AHA Consensus Statement

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

A Consensus Statement From the American Heart Association

Endorsed by the American College of Emergency Physicians and the Society of Critical Care Medicine

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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 because of 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 the hospital, and lay the foundation for further improvements in the future. (***Circulation*****. 2013;128:417-435.)**

Key Words: AHA Scientific Statements ■ cardiac arrest ■ CPR ■ CPR quality ■ outcomes ■ resuscitation

Worldwide, there are >135 million cardiovascular deaths each year, and the prevalence of coronary heart disease is increasing.[1] Globally, the incidence of out-of-hospital cardiac arrest ranges from 20 to 140 per 100 000 people, and survival ranges from 2% to 11%.[2] In the United States, >500 000 children and adults experience a cardiac arrest, and <15% survive.[3–5] This establishes cardiac arrest as one of the most lethal public health problems in the United States,

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This statement was approved by the American Heart Association Science Advisory and Coordinating Committee on May 7, 2013. A copy of the document is available at http://my.americanheart.org/statements by selecting either the "By Topic" link or the "By Publication Date" link. To purchase additional reprints, call 843-216-2533 or e-mail kelle.ramsay@wolterskluwer.com.

The American Heart Association requests that this document be cited as follows: Meaney PA, Bobrow BJ, Mancini ME, Christenson J, de Caen AR, Bhanji F, Abella BS, Kleinman ME, Edelson DP, Berg RA, Aufderheide TP, Menon V, Leary M; on behalf of the CPR Quality Summit Investigators, the American Heart Association Emergency Cardiovascular Care Committee, and the Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation. Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. *Circulation.* 2013;128:417–435.

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Circulation **is available at http://circ.ahajournals.org** **DOI: 10.1161/CIR.0b013e31829d8654**

claiming more lives than colorectal cancer, breast cancer, prostate cancer, influenza, pneumonia, auto accidents, HIV, firearms, and house fires combined.[6] In many cases, as Claude Beck noted, cardiac arrest victims have "hearts too good to die."[7] 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 prehospital and in-hospital settings. Examples include the following:

- In the prehospital setting, among participating centers in the Resuscitation Outcomes Consortium (ROC) Epistry, survival from out-of-hospital arrest ranged from 3.0% to 16.3%.[3] In the United Kingdom, survival-to-discharge rates within the National Health Service ambulance system ranged from 2% to 12%.[8]
- In the hospital setting, among 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%–22%) and from pediatric cardiac arrest, it is 36% (interquartile range, 33%–49%).
- In a hospital setting, survival is >20% if the arrest occurs between the hours of 7 AM and 11 PM but only 15% if the arrest occurs between 11 PM and 7 AM.[9] There is significant variability with regard to location, with 9% survival at night in unmonitored settings compared with nearly 37% survival in operating room/postanesthesia care unit locations during the day.[9]
- Patient survival is linked to quality of cardiopulmonary resuscitation (CPR). When rescuers compress at a depth of <38 mm, survival-to-discharge rates after out-of-hospital arrest are reduced by 30%.[10] Similarly, when rescuers compress too slowly, return of spontaneous circulation (ROSC) after in-hospital cardiac arrest falls from 72% to 42%.[11]

The variations in performance and survival described in these studies provide the resuscitation community with 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.[12–14] 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.[3,15] 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 brain[16–19] 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,[20] and a standardized approach has been advocated to improve outcomes and reduce preventable harms.[21] The use of a systematic continuous quality improvement (CQI) approach has been shown to optimize outcomes in a number of urgent healthcare conditions.[22–24] 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, which leads to preventable deaths attributable to cardiac arrest. Resuscitative 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 the present consensus statement is to stimulate transformative change on a large scale by providing healthcare practitioners and healthcare systems a tangible framework with which 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" [2010 AHA Guidelines for CPR and ECC]) 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 factors—population (eg, neonatal), chain of survival (eg, bystander CPR, postresuscitation care), CPR mechanics (hand position, duty cycle, airway adjuncts), and education (adult learning principles, feedback devices during training)—that impact patient survival, this consensus statement is focused on the critical parameters of CPR that can be enhanced to help trained providers 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
- CQI for CPR

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

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 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 the International Liaison Committee on Resuscitation's "2010 International Consensus on CPR and ECC Science With Treatment Recommendations" statement and the 2010 International Liaison Committee on Resuscitation worksheets, PubMed, Embase, and an AHA master resuscitation reference library. This was supplemented by manual searches of key articles and abstracts. Statements generated from literature review were drafted by the writing group and presented to leaders in CPR quality at a CPR Quality Summit held May 20–21, 2012, in Irving, TX. 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 Emergency Cardiovascular Care Committee and Science Advisory and Coordinating Committee approved the final version for publication.

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 after CPR is dependent on adequate myocardial oxygen delivery and myocardial blood flow during CPR.[16–18] 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.[25–27] Therefore, maximizing CPP during CPR is the primary physiological goal. Because CPP cannot be measured easily in most patients, 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 because of 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, for educators to improve the quality of resuscitation training, for administrators to monitor performance to ensure high quality within the healthcare system, and for vendors to develop the necessary equipment needed to optimize CPR quality for providers, educators, and administrators.

Minimize Interruptions: CCF >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.[12,28] 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. 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.[29,30] One method to increase CCF that has improved survival is through reduction in preshock pause[31]; other techniques are discussed later in "Team-Level Logistics."

Chest Compression Rate of 100 to 120/min

The 2010 AHA Guidelines for CPR and ECC recommend a chest compression rate of ≥100/min.[28] As chest compression rates fall, a significant drop-off in ROSC occurs, and higher rates may reduce coronary blood flow[11,32] and decrease the percentage of compressions that achieve target depth.[10,33] Data from the ROC Epistry provide the best evidence of association between compression rate and survival and suggest an optimum target of between 100 and 120 compressions per minute.[34] Consistent rates above or below that range appear to reduce survival to discharge.

Chest Compression Depth of ≥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 and 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 ≥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 (≈1½ inches, or 4 cm, in infants and ≈2 inches, or 5 cm, in children).[35,36]

Although a recent study suggested that a depth of ≥44 mm in adults may be adequate to ensure optimal outcomes,[37] the preponderance of literature suggests that rescuers often do not compress the chest deeply enough despite recommendations.[10,37–39] Earlier studies suggested that compressions at a depth >50 mm may improve defibrillation success and ROSC in adults.[40–43] A recent study examined chest compression depth and survival in out-of-hospital cardiac arrest in adults and concluded that a depth of <38 mm was associated with a decrease in ROSC and rates of survival.[10] 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 the 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.

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.[44,45] This can occur when a rescuer leans over the patient's chest, impeding full chest expansion. Leaning is known to decrease the blood flow throughout the heart and can decrease venous return and cardiac output.[46] 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.[46–48] Human studies show that a majority of rescuers often lean during CPR and do not allow the chest to recoil fully.[49,50] Therefore, the expert panel agrees that leaning should be minimized.

Avoid Excessive Ventilation: Rate <12 Breaths per Minute, 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 nonasphyxial arrests.[51–54] 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.[55,56]

Providing sufficient oxygen to the blood without impeding perfusion is the goal of assisted ventilation during CPR. Positive-pressure ventilation reduces CPP during CPR,[57] and synchronous ventilation (recommended in the absence of an advanced airway)[35] requires interruptions, which reduces CCF. Excessive ventilation, either by rate or tidal volume, is common in resuscitation environments.[38,57–60] Although chest compression–only CPR by bystanders has yielded similar survival outcomes from out-of-hospital arrest as standard CPR,[38,51,52] there is presently not enough evidence to define when or if ventilation should be withheld by experienced providers, and more data will be required.

Rate <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). When other recommended goals are achieved (ie, compression rate of 100 to 120/min, inflation time of 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 with high ventilation rates,[57,61] 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 CO_2 clearance of the blood. The expert panel supports the 2010 AHA Guidelines for CPR and ECC and recommends a ventilation rate of <12 breaths per minute to minimize the impact of positive-pressure ventilation on blood flow.

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.[57,62–65] Use of lower tidal volumes during prolonged cardiac arrest was not associated with significant differences in Pao_2[66] and is currently recommended.[67] Additionally, positive-pressure ventilation in an unprotected airway may cause gastric insufflation and aspiration of gastric contents. Lung compliance is affected by compressions during cardiac arrest,[68] and the optimal inflation pressure is not known. Although the conceptual relevance of ventilation pressure and volume monitoring during CPR is 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.

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 of compressions, and compression-ventilation rates,[39,57,58,69] which were associated with worse outcomes.[11,34] With monitoring, there is increased clarity about optimal preshock pause, CCF, and chest compression depth.[10,29,31] With newer technology capable of monitoring CPR parameters during resuscitation, 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 (how the rescuers are doing) metrics. 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.

How the Patient Is Doing: Monitoring the Patient's Physiological Response 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 ($ETCO_2$). Abundant experimental literature has established that (1) survival after 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.[17,18,25,26,70,71] 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 $ETCO_2$ monitoring during CPR is 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 CPR Quality Summit strongly support prioritizing use of hemodynamic and $ETCO_2$ 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:

1. Invasive Monitoring: CPP >20 mm Hg

Successful adult resuscitation is more likely when CPP is >20 mm Hg and when diastolic blood pressure is >25 to 30 mm Hg.[16,17,25–27,72–77] Although optimal CPP has not been established, the expert panel agrees with the 2010 AHA Guidelines for CPR and ECC that monitoring and titration of CPP during CPR is reasonable.[13] 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.

2. Arterial Line Only: Arterial Diastolic Pressure >25 mm Hg

Consistent with these experimental data, limited published clinical studies indicate that the provision of successful adult resuscitation depends on maintaining diastolic blood pressure at >25 mm Hg.[26,75,76] The expert panel recommends that 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 <20 mm Hg.[13] The expert panel recommends that rescuers titrate to a diastolic blood pressure >25 mm Hg for adult victims of cardiac arrest.

3. Capnography Only: $ETCO_2$ >20 mm Hg

$ETCO_2$ concentrations during CPR are primarily dependent on pulmonary blood flow and therefore reflect cardiac output.[78,79] Failure to maintain $ETCO_2$ at >10 mm Hg during adult CPR reflects poor cardiac output and strongly predicts unsuccessful resuscitation.[80–82] The 2010 AHA Guidelines for CPR and ECC recommend monitoring $ETCO_2$ during CPR to assess blood flow in 2 ways: to improve chest compression performance if $ETCO_2$ is <10 mm Hg during CPR and to consider an abrupt sustained increase to a normal value (35 to 40 mm Hg) as an indicator of ROSC.[13] The expert panel recommends that when available, $ETCO_2$ should be the primary physiological metric when neither an arterial nor a 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 $ETCO_2$ of >20 mm Hg while not excessively ventilating the patient (rate <12 breaths per minute, with only minimal chest rise).

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 after 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, depth, and recoil. Currently, certain important parameters (CCF and preshock, perishock, and postshock pauses) can be reviewed only retrospectively, whereas others (ventilation rate, airway pressure, tidal volume, and inflation duration) cannot be assessed adequately by current technology. Additionally, accelerometers are insensitive to mattress compression, and current devices often prioritize the order of feedback by use of a rigid algorithm in a manner that may not be optimal or realistic (eg, an accelerometer cannot measure depth if there is too much leaning, so the device will prioritize feedback to correct leaning before correcting depth). Although 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.

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 (eg, 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, semiquantitative determination of chest compression depth and rate can be developed by rescuers with increasing experience, especially after effective feedback. Healthcare providers 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 problems[83–85] and is therefore not recommended as a reliable means of monitoring the effectiveness of CPR.[28,35] Observers can quickly identify rescuer-patient mismatch (eg, a 40-kg rescuer versus a 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 $ETCO_2$) with quantitative feedback of CPR quality parameters (depth, rate, leaning) to best achieve optimal CPR delivery.[86]

New methods and technology that accurately monitor both team performance and a patient's physiology during cardiac arrest should be developed. These may include additional markers of perfusion such as ventricular fibrillation waveform analysis, cerebral oximetry, impedance, and near-infrared spectroscopy. We challenge both researchers and industry to provide rescuers with robust solutions to monitor patient and provider performance.

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.[87] 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.[88]

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 about the optimal number and background of professional rescuers.[89] Examples of high-functioning resuscitation teams for both prehospital and in-hospital cardiac arrest are presented at http://www.heart.org/cprquality. 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 are, however, data to suggest that resuscitation team leadership training and demonstration of leadership behaviors (eg, setting clear expectations, being decisive, and taking a hands-off approach) are associated with improved CPR performance, especially an increase in CCF.[90–92] 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.

Interactions of CPR Performance Characteristics

There are no clear data on the interactions between compression fraction, rate or depth of compressions, leaning while performing compressions, 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 (eg, 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 expert panel proposes that if the patient is not responding to resuscitative efforts (ie, $ETCO_2$ <20 mm Hg), team leaders should 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) avoidance of excessive ventilation. This order is recommended in part because of the strength of the science as discussed in the prior sections (eg, there is stronger evidence for compression fraction, rate, and depth than leaning) but also for the sake of feasibility, as discussed below.

Maximization of CCF

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

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 performed 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.

Table 1. Compression Pause Requirements for Resuscitation Tasks

Pause Requirement	Task
Generally required	Defibrillation Rhythm analysis Rotation of compressors Backboard placement Transition to mechanical CPR or ECMO
Sometimes required	Complicated advanced airway placement in patients who cannot be ventilated effectively by bag-valve-mask Assessment for return of spontaneous circulation
Generally not required	Application of defibrillator pads Uncomplicated advanced airway placement IV/IO placement

CPR indicates cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; and IV/IO, intravenous/intraosseous.

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.[93] 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.[94] Patients who can be ventilated adequately by a bag-mask device may not need an advanced airway at all.[95] 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 <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.

Avoid Unnecessary Pulse Checks

Manual palpation for a pulse can result in unnecessarily long pauses and is often unreliable.[83,85,96–100] 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.

Minimize Perishock Pauses

The preshock phase may be particularly vulnerable to interruption of chest compressions because of the need to provide a safe environment for the rescuer. It is important to minimize preshock pauses, because outcomes are improved with decreasing duration of pauses before shock delivery, possibly as short as 9 seconds.[31,41,101] A strategy of applying the pads and charging the defibrillator during ongoing chest compressions results in shorter perishock pauses, and this practice is recommended.[33,102] Development of technology that minimizes all interruptions (eg, compression artifact waveform filters that enable rhythm analysis during ongoing chest compressions)[103] in blood flow, particularly around defibrillation, is encouraged. Chest compressions should be restarted without delay after delivery of the shock. In one study, elimination of stacked shocks and extension of the duration of CPR from 1 to 2 minutes before postshock rhythm analyses increased CCF from 48% to 69% and was associated with increased survival.[104]

Tight Regulation of 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 compression rates closer to the target rate of 100 to 120/min.[58,105,106] It is essential to continue to monitor and adjust for degradation in compression rate over time and after modifications to other parameters.

Maximizing Compression Depth

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

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[107–109] and reduce rescuer exertion,[110] but their placement interrupts CPR.[111] 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.

2. Optimize Provider Mechanics of Compressions

Compression mechanics often degrade over time,[112] and rescuers often do not perceive fatigue before skill deterioration.[113–115] Although the 2010 AHA Guidelines for CPR and ECC recommend rotating chest compressors every 2 minutes,[12] large interindividual differences in chest compression quality exist.[114,116] Some can perform good-quality compressions for up to 10 minutes, whereas inadequate chest compression depths have been observed after only 1 minute of continuous chest compressions[114,116] or even at the initiation of CPR.[114,116] Others have demonstrated that a switch at 2 minutes may be trading optimal compressions for significant leaning after the switch[86] and decreased CCF caused by the frequency of switching.[117] The use of feedback devices, especially visual, can counteract degradation of CPR mechanics to some degree.[118,119] 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 <3 seconds.[86]

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,[111,120,121] rescuer work appears to increase in the standing position compared with use of a step stool or when kneeling.[122,123] In addition, step stools have been shown to increase compression depth, especially for rescuers of short stature.[124] The expert panel recommends adjustable-height surface (such as a hospital bed), that the height of the surface be lowered, or that a step stool be used to enable rescuers to achieve optimal depth during CPR.

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.[124] 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.

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 use of metronomes, are well established,[106,125] 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.[66,67,126–128]

Additional Logistic Considerations

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.[129–133] The most likely explanation is that inexperienced rescuers underestimate the time required to apply the device,[134] which leads to a significant decrease in CCF during the first 5 minutes of an arrest[135–137] despite increases in CCF later in the resuscitation.[138] There is evidence that pre-event "pit crew" team training can reduce the pause required to apply the device.[139] Three large-scale implementation studies (Circulation Improving Resuscitation Care [CIRC],[140] Prehospital Randomized Assessment of a Mechanical Compression Device in Cardiac Arrest [PARAMEDIC],[141] and LUCAS in Cardiac Arrest [LINC])[142] may provide clarity about the optimal timing and environment for mechanical CPR. In the absence of published evidence demonstrating benefit, the decision to use mechanical CPR may be influenced by system considerations such as in rural settings with limited numbers of providers and/or long transport times.

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.[143,144] There is no consensus on the ideal ambulance speed to address these concerns.[145,146] Studies of mechanical versus manual CPR in a moving ambulance show less effect on CPR quality when a mechanical device is used.[130,147]

CPR and Systematic CQI

Systematic CQI has optimized outcomes in a number of healthcare conditions,[22–24] increases safety, and reduces harm.[21] Review of the quality and performance of CPR by professional rescuers after cardiac arrest has been shown to be feasible and improves outcomes.[40,137,148] 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.

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 after 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.[40] Preexisting structures in hospitals and emergency medical services (EMS) systems can be efficiently adapted to debrief

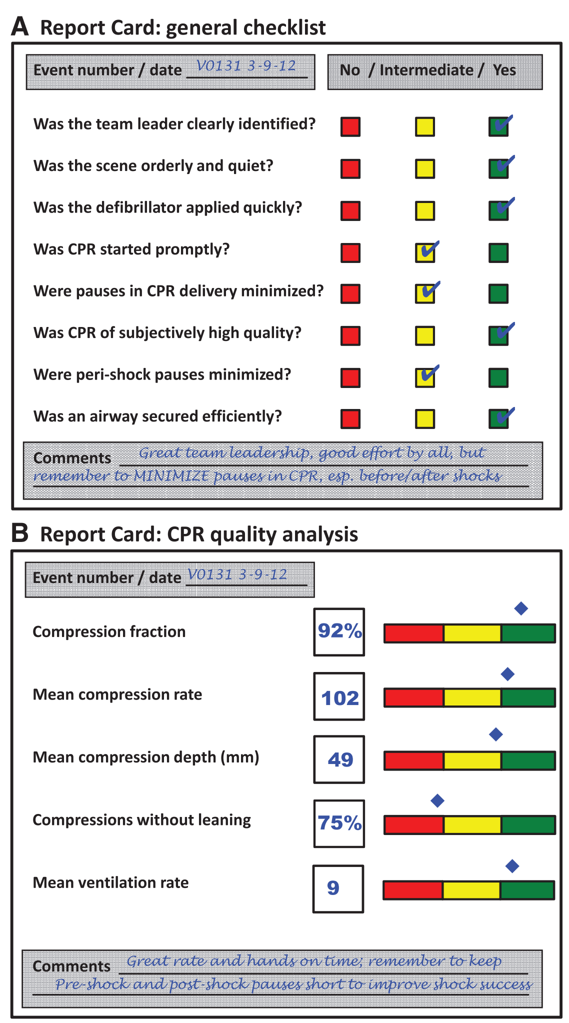

Figure 1. Illustration of proposed resuscitation "report cards." Routine use of a brief tool to document resuscitation quality would assist debriefing efforts and quality improvement efforts for hospital and emergency medical services systems. **A**, General checklist. Example of a general checklist report card that could be completed by a trained observer to a resuscitation event. **B**, CPR quality analysis. Example of a report card that relies on objective recording of CPR metrics. Ideally, both observational (**A**) and objective (**B**) reports could be used together in a combined report. CPR indicates cardiopulmonary resuscitation.

arrest events. This has also been confirmed by a number of simulation studies among rescuers of both pediatric and adult victims of cardiac arrest.[149,150] If this approach is taken, it is crucial that the actual care providers be present for the discussion.

Use of Checklists

Debriefing can be greatly enhanced by structuring the discussion; that is, 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 postevent checklists can be as simple as a short debriefing checklist (Figure 1 ["report card"]) on specific quality metrics that can be easily filled out after arrest events.

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 data set 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.

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.[151–153] Unfortunately, skills acquired during these infrequent training programs deteriorate rapidly (within 6–12 months) if not used frequently.[154–160] Recent evidence suggests that frequent short-duration "refreshing" of CPR skills prevents that decay and improves acquisition and retention of skills.[150,161,162] 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 function[163] and may prove to be an important systematic program to improve survival from cardiac arrest.[164] 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.

Systems Review/Quality Improvement

Every EMS system, hospital, and other professional rescuer program should have an ongoing CPR CQI program that provides 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 reviewed intermittently, deficiencies identified, and corrective action implemented. Routinely scheduled hospital cardiac arrest committee meetings, departmental "morbidity and mortality" meetings, and EMS quality review meetings can serve as platforms to discuss selected cases of arrest care

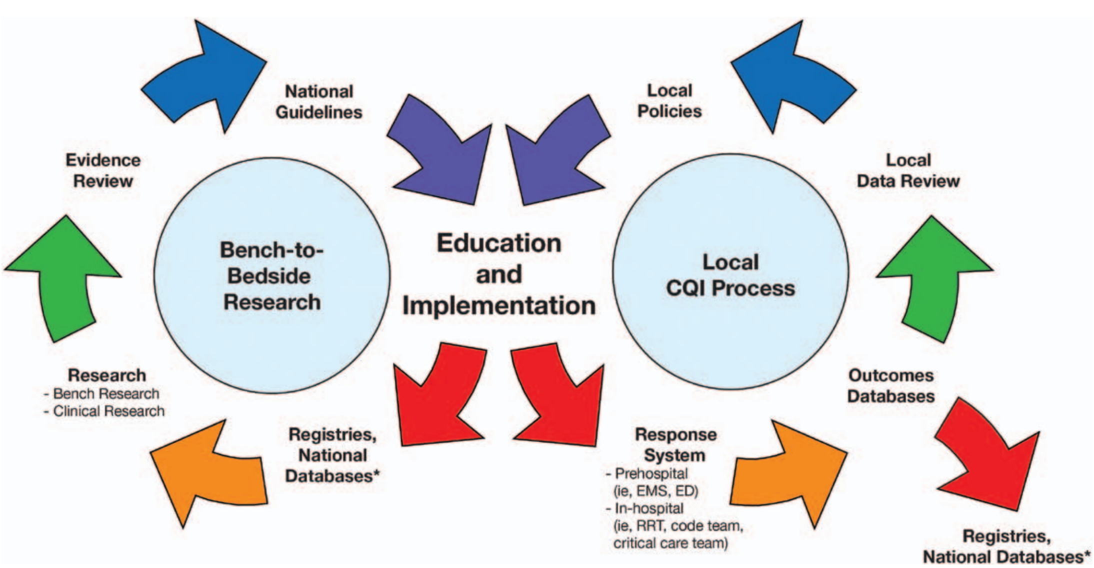

Figure 2. A continuous process evaluates and improves clinical care and generates new guidelines and therapy. Outcome data from cardiac arrest and periarrest periods are reviewed in a continuous quality-improvement (CQI) process. Research and clinical initiatives are reviewed periodically in an evidence-based process. Experts then evaluate new therapy and make clinical and educational recommendations for patient care. The process is repeated, and continual progress and care improvements are generated. ED indicates emergency department; EMS, emergency medical services; and RRT, rapid response team. *This is an overlap point in the cycle. That is, data come from outcomes databases (shown on the right) and go into registries and national databases (shown on the left).

Table 2. Final Recommendations

1. High-quality CPR should be recognized as the foundation on which all other resuscitative efforts are built. Target CPR performance metrics include
a. CCF >80%
b. Compression rate of 100–120/min
c. Compression depth of ≥50 mm in adults with no residual leaning
i. (At least one third the anterior-posterior dimension of the chest in infants and children)
d. Avoid excessive ventilation
i. (Only minimal chest rise and a rate of <12 breaths/min)
2. At every cardiac arrest attended by professional rescuers
a. Use at least 1 modality of monitoring the team's CPR performance
b. Depending on available resources, use at least 1 modality of monitoring the patient's physiological response to resuscitative efforts
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. Making sure that a team leader 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 high-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 metrics should be included and collected in national registries and databases 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

AHA indicates American Heart Association; CCF, chest compression fraction; CPR, cardiopulmonary resuscitation; CQI, continuous quality improvement; EMS, emergency medical services.

in detail and provide opportunities for feedback and reinforcement of quality goals. For example, time to first defibrillation attempt and 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 and 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 and drive regional, national, and global agendas (Figure 2). Get With The Guidelines-Resuscitation is an AHA-sponsored registry representing >250 000 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 ROC has developed Epistry, a large database of out-of-hospital cardiac arrest events, which includes granular CPR quality metrics. A consortium of the European Resuscitation Council has 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 healthcare settings, and specific resuscitation quality deficiencies. In addition, a recent study has suggested that longer participation by hospitals in Get With The Guidelines-Resuscitation is associated with improvements in rates of survival from in-hospital cardiac arrest over time.[165] 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

Table 3. Future Directions Needed to Improve CPR Quality: Research and Development

Research

- To determine the optimal targets for CPR characteristics (CCF, compression rate and depth, lean, and ventilation), as well as their relative importance to patient outcome
- To determine the effect of a victim's age and cause of arrest on optimal CPR characteristics (especially initiation and method of ventilation)
- To further characterize the relationships between individual CPR characteristics
- To further characterize which CPR characteristics and relationships between them are time dependent
- To determine the impact of the variability during the arrest of CPR characteristics (especially CCF and depth) on patient outcome
- To clarify whether ventilation characteristics (time-, pressure-, volume-based parameters) during CPR impact patient outcome
- To determine optimal titration of hemodynamic and $ETCO_2$ monitoring during human CPR
- To determine whether $ETCO_2$ monitoring of a noninvasive airway is a reliable and useful monitor of CPR quality
- To determine optimal relationship between preshock CPR characteristics (ie, depth, pause) and ROSC/survival
- To determine the optimal number of rescuers and the effect of rescuer characteristics on CPR quality and patient outcome
- To further characterize the impact of provider fatigue and recovery on patient outcome
- To determine the impact of work environment, training environment, and provider characteristics on CPR performance and patient survival
- To clarify methods of integration of CPR training into advanced courses and continuing maintenance of competency
- To determine the method of education, as well as its timing and location, at a system level to ensure optimal CPR performance and patient outcome
- To develop a global CPR metric that can be used to measure and optimize educational and systems improvement processes

Development

- To standardize the reporting of CPR quality and the integration of these data with existing systems improvement processes and registries
- To develop a device with the ability to measure and monitor CPR quality during training and delivered in real events and integrate it with existing quality improvement and registries
- To develop optimal CPR systems improvement processes that provide reliable, automated reporting of CPR quality parameters with the capacity for continuous CPR quality monitoring in all healthcare systems
- To develop feedback technology that prioritizes feedback in an optimal manner (eg, correct weighting and prioritization of the CPR characteristics themselves)
- To develop a more reliable, inexpensive, noninvasive physiological monitor that will increase our ability to optimize CPR for individual victims of cardiac arrest
- To develop training equipment that provides rescuers with robust skills to readily and reliably provide quality CPR
- To develop improved mechanical systems of monitoring CPR, including consistent and reliable capture of ventilation rate, tidal volume, inspiratory pressure, and duration, as well as complete chest recoil

CCF indicates chest compression fraction; CPR, cardiopulmonary resuscitation; and ROSC, return of spontaneous circulation.

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.

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 (Table 2), as well as future directions to close existing gaps in knowledge.

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 3). 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.

Acknowledgments

We thank the following individuals for their collaborations on the state of knowledge summary development and summit participation. Along with the writing group, the CPR Quality Summit investigators include Lance B. Becker, M. Allen McCullough, Robert M. Sutton, Dana E. Niles, Mark Venuti, Mary Fran Hazinski, Jose G. Cabanas, Thomas Rea, Andrew Travers, Elizabeth A. Hunt, Graham Nichol, Michael A. Rosen, Kathy Duncan, Vinay M. Nadkarni, and Michael R. Sayre.

Sources of Funding

Unrestricted funding for the CPR Quality Summit was provided by the CPR Improvement Working Group (Laerdal Medical, Philips Healthcare, and ZOLL Medical Corporation).

Disclosures

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Benjamin S. Abella	University of Pennsylvania	Medtronic Foundation: project on cardiac arrest outcomes; payment to institution†; Doris Duke Foundation: project on postresuscitation injury; payment to institution†; NIH NHLBI R18: project on CPR training of lay public; payment to institution†; Philips Healthcare: project on CPR hemodynamics and quality; payment to institution†; Stryker Medical: postarrest care; payment to institution†	None	Medivance: honoraria for lectures pertaining to hypothermia after arrest*	Resuscor, a company focused on healthcare provider education in resuscitation science: ownership stake*	HeartSine Corp: advisory board role to evaluate AED development*; Velomedix Corp: postarrest care*	None
Tom P. Aufderheide	Medical College of Wisconsin	NHLBI: Resuscitation Outcomes Consortium; money comes to institution, not to me directly†; NHLBI: Immediate Trial; money comes to institution†; NHLBI: ResQTrial; money comes to institution†; NINDS: Neurological Emergency Treatment Trials (NETT) Network; money comes to institution†	Zoll Medical: software provided directly from Zoll Medical to Milwaukee County Emergency Medical Services to complete research trials for the Resuscitation Outcomes Consortium and Immediate Trials†	None	None	President, Citizen CPR Foundation (volunteer)*; Secretary, Take Heart America (volunteer)*; Medtronic paid consultant; consultant on an acute MI trial; money went to my institution; discontinued consultant position November 2010*	National American Heart Association volunteer on Basic Life Support Subcommittee and Research Working Group*; As a member of the Institute of Medicine (IOM) and a member of the AHA Research Working Group, works with both institutions to generate funding for an IOM report on cardiac arrest (volunteer)*

(Continued)

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Jim Christenson	University of British Columbia, Faculty of Medicine	Resuscitation Outcomes Consortium group grant funded until 2016 on CPR quality; has published a paper on chest compression fraction and its relationship to survival and is coauthor on several papers evaluating various potential aspects of CPR quality†	None	None	None	None	None
Allan R. de Caen	Self-employed	None	None	None	None	None	None
Dana P. Edelson	University of Chicago	Philips Healthcare: funds paid to institution for projects on CPR quality and hemodynamics; Laerdal Medical: funds paid to institution for piloting new Basic Life Support training†; NIH NHLBI: funds paid to institution for strategies to prevent and predict in-hospital cardiac arrests†	None	None	Quant HC: Develops products for risk stratification of hospitalized patients†	CARES Advisory Council: Member*; Sudden Cardiac Arrest Foundation Board of Directors: Member*; FIERCE Certification Advisory Council: Member*	
Monica E. Kleinman	Children's Hospital Anesthesia Foundation	None	None	None	None	None	Expert witness: Review of medical-legal cases on behalf of defendants*
Marion Leary	University of Pennsylvania	None	None	Speaking honoraria a few years ago from Philips Healthcare*	None	Have reviewed devices for Philips Healthcare and Laerdal surrounding CPR quality devices, neither for any money*	Philips Healthcare has given research group QCPR devices to use for research*

(*Continued*)

Writing Group Disclosures, *Continued*

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Mary E. Mancini	The University of Texas at Arlington	None	None	Received honoraria for keynote speeches at national professional meetings such as National League for Nursing Education Summit on Nursing education. Topics included the importance of maintenance of competency and simulation; no long-term agreements to provide services related to a speakers' bureau.*	No personal financial interest but named on a patent for CPR device. University will receive the royalty if and when the device is commercialized.*	Serves on an advisory board for an LWW nursing product in development that will support nursing students in developing critical thinking skills; one situation to be covered is care of the patient with a cardiac arrest.*	None
Venu Menon	Cleveland Clinic	None	None	None	None	None	None

This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be "significant" if (1) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (2) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Modest.

†Significant.

Reviewer Disclosures

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Gavin Perkins	Warwick Medical School and Heart of England NHS Foundation Trust, United Kingdom	NIH (money paid to institution)†	None	None	None	None	None	None
Elizabeth H. Sinz	Penn State Hershey Medical Center	None	None	None	None	None	None	AHA, Associate Science Editor (money paid to institution)†
Kjetil Sunde	University of Oslo, Norway	None	None	None	None	None	None	None

This table represents the relationships of reviewers that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all reviewers are required to complete and submit. A relationship is considered to be "significant" if (1) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (2) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

†Significant.

References

1. Ahern RM, Lozano R, Naghavi M, Foreman K, Gakidou E, Murray CJ. Improving the public health utility of global cardiovascular mortality data: the rise of ischemic heart disease. *Popul Health Metr*. 2011;9:8.
2. Berdowski J, Berg RA, Tijssen JG, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. *Resuscitation*. 2010;81:1479–1487.
3. Nichol G, Thomas E, Callaway CW, Hedges J, Powell JL, Aufderheide TP, Rea T, Lowe R, Brown T, Dreyer J, Davis D, Idris A, Stiell I; Resuscitation Outcomes Consortium Investigators. Regional variation in out-of-hospital cardiac arrest incidence and outcome [published correction appears in *JAMA*. 2008;300:1763]. *JAMA*. 2008;300:1423–1431.
4. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Borden WB, Bravata DM, Dai S, Ford ES, Fox CS, Franco S, Fullerton HJ, Gillespie C, Hailpern SM, Heit JA, Howard VJ, Huffman MD, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Magid D, Marcus GM, Marelli A, Matchar DB, McGuire DK, Mohler ER, Moy CS, Mussolino ME, Nichol G, Paynter NP, Schreiner PJ, Sorlie PD, Stein J, Turan TN, Virani SS, Wong ND, Woo D, Turner MB; American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics–2013 update: a report from the American Heart Association [published correction appears in *Circulation*. 2013;127:doi:10.1161/CIR.0b013e31828124ad]. *Circulation*. 2013;127:e6–e245.
5. Merchant RM, Yang L, Becker LB, Berg RA, Nadkarni V, Nichol G, Carr BG, Mitra N, Bradley SM, Abella BS, Groeneveld PW; American Heart Association Get With The Guidelines-Resuscitation Investigators. Incidence of treated cardiac arrest in hospitalized patients in the United States. *Crit Care Med*. 2011;39:2401–2406.
6. Centers for Disease Control and Prevention. National Vital Statistics Reports, December 29, 2011. http://www.cdc.gov/nchs/data/nvsr/nvsr60/nvsr60_03.pdf. Accessed October 31, 2012.
7. Beck CS, Leighninger DS. Death after a clean bill of health: so-called “fatal” heart attacks and treatment with resuscitation techniques. *JAMA*. 1960;174:133–135.
8. Perkins GD, Cooke MW. Variability in cardiac arrest survival: the NHS Ambulance Service Quality Indicators. *Emerg Med J*. 2012;29:3–5.
9. Peberdy MA, Ornato JP, Larkin GL, Braithwaite RS, Kashner TM, Carey SM, Meaney PA, Cen L, Nadkarni VM, Praestgaard AH, Berg RA; National Registry of Cardiopulmonary Resuscitation Investigators. Survival from in-hospital cardiac arrest during nights and weekends. *JAMA*. 2008;299:785–792.
10. Stiell IG, Brown SP, Christenson J, Cheskes S, Nichol G, Powell J, Bigham B, Morrison LJ, Larsen J, Hess E, Vaillancourt C, Davis DP, Callaway CW; Resuscitation Outcomes Consortium (ROC) Investigators. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? *Crit Care Med*. 2012;40:1192–1198.
11. Abella BS, Sandbo N, Vassilatos P, Alvarado JP, O’Hearn N, Wigder HN, Hoffman P, Tynus K, Vanden Hoek TL, Becker LB. Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. *Circulation*. 2005;111:428–434.
12. Travers AH, Rea TD, Bobrow BJ, Edelson DP, Berg RA, Sayre MR, Berg MD, Chameides L, O’Connor RE, Swor RA. Part 4: CPR overview: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(suppl 3):S676–S684.
13. Neumar RW, Otto CW, Link MS, Kronick SL, Shuster M, Callaway CW, Kudenchuk PJ, Ornato JP, McNally B, Silvers SM, Passman RS, White RD, Hess EP, Tang W, Davis D, Sinz E, Morrison LJ. Part 8: adult advanced cardiovascular life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [published correction appears in *Circulation*. 2011;123:e236]. *Circulation*. 2010;122(suppl 3):S729–S767.
14. Kleinman ME, Chameides L, Schexnayder SM, Samson RA, Hazinski MF, Atkins DL, Berg MD, de Caen AR, Fink EL, Freid EB, Hickey RW, Marino BS, Nadkarni VM, Proctor LT, Qureshi FA, Sartorelli K, Topjian A, van der Jagt EW, Zaritsky AL. Part 14: pediatric advanced life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(suppl 3):S876–S908.
15. Nichol G, Aufderheide TP, Eigel B, Neumar RW, Lurie KG, Bufalino VJ, Callaway CW, Menon V, Bass RR, Abella BS, Sayre M, Dougherty CM, Racht EM, Kleinman ME, O’Connor RE, Reilly JP, Ossmann EW, Peterson E; American Heart Association Emergency Cardiovascular Care Committee; Council on Arteriosclerosis, Thrombosis, and Vascular Biology; Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation; Council on Cardiovascular Nursing; Council on Clinical Cardiology; Advocacy Committee; Council on Quality of Care and Outcomes Research. Regional systems of care for out-of-hospital cardiac arrest: a policy statement from the American Heart Association [published correction appears in *Circulation*. 2010;122:e439]. *Circulation*. 2010;121:709–729.
16. Ralston SH, Voorhees WD, Babbs CF. Intrapulmonary epinephrine during prolonged cardiopulmonary resuscitation: improved regional blood flow and resuscitation in dogs. *Ann Emerg Med*. 1984;13:79–86.
17. Michael JR, Guerci AD, Koehler RC, Shi AY, Tsitlik J, Chandra N, Niedermeyer E, Rogers MC, Traystman RJ, Weisfeldt ML. Mechanisms by which epinephrine augments cerebral and myocardial perfusion during cardiopulmonary resuscitation in dogs. *Circulation*. 1984;69:822–835.
18. Halperin HR, Tsitlik JE, Guerci AD, Mellits ED, Levin HR, Shi AY, Chandra N, Weisfeldt ML. Determinants of blood flow to vital organs during cardiopulmonary resuscitation in dogs. *Circulation*. 1986;73:539–550.
19. Rubertsson S, Karlsten R. Increased cortical cerebral blood flow with LUCAS, a new device for mechanical chest compressions compared to standard external compressions during experimental cardiopulmonary resuscitation. *Resuscitation*. 2005;65:357–363.
20. Gurses AP, Seidl KL, Vaidya V, Bochicchio G, Harris AD, Hebden J, Xiao Y. Systems ambiguity and guideline compliance: a qualitative study of how intensive care units follow evidence-based guidelines to reduce healthcare-associated infections. *Qual Saf Health Care*. 2008;17:351–359.
21. Pronovost PJ, Bo-Linn GW. Preventing patient harms through systems of care. *JAMA*. 2012;308:769–770.
22. Jollis JG, Granger CB, Henry TD, Antman EM, Berger PB, Moyer PH, Pratt FD, Rokos IC, Acuña AR, Roettig ML, Jacobs AK. Systems of care for ST-segment-elevation myocardial infarction: a report from the American Heart Association’s Mission: Lifeline. *Circ Cardiovasc Qual Outcomes*. 2012;5:423–428.
23. Nestler DM, Noheria A, Haro LH, Stead LG, Decker WW, Scanlan-Hanson LN, Lennon RJ, Lim CC, Holmes DR Jr, Rihal CS, Bell MR, Ting HH. Sustaining improvement in door-to-balloon time over 4 years: the Mayo Clinic ST-elevation myocardial infarction protocol. *Circ Cardiovasc Qual Outcomes*. 2009;2:508–513.
24. Santana MJ, Stelfox HT. Quality indicators used by trauma centers for performance measurement. *J Trauma Acute Care Surg*. 2012;72:1298–1302.
25. Niemann JT, Rosborough JP, Ung S, Criley JM. Coronary perfusion pressure during experimental cardiopulmonary resuscitation. *Ann Emerg Med*. 1982;11:127–131.
26. Paradis NA, Martin GB, Rivers EP, Goetting MG, Appleton TJ, Feingold M, Nowak RM. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. *JAMA*. 1990;263:1106–1113.
27. Sanders AB, Ogle M, Ewy GA. Coronary perfusion pressure during cardiopulmonary resuscitation. *Am J Emerg Med*. 1985;3:11–14.
28. Berg RA, Hemphill R, Abella BS, Aufderheide TP, Cave DM, Hazinski MF, Lerner EB, Rea TD, Sayre MR, Swor RA. Part 5: adult basic life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [published correction appears in *Circulation*. 2011;124:e402]. *Circulation*. 2010;122(suppl 3):S685–S705.
29. Christenson J, Andrusiek D, Everson-Stewart S, Kudenchuk P, Hostler D, Powell J, Callaway CW, Bishop D, Vaillancourt C, Davis D, Aufderheide TP, Idris A, Stouffer JA, Stiell I, Berg R; Resuscitation Outcomes Consortium Investigators. Chest compression fraction determines survival in patients with out-of-hospital ventricular fibrillation. *Circulation*. 2009;120:1241–1247.
30. Vaillancourt C, Everson-Stewart S, Christenson J, Andrusiek D, Powell J, Nichol G, Cheskes S, Aufderheide TP, Berg R, Stiell IG; Resuscitation Outcomes Consortium Investigators. The impact of increased chest compression fraction on return of spontaneous circulation for out-of-hospital cardiac arrest patients not in ventricular fibrillation. *Resuscitation*. 2011;82:1501–1507.
31. Cheskes S, Schmicker RH, Christenson J, Salcido DD, Rea T, Powell J, Edelson DP, Sell R, May S, Menegazzi JJ, Van Ottingham L, Olsufka M, Pennington S, Simonini J, Berg RA, Stiell I, Idris A, Bigham B, Morrison L; Resuscitation Outcomes Consortium (ROC) Investigators. Perishock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. *Circulation*. 2011;124:58–66.
32. Wolfe JA, Maier GW, Newton JR Jr, Glower DD, Tyson GS Jr, Spratt JA, Rankin JS, Olsen CO. Physiologic determinants of coronary blood

flow during external cardiac massage. *J Thorac Cardiovasc Surg*. 1988;95:523–532.
33. Monsieurs KG, De Regge M, Vansteelandt K, De Smet J, Annaert E, Lemoyne S, Kalmar AF, Calle PA. Excessive chest compression rate is associated with insufficient compression depth in prehospital cardiac arrest. *Resuscitation*. 2012;83:1319–1323.
34. Idris AH, Guffey D, Aufderheide TP, Brown S, Morrison LJ, Nichols P, Powell J, Daya M, Bigham BL, Atkins DL, Berg R, Davis D, Stiell I, Sopko G, Nichol G; Resuscitation Outcomes Consortium (ROC) Investigators. Relationship between chest compression rates and outcomes from cardiac arrest. *Circulation*. 2012;125:3004–3012.
35. Berg MD, Schexnayder SM, Chameides L, Terry M, Donoghue A, Hickey RW, Berg RA, Sutton RM, Hazinski MF. Part 13: pediatric basic life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(suppl 3):S862–S875.
36. Sutton RM, French B, Nishisaki A, Niles DE, Maltese MR, Boyle L, Stavland M, Eilevstjønn J, Arbogast KB, Berg RA, Nadkarni VM. American Heart Association cardiopulmonary resuscitation quality targets are associated with improved arterial blood pressure during pediatric cardiac arrest. *Resuscitation*. 2013;84:168–172.
37. Stiell IG, Brown S, Calloway CW, Aufderheide TP, Cheskes S, Vaillancourt C, Hostler D, Davis DP, Idris A, Christenson J, Morrison M, Stouffer J, Free C, Nichol G; Resuscitation Outcomes Consortium Investigators. What is the optimal chest compression depth during resuscitation from out-of-hospital cardiac arrest in adult patients? *Circulation*. 2012;126:A287. Abstract.
38. Abella BS, Alvarado JP, Myklebust H, Edelson DP, Barry A, O'Hearn N, Vanden Hoek TL, Becker LB. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. *JAMA*. 2005;293:305–310.
39. Wik L, Kramer-Johansen J, Myklebust H, Sørebø H, Svensson L, Fellows B, Steen PA. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA*. 2005;293:299–304.
40. Edelson DP, Litzinger B, Arora V, Walsh D, Kim S, Lauderdale DS, Vanden Hoek TL, Becker LB, Abella BS. Improving in-hospital cardiac arrest process and outcomes with performance debriefing. *Arch Intern Med*. 2008;168:1063–1069.
41. Edelson DP, Abella BS, Kramer-Johansen J, Wik L, Myklebust H, Barry AM, Merchant RM, Hoek TL, Steen PA, Becker LB. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. *Resuscitation*. 2006;71:137–145.
42. Kramer-Johansen J, Myklebust H, Wik L, Fellows B, Svensson L, Sørebø H, Steen PA. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. *Resuscitation*. 2006;71:283–292.
43. Babbs CF, Kemeny AE, Quan W, Freeman G. A new paradigm for human resuscitation research using intelligent devices. *Resuscitation*. 2008;77:306–315.
44. Aufderheide TP, Pirrallo RG, Yannopoulos D, Klein JP, von Briesen C, Sparks CW, Deja KA, Conrad CJ, Kitscha DJ, Provo TA, Lurie KG. Incomplete chest wall decompression: a clinical evaluation of CPR performance by EMS personnel and assessment of alternative manual chest compression-decompression techniques. *Resuscitation*. 2005;64:353–362.
45. Yannopoulos D, McKnite S, Aufderheide TP, Sigurdsson G, Pirrallo RG, Benditt D, Lurie KG. Effects of incomplete chest wall decompression during cardiopulmonary resuscitation on coronary and cerebral perfusion pressures in a porcine model of cardiac arrest. *Resuscitation*. 2005;64:363–372.
46. Zuercher M, Hilwig RW, Ranger-Moore J, Nysaether J, Nadkarni VM, Berg MD, Kern KB, Sutton R, Berg RA. Leaning during chest compressions impairs cardiac output and left ventricular myocardial blood flow in piglet cardiac arrest. *Crit Care Med*. 2010;38:1141–1146.
47. Sutton RM, Niles D, Nysaether J, Stavland M, Thomas M, Ferry S, Bishnoi R, Litman R, Allen J, Srinivasan V, Berg RA, Nadkarni VM. Effect of residual leaning force on intrathoracic pressure during mechanical ventilation in children. *Resuscitation*. 2010;81:857–860.
48. Niles DE, Sutton RM, Nadkarni VM, Glatz A, Zuercher M, Maltese MR, Eilevstjønn J, Abella BS, Becker LB, Berg RA. Prevalence and hemodynamic effects of leaning during CPR. *Resuscitation*. 2011;82(suppl 2):S23–S26.
49. Fried DA, Leary M, Smith DA, Sutton RM, Niles D, Herzberg DL, Becker LB, Abella BS. The prevalence of chest compression leaning during in-hospital cardiopulmonary resuscitation. *Resuscitation*. 2011;82:1019–1024.
50. Niles D, Nysaether J, Sutton R, Nishisaki A, Abella BS, Arbogast K, Maltese MR, Berg RA, Helfaer M, Nadkarni V. Leaning is common during in-hospital pediatric CPR, and decreased with automated corrective feedback. *Resuscitation*. 2009;80:553–557.
51. Hallstrom A, Cobb L, Johnson E, Copass M. Cardiopulmonary resuscitation by chest compression alone or with mouth-to-mouth ventilation. *N Engl J Med*. 2000;342:1546–1553.
52. Van Hoeyweghen RJ, Bossaert LL, Mullie A, Calle P, Martens P, Buylaert WA, Delooz H. Quality and efficiency of bystander CPR: Belgian Cerebral Resuscitation Study Group. *Resuscitation*. 1993;26:47–52.
53. Bobrow BJ, Clark LL, Ewy GA, Chikani V, Sanders AB, Berg RA, Richman PB, Kern KB. Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. *JAMA*. 2008;299:1158–1165.
54. Dorph E, Wik L, Strømme TA, Eriksen M, Steen PA. Oxygen delivery and return of spontaneous circulation with ventilation:compression ratio 2:30 versus chest compressions only CPR in pigs. *Resuscitation*. 2004;60:309–318.
55. Kitamura T, Iwami T, Kawamura T, Nagao K, Tanaka H, Nadkarni VM, Berg RA, Hiraide A; Implementation Working Group for All-Japan Utstein Registry of the Fire and Disaster Management Agency. Conventional and chest-compression-only cardiopulmonary resuscitation by bystanders for children who have out-of-hospital cardiac arrests: a prospective, nationwide, population-based cohort study. *Lancet*. 2010;375:1347–1354.
56. Berg RA, Hilwig RW, Kern KB, Babar I, Ewy GA. Simulated mouth-to-mouth ventilation and chest compressions (bystander cardiopulmonary resuscitation) improves outcome in a swine model of prehospital pediatric asphyxial cardiac arrest. *Crit Care Med*. 1999;27:1893–1899.
57. Aufderheide TP, Sigurdsson G, Pirrallo RG, Yannopoulos D, McKnite S, von Briesen C, Sparks CW, Conrad CJ, Provo TA, Lurie KG. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. *Circulation*. 2004;109:1960–1965.
58. Milander MM, Hiscok PS, Sanders AB, Kern KB, Berg RA, Ewy GA. Chest compression and ventilation rates during cardiopulmonary resuscitation: the effects of audible tone guidance. *Acad Emerg Med*. 1995;2:708–713.
59. O'Neill JF, Deakin CD. Do we hyperventilate cardiac arrest patients? *Resuscitation*. 2007;73:82–85.
60. McInnes AD, Sutton RM, Orioles A, Nishisaki A, Niles D, Abella BS, Maltese MR, Berg RA, Nadkarni V. The first quantitative report of ventilation rate during in-hospital resuscitation of older children and adolescents. *Resuscitation*. 2011;82:1025–1029.
61. Gazmuri RJ, Ayoub IM, Radhakrishnan J, Motl J, Upadhyaya MP. Clinically plausible hyperventilation does not exert adverse hemodynamic effects during CPR but markedly reduces end-tidal PCO_2. *Resuscitation*. 2012;83:259–264.
62. Woda RP, Dzwonczyk R, Bernacki BL, Cannon M, Lynn L. The ventilatory effects of auto-positive end-expiratory pressure development during cardiopulmonary resuscitation. *Crit Care Med*. 1999;27:2212–2217.
63. Pepe PE, Marini JJ. Occult positive end-expiratory pressure in mechanically ventilated patients with airflow obstruction: the auto-PEEP effect. *Am Rev Respir Dis*. 1982;126:166–170.
64. Cournand A, Motley HL. Physiological studies of the effects of intermittent positive pressure breathing on cardiac output in man. *Am J Physiol*. 1948;152:162–174.
65. Sykes MK, Adams AP, Finlay WE, McCormick PW, Economides A. The effects of variations in end-expiratory inflation pressure on cardiorespiratory function in normo-, hypo-and hypervolaemic dogs. *Br J Anaesth*. 1970;42:669–677.
66. Langhelle A, Sunde K, Wik L, Steen PA. Arterial blood-gases with 500- versus 1000-ml tidal volumes during out-of-hospital CPR. *Resuscitation*. 2000;45:27–33.
67. Wenzel V, Keller C, Idris AH, Dörges V, Lindner KH, Brimacombe JR. Effects of smaller tidal volumes during basic life support ventilation in patients with respiratory arrest: good ventilation, less risk? *Resuscitation*. 1999;43:25–29.
68. Fuerst R, Idris A, Banner M, Wenzel V, Orban D. Changes in respiratory system compliance during cardiopulmonary arrest with and without closed chest compressions. *Ann Emerg Med*. 1993;22:931.
69. Valenzuela TD, Kern KB, Clark LL, Berg RA, Berg MD, Berg DD, Hilwig RW, Otto CW, Newburn D, Ewy GA. Interruptions of chest compressions during emergency medical systems resuscitation. *Circulation*. 2005;112:1259–1265.
70. Crile G, Dolley DH. An experimental research into the resuscitation of dogs killed by anesthetics and asphyxia. *J Exp Med*. 1906;8:713–725.

71. Berg RA, Kern KB, Hilwig RW, Ewy GA. Assisted ventilation during "bystander" CPR in a swine acute myocardial infarction model does not improve outcome. *Circulation*. 1997;96:4364–4371.
72. Redding JS, Pearson JW. Resuscitation from ventricular fibrillation: drug therapy. *JAMA*. 1968;203:255–260.
73. Kern KB, Ewy GA, Voorhees WD, Babbs CF, Tacker WA. Myocardial perfusion pressure: a predictor of 24-hour survival during prolonged cardiac arrest in dogs. *Resuscitation*. 1988;16:241–250.
74. Lindner KH, Prengel AW, Pfenninger EG, Lindner IM, Strohmenger HU, Georgieff M, Lurie KG. Vasopressin improves vital organ blood flow during closed-chest cardiopulmonary resuscitation in pigs. *Circulation*. 1995;91:215–221.
75. Martin GB, Carden DL, Nowak RM, Lewinter JR, Johnston W, Tomlanovich MC. Aortic and right atrial pressures during standard and simultaneous compression and ventilation CPR in human beings. *Ann Emerg Med*. 1986;15:125–130.
76. Timerman S, Cardoso LF, Ramires JA, Halperin H. Improved hemodynamic performance with a novel chest compression device during treatment of in-hospital cardiac arrest. *Resuscitation*. 2004;61:273–280.
77. Pearson JW, Redding JS. Peripheral vascular tone on cardiac resuscitation. *Anesth Analg*. 1965;44:746–752.
78. Ornato JP, Garnett AR, Glauser FL. Relationship between cardiac output and the end-tidal carbon dioxide tension. *Ann Emerg Med*. 1990;19:1104–1106.
79. Weil MH, Bisera J, Trevino RP, Rackow EC. Cardiac output and end-tidal carbon dioxide. *Crit Care Med*. 1985;13:907–909.
80. Levine RL, Wayne MA, Miller CC. End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest. *N Engl J Med*. 1997;337:301–306.
81. Sanders AB, Kern KB, Otto CW, Milander MM, Ewy GA. End-tidal carbon dioxide monitoring during cardiopulmonary resuscitation: a prognostic indicator for survival. *JAMA*. 1989;262:1347–1351.
82. Cantineau JP, Lambert Y, Merckx P, Reynaud P, Porte F, Bertrand C, Duvaldestin P. End-tidal carbon dioxide during cardiopulmonary resuscitation in humans presenting mostly with asystole: a predictor of outcome. *Crit Care Med*. 1996;24:791–796.
83. Eberle B, Dick WF, Schneider T, Wisser G, Doetsch S, Tzanova I. Checking the carotid pulse check: diagnostic accuracy of first responders in patients with and without a pulse. *Resuscitation*. 1996;33:107–116.
84. Tibballs J, Russell P. Reliability of pulse palpation by healthcare personnel to diagnose paediatric cardiac arrest. *Resuscitation*. 2009;80:61–64.
85. Lapostolle F, Le Toumelin P, Agostinucci JM, Catineau J, Adnet F. Basic cardiac life support providers checking the carotid pulse: performance, degree of conviction, and influencing factors. *Acad Emerg Med*. 2004;11:878–880.
86. Sutton RM, Maltese MR, Niles D, French B, Nishisaki A, Arbogast KB, Donoghue A, Berg RA, Helfaer MA, Nadkarni V. Quantitative analysis of chest compression interruptions during in-hospital resuscitation of older children and adolescents. *Resuscitation*. 2009;80:1259–1263.
87. Hazinski MF, ed. *BLS for Healthcare Providers Student Manual*. Dallas, TX: American Heart Association; 2011.
88. Tschan F, Vetterli M, Semmer NK, Hunziker S, Marsch SC. Activities during interruptions in cardiopulmonary resuscitation: a simulator study. *Resuscitation*. 2011;82:1419–1423.
89. Eschmann NM, Pirrallo RG, Aufderheide TP, Lerner EB. The association between emergency medical services staffing patterns and out-of-hospital cardiac arrest survival. *Prehosp Emerg Care*. 2010;14:71–77.
90. Yeung JH, Ong GJ, Davies RP, Gao F, Perkins GD. Factors affecting team leadership skills and their relationship with quality of cardiopulmonary resuscitation. *Crit Care Med*. 2012;40:2617–2621.
91. Hunziker S, Bühlmann C, Tschan F, Balestra G, Legeret C, Schumacher C, Semmer NK, Hunziker P, Marsch S. Brief leadership instructions improve cardiopulmonary resuscitation in a high-fidelity simulation: a randomized controlled trial [published correction appears in *Crit Care Med*. 2010;38:1510]. *Crit Care Med*. 2010;38:1086–1091.
92. Cooper S, Wakelam A. Leadership of resuscitation teams: "Lighthouse Leadership." *Resuscitation*. 1999;42:27–45.
93. Wang HE, Simeone SJ, Weaver MD, Callaway CW. Interruptions in cardiopulmonary resuscitation from paramedic endotracheal intubation. *Ann Emerg Med*. 2009;54:645–652.e1.
94. Wang HE, Szydlo D, Stouffer JA, Lin S, Carlson JN, Vaillancourt C, Sears G, Verbeek RP, Fowler R, Idris AH, Koenig K, Christenson J, Minokadeh A, Brandt J, Rea T; ROC Investigators. Endotracheal intubation versus supraglottic airway insertion in out-of-hospital cardiac arrest. *Resuscitation*. 2012;83:1061–1066.
95. Hanif MA, Kaji AH, Niemann JT. Advanced airway management does not improve outcome of out-of-hospital cardiac arrest. *Acad Emerg Med*. 2010;17:926–931.
96. Bahr J, Klingler H, Panzer W, Rode H, Kettler D. Skills of lay people in checking the carotid pulse. *Resuscitation*. 1997;35:23–26.
97. Moule P. Checking the carotid pulse: diagnostic accuracy in students of the healthcare professions. *Resuscitation*. 2000;44:195–201.
98. Nyman J, Sihvonen M. Cardiopulmonary resuscitation skills in nurses and nursing students. *Resuscitation*. 2000;47:179–184.
99. Ochoa FJ, Ramalle-Gómara E, Carpintero JM, García A, Saralegui I. Competence of health professionals to check the carotid pulse. *Resuscitation*. 1998;37:173–175.
100. Mather C, O'Kelly S. The palpation of pulses. *Anaesthesia*. 1996;51:189–191.
101. Sell RE, Sarno R, Lawrence B, Castillo EM, Fisher R, Brainard C, Dunford JV, Davis DP. Minimizing pre- and post-defibrillation pauses increases the likelihood of return of spontaneous circulation (ROSC). *Resuscitation*. 2010;81:822–825.
102. Perkins GD, Davies RP, Soar J, Thickett DR. The impact of manual defibrillation technique on no-flow time during simulated cardiopulmonary resuscitation. *Resuscitation*. 2007;73:109–114.
103. Li Y, Bisera J, Weil MH, Tang W. An algorithm used for ventricular fibrillation detection without interrupting chest compression. *IEEE Trans Biomed Eng*. 2012;59:78–86.
104. Rea TD, Helbock M, Perry S, Garcia M, Cloyd D, Becker L, Eisenberg M. Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes. *Circulation*. 2006;114:2760–2765.
105. Chung TN, Bae J, Kim EC, Cho YK, You JS, Choi SW, Kim OJ. Induction of a shorter compression phase is correlated with a deeper chest compression during metronome-guided cardiopulmonary resuscitation: a manikin study. *Emerg Med J*. July 25, 2012. doi:10.1136/emermed-2012-201534. http://emj.bmj.com/content/early/2012/07/24/emermed-2012-201534.long. Accessed June 11, 2013.
106. Kern KB, Stickney RE, Gallison L, Smith RE. Metronome improves compression and ventilation rates during CPR on a manikin in a randomized trial. *Resuscitation*. 2010;81:206–210.
107. Sato H, Komasawa N, Ueki R, Yamamoto N, Fujii A, Nishi S, Kaminoh Y. Backboard insertion in the operating table increases chest compression depth: a manikin study. *J Anesth*. 2011;25:770–772.
108. Nishisaki A, Maltese MR, Niles DE, Sutton RM, Urbano J, Berg RA, Nadkarni VM. Backboards are important when chest compressions are provided on a soft mattress. *Resuscitation*. 2012;83:1013–1020.
109. Andersen LØ, Isbye DL, Rasmussen LS. Increasing compression depth during manikin CPR using a simple backboard. *Acta Anaesthesiol Scand*. 2007;51:747–750.
110. Noordergraaf GJ, Paulussen IW, Venema A, van Berkom PF, Woerlee PH, Scheffer GJ, Noordergraaf A. The impact of compliant surfaces on in-hospital chest compressions: effects of common mattresses and a backboard. *Resuscitation*. 2009;80:546–552.
111. Perkins GD, Smith CM, Augre C, Allan M, Rogers H, Stephenson B, Thickett DR. Effects of a backboard, bed height, and operator position on compression depth during simulated resuscitation. *Intensive Care Med*. 2006;32:1632–1635.
112. Sugerman NT, Edelson DP, Leary M, Weidman EK, Herzberg DL, Vanden Hoek TL, Becker LB, Abella BS. Rescuer fatigue during actual in-hospital cardiopulmonary resuscitation with audiovisual feedback: a prospective multicenter study. *Resuscitation*. 2009;80:981–984.
113. Ochoa FJ, Ramalle-Gómara E, Lisa V, Saralegui I. The effect of rescuer fatigue on the quality of chest compressions. *Resuscitation*. 1998;37:149–152.
114. Ashton A, McCluskey A, Gwinnutt CL, Keenan AM. Effect of rescuer fatigue on performance of continuous external chest compressions over 3 min. *Resuscitation*. 2002;55:151–155.
115. Hightower D, Thomas SH, Stone CK, Dunn K, March JA. Decay in quality of closed-chest compressions over time. *Ann Emerg Med*. 1995;26:300–303.
116. Bjørshol CA, Sunde K, Myklebust H, Assmus J, Søreide E. Decay in chest compression quality due to fatigue is rare during prolonged advanced life support in a manikin model. *Scand J Trauma Resusc Emerg Med*. 2011;19:46.
117. Manders S, Geijsel FE. Alternating providers during continuous chest compressions for cardiac arrest: every minute or every two minutes? *Resuscitation*. 2009;80:1015–1018.

118. Cason CL, Trowbridge C, Baxley SM, Ricard MD. A counterbalanced cross-over study of the effects of visual, auditory and no feedback on performance measures in a simulated cardiopulmonary resuscitation. *BMC Nurs*. 2011;10:15.
119. Pozner CN, Almozlino A, Elmer J, Poole S, McNamara D, Barash D. Cardiopulmonary resuscitation feedback improves the quality of chest compression provided by hospital health care professionals. *Am J Emerg Med*. 2011;29:618–625.
120. Chi CH, Tsou JY, Su FC. Effects of rescuer position on the kinematics of cardiopulmonary resuscitation (CPR) and the force of delivered compressions. *Resuscitation*. 2008;76:69–75.
121. Jäntti H, Silfvast T, Turpeinen A, Kiviniemi V, Uusaro A. Quality of cardiopulmonary resuscitation on manikins: on the floor and in the bed. *Acta Anaesthesiol Scand*. 2009;53:1131–1137.
122. Foo NP, Chang JH, Lin HJ, Guo HR. Rescuer fatigue and cardiopulmonary resuscitation positions: a randomized controlled crossover trial. *Resuscitation*. 2010;81:579–584.
123. Jones AY, Lee RY. Rescuer's position and energy consumption, spinal kinetics, and effectiveness of simulated cardiac compression. *Am J Crit Care*. 2008;17:417–425.
124. Edelson DP, Call SL, Yuen TC, Vanden Hoek TL. The impact of a step stool on cardiopulmonary resuscitation: a cross-over mannequin study. *Resuscitation*. 2012;83:874–878.
125. Lim JS, Cho YC, Kwon OY, Chung SP, Yu K, Kim SW. Precise minute ventilation delivery using a bag-valve mask and audible feedback. *Am J Emerg Med*. 2012;30:1068–1071.
126. Sherren PB, Lewinsohn A, Jovaisa T, Wijayatilake DS. Comparison of the Mapleson C system and adult and paediatric self-inflating bags for delivering guideline-consistent ventilation during simulated adult cardiopulmonary resuscitation. *Anaesthesia*. 2011;66:563–567.
127. Nehme Z, Boyle MJ. Smaller self-inflating bags produce greater guideline consistent ventilation in simulated cardiopulmonary resuscitation. *BMC Emerg Med*. 2009;9:4.
128. Terndrup TE, Rhee J. Available ventilation monitoring methods during pre-hospital cardiopulmonary resuscitation. *Resuscitation*. 2006;71:10–18.
129. Dickinson ET, Verdile VP, Schneider RM, Salluzzo RF. Effectiveness of mechanical versus manual chest compressions in out-of-hospital cardiac arrest resuscitation: a pilot study. *Am J Emerg Med*. 1998;16:289–292.
130. Hallstrom A, Rea TD, Sayre MR, Christenson J, Anton AR, Mosesso VN Jr, Van Ottingham L, Olsufka M, Pennington S, White LJ, Yahn S, Husar J, Morris MF, Cobb LA. Manual chest compression vs use of an automated chest compression device during resuscitation following out-of-hospital cardiac arrest: a randomized trial. *JAMA*. 2006;295: 2620–2628.
131. Smekal D, Johansson J, Huzevka T, Rubertsson S. A pilot study of mechanical chest compressions with the LUCAS™ device in cardiopulmonary resuscitation. *Resuscitation*. 2011;82:702–706.
132. Axelsson C, Nestin J, Svensson L, Axelsson AB, Herlitz J. Clinical consequences of the introduction of mechanical chest compression in the EMS system for treatment of out-of-hospital cardiac arrest: a pilot study. *Resuscitation*. 2006;71:47–55.
133. Rubertsson S, Silfverstolpe J, Rehn L, Nyman T, Lichtveld R, Boomars R, Bruins W, Ahlstedt B, Puggioli H, Lindgren E, Smekal D, Skoog G, Kastberg R, Lindblad A, Halliwell D, Box M, Arnwald F, Hardig BM, Chamberlain D, Herlitz J, Karlsten R. The study protocol for the LINC (LUCAS in cardiac arrest) study: a study comparing conventional adult out-of-hospital cardiopulmonary resuscitation with a concept with mechanical chest compressions and simultaneous defibrillation. *Scand J Trauma Resusc Emerg Med*. 2013;21:5.
134. Yost D, Phillips RH, Gonzales L, Lick CJ, Satterlee P, Levy M, Barger J, Dodson P, Poggi S, Wojcik K, Niskanen RA, Chapman FW. Assessment of CPR interruptions from transthoracic impedance during use of the LUCAS™ mechanical chest compression system. *Resuscitation*. 2012;83:961–965.
135. Ong ME, Annathurai A, Shahidah A, Leong BS, Ong VY, Tiah L, Ang SH, Yong KL, Sultana P. Cardiopulmonary resuscitation interruptions with use of a load-distributing band device during emergency department cardiac arrest. *Ann Emerg Med*. 2010;56:233–241.
136. Fischer H, Neuhold S, Zapletal B, Hochbrugger E, Koinig H, Steinlechner B, Frantal S, Stumpf D, Greif R. A manually powered mechanical resuscitation device used by a single rescuer: a randomised controlled manikin study. *Resuscitation*. 2011;82:913–919.
137. Fischer H, Neuhold S, Hochbrugger E, Steinlechner B, Koinig H, Milosevic L, Havel C, Frantal S, Greif R. Quality of resuscitation: flight attendants in an airplane simulator use a new mechanical resuscitation device: a randomized simulation study. *Resuscitation*. 2011;82:459–463.
138. Tomte O, Sunde K, Lorem T, Auestad B, Souders C, Jensen J, Wik L. Advanced life support performance with manual and mechanical chest compressions in a randomized, multicentre manikin study. *Resuscitation*. 2009;80:1152–1157.
139. Ong ME, Quah JL, Annathurai A, Noor NM, Koh ZX, Tan KB, Pothiawala S, Poh AH, Loy CK, Fook-Chong S. Improving the quality of cardiopulmonary resuscitation by training dedicated cardiac arrest teams incorporating a mechanical load-distributing device at the emergency department. *Resuscitation*. 2013;84:508–514.
140. Circulation Improving Resuscitation Care (CIRC Study). ClinicalTrials.gov Web site. http://clinicaltrials.gov/ct2/show/record/nct00597207. Accessed February 28, 2013.
141. Perkins GD, Woollard M, Cooke MW, Deakin C, Horton J, Lall R, Lamb SE, McCabe C, Quinn T, Slowther A, Gates S; PARAMEDIC Trial Collaborators. Prehospital randomised assessment of a mechanical compression device in cardiac arrest (PaRAMeDIC) trial protocol. *Scand J Trauma Resusc Emerg Med*. 2010;18:58.
142. A Comparison of Conventional Adult Out-of-hospital Cardiopulmonary Resuscitation Against a Concept With Mechanical Chest Compressions and Simultaneous Defibrillation (LINC Study). ClinicalTrials.gov Web site. http://clinicaltrials.gov/ct2/show/nct00609778?term=linc&rank=1. Accessed February 28, 2013.
143. Havel C, Schreiber W, Riedmuller E, Haugk M, Richling N, Trimmel H, Malzer R, Sterz F, Herkner H. Quality of closed chest compression in ambulance vehicles, flying helicopters and at the scene. *Resuscitation*. 2007;73:264–270.
144. Olasveengen TM, Wik L, Steen PA. Quality of cardiopulmonary resuscitation before and during transport in out-of-hospital cardiac arrest. *Resuscitation*. 2008;76:185–190.
145. Chung TN, Kim SW, Cho YS, Chung SP, Park I, Kim SH. Effect of vehicle speed on the quality of closed-chest compression during ambulance transport. *Resuscitation*. 2010;81:841–847.
146. Kurz MC, Dante SA, Puckett BJ. Estimating the impact of off-balancing forces upon cardiopulmonary resuscitation during ambulance transport. *Resuscitation*. 2012;83:1085–1089.
147. Sunde K, Wik L, Steen PA. Quality of mechanical, manual standard and active compression-decompression CPR on the arrest site and during transport in a manikin model. *Resuscitation*. 1997;34:235–242.
148. Zebuhr C, Sutton RM, Morrison W, Niles D, Boyle L, Nishisaki A, Meaney P, Leffelman J, Berg RA, Nadkarni VM. Evaluation of quantitative debriefing after pediatric cardiac arrest. *Resuscitation*. 2012;83:1124–1128.
149. Dine CJ, Gersh RE, Leary M, Riegel BJ, Bellini LM, Abella BS. Improving cardiopulmonary resuscitation quality and resuscitation training by combining audiovisual feedback and debriefing. *Crit Care Med*. 2008;36:2817–2822.
150. Sutton RM, Niles D, Meaney PA, Aplenc R, French B, Abella BS, Lengetti EL, Berg RA, Helfaer MA, Nadkarni V. Low-dose, high-frequency CPR training improves skill retention of in-hospital pediatric providers. *Pediatrics*. 2011;128:e145–e151.
151. Dane FC, Russell-Lindgren KS, Parish DC, Durham MD, Brown TD. In-hospital resuscitation: association between ACLS training and survival to discharge. *Resuscitation*. 2000;47:83–87.
152. Moretti MA, Cesar LA, Nusbacher A, Kern KB, Timerman S, Ramires JA. Advanced cardiac life support training improves long-term survival from in-hospital cardiac arrest. *Resuscitation*. 2007;72: 458–465.
153. Bobrow BJ, Vadeboncoeur TF, Stolz U, Silver AE, Tobin JM, Crawford SA, Mason TK, Schirmer J, Smith GA, Spaite DW. The influence of scenario-based training and real-time audiovisual feedback on out-of-hospital cardiopulmonary resuscitation quality and survival from out-of-hospital cardiac arrest. *Ann Emerg Med*. March 7, 2013. doi:10.1016/j.annemergmed.2012.12.010. http://www.annemergmed.com/article/S0196-0644(12)01853-7/abstract. Accessed June 11, 2013.
154. Yang CW, Yen ZS, McGowan JE, Chen HC, Chiang WC, Mancini ME, Soar J, Lai MS, Ma MH. A systematic review of retention of adult advanced life support knowledge and skills in healthcare providers. *Resuscitation*. 2012;83:1055–1060.
155. Roppolo LP, Pepe PE, Campbell L, Ohman K, Kulkarni H, Miller R, Idris A, Bean L, Bettes TN, Idris AH. Prospective, randomized trial of the effectiveness and retention of 30-min layperson training for cardiopulmonary resuscitation and automated external defibrillators: the American Airlines Study. *Resuscitation*. 2007;74:276–285.

156. Einspruch EL, Lynch B, Aufderheide TP, Nichol G, Becker L. Retention of CPR skills learned in a traditional AHA Heartsaver course versus 30-min video self-training: a controlled randomized study. *Resuscitation*. 2007;74:476–486.
157. Wik L, Myklebust H, Auestad BH, Steen PA. Retention of basic life support skills 6 months after training with an automated voice advisory manikin system without instructor involvement. *Resuscitation*. 2002;52:273–279.
158. Wik L, Myklebust H, Auestad BH, Steen PA. Twelve-month retention of CPR skills with automatic correcting verbal feedback. *Resuscitation*. 2005;66:27–30.
159. Smith KK, Gilcreast D, Pierce K. Evaluation of staff's retention of ACLS and BLS skills. *Resuscitation*. 2008;78:59–65.
160. Meaney PA, Sutton RM, Tsima B, Steenhoff AP, Shilkofski N, Boulet JR, Davis A, Kestler AM, Church KK, Niles DE, Irving SY, Mazhani L, Nadkarni VM. Training hospital providers in basic CPR skills in Botswana: acquisition, retention and impact of novel training techniques. *Resuscitation*. 2012;83:1484–1490.
161. Niles D, Sutton RM, Donoghue A, Kalsi MS, Roberts K, Boyle L, Nishisaki A, Arbogast KB, Helfaer M, Nadkarni V. "Rolling Refreshers": a novel approach to maintain CPR psychomotor skill competence. *Resuscitation*. 2009;80:909–912.
162. Oermann MH, Kardong-Edgren SE, Odom-Maryon T. Effects of monthly practice on nursing students' CPR psychomotor skill performance. *Resuscitation*. 2011;82:447–453.
163. Hunziker S, Johansson AC, Tschan F, Semmer NK, Rock L, Howell MD, Marsch S. Teamwork and leadership in cardiopulmonary resuscitation. *J Am Coll Cardiol*. 2011;57:2381–2388.
164. Andreatta P, Saxton E, Thompson M, Annich G. Simulation-based mock codes significantly correlate with improved pediatric patient cardiopulmonary arrest survival rates. *Pediatr Crit Care Med*. 2011;12:33–38.
165. Bradley SM, Huszti E, Warren SA, Merchant RM, Sayre MR, Nichol G. Duration of hospital participation in Get With the Guidelines-Resuscitation and survival of in-hospital cardiac arrest. *Resuscitation*. 2012;83:1349–1357.