Cardiopulmonary Resuscitation and Automated External Defibrillator Use

Automated External Defibrillator Use in Drowning Resuscitation

Last Full Review: ILCOR 2023

Out-of-hospital cardiac arrest with a shockable rhythm (i.e., ventricular fibrillation/ventricular tachycardia) attributed to drowning has been reported in only 2% to 14% of patients (Bierens et al. 2021, 205; Wyckoff et al. 2022, e645). Although concerns have been expressed over the use of an automated external defibrillator (AED) on a person in cardiac arrest in an aquatic environment, the use of AEDs in simulation studies appears feasible and safe (Olasveengen et al. 2017, e424; Olasveengen et al. 2020, S41). The use of AEDs is recommended by the Red Cross after beginning cardiopulmonary resuscitation (CPR) and once available, where feasible and safe.

Should an AED be used before CPR in cardiac arrest following drowning or should CPR be provided before using an AED?

Red Cross Guidelines and Best Practices

- For adults, children or infants in cardiac arrest following a drowning event, begin cardiopulmonary resuscitation and initiate automated external defibrillator use as soon as one is available and where feasible and safe.

Evidence Summary

A 2022 International Liaison Committee on Resuscitation (ILCOR) systematic review and Consensus on Science with Treatment Recommendations (Beerman et al. 2022; Wyckoff et al. 2022, e483) of AED-use-first versus CPR-first in cardiac arrest following drowning did not identify any studies that addressed the question. Previous reviews have identified simulation studies showing that AED use for cardiac arrest following drowning appears feasible (de Vries et al. 2006, 247; Wyckoff et al. 2022, e645).

Related literature was reviewed and discussed by the review authors (Beerman et al. 2022; Wyckoff et al. 2022, e483). While cardiac arrest following drowning is most commonly the result of the hypoxic drowning process, it may be secondary to a primary cardiac event in adults and children (Beerman et al. 2022). Shockable rhythms are rare in cardiac arrest following drowning, but are slightly higher in children and witnessed events. However, there is conflicting data if outcomes are improved when shockable rhythms are present. One study (Dyson et al. 2013, 1114) discussed a review of 336 drowning related out-of-hospital cardiac arrests, reported 6% to be in a shockable rhythm, 79% in asystole and 13% in a pulseless electrical rhythm (i.e., nonshockable rhythms). Improved outcomes were found to be associated with an initial shockable rhythm, with higher adjusted odds of survival to hospital discharge (aOR 48.70; 95% CI, 3.80–624.86).

The ILCOR systematic review authors weighed the potential benefits versus risks and disadvantages of adding the use of an AED to CPR following drowning. A good practice statement by ILCOR recommends that, when available, an AED be used in cardiac arrest following drowning in adults and children. Cardiopulmonary resuscitation should be started first and continued until an AED has been obtained and is ready for use for adults and children in cardiac arrest caused by drowning (Beerman et al. 2022; Wyckoff et al. 2022, e483).

Insights and Implications

While cardiac arrest following drowning is most commonly the result of hypoxia and the drowning process, it may also be the result of a primary cardiac event in both adults and children. The ILCOR good practice statement is consistent with the Red Cross guidelines for the use of an AED for cardiac arrest and supports a CPR-first approach to resuscitation from drowning. Concerns for safety related to the use of an AED in the aquatic environment have not been substantiated in the 2022 ILCOR review, however AED use should not be attempted while the drowning person is in water, and the chest should be dried off prior to use. For infants in cardiac arrest, AED use is recommended by Red Cross (American Red Cross Scientific Advisory Council 2023).

CPR Start Sequence for Drowning

Last Full Review: ILCOR 2022; American Red Cross Scientific Advisory Council 2021

Last Update: 2023

The pathophysiology of the drowning process is unique and is a continuum of events that results in asphyxia. Severe hypoxemia ensues, leading to cardiac arrest. This process contrasts with cardiac arrest from primary cardiac etiologies. A 2021 American Red Cross Scientific Advisory Council scientific review led to the Red Cross guidelines recommending a ventilations-first approach to starting cardiopulmonary resuscitation (CPR) (American Red Cross Scientific Advisory Council 2021).

Red Cross Guidelines and Best Practices

- For infants, children, adolescents and adults with the drowning process and after determining the presence of cardiac arrest, resuscitation should start by opening the airway, providing 2 rescue breaths/manual ventilations and then continuing cardiopulmonary resuscitation (CPR) by providing cycles of 30 compressions followed by 2 rescue breaths/manual ventilations.
- A CPR compression-to-ventilation ratio of 15:2 should be used for children and infants with the drowning process and cardiac arrest when two healthcare professionals or trained lay responders are available.
- For lay persons, if compression-ventilation CPR is not possible or someone is unwilling to provide compression-ventilation CPR, compression-only CPR should be performed.

Evidence Summary

A systematic review by the American Red Cross Scientific Advisory Council in 2021 (American Red Cross Scientific Advisory Council 2021) evaluated evidence for the use of a ventilations-first approach to CPR in drowning persons with cardiac arrest, compared with a compressions-first CPR approach. Indirect evidence identified an association between ventilations with CPR in drowning persons and improved outcomes. One observational study reported a higher odds ratio for survival following cardiac arrest in drowning persons who received bystander ventilations compared with those who did not receive ventilations (Hubert et al. 2016, 924). A retrospective analysis of cardiac arrest registry data, including drowning persons, reported improved neurologically favorable survival in patients aged 5 to 15 years and improved survival to hospital discharge in all age groups who received compression-ventilation CPR (CV-CPR), compared with CPR without ventilations (Tobin et al. 2020, 141).

A 2022 systematic review and Consensus on Science with Treatment Recommendations (Dunne et al. 2022; Wyckoff et al. 2022, e483) by the International Liaison Committee on Resuscitation reviewed evidence for a compression-first resuscitation strategy in adults and children in cardiac arrest following drowning compared with a ventilation-first strategy. No studies were identified that were considered relevant to the question. The authors reviewed consensus statements and literature to help inform good practice statements. One study noted was a 2004 retrospective analysis of 46 nonbreathing drowning persons rescued by lifeguards, of which 19 (41.3%) received in-water immediate resuscitation with ventilations, and 27 (58.7%) received delayed resuscitation after being brought to shore (Szpilman and Soares 2004, 25). Survival was significantly higher in the group receiving in-water resuscitation with ventilations compared with the in-water resuscitation with no ventilations group (87.5% versus 25%, P<0.001). Survival with favorable functional outcome was also higher in the in-water resuscitation with ventilations group compared with the in-water resuscitation with no ventilations group (52.6% versus 7.4%).

A second study of pediatric drowning cases reported worse functional outcomes in children with cardiac arrest compared with respiratory arrest alone (81% versus 0%, P<0.001), suggesting that early intervention with ventilations before cardiac arrest may improve outcomes (Mtaweh et al. 2015, 91).

Insights and Implications

Analysis of the Cardiac Arrest Registry to Enhance Survival (CARES) database between 2020 and 2021 shows that of 1767 drowning cases in the U.S., 11.9% survived to hospital discharge (Ryan et al. 2023, 109788). The asphyxia nature of the drowning process, however, can lead to brain damage in survivors and long-term neurological disability.

Data from CARES also shows that, compared to emergency medical services and first responders initiating CPR, the odds of survival with a favorable neurological status is significantly higher with bystander-initiated CPR (OR, 2.85; 95% CI, 2.02–5.01). The Red Cross guidelines recommending a ventilations-first approach to CPR reflect indirect evidence suggesting that earlier ventilations may improve outcomes. The rationale for a ventilations-first approach to CPR for infants, children and adults is the hypoxic mechanism of cardiac arrest for most drownings, and uniformity of training for all drowning-related cardiac arrest. For lay persons who are not trained or willing to provide CV-CPR, a compression-only CPR approach continues to be recommended.

Compression-Only and Compression-Ventilation CPR for Drowning Process Resuscitation

Last Full Review: ILCOR 2023; American Red Cross Scientific Advisory Council 2021

Current Red Cross Basic Life Support guidelines for adults recommend the use of standard cardiopulmonary resuscitation (CPR) with ventilations by a trained lay responder, with a 30:2 compression-to-ventilation ratio. The use of compression-only CPR (CO-CPR) is an alternative to compression-ventilation CPR (CV-CPR) when a responder is unwilling or unable to provide ventilations. For healthcare professionals, CV-CPR is also recommended—with a 30:2 compression-to-ventilation ratio in the absence of an advanced airway.

For children and infants, CPR with compressions and ventilations is recommended for both lay responders and healthcare professionals—with a compression-to-ventilation ratio of 30:2. When two healthcare professionals are present, a ratio of 15:2 should be used. Compression-only CPR may be used as an alternative to CPR with compressions and ventilations when someone is unwilling or unable to provide ventilations. However, the hypoxic mechanism of CPR has raised the question of whether CO-CPR is of any benefit compared to no compressions for a cardiac arrest secondary to drowning.

Red Cross Guidelines and Best Practices

- Initiate compression-ventilation cardiopulmonary resuscitation (CV-CPR) for cardiac arrest following drowning in adults, children and infants. If CV-CPR is not possible, compression-only CPR should be performed.
- For adults, children and infants with the drowning process and after determining the presence of cardiac arrest, resuscitation should start by opening the airway, providing 2 rescue breaths/manual ventilations and then continuing CPR by providing cycles of 30 compressions followed by 2 rescue breaths/manual ventilations.
- A CPR compression-to-ventilation ratio of 15:2 should be used for children and infants with the drowning process and cardiac arrest when two healthcare professionals or trained lay responders are available.

Evidence Summary

A 2021 systematic review (American Red Cross Scientific Advisory Council 2021) by the American Red Cross Scientific Advisory Council evaluated the sequence of actions and the compression-to-ventilation

(CV) ratio for cardiac arrest due to drowning. Four indirect observational studies were included in the review:

1. A 2018 retrospective study (Chan, Ng and Ng 2018, 44) of drowning cases in swimming pools in Singapore treated by emergency medical services over a 2-year period found that of the 93 patients who received CPR, four were reported to regain consciousness with ventilations alone.
2. One observational study (Hubert et al. 2016, 924) prospectively analyzed all drowning cardiac arrest patients reported to the French Cardiac Arrest Registry. The patients who received bystander ventilations displayed a much higher rate of intact vital signs on hospital admission compared to those who did not. Additionally, they reported a statistically significant higher odds ratio for survival with bystander ventilations (OR, 6.742).
3. An observational cohort study (Fukuda et al. 2019, 166) analyzed all drowning cardiac arrest patients presenting to Japanese emergency departments over a 3-year span to evaluate the effect of bystander CPR using compressions and ventilations, compared with CO-CPR. No statistical difference was shown for the outcomes of favorable neurological status at hospital discharge at 30 days when comparing the conventional CPR group with the compression-only group. However, more than 90% of the study population was over the age of 18, with more than 80% of the population aged 65 and over.
4. Tobin et al (Tobin et al. 2020, 141) used 4 years of data from the Cardiac Arrest Registry to Enhance Survival registry to retrospectively analyze 548 cases of cardiac arrest following drowning on whom information was available about the type of bystander CPR performed. The study reported that between 2013 and 2017, patients in the conventional CPR with ventilations group (71/29.7%) had a greater odds of survival to hospital discharge compared with the CO-CPR group (59/24.7%) (aOR, 1.54; 95% CI, 1.01–2.36; P=0.046). However, there was no significant difference found for the outcome of neurologically favorable survival for the group of patients in the CV-CPR group (59/24.7%) compared with the patients (50/16.2%) in the CO-CPR group (aOR, 1.35; 95% CI, 0.86–2.10; P=0.19). A subgroup analysis of patients aged 5 to 15 years showed conventional CV-CPR to be associated with greater odds of neurologically favorable survival (aOR, 2.68;95% CI, 1.10–6.77; P= 0.03).

A 2023 systematic review (Bierens et al. 2023, 100406) and Consensus on Science with Treatment Recommendations (Berg et al. 2023, e187; Sempsrott et al. 2022) by the International Liaison Committee on Resuscitation looked for studies of adults and children in cardiac arrest following drowning who received CO-CPR compared with CV-CPR. This review included two studies evaluated in the American Red Cross Scientific Advisory Council review (Fukuda et al. 2019, 166; Tobin et al. 2020, 141). A good practice statement was made that CPR in drowned out-of-hospital cardiac arrest patients who have been removed from the water remains consistent with CPR for all patients in cardiac arrest. This includes a recommendation that bystanders perform chest compressions for all adults in cardiac arrest, and it is suggested that bystanders who are trained, able and willing to give rescue breaths and chest compressions do so for adults in cardiac arrest. It is suggested that bystanders provide CPR with ventilation for infants and children younger than 18 years with out-of-hospital cardiac arrest. If bystanders cannot provide rescue breaths as part of CPR for infants and children younger than 18 years with out-of-hospital cardiac arrest, it is recommended that they should at least provide chest compressions. The International Liaison Committee on Resuscitation specifically makes a good practice statement for healthcare professionals and those with a duty to respond to drowning (e.g., lifeguards) to provide ventilations in addition to chest compressions if they have been trained and are able and willing to do so.

Insights and Implications

Given the unique role of airway and respiratory pathophysiology in the drowning process, with cardiac arrest primarily the result of anoxia, ventilations should be a priority of treatment. Studies in the American Red Cross Scientific Advisory Council systematic review (American Red Cross Scientific Advisory Council 2021) suggest an association between ventilations and improved outcomes. This includes an association between bystander ventilations without compressions and higher odds of survival, and a significant finding of increased neurologically favorable survival in patients aged 5 years to 15 years who received CV-CPR compared with CO-CPR. The typical drowning victim is young, lacks underlying cardiac disease, and is often identified and rescued early in the drowning process, making them potentially at greater odds of survival through early ventilations and CPR with ventilations. The Red Cross supports the training of all lay responders in CPR with ventilations, while recommending the use of CO-CPR by lay responders and others who are unable or unwilling to provide ventilations with CPR.

Providing High-Quality CPR: Hand Position

Last Full Review: American Red Cross Scientific Advisory Council 2020 (Infants); ILCOR 2020
Last Update: 2023

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the CPR hand position guidelines.

Red Cross Guidelines and Best Practices

- For adults and children, chest compressions should be performed on the lower half of the sternum.
- For infants, chest compressions should be performed just below the inter-mammary line (middle of the chest).
- For adults, the two-hand technique should be used for chest compressions.
- For children, either a two-hand or one-hand technique should be used for chest compressions.
- For infants, the two-thumb encircling hands technique should be used for chest compressions.
- For infants, the two-finger technique (two or three fingers placed in the middle of the chest) may be considered.
- For infants, if the required depth cannot be achieved with either the two-thumb encircling hands technique or the two-finger technique, a one-hand technique may be considered.

Evidence Summary

Since 2015, it has been recommended to perform chest compressions on the lower half of the sternum on adults. The evidence to support this recommendation has been considered lower certainty, and no studies demonstrate a specific hand position to be optimal in terms of survival from cardiac arrest. In 2020, the International Liaison Committee on Resuscitation (ILCOR) published a systematic review with Consensus on Science with Treatment Recommendations for hand positions for chest compression in adults (Olasveengen et al. 2020, S41). The review did not find studies reporting clinical outcomes such as survival or return of spontaneous circulation, but identified some studies that evaluated physiological endpoints. One small study (Cha et al. 2013, 691) with 17 adults in nontraumatic cardiac arrest reported improved peak arterial pressure during compression systole and improved end-tidal carbon dioxide levels when compressions were performed over the lower third of the sternum compared with the center of the chest, while other physiological measures including coronary perfusion pressure did not differ. A second small study (Qvigstad et al. 2013, 1203) in adults with cardiac arrest did not report a difference in end-tidal carbon dioxide levels with change in hand placement. A third study (Orlowski 1986, 667) in 10 children reported higher peak systolic pressures and mean arterial pressure with compressions on the lower third of the sternum compared with the middle of the sternum. A 2023 evidence update by ILCOR did not find additional studies of hand position during CPR (Berg et al. 2023, e187).

A 2020 American Red Cross Scientific Advisory Council systematic review (American Red Cross Scientific Advisory Council 2020) of hand placement for chest compressions on infants used data from simulation studies and concluded that for CPR performed on an infant manikin by a single rescuer, the two-thumb encircling hands technique improves chest compression quality without compromising ventilation. Pooled data from 16 observational studies in this review reported that the use of the two-thumb encircling hands technique resulted in greater compression depth compared with two-finger technique and 36.91% more compressions of adequate depth. A 2023 triennial update of infant Basic Life Support techniques reaffirms recommendations for the use of the two-thumb encircling hands technique (American Red Cross Scientific Advisory Council 2023).

Insights and Implications

Hand position is an important component of chest compression effectiveness. A limited number of studies identified in the 2020 ILCOR systematic review (Olasveengen et al. 2020, S41) showed improved physiological measures when compressions are performed over the lower third of the sternum for both adults and children compared with compressions over the center of the chest or in the middle of the sternum. However, the lower half of the sternum is considered easily identifiable by rescuers, and in the absence of clinical evidence to support a change in recommendations, the Red Cross guidelines continue to recommend that compressions be provided over the lower half of the sternum for both adults and children. For infants, despite the limitations of manikin studies, the potential survival benefit from increased quality of CPR supports the recommendations to use two-thumb encircling hands technique for single-rescuer CPR, while retaining the option of two-finger or one-hand compressions. Lay responders with thumb, finger, hand or wrist arthritis now have the option to use the technique that can be performed best, including the one-hand technique, within their physical limitations in order to deliver compressions of recommended depth.

Providing High-Quality CPR: Chest Compression Rate

Last Full Review: ILCOR 2022

Last Update: 2023

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the CPR compression rate guidelines.

Red Cross Guidelines and Best Practices

- Chest compressions should be performed at a rate of 100 to 120 per minute for adults, children and infants.

Evidence Summary

A 2021 American Red Cross Scientific Advisory Council literature update on chest compression rate during CPR did not identify new relevant studies since January 2020, and guidelines remain unchanged. Evidence for chest compression rates used in CPR was last reviewed systematically in 2015 by the International Liaison Committee on Resuscitation (ILCOR) (Travers et al. 2015, S51), followed by a scoping review in 2020 (Considine et al. 2020, 188; Olasveengen et al. 2020, S41).

The 2015 systematic review included large observational studies showing an association between increasing chest compression rates and declining chest compression depth, and a decrease in survival to hospital discharge with compression rates above 140 per minute (Travers et al. 2015, S51). An evidence update (Berg et al. 2023, e187) by ILCOR identified six new observational studies on compression rate and depth since the 2020 scoping review (Considine et al. 2020, 188; Olasveengen et al. 2020, S41). Findings from the studies were reported to be consistent with current guidelines.

Insights and Implications

The chest compression rate is defined as the rate used during each continuous period of chest compressions over 1 minute, excluding pauses (Travers et al. 2015, S51). Studies evaluating chest compression rate are primarily observational, from the out-of-hospital cardiac arrest setting, and do not account for potential interactions from chest compression depth, hand position and other components of chest compression. More recent studies of chest compression rate have focused on rescuer fatigue with compressions, use of automatic compression devices compared with manual compression, and real-time CPR feedback devices to help maintain correct compression rates and quality of chest compressions.

Providing High-Quality CPR: Chest Compression Depth

Last Full Review: ILCOR 2020
Last Update: 2023

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004 ; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the CPR compression depth guidelines.

Red Cross Guidelines and Best Practices

- During cardiopulmonary resuscitation (CPR), an adult chest should be compressed to a depth of at least 2 inches.
- During CPR, a child's and infant's chest should be compressed to a depth of at least one-third the anteroposterior diameter of the chest (about 2 inches for a child and about 1 1/2 inches for an infant).

Evidence Summary

No new relevant studies of chest compression depth during CPR were identified by the American Red Cross Scientific Advisory Council in a 2021 literature update, and the guidelines remain unchanged. Evidence for chest compression depth during CPR was last reviewed systematically in 2015 by the International Liaison Committee on Resuscitation (ILCOR) (Travers et al. 2015, S51), followed by a scoping review in 2020. (Considine et al. 2020, 188; Olasveengen et al. 2020, S41).

The 2015 ILCOR systematic review (Travers et al. 2015, S51) led to a strong treatment recommendation for a manual chest compression depth of approximately 2 inches (5 cm) in adults, and a weak recommendation was made for avoiding excessive chest compression depths (greater than 2.4 inches [6 cm] in an average adult). The upper limit for chest compression depth reflected evidence suggesting that a depth of more than 2.4 inches (6 cm) is associated with a higher rate of injuries in adults compared with a depth of 2 inches to 2.4 inches (5 cm to 6 cm). An evidence update (Berg et al. 2023, e187) by ILCOR in 2023 identified six new relevant observational studies since the 2020 scoping review (Considine et al. 2020, 188; Olasveengen et al. 2020, S41). Findings were described as consistent with current guidelines for compression depth.

Insights and Implications

Studies evaluating chest compression depth in isolation are commonly confounded by many factors, including body and chest size, as well as chest wall compliance. Studies identified but excluded in the American Red Cross Scientific Advisory Council literature update focus on other factors that may impact compression depth including:

- Leaning on the chest.

- Kneeling on a bed to deliver compressions.
- Rescuer height and weight.
- Firmness of surfaces under a body.
- Use of mechanical compression devices versus manual compression.
- Compression cycle length.
- Use of real-time feedback devices.

Future guidance will likely reflect some of these factors as new studies emerge.

Providing High-Quality CPR: Chest Wall Recoil

Last Full Review: ILCOR 2020

Last Update: 2023

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the CPR chest wall recoil guidelines.

Red Cross Guidelines and Best Practices

- During compressions for adults, children and infants, the chest wall should be allowed to fully recoil, and compression and recoil times should be approximately equal.

Evidence Summary

Evidence for chest wall recoil during CPR was the subject of a 2021 American Red Cross Scientific Advisory Council literature update and was last reviewed systematically in 2015 by the International Liaison Committee on Resuscitation (ILCOR) (Travers 2015, S51) followed by a scoping review in 2020 (Considine et al. 2020, 188; Olasveengen et al. 2020, S41).

The 2021 American Red Cross Scientific Advisory Council literature update identified one recent randomized simulation trial that reported an association between rescuers' height and weight and the chest compression depth and chest wall recoil (Bibl et al. 2020, 1831). A simulation study also reported an association between higher weight and body mass index, male sex and height, and a lower likelihood to achieve a complete chest wall recoil (Contri et al. 2017, 1266). Other studies of chest wall recoil focus on the impact of real-time CPR feedback devices and rescuer physical fitness when providing CPR.

The 2015 ILCOR systematic review (Travers 2015, S51) included evidence from two animal studies and one observational study in anesthetized children not in cardiac arrest, all reporting reduced coronary perfusion pressure with incomplete chest wall recoil. The pediatric study applied a force on the chest corresponding to 10% to 20% of body weight, with the finding of a proportional reduction in coronary perfusion pressure, but without effect on cardiac output (Travers et al. 2015, S51).

The 2020 ILCOR scoping review (Considine et al. 2020, 188; Olasveengen et al. 2020, S41) did not identify new studies of chest wall recoil, while a 2022 evidence update (Berg et al. 2023, e187) noted four new observational studies with findings reported as consistent with current guidelines.

Insights and Implications

Chest wall recoil allows the chest to return to its normal position following a chest compression, allowing for venous return to the heart. Leaning on the chest wall between compressions is common and restricts recoil, increasing intrathoracic pressure and reducing right heart filling and coronary perfusion pressure. The limited evidence supports full chest wall recoil between chest compressions to improve CPR quality. Factors impacting chest wall recoil include the release or recoil velocity, release time and release height. Release or recoil velocity is the maximum velocity during the recoil phase, has been reported to be independently associated with improved survival and favorable neurological outcomes at discharge following out-of-hospital cardiac arrest (Kovacs et al. 2015, 107) while a benefit was not shown in another study using adjusted data (Cheskes et al. 2015, 38) Although recoil velocity has been proposed as a future quality metric for CPR, further research is needed to define its impact on survival from cardiac arrest.

Providing High-Quality CPR: Compression-to-Ventilation Ratios

Last Full Review: ILCOR 2017

Last Update: 2023 (Adults); 2021 (Children)

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind CPR compression-to-ventilation ratios guidelines.

Red Cross Guidelines and Best Practices

- A cardiopulmonary resuscitation (CPR) compression-to-ventilation ratio of 30:2 should be used for adults with cardiac arrest without an advanced airway.
- For children and infants, a compression-to-ventilation ratio of 30:2 should be used by one healthcare professional and a ratio of 15:2 should be used by two healthcare professionals, while a ratio of 30:2 should be used by a lay responder.
- Compression-only CPR may be used as an alternative to CPR with compressions and ventilations when someone is unwilling or unable to provide ventilations.

Evidence Summary

A 2017 International Liaison Committee Resuscitation (ILCOR) review (Ashoor et al. 2017, 112; Olasveengen et al. 2017, e424), updated in 2020 (Olasveengen et al. 2020, S41), evaluated patients of all ages with cardiac arrest from any cause and across all settings who received all-manual CPR methods including compressions-only CPR (CO-CPR; no ventilations), continuous-compression CPR (CC-CPR, including compression with asynchronous ventilations or minimally interrupted cardiac resuscitation) and CPR with different compression-to-ventilation ratios. Comparators included at least two different CPR methods from eligible interventions, and outcomes included favorable neurological outcomes. Secondary outcomes included survival, return of spontaneous circulation (ROSC) and quality of life.

Adults

The arm of the review specific to CPR for adults identified two cohort studies (Kudenchuk et al. 2012, 1787; Olasveengen et al. 2009, 407) that, in meta-analysis, showed improved favorable neurological function in patients who received 30:2 compression-ventilation-CPR (CV-CPR) compared with 15:2 CPR (RR, 1.34; 95% CI, 1.02–1.72; RD, 1.72; 95% CI, 0.52–2.91). A meta-analysis of six cohort studies (Deasy et al. 2011, 984; Kudenchuk et al. 2012, 1787; Olasveengen et al. 2009, 407; Robinson et al. 2010, 1648; Sayre et al. 2009, 469; Steinmetz et al. 2008, 908) reported an association between 30:2 CPR and improved survival when compared with 15:2 CPR (RR, 1.37; 95% CI, 1.19–1.59; RD, 2.48, 95% CI, 1.57–3.38) (Ashoor et al. 2017, 112).

A meta-analysis of seven cohort studies (Deasy et al. 2011, 984; Kudenchuk et al. 2012, 1787; Olasveengen et al. 2009, 407; Robinson et al. 2010, 1648; Sayre et al. 2009, 469; Steinmetz et al. 2008, 908; Hostler et al. 2007, 446) found an association between 30:2 CPR and a slightly higher ROSC (RR, 1.11; 95% CI, 1.00–1.23; RD, 10.48, 0.41–20.55) compared with 15:2 CPR (Ashoor et al. 2017, 112).

A 2022 evidence update (Berg et al. 2023, e187) did not identify relevant new studies and guidance for a 30:2 compression-ventilation ratio in patients with cardiac arrest remains unchanged.

Children and Infants

A 2018 ILCOR Consensus on Science with Treatment Recommendations (CoSTR) (Olasveengen et al. 2017, e424) updated in 2021 identified two cohort studies (Goto, Maeda and Goto 2014, e000499 ; Kitamura et al. 2010, 1347) that evaluated Japanese out-of-hospital cardiac arrest registry data that included out-of-hospital cardiac arrest of noncardiac origin. Bystander delivery of CO-CPR was compared with CV-CPR in infants and children between 2005 and 2007 when guidelines were transitioning from a 15:2 compression-to-ventilation ratio to a 30:2 compression-to-ventilation ratio. The use of CO-CPR was associated with poorer outcomes of survival to 1 month, compared with CPR with ventilations (Olasveengen et al. 2017, e424).

An evidence update (Wyckoff et al. 2022, e483) of a 2017 ILCOR CoSTR (Olasveengen et al. 2017, e424) on CO-CPR in pediatric patients identified one relevant study, a retrospective review of data from the Cardiac Arrest Registry to Enhance Survival (CARES) database (Naim et al. 2021, 1042). The review included 13,060 pediatric (18 years of age or younger) nontraumatic, out-of-hospital cardiac arrests. In multivariable analysis of the overall cohort, neurologically favorable survival was associated with the use of rescue-breathing CPR (RB-CPR) (aOR, 2.16; 95% CI, 1.78–2.62) and with CO-CPR (aOR, 1.61; 95% CI, 1.34–1.94) compared with no CPR. Rescue-breathing CPR was associated with higher odds of neurologically favorable survival compared with CO-CPR (aOR, 1.36; 95% CI, 1.10–1.68). Risk stratification by age group was also reported. For the comparison of RB-CPR with no CPR, adjusted OR for neurologically favorable survival was greater for infants younger than 1 year old (aOR, 1.65; 95% CI, 1.19–2.3; $P<0.003$), children (1 to 11 years of age) (aOR, 2.73; 95% CI, 2.00–3.72; $P<0.001$) and adolescents (12 years of age or older) (aOR 2.12; 95% CI, 1.44–3.11; $P<0.001$). When comparing data for patients who received CO-CPR with data for patients with no CPR, CO-CPR was associated with better neurologically favorable survival in children (aOR 1.94; 95% CI, 1.41–2.68; $P<0.001$) and adolescents (aOR, 1.71; 95% CI, 1.23–2.37; $P<0.001$), but not for infants (aOR, 1.16; 95% CI, 0.083–1.62; $P=0.294$) (Naim et al. 2021, 1042).

The International Liaison Committee on Resuscitation recommends that bystanders provide CPR with ventilation for infants and children younger than 18 years of age with out-of-hospital cardiac arrest, and continues to recommend that if bystanders cannot provide rescue breaths as part of CPR for infants and children with out-of-hospital cardiac arrest, they should at least provide chest compressions (Olasveengen et al. 2017, e424).

Insights and Implications

Since 2015, CO-CPR has been recommended as an alternative to conventional CPR for adults and children in cardiac arrest when a lay responder or healthcare professional is unable or unwilling to provide ventilations. Both healthcare professionals and trained lay responders, including lifeguards and those with a duty to respond, should provide CPR with ventilations in addition to compressions. The findings of the ILCOR review suggest that the change from a compression-to-ventilation ratio of 15:2 to a compression-to-ventilation ratio of 30:2 resulted in more lives being saved. The rationale for a compression-to-ventilation ratio of 30:2 for lay providers who are trained and for a single healthcare professional is maintaining uniformity of recommendations while recognizing the importance of delivering ventilations during CPR. For children, the etiology of cardiac arrest is most commonly a respiratory event with hypoxia; a strategy for

CPR in children and infants that emphasizes ventilations is consistent with both current evidence and the pathophysiology of cardiac arrest in this population.

Providing High-Quality CPR: Ventilation Rates and Tidal Volumes

Last Full Review: ILCOR 2020 (Children and Infants); ILCOR 2010 (Adults)
Last Update: 2023 (Adults)

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al. 2017, 39; Idris et al. 2012, 3004; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the CPR tidal volumes and ventilations rates guidelines.

Red Cross Guidelines and Best Practices

- For adults with a pulse but insufficient respiratory effort, and during cardiopulmonary resuscitation (CPR) with an advanced airway in place, 1 rescue breath/manual ventilation should be provided every 6 seconds.
- For children and infants with a pulse but insufficient respiratory effort, and during CPR with an advanced airway in place, 1 rescue breath/manual ventilation should be provided every 2 to 3 seconds.
- Rescue breaths and manual ventilations should be delivered over 1 second in adults, children and infants and with a volume that produces visible initiation of chest rise.

Evidence Summary

A 2021 American Red Cross Scientific Advisory Council literature update did not identify new studies of inspiratory times, ventilation rates or tidal volumes for adults or children without advanced airways in place, and guidelines are unchanged. Historically, guidelines for the inspiratory time to deliver mouth-to-mouth and bag-mask ventilations in adults stem from a 2005 International Liaison Committee on Resuscitation Consensus on Science with Treatment Recommendations (ILCOR CoSTR) (International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations 2005, 187), while guidelines for adult ventilatory rates and tidal volume reflect the treatment recommendations from a 2010 ILCOR review (Sayre et al. 2010, S298) of airway management.

The Red Cross guidelines for children and infants in respiratory arrest or cardiac arrest with an advanced airway in place changed in 2020 following publication of a large multicenter cohort study of ventilation rates in children receiving CPR with an advanced airway in place (Sutton et al. 2019, 1627). The recommended ventilatory rate was changed to 1 breath or ventilation every 2 to 3 seconds. This change reflects:

- A closer approximation with baseline physiological pediatric respiratory rates.
- The likelihood of an underlying respiratory process preceding a cardiac event in children.
- The findings from the 2019 multicenter cohort study, showing that higher ventilation rates (at least 30 breaths/minute in infants and 25 or more breaths/minute in older children) were associated with higher odds of return of spontaneous circulation (ROSC) and survival to hospital discharge (Sutton et al. 2019, 1627).

There are no recommendations by ILCOR regarding ventilation rates for children and infants with a perfusing rhythm and respiratory arrest (Maconochie et al. 2020, S140).

For adults, evidence supporting the guidelines for delivery of a rescue breath or manual ventilation over 1 second includes a secondary analysis of case series (Aufderheide and Lurie 2004, S345; Aufderheide et al. 2004, 1960) that included patients with advanced airways after out-of-hospital cardiac arrest. Ventilation rates above 10 per minute and inspiration times greater than 1 second were associated with no survival (International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations 2005, 187). In addition, a 2005 study using a model of a simulated unprotected airway reported that a reduction of peak inspiratory time from 2 seconds to 1 second resulted in a significant increase in peak airway pressure and peak inspiratory flow rate, with no increase in stomach inflation (von Goedecke et al. 2005, 321).

Evidence supporting guidelines for ventilatory rates and tidal volume in adults includes human studies showing that oxygenation and normocarbia were maintained in apneic adults who were ventilated with room air and tidal volumes of 600 mL, while supplemental oxygen was needed to reach adequate saturation levels when tidal volumes of 500 mL were used (Sayre et al. 2010, S298).

An evidence update (Berg et al. 2023, e187) by ILCOR in 2022 did not identify new relevant studies of tidal volume or ventilation rate. Of note, neonatal and infant studies were excluded from the literature update search, as were studies involving patients who were intubated.

Insights and Implications

Excessive ventilation (i.e., inspiration duration, rate of ventilations and volume) can cause gastric insufflation with regurgitation and aspiration, increased intrathoracic pressure, and decreased cardiac venous return and output, and should be avoided. For patients with an advanced airway in place during CPR, the reduced cardiac output should support a lower minute ventilation and tidal volume of about 500 ml to 600 mL (6 mL/kilogram to 7 mL/kilogram). For patients without an advanced airway in place, this volume equates to seeing the initiation of chest rise. Delivering ventilations over 1 second instead of 2 seconds also allows for higher chest compression rates without increased risk of gastric insufflation. The Red Cross guidelines for ventilation rates in children and infants with a pulse but with respiratory insufficiency are based largely on indirect evidence from the 2019 multicenter cohort study (Sutton et al. 2019, 1627) showing that among intubated patients, higher ventilation rates (at least 30 breaths/minute in infants and 25 or more breaths/minute in older children) were associated with higher odds of return of spontaneous circulation and survival to hospital discharge.

Providing High-Quality CPR: Minimizing Pauses in Chest Compressions

Last Full Review: ILCOR 2022

High-quality cardiopulmonary resuscitation (CPR) has been shown to improve the chances of survival and favorable neurological outcome in patients with cardiac arrest (Brouwer et al. 2015, 1030; Cheskes et al.

2017, 39; Idris et al. 2012, 3004 ; Park et al. 2020, 8356201). Individual components of CPR have been studied to define rescuer performance metrics. Rescuer performance components, or mechanics, that have been identified as contributing to high-quality CPR include proper hand position, chest compression rates, chest compression depth, chest recoil, chest compression fraction (CCF) (minimizing pauses in chest compressions) and avoiding excess ventilations. These components all contribute to maintaining an adequate coronary perfusion pressure, or flow through the coronary arteries during cardiac arrest. Each component can be observed and/or measured using audiovisual feedback devices both in training and during real-time performance of CPR, and when performed within recommended measures or metrics, contribute to the delivery of high-quality CPR. This section of the guidelines describes the evidence behind the minimizing pauses in chest compressions guidelines.

Red Cross Guidelines and Best Practices

- Pauses during cardiopulmonary resuscitation (CPR), including peri-shock pauses, changing roles, and moving between ventilations and compressions for a single rescuer, should be as short as possible.
- Chest compression fraction (CCF) should be as high as possible and at least 60%.
- Where system resources permit, monitoring of peri-shock pauses and CCF may be considered as part of a comprehensive quality improvement program.

Evidence Summary

A systematic review and Consensus on Science with Treatment Recommendations (Olasveengen et al. 2022; Wyckoff et al. 2022, e483) by the International Liaison Committee on Resuscitation (ILCOR) updated in 2022 evaluated the evidence for minimizing pauses in chest compressions in adults in cardiac arrest in any setting (i.e., a higher CPR fraction or CCF, or shorter peri-shock pauses), compared with conventional CPR (with a lower CPR or CCF, or longer peri-shock pauses). For peri-shock pauses, most observational studies reported higher survival in patients with shorter pre-shock pauses (less than 10 seconds) compared with longer pauses (greater than 10 to 20 seconds), and a few studies reported higher survival in patients with shorter peri-shock pauses (less than 20 seconds) compared with longer pauses (greater than 20 to 40 seconds). In adjusted analysis, the most recent study enrolling 15,568 patients did not report higher odds of survival with shorter pre-shock pauses (less than 10 seconds) compared with longer pauses (greater than 10 seconds) (Cheskes et al. 2017, 39). (See Infographic: *Minimizing Pauses During CPR*)

Insights and Implications

Chest compression fraction is the proportion of time spent providing chest compressions during CPR and is measured by dividing the cumulative time spent providing chest compressions by the total time taken for the entire resuscitation. The interruption of chest compressions during CPR to perform rescue breaths, rhythm analysis, pulse checks and defibrillation all reduce CCF, leading to decreased coronary and cerebral blood flow and the potential for decreased survival (Aramendi and Irusta 2016, E121).

A CCF of greater than 80% is considered a high-quality CPR metric. To achieve this CCF, it is necessary to minimize pauses that can occur with interventions, such as intubation and peri-shock pauses. While the ILCOR systematic review (Olasveengen et al. 2022; Wyckoff et al. 2022, e483) did not find strong evidence of a survival benefit with higher CCFs and decreased peri-shock pauses, the authors note that observational studies of pauses in compressions are challenging to interpret because short-duration resuscitation efforts in patients with shockable rhythms tend to have better outcomes than long-duration resuscitation efforts in patients with nonshockable rhythms. The cardiac rhythm and the duration of resuscitation will impact the number and duration of pauses. This makes it difficult to determine optimal pause duration or frequency for guidance.

Minimizing Pauses During CPR

Chest compression fraction (CCF):

- Is the proportion of time spent doing chest compressions during resuscitation for cardiac arrest.
- Is a component of high-quality CPR.
- Should be as high as possible and at least 60%.

Pauses during chest compressions decrease the CCF and may occur:

- Before, during and immediately after shock delivery.
- While changing roles during CPR.
- When switching from compressions to ventilations (single rescuer).
- During delivery of ventilations with conventional CPR.
- During airway management or rhythm analysis.

KEY POINT

Pauses during chest compressions should be kept as short as possible.