Section 4: Devices to Assist Circulation

Alternative CPR Techniques

Alternative techniques to standard manual CPR have been developed to improve perfusion during CPR. These include interposed abdominal compression (IAC) CPR, high-frequency CPR, active compression-decompression (ACD) CPR, vest CPR, mechanical (piston) CPR, simultaneous ventilation-compression (SVC) CPR, phased thoracic-abdominal compression-decompression (PTACD) CPR, and invasive CPR. Each of these approaches has been evaluated initially in animal models and then in patients. For some the data is sufficient to recommend them as alternatives to standard CPR in specific clinical settings as described below.

Compared with standard CPR, CPR adjuncts generally require additional personnel, training, or equipment. The added effort may increase forward blood flow during CPR from 20% to 100%—levels that are still significantly less than normal cardiac output. Maximum benefits are reported when adjuncts are begun early in the treatment of cardiac arrest, so their use is often limited to in-hospital settings. Adjunctive techniques produce little benefit when started late in a prolonged resuscitative effort or when performed as a last-ditch measure after failed ACLS. To date no adjunct has been shown to be universally superior to standard manual CPR for prehospital BLS.

IAC-CPR

IAC-CPR includes manual compression of the abdomen by an extra rescuer during the relaxation phase of chest compression. The abdominal compression point is located in the midline, halfway between the xiphoid process and the umbilicus (Figure). The recommended force of abdominal compression should be sufficient to generate approximately 100 mm Hg external pressure on the abdominal aorta and vena cava and is equivalent to that required to optimally palpate the aortic pulse when the heart is beating normally.

Two randomized clinical trials of IAC-CPR for in-hospital cardiac arrest have been shown statistically significant improvement in outcome measures. Results of the first trial found improved return of spontaneous circulation (ROSC), 24-hour survival, and hospital discharge in 48 of 103 patients randomly assigned to IAC-CPR. Results of the second trial also found improved ROSC and 24-hour survival with IAC-CPR, although none of the patients with an initial rhythm of asystole or pulseless electrical activity survived to hospital discharge. Pooled data from these 2 randomized in-hospital studies shows a difference in 24-hour survival of 33% versus 13%. One smaller trial randomly assigned patients on arrival at the emergency department. If spontaneous circulation could not be successfully restored within 20 minutes, patients were assigned to the other therapy, with each patient acting as his or her own control. Mean end-tidal Pco2 was 17.1 mm Hg during IAC-CPR versus 9.6 mm Hg during standard CPR. Six of 16 patients were resuscitated before crossover with IAC-CPR versus 3 of 17 with standard CPR (P = 0.19). One randomized trial of prehospital IAC-CPR showed no difference in outcome or complications. In this study, however, most patients randomly assigned to IAC-CPR received both standard CPR and IAC-CPR during at least some of the resuscitative attempt.

Analysis of all available data for both prehospital and in-hospital resuscitations shows improvement in ROSC with IAC-CPR compared with standard CPR. When only in-hospital studies are examined, the effect of IAC becomes much greater. Data from 2 studies that examined long-term, neurologically intact survival following in-hospital resuscitations shows a positive benefit of IAC-CPR compared with standard CPR. This clinical data is consistent with a series of theoretical and animal studies documenting the “abdominal pump” mechanism for hemodynamic augmentation.

The safety of IAC has been reviewed. Increased emesis and aspiration from IAC have not been reported. In fact, there is evidence that positive abdominal pressure applied during ventilations from the beginning of an arrest reduces the rate of gastric inflation before tracheal intubation.

In summary, randomized clinical studies have demonstrated improved outcome when IAC-CPR was compared with standard CPR for in-hospital resuscitation, but no survival benefit for out-of-hospital arrest has been shown. CPR-induced injuries do not appear to be more common with IAC-CPR than with standard CPR. Because of the positive hemodynamic advantages, safety record, and encouraging in-hospital results, the use of IAC-CPR for in-hospital resuscitations is recommended as an alternative intervention to standard CPR whenever sufficient personnel trained in the technique are available (Class IIb). The safety and efficacy of IAC-CPR has not been studied in patients with aortic aneurysms, pregnancy, or recent abdominal surgery.

High-Frequency (“Rapid Compression Rate”) CPR

High-frequency (>100 compressions per minute) manual CPR has been advocated as a technique for improving resuscitation from cardiac arrest. Studies in some, but not all, laboratories have shown that rapid compression rates improve cardiac output, aortic and myocardial perfusion pressures, coronary blood flow, and 24-hour survival compared with standard CPR. Clinical studies on the use of high-frequency CPR are limited. There is evidence for
improved hemodynamics with manual but not mechanical rapid chest compression rates in patients.\textsuperscript{22,\textasciitilde24} Thus, high-frequency CPR shows some promise for improving CPR. Outcome studies in humans are needed to determine the efficacy of this technique in the management of patients in cardiac arrest (Class Indeterminate).

**ACD-CPR**

ACD-CPR is another technique developed to improve the efficiency of CPR.\textsuperscript{16,25\textasciitilde35} Decreasing intrathoracic pressure during the decompression phase of CPR is thought to enhance venous return and thereby "prime the pump" for the next compression. ACD-CPR is performed with a hand-held device equipped with a suction cup to actively lift the anterior chest during decompression. Early laboratory and clinical data showed that acute hemodynamic parameters such as arterial blood pressure and vital organ perfusion are superior with use of ACD-CPR compared with standard CPR.\textsuperscript{36\textasciitilde40} Clinical outcome data is less consistent and suggests that technique and training are critical. The most promising results are from Paris, France, where 1-year survival rates increased from 2\% (7 of 377 patients) to 5\% (17 of 373 patients) with the use of ACD-CPR.\textsuperscript{41} A number of clinical studies, however, have found no significant benefit from the use of ACD-CPR.\textsuperscript{42,\textasciitilde45} Factors associated with clinical improvement with ACD-CPR include rigorous and repetitive training, concurrent use of low- rather than high-dose epinephrine,\textsuperscript{35} use of the force gauge, and performance of CPR for a duration sufficient to prime the pump.

There is some concern that the extra force and energy applied to the chest wall during ACD-CPR tends to induce a higher incidence of rib fractures than that which occurs during standard CPR.\textsuperscript{46,47} One case report describes massive cardiac injury in an area of myocardial infarction with pericardial tamponade.\textsuperscript{48} In women with large breasts, the presence of a deeper sternum may cause greater force to be transmitted to the lateral rims of the ACD device, enhancing the likelihood of rib fracture.\textsuperscript{49} Design improvements, such as the inclusion of cushions, may well eliminate this problem, which should not be considered fundamental. Other published concerns include difficulties with application of the technique and increased energy expenditure by rescuers.

In summary, laboratory and clinical studies to date have demonstrated that there is often measurable improvement in resuscitation hemodynamics with ACD-CPR compared with standard CPR. Clinical long-term results with ACD-CPR have been favorable (4 studies)\textsuperscript{26,28,30,50} or at least neutral (4 studies)\textsuperscript{22,51\textasciitilde53} compared with standard CPR. Complications of ACD are noteworthy but not of major concern. ACD-CPR is considered an acceptable alternative to standard CPR when rescue personnel adequately trained in use of the device are available (Class IIb).

(Note: In hearings conducted several years ago the FDA concluded that the evidence did not support the labeling information included with the device. On that basis the FDA did not approve the device for sale and distribution. This conclusion does not conflict with the International Guidelines 2000 recommendations noted above: not proved effective in the out-of-hospital setting; acceptable but weak data supports in-hospital use—Class IIb.)

**Vest CPR**

The CPR vest was an earlier attempt to take advantage of the thoracic pump mechanism of blood flow.\textsuperscript{24,54\textasciitilde59} Vest CPR uses a circumferential thoracic vest, analogous to a large blood pressure cuff, that is cyclically inflated and deflated, vest CPR produces increases in intrathoracic pressure. Vest CPR has shown improved myocardial and cerebral blood flow in animals and improved peak aortic and coronary perfusion pressures during CPR in animals and humans.\textsuperscript{60,61} A preliminary report of vest CPR did find improved 6-hour survival but not 24-hour survival.\textsuperscript{62} Large randomized trials have not been completed. One such trial was unfortunately interrupted secondary to a lack of continued funding.\textsuperscript{63} There is no evidence of increased resuscitation trauma with vest CPR. The present size and energy requirements for operation of the device continue to be substantial barriers for its widespread use. The size and weight of the device require that it be used for patients who can readily undergo vest CPR without substantial delay in either the hospital or emergency vehicle settings. Long-term survival studies of this approach are needed.

Vest CPR may be considered an alternative to standard CPR in-hospital or during ambulance transport, because vest CPR (1) shows hemodynamic improvement in animal and clinical studies, (2) does not substantially delay starting CPR, (3) presents no significant known disadvantages, (4) has been assessed for hemodynamic effect in patients in cardiac arrest, and (5) does not interfere with defibrillation efforts. Vest CPR should be used only when there are an adequate number of well-trained, in-hospital personnel to properly perform CPR (Class IIb). The manufacturer of the vest-CPR device has not yet sought and obtained FDA permission for its distribution and sale.

**Mechanical (Piston) CPR**

Mechanical devices that depress the sternum are not a substitute for manual external chest compression but rather an
adjunct to be used by trained personnel to optimize compression and reduce rescuer fatigue in prolonged resuscitative efforts. The efficacy and safety of these devices have not been demonstrated in infants and children; their use should be limited to adults. A disadvantage of any mechanical chest compression device is the potential for interrupting chest compressions for extended periods while setting up and initiating compressions. Mechanical chest compressors can be manual or automatic.

Simple, manually operated mechanical chest compressors can provide effective external chest compressions. Automatic mechanical chest compressors such as the Mechanical Thumper consist of a compressed gas-powered plunger mounted on a backboard. The devices can be programmed to deliver standard CPR in a compression-ventilation ratio of 5:1, with a compression duration that is 50% of the cycle length, or other ratios. Most animal and clinical studies have shown variable hemodynamic results compared with other CPR techniques (standard, ACD, and SVC CPR). Results of the 2 most recent clinical trials both showed improved expired end-tidal CO2 compared with standard manual CPR. The limited clinical data has thus far shown no improvement in survival outcome when mechanical CPR was compared with standard CPR in patients with cardiac arrest.

An advantage of the mechanical devices is delivery of a consistent rate and depth of compression by eliminating such variables as operator technique and fatigue. Problems related to the use of automatic mechanical chest compressors, however, include sternal fracture, expense, size, weight, restrictions on mobility, and dislocation of the plunger in relation to the sternum. Ventilation or chest compression, or both, may be inadequate when these devices are improperly positioned or operated. In addition, the weight of the compressor on the chest may limit chest wall recoil and venous return during decompression, especially after one or more rib fractures have occurred. There is no consistent measurable improvement in hemodynamics and no observed survival outcome data showing that mechanical resuscitators similar to mechanical chest compressors are superior to standard CPR. The mechanical resuscitator is an acceptable alternative to standard manual CPR in circumstances that make manual chest compressions difficult, ie, certain transport situations or lack of adequate personnel (Class IIb).

Simultaneous Ventilation-Compression CPR

The technique of SVC-CPR was conceived to take advantage of the entire thorax as a pump in producing blood flow during cardiac arrest. Pressure gradients are developed between intrathoracic and extrathoracic vascular beds. Studies in experimental models showed that SVC-CPR resulted in improved peak compression ("systolic") pressures and carotid artery blood flows. On the basis of these studies, a mechanical CPR device that provides simultaneous ventilation and chest compression was developed and tested clinically. Laboratory studies showed improvement in short-term survival when SVC-CPR was compared with standard CPR in some laboratories but not others. Clinical studies have failed to identify any benefits of SVC-CPR. Instead the studies show standard CPR to be superior to SVC-CPR in hemodynamics and survival. SVC-CPR is not currently available for clinical use.

Phased Thoracic-Abdominal Compression-Decompression CPR

PTACD-CPR uses a hand-held device that alternates chest compression and abdominal decompression with chest decompression and abdominal compression. This innovative technique basically combines the concepts of IAC-CPR and ACD-CPR. Theoretically the combined 4-phase approach, including both compression and decompression of the chest and abdomen, could increase blood flow during cardiac arrest and CPR. The use of PTACD-CPR has led to hemodynamic improvement in animal and clinical studies. PTACD-CPR does not substantially delay starting CPR and presents no significant known disadvantages or harm when used correctly. No clinical outcome data is available, and the device is not yet approved by the FDA (Class Indeterminate).

Other Adjunctive CPR Devices

Several mechanical devices have been developed as adjuncts to CPR. These devices do not replace basic CPR but rather are additions to the ongoing resuscitative effort. They can be combined with a variety of CPR techniques, eg, standard CPR, IAC-CPR, ACD-CPR, vest CPR, and mechanical CPR. Such adjunctive CPR devices can be recommended only after they have been shown to improve the efficacy of CPR in patients in cardiac arrest (hemodynamic changes are equal or better) and to have no significant increase in complications compared with standard manual CPR.

Impedance Threshold Valve

The impedance threshold valve (ITV, or ResQ-Valve) is associated with lower intrathoracic pressure. When used with a compression/decompression device, the valve is inserted into a standard tracheal tube ventilation circuit and does not disrupt CPR performance. The airway must be secured with a cuffed tracheal tube. By preventing inspiration during chest decompression, the impedance threshold valve produces more negative intrathoracic pressure, enhancing blood return to the thorax. The impedance threshold valve (ResQ-Valve) is not intended for use with standard CPR. Future clinical studies may indicate efficacy of the impedance valve during standard CPR, but no recommendation can now be made for this device as an adjunct for standard CPR (Class Indeterminate). Observations from 2 animal studies and 1 small (n=11) human trial showed significant improvements in hemodynamic parameters when this device was used as an adjunct to ACD-CPR. Despite better hemodynamics, no improvement in short- or long-term outcome occurred, and no complications were noted in the 11 study patients. The impedance threshold valve is acceptable as an adjunct to be used with a cardiac compression/decompression device to augment hemodynamic parameters (Class IIb).

Invasive CPR

Direct cardiac compression is a special technique that may provide near-normal perfusion of the brain and heart.
Experimental studies have shown that direct cardiac massage used early in cardiac arrest after a short period of ineffective closed-chest CPR can improve survival from cardiac arrest. Limited clinical series have shown similar beneficial hemodynamic effects with open-chest massage. Experimental and clinical studies have shown that direct cardiac massage does not improve outcome when applied late (after >25 minutes of total arrest time) in the treatment of patients in cardiac arrest. One prospective, nonrandomized, historically controlled series, however, did show improved ROSC with the use of open-chest direct cardiac massage.

In the emergency thoracotomy, open-chest cardiac massage is, by necessity, associated with some morbidity. An experienced team is needed to successfully perform this technique and optimally care for the patient afterward. We do not recommend its routine use for cardiac arrest victims. In particular, it should not be used as a last effort at the end of a lengthy resuscitation treatment sequence. Outcome studies assessing the use of open-chest direct cardiac massage early in the cardiac arrest treatment sequence are needed.

Specific indications for the use of open-chest direct cardiac compression in the clinical setting are changing. Previous recommendations included cardiac arrest from nonpenetrating, blunt trauma. Blunt abdominal trauma associated with cardiac arrest does not respond to invasive resuscitative efforts and should not be considered an indication. A thoracotomy is indicated for patients with penetrating chest trauma who develop cardiac arrest. Other clinical circumstances in which a thoracotomy could be considered include (1) cardiac arrest caused by hypothermia, pulmonary embolism, or pericardial tamponade; (2) chest deformity where closed-chest CPR is ineffective; and (3) penetrating abdominal trauma with deterioration and cardiac arrest. The use of open-chest direct cardiac massage can be considered under special circumstances but should not be done simply as a late last-ditch effort (Class IIb).

Emergency cardiopulmonary bypass has been advocated as a circulatory adjunct for treatment of patients in cardiac arrest. The bypass pump can be applied by using the femoral artery and vein without requiring a thoracotomy. Experimental studies have shown improved hemodynamics and survival when cardiopulmonary bypass is used after prolonged cardiac arrest. Clinical studies have shown the feasibility of cardiopulmonary bypass in the treatment of patients in cardiac arrest from specific, potentially reversible causes (such as drug overdoses and poisonings). No outcome studies of significance have been done to date. Further clinical studies are needed to define the role of cardiopulmonary bypass in the treatment of patients in cardiac arrest (Class Indeterminate). Its success in the special situations of drug overdoses and hypothermic arrest may be sufficient justification alone for its use in specific hospital settings.

Assessment of CPR
At present there are no good prognostic criteria that clinicians can use to assess the efficacy of CPR. Clinical outcome—either resuscitation or death—is often the only way to judge the adequacy of CPR efforts. Assessment of ongoing CPR efforts would allow clinicians to modify resuscitative efforts and individualize treatment protocols for patients in cardiac arrest. Ideally clinicians could judge the value of specific adjuncts in individual patients. If a less-than-optimal response were documented, a new strategy could be attempted and individualized, depending on such real-time feedback during the resuscitative effort. Several adjuncts may be useful in the assessment of ongoing CPR efforts.

Assessment of Hemodynamics
Perfusion pressures. Studies in experimental models have repeatedly shown the importance of the aortic diastolic and myocardial perfusion (aortic-to-right atrial diastolic gradient) pressures during CPR for successful resuscitation from cardiac arrest. The aortic diastolic and myocardial perfusion pressures have been correlated with coronary blood flow during CPR. Much CPR research has focused on drugs or adjuncts that improve these pressures. Although the placement of arterial and central venous lines during resuscitative efforts has been accomplished by a resuscitation research team in some settings, placement of these lines is impractical in most clinical settings. When arterial lines are available, the clinician should attempt to optimize the aortic diastolic and myocardial perfusion pressures during the resuscitative effort.

Pulses. Clinicians frequently use the presence or absence of pulses resulting from chest compressions during the resuscitative effort to assess the adequacy of artificial perfusion during CPR. The presence of pulses does not indicate any meaningful arterial blood flow during CPR. No studies have shown the clinical utility of checking pulses during ongoing CPR. A palpable pulse represents the difference between the peak pressure and nadir pressure within a vascular bed. The important factor for perfusion of the myocardium is coronary perfusion pressure (aortic minus right atrial pressure during the relaxation phase of chest compressions). The difference in peak and nadir pressures does not correlate with perfusion. It is important to remember that because there are no valves in the inferior vena cava, retrograde blood flow may occur in the femoral vein. Palpation of a pulse in the femoral area may be misleading and may indicate venous rather than arterial blood flow. In summary, the presence of carotid pulses during CPR may indicate the presence of a pulse wave and perhaps some forward blood flow, but it cannot be used to gauge the efficacy of myocardial or cerebral perfusion from ongoing CPR efforts.

Assessment of Respiratory Gases
Some clinicians use arterial blood gases to gauge the efficacy of ongoing CPR efforts. Adequate oxygen concentration in arterial blood during low-flow states may not imply adequate oxygen delivery to the peripheral tissue beds. Physiologically, arterial blood gases do not reflect tissue pH and Pco2. Mixed venous gases often show severe hypercarbia despite normal arterial gases. No correlation between arterial blood gases and resuscitation success has been demonstrated in experimental models of cardiac arrest. Thus, arterial blood gases can be useful for evaluating oxygenation but should not be used to assess adequacy of CPR efforts.
Studies on the use of oximetry for assessing tissue perfusion during CPR have shown that transconjunctival oxygen tension falls rapidly when a patient goes into cardiac arrest and returns to baseline when spontaneous circulation is restored.\textsuperscript{97} Oximetry, however, has not been shown to be a useful prognostic guide for predicting resuscitation from cardiac arrest. Pulse oximetry is commonly used in emergency departments and critical care units. However, measurements depend on the presence of a peripheral pulse, and the technique is unreliable when used on patients in cardiac arrest.

Capnometry shows the most promise as a measurement of CPR effectiveness. Measuring expired end-tidal CO\textsubscript{2} is a noninvasive technique for monitoring cardiac output generated during ongoing CPR.\textsuperscript{98} During cardiac arrest CO\textsubscript{2} continues to be generated throughout the body. Once delivered to the lungs, it is excreted. The major determinant of CO\textsubscript{2} excretion is its rate of delivery from the peripheral production sites to the lungs. If ventilation is reasonably constant, then end-tidal CO\textsubscript{2} concentration reflects cardiac output. Capnometry measures CO\textsubscript{2} excretion through the tracheal tube. In experimental models, end-tidal CO\textsubscript{2} concentration during ongoing CPR correlated with cardiac output, coronary perfusion pressure, and successful resuscitation from cardiac arrest.\textsuperscript{99–103} Clinical studies have shown that patients who were successfully resuscitated from cardiac arrest had significantly higher end-tidal CO\textsubscript{2} levels than patients who could not be resuscitated.\textsuperscript{102–106} Capnometry can also be used as an early indicator of ROSC.\textsuperscript{102–104}

Despite these promising studies, other variables can cause changes in CO\textsubscript{2} excretion. Large changes in the minute ventilations will affect the end-tidal CO\textsubscript{2} reading. Ventilations must be held relatively constant during the resuscitative effort. Administration of bicarbonate will increase CO\textsubscript{2} excretion for several minutes before it returns to stable conditions for measurement.\textsuperscript{104,105} High doses of pressor agents such as epinephrine will increase myocardial perfusion pressure but decrease cardiac output. CO\textsubscript{2} excretion will decrease with decreased blood flow to the lungs.\textsuperscript{107,108} In summary, end-tidal CO\textsubscript{2} monitoring during cardiac arrest can be useful as a noninvasive indicator of cardiac output generated during CPR (Class Ia). Research is needed to define the ability of end-tidal CO\textsubscript{2} monitoring to predict cardiac arrest victims who could be resuscitated with more aggressive interventions or prolonged resuscitations.

Assessment of Chest Compression

The quality of chest compressions and resuscitative effort is an important aspect of CPR. Even physicians recently trained in ACLS have difficulty meeting the recommended compression and ventilatory rates. Simple metronome guidance can correct this.\textsuperscript{109} Guaranteening the depth of chest compressions has been even more difficult to ensure. A device called CPR-Plus has been developed to improve the rescuer’s performance of chest compression. When this device is placed on the victim’s chest and used as a baseplate for chest compressions, the rescuer obtains feedback that includes a metronome-guided rate and force of compression performed. To date, only manikin studies using the CPR-Plus device have been reported.\textsuperscript{110,111} These studies showed that performance of chest compressions was significantly improved when rescuers used the CPR-Plus device rather than standard CPR alone. Animal and clinical studies, however, are needed to assess whether CPR-Plus improves or detracts from resuscitation hemodynamics in animal models and patients with cardiac arrest. Until such studies are available, informed commentary on this promising device is not possible. We do not recommend the use of CPR-Plus during CPR (Class Indeterminate).

References


Part 6: Advanced Cardiovascular Life Support: Section 4: Devices to Assist Circulation

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