrival times, CPR initiation, AED application, and patient outcomes is also necessary to assess system performance. Overall, first responder networks represent an important strategy for reducing prehospital treatment delays and improving the chances of survival after OHCA.

How to Improve the System

Despite advances in resuscitation science, emergency medical services, and cardiac arrest management, survival following out-of-hospital cardiac arrest (OHCA) remains low in many regions. Improving these outcomes requires coordinated interventions across the entire chain of survival, from early recognition and bystander response to advanced life support and post-resuscitation care. These interventions should address not only clinical procedures but also public awareness, healthcare infrastructure, emergency response organization, and national health policies. A central priority is expanding public access to cardiopulmonary resuscitation (CPR) training and improving community confidence in responding to cardiac emergencies. National CPR education programs can increase the proportion of cardiac arrest patients who receive bystander CPR before the arrival of emergency medical services (EMS). Integrating CPR education into school curricula, university programs, workplace training, and community-based initiatives provides opportunities to reach different population groups. Early education is particularly important because it enables individuals to acquire resuscitation skills before encountering an emergency. Countries that have incorporated CPR training into school education, particularly in Scandinavia, have reported high levels of bystander intervention and favorable OHCA survival outcomes. These experiences support the implementation of structured and repeated CPR education as a component of national public health strategies [17].

The European Resuscitation Council (ERC) has supported several initiatives designed to increase public participation in cardiac arrest response. The "Kids Save Lives" initiative, introduced in 2015, promotes CPR education among schoolchildren, including those aged 12 years and older. This approach aims to establish resuscitation knowledge at an early stage and encourage children to become capable bystanders. Similarly, the "Learn to Drive, Learn CPR" initiative promotes the integration of CPR training into driver education programs across Europe. This strategy can expand the number of trained individuals within the community by using an established educational process to reach young adults. Another initiative, "Get Trained, Save Lives," developed in collaboration with the Union of European Football Associations (UEFA), uses the reach of major sporting events to promote CPR awareness and encourage public participation in resuscitation training [17]. Public awareness campaigns can also strengthen the impact of formal training programs. The European Parliament has supported initiatives to encourage large-scale CPR education, including the establishment of "Restart a Heart Day" on 16 October. Such campaigns provide opportunities to deliver practical demonstrations, organize public training sessions, and communicate the importance of immediate intervention during cardiac arrest. Participants may also share the knowledge and skills they acquire with family members, colleagues, and other community members. This creates a multiplier effect in which the benefits of training extend beyond the individuals who attend formal courses. Consequently, community education can improve public recognition of cardiac arrest and reduce hesitation to initiate CPR [5].

However, expanding CPR education requires addressing barriers that limit access to training. Coverage remains inconsistent because of differences in socioeconomic conditions, geographical accessibility, cultural attitudes, available educational resources, and national implementation policies. Rural populations may have fewer opportunities to attend certified training courses than residents of urban areas. Language and communication barriers may also affect access among specific population groups, while older adults may require adapted educational approaches. In addition, the absence of coordinated national strategies can result in fragmented initiatives, inconsistent training standards, and limited opportunities for skills renewal [19]. Improving the system therefore requires sustained investment in accessible, standardized, and regularly updated CPR education. Governments and healthcare authorities should establish national training targets, incorporate resuscitation education into school and university curricula, and support workplace and community-based programs. Training should include practical compression exercises, recognition of cardiac arrest, emergency activation, and AED use. Refresher sessions are also important to maintain skills and confidence over time. Furthermore, authorities should evaluate training coverage and its relationship with bystander CPR rates and patient outcomes. These measures would help identify underserved populations and guide the allocation of educational resources. Public CPR education should form part of a broader strategy that also strengthens dispatcher-assisted CPR, first responder networks, AED accessibility, EMS response, and post-cardiac arrest care. Increasing the number of trained citizens is unlikely to achieve its full potential without effective emergency communication and accessible defibrillation. A coordinated approach that connects community education with emergency healthcare services is therefore essential to improving OHCA outcomes and reducing preventable deaths.

Future Directions

Despite improvements in cardiac arrest recognition, resuscitation training, emergency response systems, and public access to defibrillation, several challenges remain in the prevention and management of out-of-hospital cardiac arrest (OHCA). Future progress will depend on developing integrated strategies that combine legislative support,

public education, accessible emergency equipment, expanded first responder networks, and the use of digital technologies. These measures should aim to reduce delays in recognizing cardiac arrest, initiating cardiopulmonary resuscitation (CPR), and delivering the first defibrillation shock. Legislative support represents an important requirement for achieving sustainable improvements in community resuscitation. Governments should establish policies that promote CPR education as a standard component of school curricula and support its implementation across educational institutions. Introducing mandatory CPR training can ensure that successive generations acquire the knowledge and practical skills required to respond to cardiac emergencies. However, legislation alone is insufficient. Effective implementation requires adequate funding, trained instructors, standardized educational materials, and regular assessment of students' practical competencies. Limited financial resources, insufficient teacher preparation, and differences in educational infrastructure may prevent the consistent application of these policies, particularly in rural and underserved regions. Therefore, national authorities should establish implementation frameworks that include funding mechanisms, teacher certification, periodic refresher training, and measurable educational targets [28].

Another priority is expanding the geographical coverage and operational capacity of first responder (FR) networks. Current systems do not provide equal access to trained responders across all communities. Future programs should extend beyond major cities and include rural areas, residential neighborhoods, industrial zones, and locations with limited ambulance coverage. This expansion requires stronger coordination between emergency medical services (EMS), dispatch centers, police departments, fire services, volunteer organizations, and community-based responders. Mobile applications and GPS-based alert systems should support rapid responder activation and provide accurate information about the location of the suspected cardiac arrest. Continuous evaluation of responder arrival times, activation rates, and clinical outcomes will help determine whether these networks achieve their intended objectives. Improving public access to automated external defibrillators (AEDs) is also essential. AED installation programs should prioritize locations with high population density and frequent public activity, including transport hubs, shopping centers, educational institutions, workplaces, and sports facilities. However, the availability of an AED does not necessarily guarantee its use. Devices must remain accessible during emergencies, clearly identified through visible signs, and stored in unlocked cabinets whenever possible. Mandatory registration of AED locations in national databases would support their integration with emergency dispatch centers and first responder applications. Real-time geolocation systems could then direct callers, bystanders, and nearby responders to the closest available device. The 2025 European Resuscitation Council (ERC) recommendations emphasize the importance of improving AED accessibility and integrating defibrillation programs into organized community response systems [17].

Digital technologies represent another area with potential to improve different stages of the chain of survival. Smartphone applications can provide real-time feedback on chest compression rate, depth, and quality, helping rescuers maintain effective CPR. Artificial intelligence (AI) algorithms may support emergency dispatchers by analyzing caller descriptions, speech patterns, and available audio information to identify signs of cardiac arrest, including agonal breathing. Earlier recognition could reduce delays in dispatcher-assisted CPR and improve the likelihood that bystanders initiate resuscitation promptly. In addition, smart-city infrastructure may contribute to early cardiac arrest detection in public spaces. Surveillance cameras, connected sensors, and automated monitoring systems could identify sudden collapses and transmit alerts to emergency services. These technologies may be particularly useful in transport stations, shopping centers, airports, and other crowded environments where cardiac arrest can occur without immediate recognition by nearby individuals [29,30]. Nevertheless, integrating these technologies into emergency systems requires attention to technical reliability, data protection, cybersecurity, financial sustainability, and interoperability with existing EMS infrastructure. AI-supported recognition tools should undergo clinical validation to establish their accuracy and minimize false alerts. Digital applications should also remain accessible to individuals with different levels of technological literacy and should not replace established emergency communication procedures. Future research should assess whether these interventions reduce response times and improve meaningful clinical outcomes, including survival to hospital discharge and neurological recovery. Finally, future OHCA research should prioritize large, geographically representative registries that allow comparisons between regions and healthcare systems. Standardized reporting of patient characteristics, bystander interventions, EMS response times, AED use, survival, and neurological outcomes will help identify gaps in care. Implementation studies should also examine the cost-effectiveness of school-based CPR education, FR networks, public AED programs, and digital technologies. Overall, improving OHCA survival will require sustained legislative commitment, equitable access to training and equipment, effective integration of emergency response services, and careful evaluation of emerging technologies. These developments should strengthen the entire chain of survival and support more

consistent cardiac arrest outcomes across different populations and healthcare settings.

Individualized Strategies for Cardiac Arrest Management

Although the Advanced Cardiovascular Life Support (ACLS) algorithm provides a standardized framework for cardiac arrest management, emerging evidence supports adapting resuscitation strategies according to individual patient characteristics and physiological responses. Factors such as low-flow duration, end-tidal carbon dioxide trends, ventricular fibrillation (VF) waveform morphology, thoracic impedance, and myocardial characteristics may help identify patients who are unlikely to respond to repeated standard defibrillation. Therefore, early recognition of refractory VF and timely escalation to alternative interventions may improve clinical outcomes [31–33]. Alternative defibrillation strategies include vector-change (VC) defibrillation and double sequential external defibrillation (DSED). VC involves repositioning defibrillator pads from the standard anterior-lateral configuration to an anterior-posterior position, whereas DSED delivers two sequential shocks using separate defibrillators. These approaches aim to improve defibrillation effectiveness by changing the electrical current pathway or increasing the cumulative energy delivered to the myocardium. The DOSE-VF trial, which included 405 patients, reported higher survival to hospital discharge with DSED (30.4%) and VC defibrillation (21.7%) compared with standard defibrillation (13.3%). DSED was also associated with improved neurological outcomes. Based on these findings, alternative defibrillation should be considered when VF persists despite repeated standard shocks. Protocols commonly recommend reassessment and escalation after three unsuccessful shocks. VC represents a rapid intervention requiring limited additional resources, while DSED may be considered when equipment and trained personnel are available. Successful implementation requires team training and sequential rather than simultaneous shock delivery to reduce equipment interference and interruptions in chest compressions [31–38].

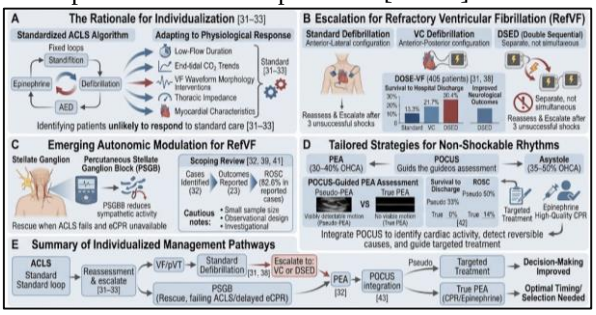


Figure-5: Individualized Strategies for Cardiac Arrest Management.

Autonomic modulation represents another emerging approach for refractory VF. Percutaneous stellate ganglion block (PSGB) aims to reduce sympathetic activity and myocardial excitability, potentially interrupting recurrent ventricular arrhythmias. A scoping review identified 32 published cases of intra-arrest PSGB, with outcomes reported in 23 cases. Return of spontaneous circulation (ROSC) occurred in 82.6% of these reported cases. However, these findings require cautious interpretation because of the small sample size, observational study designs, and potential publication bias. Although PSGB has been described as a possible rescue intervention when standard ACLS fails and extracorporeal CPR is unavailable or delayed, it remains investigational. Randomized controlled trials and further prospective studies are required to establish its safety, effectiveness, and appropriate clinical application [32,39–41]. Management of non-shockable rhythms also requires approaches that reflect differences in underlying cardiac activity. Pulseless electrical activity (PEA) accounts for approximately 30–40% of OHCA cases, while asystole represents 35–50%. Point-of-care ultrasound (POCUS) may help distinguish true PEA, characterized by the absence of visible cardiac motion, from pseudo-PEA, in which cardiac contractions remain detectable despite the absence of a palpable pulse. Pseudo-PEA occurs in approximately 18–35% of PEA cases and is associated with better outcomes. One prospective study reported survival to discharge of 33% in pseudo-PEA compared with 0% in true PEA, while ROSC rates were 50% and 14%, respectively. Meta-analyses have also associated detectable cardiac activity during PEA with improved ROSC and neurological outcomes. In asystole, early epinephrine administration during high-quality CPR may increase ROSC, although neurological recovery remains uncommon. Future approaches should therefore integrate POCUS to identify cardiac activity, detect reversible causes, and guide targeted treatment while minimizing interruptions in CPR [42,43]. Overall, cardiac arrest management should combine standardized resuscitation algorithms with individualized escalation strategies. Alternative defibrillation, emerging autonomic interventions, and ultrasound-guided assessment may improve decision-making, particularly in refractory VF and non-shockable rhythms. However, further clinical evidence is necessary to establish the optimal timing, selection criteria, and effectiveness of these interventions.

In-Hospital Care of Resuscitated OHCA

Post-resuscitation care is essential for improving survival and neurological recovery after out-of-hospital cardiac arrest (OHCA). Priorities include temperature control, coronary revascularization, and antiplatelet therapy. Temperature management remains central to neuroprotection. Earlier evidence, including the HACA study, supported therapeutic hypothermia at

32–34 °C in comatose survivors. However, TTM1 and TTM2 found no survival or neurological advantage of active hypothermia over normothermia. Accordingly, the 2025 European Resuscitation Council Guidelines emphasize active temperature control and fever prevention rather than routine therapeutic hypothermia. Temperature should be monitored and maintained within 32–36 °C for at least 72 hours, with attention to preventing fever above 37.7 °C. Surface or endovascular devices, antipyretics, and sedation to control shivering may support management. Routine intra-arrest cooling and post-resuscitation hypothermia are discouraged, except when treating severe hyperthermia. Deeper cooling should be reserved for research or selected cases. Coronary angiography is important because myocardial ischemia is a leading cause of OHCA. Following return of spontaneous circulation (ROSC), patients with persistent ST-segment elevation should undergo immediate angiography and primary percutaneous coronary intervention (PCI). In patients without ST-elevation, a selective or delayed invasive approach is appropriate unless electrical or hemodynamic instability indicates ongoing ischemia. Early electrocardiograms may be difficult to interpret because global ischemia, myocardial stunning, and metabolic disturbances can produce transient changes that mimic infarction. Repeating the ECG or allowing a short interval before interpretation may improve specificity without delaying reperfusion. Airway management, hemodynamic stabilization, temperature control, and additional imaging can delay catheterization. Care pathways should avoid unnecessary steps that postpone reperfusion in patients with confirmed acute coronary occlusion.

The optimal PCI strategy for multivessel disease after OHCA remains uncertain. Complete revascularization improves outcomes in some hemodynamically stable STEMI populations, whereas the CULPRIT-SHOCK trial supports culprit-only PCI in cardiogenic shock because immediate treatment of all lesions may worsen short-term outcomes. OHCA patients also face ischemia-reperfusion injury, myocardial dysfunction, systemic inflammation, uncertain neurological recovery, and procedural risks. The Lombardia CARe registry, involving 230 patients, associated complete revascularization with lower one-year mortality (20.8% versus 53.3%) and better neurological outcomes, without increased bleeding. However, observational findings cannot establish causality. Randomized trials must clarify patient selection and timing of non-culprit intervention. Antiplatelet therapy after cardiac arrest requires careful consideration. Hypoperfusion, sedation, mechanical ventilation, vasopressors, and temperature interventions can impair gastrointestinal absorption and delay oral P2Y12 inhibitor effects. Meanwhile, chest-compression injuries, coagulopathy, vascular access procedures, and mechanical circulatory support increase bleeding risk. Intravenous cangrelor provides rapid, reversible P2Y12 inhibition without relying on enteral absorption. Pharmacodynamic studies report stronger platelet inhibition than oral alternatives in comatose OHCA patients, although samples remain small. Multicenter evidence associated cangrelor with higher hospital-discharge survival but increased major bleeding. Intravenous P2Y12 inhibition may be useful during early PCI, but randomized trials must clarify the preferred agent, dose, safety, and transition to oral treatment. Overall, post-arrest care requires patient-specific decisions that balance myocardial salvage, neurological protection, thrombosis prevention, and bleeding risk. Further clinical trials should define temperature targets, revascularization strategies, and antiplatelet regimens for distinct OHCA patient groups.

Management of Non-ischemic OHCA:

Non-ischemic OHCA survivors require a diagnostic and therapeutic approach that differs from the coronary revascularization pathway used for ischemic cases. Approximately 25–35% have non-ischemic causes, including cardiomyopathies and inherited channelopathies. Patients with heart failure with reduced ejection fraction should receive guideline-directed therapy, including sodium-glucose cotransporter-2 inhibitors, angiotensin receptor-neprilysin inhibitors, beta-blockers, and mineralocorticoid receptor antagonists. These treatments have been associated with a 50–60% reduction in rehospitalization. Early cardiac magnetic resonance imaging can identify myocardial edema, reported in 18% of patients, and help distinguish reversible injury from established scar. This information may contribute to assessment of implantable cardioverter-defibrillator-free survival [49],[63]. Identifying an inherited cause is particularly important in younger survivors. Genetic screening detects inherited arrhythmias or cardiomyopathies in approximately 40–50% of survivors younger than 50 years. Diagnosis can guide prevention of recurrent events and enable cascade screening of relatives. The 2022 European Society of Cardiology guidelines recommend blood sampling for genetic and toxicological analysis, echocardiography, and evaluation of cardiac structure and function. When the cause remains uncertain, assessment may include a 12-lead electrocardiogram, coronary imaging, cardiac magnetic resonance with late gadolinium enhancement, sodium-channel blocker testing, and exercise testing. These investigations can identify conditions such as Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia, and long QT syndrome [64]. However, access to specialist testing, standardized protocols, and consistent emergency medical service procedures remains limited. Field blood sampling, family counselling, and multidisciplinary follow-up could improve diagnostic coverage, as recommended

by the 2025 European Resuscitation Council Guidelines [8].

Long-term recovery after hospital discharge is another component of care. Survival alone does not establish recovery, because survivors may experience physical, cognitive, and psychological difficulties. Up to 70% report fatigue or cognitive impairment, involving memory, attention, executive function, and processing speed. A systematic review estimated prevalence rates of depression, anxiety, and post-traumatic stress disorder at approximately 19%, 26%, and 20%, respectively. These symptoms may affect daily activities, relationships, return to work, and quality of life [47],[65],[66]. The 2025 guidelines recommend assessing physical and non-physical impairments before discharge and referring patients to rehabilitation when needed. Conventional cardiac rehabilitation, including aerobic and resistance exercise, supports physical recovery but may not adequately address cognitive and psychological problems. Although cardiac-arrest-specific cognitive rehabilitation studies are lacking, approaches used after other brain injuries, including compensatory memory techniques and metacognitive strategy training, may guide care. Integrated cardiac and cognitive rehabilitation models require evaluation [47],[67–69]. Structured follow-up within three months of discharge should assess cognition, emotional health, fatigue, and quality of life. Tools include EQ-5D-5L for health-related quality of life, the Montreal Cognitive Assessment for cognitive screening, and the Hospital Anxiety and Depression Scale for emotional symptoms. Fatigue can be evaluated using the Modified Fatigue Impact Scale, Multidimensional Fatigue Inventory-20, or Fatigue Severity Scale [15],[66]. Family observations can help identify unreported difficulties. Nevertheless, cognitive and psychological problems may remain underdetected because screening protocols are inconsistent, specialist rehabilitation is not widely available, and cardiology teams may lack training. Future care should provide multidisciplinary follow-up to support functional independence, psychological recovery, social reintegration, and quality of life alongside survival.

Conclusion:

Improving survival after out-of-hospital cardiac arrest requires coordinated action across the chain of survival. Early recognition, dispatcher-assisted CPR, bystander intervention, defibrillation, and first-responder networks can reduce delays. Public education, training, accessible AEDs, and standardized registries can strengthen preparedness and reduce disparities, including sex-related differences. Resuscitation should reflect the presenting rhythm and clinical context, while emerging approaches for refractory ventricular fibrillation need further evaluation. After return of spontaneous circulation, hospital teams should individualize temperature control and coronary assessment, investigate non-ischemic causes, and identify patients requiring cardiac imaging or genetic evaluation. Survival alone does not define recovery. Cognitive, physical, and psychological consequences can affect independence, relationships, employment, and quality of life. Assessment, rehabilitation, and multidisciplinary follow-up should therefore form part of post-arrest care. Future research should prioritize comparative trials, consistent outcome reporting, equitable implementation, and patient-centered outcomes. A connected system from the emergency call through rehabilitation can improve both survival and recovery.

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