



CPR Quality: Improving Cardiac Resuscitation Outcomes Both Inside and Outside the Hospital

A Scientific Statement From the American Heart Association

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Abstract

The 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care increased the focus on methods to ensure that high-quality cardiopulmonary resuscitation (CPR) is performed in all resuscitation attempts. There are 5 critical components of high-quality CPR: minimize interruptions in chest compressions, provide compressions of adequate rate and depth, avoid leaning between compressions, and avoid excessive ventilation. Although it is clear that high-quality CPR is the primary component in influencing survival from cardiac arrest, there is considerable variation in monitoring, implementation, and quality improvement. As such, CPR quality varies widely between systems and locations. Victims often do not receive high-quality CPR due to provider ambiguity in prioritization of resuscitative efforts during an arrest. This ambiguity also impedes the development of optimal systems of care to increase survival from cardiac arrest. This consensus statement addresses the following key areas of CPR quality for the trained rescuer: metrics of CPR performance; monitoring, feedback, and integration of the patient's response to CPR; team-level logistics to ensure performance of high-quality CPR; and continuous quality improvement

on provider, team, and systems levels. Clear definitions of metrics and methods to consistently deliver and improve the quality of CPR will narrow the gap between resuscitation science and the victims, both in and out of hospital, and lay the foundation for further improvements in the future.

Key Words

■ AHA Scientific Statements ■ CPR ■ quality ■ cardiac arrest ■ outcomes

Worldwide, there are over 135 million cardiovascular deaths each year, and the prevalence of coronary heart disease is increasing.[ref] Globally, the incidence of out-of-hospital cardiac arrest ranges from 20-140/100,000 persons and survival ranges from 2-11%. In the United States, more than 500,000 children and adults experience a cardiac arrest, and less than 15% survive.¹⁻³ This establishes cardiac arrest as one of the United States' most lethal public health problems, claiming more lives than colorectal cancer, breast cancer, prostate cancer, influenza, pneumonia, auto accidents, human immunodeficiency virus (HIV), firearms, and house fires combined.⁴ In many cases, as Claude Beck noted, cardiac arrest victims have "hearts too good to die."⁵ In these cases, prompt intervention can result in successful resuscitation. Yet overall survival rates remain low. Why? An increasing body of evidence indicates that even after controlling for patient and event characteristics there is significant variability in survival rates both across and within pre-hospital and in-hospital settings. For example:

- In the pre-hospital setting, of participating centers in the Resuscitation Outcomes Consortium (ROC) registry, survival from out-of-hospital arrest ranged from 3% to 16.3%.¹ In the UK, survival to discharge within the National Health Service ambulance system ranged from 2-12%.
- In the hospital setting, of participating centers in the Get With The Guidelines®–Resuscitation quality-improvement program, the median hospital survival rate from adult cardiac arrest is 18% (interquartile range, 12% to 22%) and from pediatric cardiac arrest, 36% (interquartile range, 33% to 49%).
- In a hospital setting, survival is more than 20% if the arrest occurs between the hours of 7:00 AM and 11:00 PM but only 15% if the arrest occurs between 11:00 PM and 7:00 AM.⁶ There is significant variability with regard to location, with 9% survival at night in

unmonitored settings compared with nearly 37% survival in operating room/post-anesthesia care unit locations during the day.⁶

- Patient survival is linked to quality of cardiopulmonary resuscitation (CPR). When rescuers compress at a depth of less than 38 mm, survival-to-discharge rates after out-of-hospital arrest are reduced by 30%.⁷ Similarly, when rescuers compress too slowly, return of spontaneous circulation (ROSC) after in-hospital cardiac arrest falls from 72% to 42%.⁸

The variations in performance and survival described in these studies provide the resuscitation community an incentive to improve outcomes. To maximize survival from cardiac arrest, the time has come to focus efforts on optimizing the quality of CPR specifically as well as the performance of resuscitation processes in general.

CPR is a lifesaving intervention and the cornerstone of resuscitation from cardiac arrest.⁹⁻¹¹ Survival from cardiac arrest depends on early recognition of the event and immediate activation of the emergency response system, but equally critical is the quality of CPR delivered. Both animal and clinical studies demonstrate that the quality of CPR during resuscitation has a significant impact on survival and contributes to the wide variability of survival noted between and within systems of care.^{1,12} CPR is inherently inefficient; it provides only 10% to 30% of normal blood flow to the heart and 30% to 40% of normal blood flow to the brain¹³⁻¹⁵ even when delivered according to guidelines. This inefficiency highlights the need for trained rescuers to deliver the highest-quality CPR possible.

Poor-quality CPR should be considered a preventable harm. In healthcare environments, variability in clinician performance has affected the ability to reduce healthcare-associated complications,¹⁶ and a standardized approach has been advocated to improve outcomes and reduce preventable harms.¹⁷ The use of a systematic continuous quality improvement (CQI) approach has been shown to optimize outcomes in a number of urgent healthcare conditions.¹⁸⁻²⁰ Despite this evidence, few healthcare organizations apply these techniques to cardiac arrest by consistently monitoring CPR quality and outcomes. As a result, there remains an unacceptable disparity in the quality of resuscitation care delivered, as well as the presence of significant opportunities to save more lives.

Today, a large gap exists between current knowledge of CPR quality and its optimal implementation, leading to preventable deaths from cardiac arrest. Resuscitation efforts must be tailored to each patient. Cardiac arrest occurs in diverse settings with varying epidemiology and resources, yet effective solutions exist to improve CPR quality in each of these settings. The purpose of this consensus statement is to stimulate transformative change on a large scale by providing healthcare practitioners and healthcare systems a tangible framework to maximize the quality of CPR and save more lives. The intent is to fill the gap between the existing scientific evidence surrounding resuscitation (as presented in the *2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care*) and the translation of the Guidelines into routine clinical practice. The approach taken is the use of expert opinion and interpretation of existing studies to provide a practical hands-on approach to implementing the *2010 AHA Guidelines for CPR and ECC*. Although there are many population (e.g. neonatal), chain of survival (e.g., bystander CPR, post resuscitation care), CPR mechanics (hand position, duty cycle, airway adjuncts) and education (adult learning principles, feedback devices during in training) factors that impact patient survival, this consensus statement is focused on the critical parameters of CPR that can be enhanced to assist trained providers to optimize performance during cardiac arrest in an adult or a child.

Four areas related to CPR quality will be addressed:

- Metrics of CPR performance by the provider team
- Monitoring and feedback: options and techniques for monitoring patient response to resuscitation as well as team performance
- Team-level logistics: how to ensure high-quality CPR in complex settings
- Continuous Quality Improvement (CQI) for CPR

In addition, gaps in existing knowledge and technologies will be reviewed and prioritized and recommendations for optimal resuscitation practice made.

[h1]Methods

The contributors to this statement were selected for their expertise in the disciplines relevant to adult and pediatric cardiac resuscitation and CPR quality. Selection of participants and

contributors was restricted to North America, and other international groups were not represented. After a series of telephone conferences and webinars between the chair and program planning committee, members of the writing group were selected and writing teams were formed to generate the content of each section. Selection of the writing group was performed in accordance with the AHA's conflict of interest management policy. The chair of the writing group assigned individual contributors to work on 1 or more writing teams that generally reflected their area of expertise. Articles and abstracts presented at scientific meetings relevant to CPR quality and systems improvement were identified through International Liaison Committee on Resuscitation (ILCOR) International Consensus on CPR and ECC Science With Treatment Recommendations (CoSTR) statements and the 2010 ILCOR Worksheets, PubMed, EMBASE, and an American Heart Association (AHA) master resuscitation reference library. This was supplemented by manual searches of key papers and abstracts. Statements generated from literature review were drafted by the writing groups and presented to leaders in CPR quality at a CPR quality summit held May 20-21, 2012 in Irving, Texas. Participants evaluated each statement, and suggested modifications were incorporated into the draft. Drafts of each section were written and agreed on by members of the writing team and then sent to the chair for editing and incorporation into a single document. The first draft of the complete document was circulated among writing team leaders for initial comments and editing. A revised version of the document was circulated among all contributors, and consensus was achieved. This revised consensus statement was submitted for independent peer review and endorsed by several major professional organizations (see endorsements). The AHA Science Advisory and Coordinating Committee approved the final version for publication.

[h1]Metrics of CPR Performance by the Provider Team

Oxygen and substrate delivery to vital tissues is the central goal of CPR during the period of cardiac arrest. To deliver oxygen and substrate, adequate blood flow must be generated by effective chest compressions during a majority of the total cardiac arrest time. ROSC following CPR is dependent on adequate myocardial oxygen delivery and myocardial blood flow during CPR.¹³⁻¹⁵ Coronary perfusion pressure (CPP, the difference between aortic diastolic and right atrial diastolic pressure during the relaxation phase of chest compressions) is the primary determinant of myocardial blood flow during CPR.²¹⁻²³ Therefore, maximizing CPP during CPR is the primary physiological goal. Because CPP cannot be measured, rescuers should focus on

the specific components of CPR that have evidence to support either better hemodynamics or human survival.

Five main components of high-performance CPR have been identified: chest compression fraction (CCF), chest compression rate, chest compression depth, chest recoil (residual leaning), and ventilation. These CPR components were identified due to their contribution to blood flow and outcome. Understanding the importance of these components and their relative relationships is essential for providers to improve outcomes for individual patients, educators to improve the quality of resuscitation training, administrators to monitor performance to ensure high quality within the healthcare system, and vendors to develop the necessary equipment needed to optimize CPR quality for providers, educators, and administrators.

[h2]Minimize Interruptions: Chest Compression Fraction Greater Than 80%

For adequate tissue oxygenation, it is essential that healthcare providers minimize interruptions in chest compressions and therefore maximize the amount of time chest compressions generate blood flow.^{9,24} CCF is the proportion of time that chest compressions are performed during a cardiac arrest. The duration of arrest is defined as the time cardiac arrest is first identified until time of first return of sustained circulation (20 minutes or more). To maximize perfusion, the *2010 AHA Guidelines for CPR and ECC* recommend minimizing pauses in chest compressions. Expert consensus is that a CCF of 80% is achievable in a variety of settings. Data on out-of-hospital cardiac arrest indicate that lower CCF is associated with decreased ROSC and survival to hospital discharge.^{25,26} One method to increase CCF that has improved survival outcomes is through reduction in pre shock pause,²⁷ and other techniques are discussed later in Team Level Logistics.

[h2]Chest Compression Rate of 100 to 120/min

The *2010 AHA Guidelines for CPR and ECC* recommend a chest compression rate of at least 100/min.²⁴ As chest compression rates fall, a significant drop-off in ROSC occurs, and higher rates may reduce coronary blood flow⁸ and decrease the percentage of compressions achieving target depth.²⁹ Data from the ROC Registry provide the best evidence of association between compression rate and survival and suggest an optimum target of between 100 and 120 compressions per minute.²⁸ Consistent rates above or below that range appear to reduce survival to discharge.

[h2]Chest Compression Depth at Least 50 mm in Adults and at Least One Third the Anterior-Posterior Dimension of the Chest in Infants and Children

Compressions generate critical blood flow, oxygen and energy delivery to the heart and brain. The *2010 AHA Guidelines for CPR and ECC* recommend a single minimum depth for compressions of at least 2 inches (50 mm) in adults. Less information is available for children, but it is reasonable to aim for a compression depth of at least one third of the anterior-posterior dimension of the chest in infants and children (approximately 4 cm in infants and approximately 5 cm in children).^{36,37}

While a recent study suggests that a depth of at least 44 mm in adults may be adequate to assure optimal outcomes,⁷ the preponderance of literature suggests that rescuers often do not compress the chest deeply enough despite recommendations.^{7,29-31} Earlier studies suggest that compressions at a depth of more than 50 mm may improve defibrillation success and ROSC in adults.^{32,33,34,35} A recent study examined chest compression depth and survival in out-of-hospital cardiac arrest in adults and concluded that a depth of less than 38 mm is associated with a decrease in ROSC and rates of survival.²⁹ Confusion may result when a range of depths is recommended and training targets differ from operational performance targets. Optimal depth may depend on factors such as patient size, compression rate, and environmental features (such as presence of a supporting mattress). Outcome studies to date have been limited by the use of mean compression depth of CPR, the impact of the variability of chest compression depth and the change in chest compliance over time.

[h2]Full Chest Recoil: No Residual Leaning

Incomplete chest wall release occurs when the chest compressor does not allow the chest to fully recoil on completion of the compression.^{38,39} This can occur when a rescuer leans over the chest of the patient, impeding full chest expansion. Leaning is known to decrease the blood flow throughout the heart and can decrease venous return as well as cardiac output.⁴⁰ Although data are sparse regarding outcomes related to leaning, animal studies have shown that leaning increases right atrial pressure and decreases cerebral and coronary perfusion pressure, cardiac index, and left ventricular myocardial flow.⁴⁰⁻⁴² Human studies show that a majority of rescuers often lean during CPR and do not allow the chest to fully recoil.^{43,44} Therefore, the expert panel agrees that leaning should be minimized.

[h2]Avoid Excessive Ventilation: Rate < 12/min; Minimal Chest Rise

Although oxygen delivery is essential during CPR, the appropriate timeframe for interventions to supplement existing oxygen in the blood is unclear and likely varies with the type of arrest (arrhythmic versus asphyxial). The metabolic demands for oxygen are also substantially reduced in the patient in arrest even during chest compressions. When sudden arrhythmic arrest is present, oxygen content is initially sufficient and high-quality chest compressions can circulate oxygenated blood throughout the body. Studies in animals and humans suggest that compressions without ventilations may be adequate early in non-asphyxial arrests.^{45,46} When asphyxia is the cause of the arrest, the combination of assisted ventilation and high-quality chest compressions is critical to ensure sufficient oxygen delivery. Animal and human studies of asphyxial arrests have found improved outcomes when both assisted ventilations and high-quality chest compressions are delivered.^{47,48}

Providing sufficient oxygen to the blood without impeding perfusion is the goal of assisted ventilation during CPR. Positive-pressure ventilation reduces CPP during CPR,⁴⁹ and synchronous ventilation (recommended in the absence of an advanced airway)³⁶ requires interruptions, which reduces CCF. Excessive ventilation, either by rate or tidal volume, is common in resuscitation environments.^{30,49-52} Although chest compression–only CPR by bystanders has yielded similar survival outcomes from out-of-hospital arrest compared with standard CPR,^{30, 45, 46} there is presently not enough evidence to define when or if ventilation should be withheld by experienced providers and more data will be required.

[h3]Rate of Less Than 12 Breaths per Minute

Current guideline recommendations for ventilation rate (breaths per minute) are dependent on the presence of an advanced airway (8 to 10 breaths per minute), as well as the patient's age and the number of rescuers present (compression-to-ventilation ratio of 15:2 versus 30:2). Assuming other recommended goals are achieved (i.e., compression rate of 100 to 120/min, inflation time 1 second for each breath), these ratios lead to ventilation rates of between 6 and 12 breaths per minute. Animal studies have yielded mixed results regarding harm in high ventilation rates,^{49, 53} but there are no data showing that ventilating a patient at a higher rate is beneficial. Currently recommended compression–ventilation ratios are designed as a memory aid to optimize myocardial blood flow while adequately maintaining oxygenation and CO₂ clearance of the blood. The expert panel supports the *2010 AHA Guidelines for CPR and ECC* and recommends a

ventilation rate of less than 12 breaths per minute to minimize the impact of positive pressure ventilation on blood flow.

[h3]Minimal Chest Rise: Optimal Ventilation Pressure and Volume

Ventilation volume should produce no more than visible chest rise. Positive-pressure ventilation significantly lowers cardiac output in both spontaneous circulation and during CPR.^{49,54-57} Use of lower tidal volumes during prolonged cardiac arrest was not associated with significant differences in PaO₂, and is currently recommended. Additionally, positive pressure ventilation in an unprotected airway may cause gastric insufflation as well as aspiration of gastric contents. Lung compliance is affected by compressions during cardiac arrest,⁵⁸ and the optimal inflation pressure is not known. Although the conceptual relevance of ventilation pressure and volume monitoring during CPR are well established, current monitoring equipment and training equipment do not readily or reliably measure these parameters, and clinical studies supporting the optimal titration of these parameters during CPR are lacking.

[h1]Monitoring and Feedback: Options and Techniques for Monitoring Patient Response to Resuscitation

The adage “if you don’t measure it, you can’t improve it” applies directly to monitoring CPR quality. Monitoring the quality and performance of CPR by rescuers at the scene of cardiac arrest has been transformative to resuscitation science and clinical practice. Studies have demonstrated that trained rescuers often had poor CCF ratios, depth, and compression-ventilation rates^{31, 49, 50, 59} and were associated with worse outcomes.^{8,28} With monitoring, there is increased clarity about optimal pre shock pause, CCF, and chest compression depth.^{25, 27, 29} With newer technology capable of monitoring CPR parameters during CPR, investigators and clinicians are now able to monitor the quality of CPR in real time. Given the insights into clinical performance and discoveries in optimal practice, monitoring of CPR quality is arguably one of the most significant advances in resuscitation practice in the past 20 years, and one that should be incorporated into every resuscitation and every professional rescuer program.

The types of monitoring for CPR quality can be classified (and prioritized) into physiological (how the patient is doing) and CPR performance metrics (how the rescuers are doing). Both types of monitoring can provide both real-time feedback to rescuers and retrospective system-wide

feedback. It is important to emphasize that types of CPR quality monitoring are not mutually exclusive and that several types can (and should) be used simultaneously.

[h2]How the Patient Is Doing: Monitoring the Physiological Response of the Patient to Resuscitative Efforts

Physiological data during CPR that are pertinent for monitoring include invasive hemodynamic data (arterial and central venous pressures when available) and end-tidal carbon dioxide concentrations (PETCO₂). Abundant experimental literature has established that (1) survival following CPR is dependent on adequate myocardial oxygen delivery and myocardial blood flow during CPR, and (2) CPP during the relaxation phase of chest compressions is the primary determinant of myocardial blood flow during CPR.^{14,15,21,22,60,61} CPP during cardiac arrest is the difference between aortic diastolic pressure and right atrial diastolic pressure but may be best conceptualized as diastolic blood pressure–central venous pressure. Although the conceptual relevance of hemodynamic and ETCO₂ monitoring during CPR are well established, clinical studies supporting the optimal titration of these parameters during human CPR are lacking. Nevertheless, the opinions and clinical experience of experts at the Quality CPR Summit strongly support prioritizing use of hemodynamic and ETCO₂ concentrations to adjust compression technique during CPR when available. Furthermore, the expert panel recommends a hierarchal and situational contextualization of physiological monitoring based on the available data most closely related to myocardial blood flow:

[h3]1. Invasive Monitoring: CPP Greater Than 20 mm Hg

Successful adult resuscitation is more likely when CPP is greater than 20 mm Hg and when diastolic blood pressure is greater than 25 to 30 mm Hg.^{13,14,21-23,62-67} Although optimal CPP has not been established, the expert panel agrees with the *2010 AHA Guidelines for CPR and ECC* that monitoring and titrating CPP during CPR is reasonable.¹⁰ Moreover, the expert panel recommends that this physiological target be the primary end point when arterial and central venous catheters are in place at the time of the cardiac arrest and CPR. Data are insufficient to make a recommendation for CPP goals for infants and children.

[h3]2. Arterial Line Only: Arterial Diastolic Pressure Greater Than 25 mm Hg

Consistent with these experimental data, limited published clinical studies indicate that providing successful adult resuscitation depends on maintaining diastolic blood pressure at more than 25 mm Hg.^{22,65,66} The expert panel recommends this physiological target be the primary end point

when an arterial catheter is in place without a central venous catheter at the time of the cardiac arrest and CPR. The *2010 AHA Guidelines for CPR and ECC* recommend “trying to improve quality of CPR by optimizing chest compression parameters or giving vasopressors or both” if diastolic blood pressure is less than 20 mm Hg.¹⁰ The expert panel recommends that rescuers titrate to a diastolic blood pressure greater than 25 mm Hg for adult victims of cardiac arrest.

[h3]3. Capnography Only: ETCO₂ Greater Than 20 mm Hg

ETCO₂ concentrations during CPR are primarily dependent on pulmonary blood flow and therefore reflect cardiac output.^{68,69} Failure to maintain ETCO₂ at more than 10 mm Hg during adult CPR reflects poor cardiac output and strongly predicts unsuccessful resuscitation.⁷⁰⁻⁷² The *2010 AHA Guidelines for CPR and ECC* recommends monitoring ETCO₂ during CPR to assess blood flow in two ways: to improve chest compression performance if ETCO₂ is <10 mm Hg during CPR, and to consider an abrupt sustained increase to a normal value (35-40 mm Hg) as an indicator of ROSC. The expert panel recommends this physiological target be the primary end point when neither an arterial nor central venous catheter is in place at the time of the cardiac arrest and CPR. On the basis of limited animal data and personal experience, the expert panel recommends titrating CPR performance to a goal ETCO₂ of greater than 20 mm Hg while not excessively ventilating the patient (rate less than 12 breaths per minute, with only minimal chest rise).

[h2]How the Rescuers are Doing: Monitoring CPR Performance

Monitors to measure CPR performance are now widely available. They provide rescuers with invaluable real-time feedback on the quality of CPR delivered during resuscitative efforts, data for debriefing following resuscitation, and retrospective information for system-wide CPR CQI programs. Without CPR measurement and subsequent understanding of CPR performance, improvement and optimized performance cannot occur. Providing CPR without monitoring performance can be likened to flying an airplane without an altimeter.

Routinely available feedback on CPR performance characteristics includes chest compression rate and depth. Currently, certain important parameters (CCF, pre-, peri-, and post-shock pauses) can be reviewed only retrospectively, whereas others (chest recoil and ventilation rate, airway pressure, tidal volume, and inflation duration) cannot be adequately assessed by current technology. Additionally, accelerometers are insensitive to mattress compression and current devices often prioritize the order of feedback using a rigid algorithm in a manner that may not be

optimal or realistic (e.g., an accelerometer cannot measure depth if there is too much leaning, so device will prioritize feedback to correct leaning before correcting depth). While some software (automated algorithms) and hardware solutions currently exist (smart backboard, dual accelerometers, reference markers, and others), continued development of optimal and widely available CPR monitoring is a key component to improved performance.

[h2] Human Supervision and Direction of CPR

Visual observation provides qualitative information about depth and rate of chest compressions, as well as rate and tidal volume of ventilations. Although invasive hemodynamic monitoring (via intra-arterial and central venous catheters) provides superior quantitative data about patients' physiology, direct observation can reveal important artifacts (e.g., pads were not selected on the monitor/defibrillator, "flat" arterial pressure waveform from a turned stopcock obstructed the arterial line tubing), as well as the recognized limitations of feedback technology of CPR performance described above. More rigorous, semi-quantitative determination of chest compression depth and rate can be developed by rescuers with increasing experience, especially after effective feedback. Trained rescuers may be accustomed to feel for a pulse as an indication of the adequacy of chest compression, but pulse palpation during CPR is fraught with potential problems⁷⁹⁻⁸¹ and is therefore not recommended as a reliable means of monitoring the effectiveness of CPR.^{24, 36} Observers can quickly identify rescuer: patient mismatch (i.e. a 40 kg rescuer vs. 120 kg patient) as well as recommend switching chest compressors if a rescuer manifests early signs of fatigue. In addition, observers can integrate the physiological factors (CPP, arterial relaxation pressure, or ETCO₂) with quantitative feedback of CPR quality parameters (depth, rate, leaning) to best achieve optimal CPR delivery.⁸²

New methods and technology that accurately monitor both team performance and a patient's physiology during cardiac arrest should be developed. They may include additional markers of

perfusion such as VF waveform analysis, cerebral oximetry, impedance, near infrared spectroscopy, etc. We challenge both researchers and industry to provide rescuers with robust solutions to monitor patient and provider performance.

[h1]Team Level Logistics: How to Ensure High-Quality CPR in the Complex Setting of Cardiac Resuscitation

Basic life support skills are generally taught and practiced individually or in pairs. In actual practice, CPR is frequently performed as part of a full resuscitative effort that includes multiple rescuers and advanced equipment. These additional resources allow tasks to be performed in parallel so that CPR can be optimized while the team determines and treats the underlying cause of the arrest. However, the performance of secondary tasks frequently consumes large portions of time and can detract from CPR quality if not managed carefully.

Resuscitation team composition varies widely, depending on location (in hospital versus out of hospital), setting (field, emergency department, hospital ward), and circumstances. Little is known regarding the optimal number and background of professional rescuers.⁸³ Examples of high functioning resuscitation teams for both pre-hospital and in-hospital cardiac arrest are presented at: [Insert web links here.](#) These examples are meant to be descriptive of how to maintain high quality CPR with varying team size and environment, rather than prescriptive if-then rules.

There is, however, data to suggest that resuscitation team leadership training and demonstration of leadership behaviors (e.g., setting clear expectations, being decisive and hands off) are associated with improved CPR performance, especially an increase in CCF. As such, it is the recommendation of the expert panel that every resuscitation event should have a designated team leader who directs and coordinates all components of the resuscitation with a central focus on delivering high-quality CPR. The team leader's responsibility is to organize a team of experts into an expert team, by directing and prioritizing the essential activities.

[h2]Interactions of CPR Performance Characteristics

There is no clear data on the interaction between compression fraction, rate, depth, leaning, and ventilation. All play a vital role in the transport of substrate to the vital organs during arrest. For

instance, characteristics of chest compressions may be interrelated (e.g., higher rate may be associated with lower depth, and greater depth may lead to increased leaning), and in practice the rescuer may need to alter one component at a time, holding the others constant so as not to correct one component at the expense of another. The working group proposes that team leaders prioritize the optimization of individual components of chest compression delivery in the following order: (1) compression fraction, (2) compression rate, (3) compression depth, (4) leaning, and (5) avoid excessive ventilation. This order is recommended in part due to the strength of the science as discussed in the prior sections (e.g. there is stronger evidence for compression fraction, rate and depth than leaning) but also for the sake of feasibility, as discussed below.

[h3]Maximizing Chest Compression Fraction

Prompt initiation of compressions is the first step toward maximizing CCF. However, to achieve a target CCF greater than 80%, careful management of interruptions is critical. The following strategies minimize both the frequency and duration of interruptions:

[h4]Choreograph team activities

Any tasks that can be effectively accomplished during ongoing chest compressions should be performed without introducing a pause (Table 1). Additional tasks for which a pause in compressions is needed should be coordinated and carried out simultaneously in a “pit crew” fashion. The team leader should communicate clearly with team members about impending pauses in compression to enable multiple rescuers to anticipate and then use the same brief pause to achieve multiple tasks.

[h4]Minimize interruptions for airway placement

The optimal time for insertion of an advanced airway during management of cardiac arrest has not been established. An important consideration is that endotracheal intubation often accounts for long pauses in performance of chest compressions.⁸⁴ Supraglottic airways can be used as an alternative to invasive airways, although a recent large study showed worse outcomes when supraglottic airways were compared with endotracheal intubation.⁸⁵ Patients who can be adequately ventilated by a bag-mask device may not need an advanced airway at all.⁸⁶ If endotracheal intubation is performed, the experienced provider should first attempt laryngoscopy

during ongoing chest compressions. If a pause is required, it should be kept as short as possible: ideally, less than 10 seconds. If a surgical airway is required, a longer pause may be necessary. However, in all such cases, the expert panel recommends performing any portion of the procedure that can be done during ongoing compressions to minimize the pause.

[h4]Avoid unnecessary pulse checks

Manual palpation for a pulse can result in unnecessarily long pauses and is often unreliable.^{79,81,87-91} These pauses can often be avoided when available monitoring (such as an arterial line or capnography) indicates a level of cardiac output or a rhythm (such as ventricular fibrillation) that is incompatible with organ perfusion.

[h4]Minimize peri-shock pauses

The pre-shock phase may be particularly vulnerable to interruption of chest compressions due to the need to provide a safe environment for the rescuer. It is important to minimize pre-shock pauses because outcomes are improved with decreasing duration of pauses before shock delivery, possibly as short as 9 seconds in duration.²⁷ Applying the pads and charging the defibrillator during ongoing chest compressions results in shorter peri-shock pauses, and this practice is recommended.^{33,92} Development of technology that minimizes all interruptions (e.g., compression artifact waveform filters that enable rhythm analysis during ongoing chest compressions) in blood flow, particularly around defibrillation is encouraged. Chest compressions should be restarted without delay after delivery of the shock. Elimination of stacked shocks and extending the duration of CPR from 1 to 2 minutes before post shock rhythm analyses increases CCF from 48% to 69% and is associated with increased survival.⁹³

[h3]Tightly Regulating Compression Rate

Once chest compressions have begun, achievement of the target rate is often the easiest parameter to adjust and maintain. Real-time CPR feedback devices, as well as low-cost solutions such as metronomes and music, are known to decrease variability and result in rates closer to the target rate of 100 to 120 compressions per minute.^{50,94,95,96} It is essential to continue to monitor and adjust for degradation in compression rate over time and following modifications to other parameters.

[h3]Maximizing Compression Depth

With chest compressions fraction optimized and compressions ongoing at a rate of 100 to 120/min, focus should turn to ensuring that compression depth is at least 50 mm. This parameter is one of the most difficult to achieve because of the physical force required. However, following are some strategies to help ensure adequate depth:

[h4]1. Ensure a firm, hard surface

The *2010 AHA Guidelines for CPR and ECC* recommend performing CPR on a firm, hard surface. Backboards are commonly used to achieve target depths^{97,98,99} and reduce rescuer exertion,¹⁰⁰ but their placement interrupts CPR.¹⁰¹ For this reason, the expert panel recommends placement of a backboard or firm hard surface as soon as possible and in coordination with other mandatory pauses in compressions to minimize interruption time.

[h4]2. Optimize provider mechanics of compressions

Compression mechanics often degrade over time,⁷³ and rescuers often do not perceive fatigue before skill deterioration.⁷⁴⁻⁷⁶ Although The *2010 AHA Guidelines for CPR and ECC* recommend rotating chest compressors every 2 minutes,⁹ inadequate chest compression depths have been observed after only 1 minute of continuous chest compressions,⁷⁵ while others have demonstrated that a switch at 2 minutes may be trading optimal compressions for significant leaning after the switch⁸² and decreased CCF due to the frequency of switching.¹¹² The use of feedback devices, especially visual, can counteract degradation of CPR mechanics to some degree.^{77, 78} The expert panel recommends that the team leader monitor compressors for signs of fatigue. If there is evidence of inadequate compressions being performed by a rescuer that cannot be corrected with feedback or adjustments in positioning, responsibility for chest compressions should be transferred to another team member as quickly as possible, even if 2 minutes has not passed. With proper communication and preparation for the handoff, the switch can be accomplished in less than 3 seconds.⁸²

Compression mechanics are affected by rescuer positioning, but there is no consensus on the optimal rescuer position for chest compressions. Although there may be no degradation in compression quality over a short duration,¹⁰¹⁻¹⁰³ rescuer work appears to increase in the standing position compared with use of a step stool or when kneeling.^{104,105} In addition, step stools have

been shown to increase compression depth, especially for rescuers of short stature.¹⁰⁶ The expert panel recommends adjustable height surface (such as a hospital bed), the height of the surface be lowered or a step stool utilized to enable rescuers to achieve optimal depth during CPR.

[h3]Avoid Leaning

Increasing compression depth is often accompanied by increased leaning. Leaning is a bigger concern for taller rescuers and those using a step stool.¹⁰⁶ The expert panel recommends that as modifications are made to achieve the target depth, rescuers should monitor for leaning and adjust positioning as necessary to ensure adequate depth without residual pressure on the patient's chest between compressions.

[h2]Avoid Excessive ventilation

Unlike the compression characteristics, which have effects that are intertwined, ventilation is a stand-alone skill that can be optimized in parallel with chest compressions. Methods to decrease ventilation rate such as metronomes are well established,^{96,107} whereas methods to limit excessive tidal volume and inspiratory pressure are less well developed but may include the use of smaller resuscitation bags, manometers, and direct observation.¹⁰⁸⁻¹¹¹

[h2]Additional Logistic Considerations

[h3]Incorporation of mechanical CPR

Trials of mechanical CPR devices to date have failed to demonstrate a consistent benefit in patient outcomes compared with manual CPR,¹¹³⁻¹¹⁶ The most likely explanation is that inexperienced rescuers underestimate the time required to apply the device,¹¹⁷ leading to a significant decrease in CCF during the first 5 minutes of an arrest¹¹⁸⁻¹²⁰ despite increases in CCF later in the resuscitation.¹²¹ There is evidence that pre-event “pit crew” team training can reduce the pause required to apply the device.¹²² Two large-scale implementation studies (CIRC and LINC) may provide clarity to the optimal timing and environment for mechanical CPR. The most appropriate use of mechanical CPR for the patient in cardiac arrest may be in systems dependent on small teams of experienced providers (such as in rural areas or during long transport times). In addition, mechanical CPR may have a role to play in systems that are known to have poor quality CPR metrics or for transport of OHCA patients during CPR if time to application can be minimized.

[h3]Patient Transport

Performing chest compressions in a mobile environment has additional challenges and almost uniformly requires that the rescuer be unsecured, thus posing an additional safety concern for providers. Manual chest compressions provided in a moving ambulance are affected by factors such as vehicle movement, acceleration/deceleration, and rotational forces and can compromise compression fraction, rate, and depth.^{123,124} There is no consensus on the ideal ambulance speed to address these concerns.^{125,126} Studies of mechanical versus manual CPR in a moving ambulance show less effect on CPR quality when a mechanical device is used.^{114,127}

[h1]CPR and Systematic Continuous Quality Improvement (CQI)

Systematic CQI has optimized outcomes in a number of healthcare conditions,¹⁸⁻²⁰ increases safety, and reduces harm.¹⁷ Reviewing the quality and performance of CPR by professional rescuers after cardiac arrest has been shown to be feasible and improves outcomes.^{32, 120, 128}

Despite this evidence, few healthcare organizations apply these techniques to cardiac arrest by consistently monitoring CPR quality and outcomes. As a result, there remains an unacceptable variability in the quality of resuscitation care delivered.

[h2]Debriefing

An effective approach to improving resuscitation quality on an ongoing basis is the use of debriefing after arrest events. In this context, debriefing refers to a focused discussion following a cardiac arrest event in which individual actions and team performance are reviewed. This technique can be very effective for achieving improved performance; CPR quality is reviewed while the resuscitation is fresh in the rescuer's mind. This approach, easily adaptable for either out-of-hospital or in-hospital cardiac arrest, can take a number of forms. One simple approach is represented by a "group huddle" among providers after a resuscitation attempt to briefly discuss their opinions about quality of care and what could have been improved. Similar discussions among providers who actually gave care can be performed on a regularly scheduled basis, and such an approach using weekly debriefing sessions has been shown to improve both CPR performance and ROSC after in-hospital cardiac arrest.³² Preexisting structures in hospitals and EMS systems can be efficiently adapted to debrief arrest events. This has also been confirmed by a number of simulation studies among rescuers of both pediatric and adult victims of cardiac

arrest.^{129, 130} If this approach is taken, it is crucial that the actual care providers be present for the discussion.

[h3]Use of Checklists

Debriefing can be greatly enhanced by structuring the discussion, i.e., basing it on a quality checklist prompted by a short set of questions on quality metrics. Short CPR checklists can provide invaluable feedback directly from multiple sources. Systems should develop or adapt CPR quality checklists as CQI tools. These post event checklists can be as simple as a short debriefing checklist (“report card,” Figure 1) on specific quality metrics that can be easily filled out after arrest events.

[h3]Use of Monitoring Data

Inclusion of monitoring data (physiological response of the patient to resuscitative efforts, performance of CPR by the provider) can provide an excellent dataset for debriefing because it allows a more objective approach that avoids perceptions of judgmental feedback. Every EMS system, hospital, and other professional rescuer program should strongly consider acquiring technology to capture CPR quality data for all cardiac arrests. Equipment that measures metrics of CPR performance must be able to provide resuscitation teams with the information necessary to implement immediate review sessions.

[h3]Integration With Existing Education

Quality-improvement strategies to improve CPR should include education to ensure optimal resuscitation team performance. Training in basic or advanced life support provides foundational knowledge and skills that can be lifesaving and improve outcomes.^{131,132} Unfortunately, skills acquired during these infrequent training programs deteriorate rapidly—within 6 to 12 months—if not used frequently.^{133,134-138}[ref] Recent evidence suggests that frequent short-duration “refreshing” of CPR skills prevents that decay and improves acquisition and retention of skills.^{130,139,140} Therefore, there is increasing interest in using this as the foundation for maintenance of competence/certification. Although the various continuous training strategies differ in their advantages, disadvantages, and resource intensiveness, the expert panel recommends that some form of continuous training should be a minimum standard for all CPR CQI programs.

Improved individual healthcare provider and resuscitation team performance can also be achieved through the use of simulated resuscitation exercises, or “mock codes.” Use of these kinds of “team-training” exercises also helps reinforce the importance of human factors in resuscitation team function¹⁴¹ and may prove to be an important systematic program to improve survival from cardiac arrest.¹⁴² Resuscitation training and education should not be considered a course or a single “event” but rather a long-term progression in the ongoing quest to optimize CPR quality.

[h2]Systems Review/Quality Improvement

Every EMS system, hospital, and other professional rescuer program should have an ongoing CPR CQI program providing feedback to the director, managers, and providers. CPR CQI programs can and should implement systems to acquire and centrally store metrics of CPR performance. System-wide performance (which is optimally linked with survival rate) should be intermittently reviewed, deficiencies identified, and corrective action implemented. Hospital cardiac arrest committee meetings, departmental “morbidity and mortality” meetings, and EMS quarterly quality-review meetings can serve as platforms to discuss selected cases of arrest care in detail and provide opportunities for feedback and reinforcement of quality goals. For example, time to first defibrillation attempt or CCF have both been shown to directly relate to clinical outcomes and are discrete metrics with clear meaning and opportunities for tracking over months or years. Over time, lessons learned from both a system-wide evaluation of performance as well as individual performance of teams from debriefing can provide invaluable objective feedback to systems to pinpoint opportunities for targeted training. The delivery of these messages needs to be consistent with the culture of the organization.

A number of large data collection initiatives have enriched clinical resuscitation science and represent opportunities to improve CQI processes. Similarly, the integration of local CQI processes, policies and education through registries and national databases helps determine as well as drive regional, national and global agendas (see figure 3.) Get With The Guidelines®–Resuscitation is an AHA-sponsored registry representing more than 200,000 in-hospital cardiac arrest events. The Cardiac Arrest Registry to Enhance Survival (CARES), established by the Centers for Disease Control and Prevention, collects national data on out-of-hospital cardiac arrest. The Resuscitation Outcomes Consortium has developed Epistry, a large database of out-of-hospital cardiac arrest events including granular CPR quality metrics. A consortium of the

European Resuscitation Council have created EuReCa (European Cardiac Arrest Registry) a multinational, multicultural database for out of hospital cardiac arrest. The value of these registries has been demonstrated by numerous research studies using registry data to identify variability in survival, development of standardized mortality ratios for comparing health care settings and specific resuscitation quality deficiencies. In addition, a recent study has suggested that longer participation in Get With The Guidelines–Resuscitation by hospitals is associated with improvements in rates of survival from in-hospital cardiac arrest over time.¹⁴³ Hospitals and EMS systems are strongly encouraged to participate in these collaborative registry programs. The costs of participation are modest and the potential benefits large. Not taking advantage of these mechanisms for data collection and benchmarking means that improved quality of care and survival will remain elusive.

Many existing obstacles to a systematic improvement in CPR quality are related to ease of data capture from monitoring systems for systematic review. Currently, most monitors capable of measuring mechanical parameters of CPR provide feedback to optimize performance during cardiac arrest, and some may provide for event review immediately afterward, but none readily lend themselves to systems review. In current practice, for example, most CPR-recording defibrillators require a manual downloading process. A number of challenges remain for CQI tools that are not limited to integration of these data into workflow and processing. Although many devices now exist to capture CPR quality metrics, robust wireless methods to transmit these data need to be less expensive and more widespread. To make CPR quality data collection routine, these processes need to be much more effortless. We encourage manufacturers to work with systems to develop seamless means of collecting, transmitting and compiling resuscitation quality data and linking them to registries to improve future training and survival from cardiac arrest.

[h1]Conclusions

As the science of CPR evolves, we have a tremendous opportunity to improve CPR performance during resuscitation events both inside and outside the hospital. Through better measurement, training, and systems-improvement processes of CPR quality, we can have a significant impact on survival from cardiac arrest and eliminate the gap between current and optimal outcomes. To achieve this goal, the expert panel proposes 5 recommendations as well as future directions to close existing gaps in knowledge.

[h1]Final Recommendations

- 1. Quality CPR should be recognized as the foundation on which all other resuscitation efforts are built. Target CPR performance metrics include**
 - a. CCF greater than 80%
 - b. Compression rate of 100 to 120/min
 - c. Compression depth at least 50 mm in adults with no residual leaning
 - i. (at least one third the anterior-posterior depth of the chest in children)
 - d. No Excessive Ventilation
 - i. (only minimal chest rise and a rate of less than 12 breaths per minute)
- 2. At every cardiac arrest attended by professional rescuers:**
 - a. Use at least 1 modality of monitoring the patient's physiological response to resuscitative efforts
 - b. Use at least 1 modality of monitoring the team's CPR performance
 - c. Continually adjust resuscitative efforts based on the patient's physiological response
- 3. Resuscitation teams should coordinate efforts to optimize CPR during cardiac arrest by**
 - a. Starting compressions rapidly and optimizing CPR performance early
 - b. Ensuring a team leader who oversees the effort and delegates effectively to ensure rapid and optimal CPR performance
 - c. Maintaining optimal CPR delivery while integrating advanced care and transport
- 4. Systems of care (EMS system, hospital, and other professional rescuer programs) should**
 - a. Determine a coordinated code team response with specific role responsibilities to ensure that quality CPR is delivered during the entire event

- b. Capture CPR performance data in every cardiac arrest and use an ongoing CPR CQI program to optimize future resuscitative efforts.
 - c. Implement strategies for continuous improvement in CPR quality and incorporate education, maintenance of competency, and review of arrest characteristics that include available CPR quality metrics
- 5. A national system for standardized reporting of CPR quality metrics should be developed:**
- a. CPR quality should be included in the Utstein template for reviewing, reporting, and conducting research on resuscitation
 - b. The AHA, appropriate government agencies, and device manufacturers should develop industry standards for interoperable raw data downloads and reporting from electronic data collected during resuscitation for both quality improvement and research

[h1]Future Directions

The expert panel expressed full consensus that there is a significant need to improve the monitoring and quality of CPR in all settings. Although there is a much better understanding of CPR, several critical knowledge gaps currently impede the implementation and widespread dissemination of high-quality CPR (Table 2). Research focused on these knowledge gaps will provide the information necessary to advance the delivery of optimal CPR and ultimately save more lives. Additionally, we encourage key stakeholders such as professional societies, manufacturers, and appropriate government agencies to work with systems to develop seamless means of collecting and compiling resuscitation quality data and to link them to registries to improve future training and rates of survival from cardiac arrest.

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