

Alternative cardiopulmonary resuscitation devices

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Cardiac arrest survival rates remain low despite increased access to advanced cardiac life support. Survival from cardiac arrest is, at least in part, related to the perfusion pressures and blood flow achieved during cardiopulmonary resuscitation (CPR). A number of alternative CPR devices have been developed that aim to improve the perfusion pressures and/or blood flow achieved during CPR. Active compression-decompression CPR devices are by far the most studied alternative CPR devices, but the results have been inconsistent and conflicting. A number of other devices, including the inspiratory impedance threshold valve, minimally invasive direct cardiac massage, phased chest and abdominal compression-decompression CPR, and vest CPR, are all capable of improving perfusion pressures and/or blood flow compared with standard external chest compressions. However, no convincing human outcome data has been produced yet for any of these devices. Although an interesting area of research, none of the alternative CPR devices convincingly improve long-term patient outcomes. *Curr Opin Crit Care* 2002, 8:219–223 © 2002 Lippincott Williams & Wilkins, Inc.

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Dr. Smith is engaged in research involving minimally invasive direct cardiac massage. However, Dr. Smith is not receiving any financial reward for this research and has no financial interests in the device.

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Abbreviations

ACD active compression-decompression
CPR cardiopulmonary resuscitation
MIDCM minimally invasive direct cardiac massage

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Cardiac arrest remains a common event with abysmal outcomes. Hospital discharge rates after out-of-hospital cardiac arrest vary around the world but are commonly in the 5 to 10% range [1,2]. These rates have changed little over time despite increased access to advanced cardiac life support. Survival from cardiac arrest is, at least in part, related to the perfusion pressure and blood flow achieved during cardiopulmonary resuscitation (CPR) [3]. Standard external chest compressions during CPR produce only a fraction of the perfusion pressure and blood flow achieved by a beating heart. A number of alternative CPR devices have been developed that aim to improve the perfusion pressure and blood flow achieved during CPR.

Active compression-decompression cardiopulmonary resuscitation

Active compression-decompression (ACD) CPR is performed by using a handheld suction device (*eg*, Cardiopump; Ambu International, Glostrup, Denmark) attached to the middle of the sternum and by actively pushing and pulling on the device. In theory, by actively pulling the sternum up, the negative pressure achieved within the chest cavity during the decompression phase is accentuated; this should accentuate blood return into the thoracic cavity and accentuate the blood flow achieved.

Both animal and human studies show that ACD-CPR is capable of producing higher perfusion pressures and flow than standard external chest compressions [4–6]. ACD-CPR has been the most studied alternative form of CPR in humans. The results have been conflicting and inconsistent [7••]. Most studies have shown no difference in outcomes [8–13], but two have shown improved hospital discharge rates and/or long-term survival [14,15•]. The Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [16••] recommended that ACD-CPR be considered an acceptable alternative to standard CPR when rescue personnel are adequately trained to use the technique. Despite this, few have embraced ACD-CPR, and it is used infrequently outside some sites in Europe. The Cochrane Database of Systematic Reviews [7••] concluded that ACD-CPR in patients with cardiac arrest was not associated with clear benefit. ACD-CPR requires additional training, significant additional exertion, and additional personnel to relieve the person performing CPR, and it adds complexity to resuscitation attempts.

In my opinion, ACD-CPR is an interesting area of research. Of all of the alternative CPR devices it is the only

one that has improved long-term outcomes from out-of-hospital cardiac arrest in any study. Despite this, the total human outcome data is conflicting, and I do not believe that the evidence supporting ACD-CPR is strong enough that I would recommend its use outside of a research trial. I have not introduced ACD-CPR into my own ambulance service or my own practice.

Inspiratory impedance threshold valve

The inspiratory impedance threshold valve (*eg*, Resusc Valve; CPRxLLC, Minneapolis, MN) is designed to selectively impede passive inspiratory gas movement into the endotracheal tube (or other airway device) whilst allowing for unimpeded expiration. During active ventilation there is no significant resistance to inspiratory flow. By selectively impeding passive inspiratory flow the negative pressure achieved within the thorax during the decompression phase of CPR is enhanced. In theory, this will enhance blood return into the thorax and enhance the blood flow achieved during CPR. The valve is designed to be placed between the endotracheal tube (or other airway device) and the ventilation device and should be removed once return of spontaneous circulation occurs. In pigs, the use of an inspiratory impedance threshold valve improves organ blood flow and perfusion pressures when used in conjunction with both ACD-CPR [17] and standard external chest compressions [18]. This enhancement of flow and perfusion pressures appears to be most marked when the inspiratory impedance threshold valve is used in addition to ACD-CPR. In humans, use of the inspiratory impedance threshold valve in combination with ACD-CPR results in significantly higher end tidal carbon dioxide, coronary perfusion pressure, and blood pressure than ACD-CPR alone [19,20]. Mean blood pressures of 108/55 mm Hg were achieved with the combination of the two devices. These blood pressures are truly remarkable and are the best I have seen recorded with any alternative CPR device. No studies have been published that have looked at long-term outcomes. The Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [16••] suggested that the inspiratory impedance threshold valve was an acceptable adjunct for use with a cardiac compression-decompression device to augment hemodynamic parameters. The inspiratory impedance threshold valve is simple, easy to use, requires little in the way of additional training, and does not add significantly to the complexity of resuscitation attempts.

In my opinion, the inspiratory impedance threshold valve is an interesting area of research. I am particularly interested in the flow and perfusion pressures achieved when it is combined with ACD-CPR, and the combination of these two devices deserves a randomized trial. The evidence is not yet sufficient enough that I would recommend its use outside of a research trial, and I have

not incorporated it into my own ambulance service or my own practice.

Minimally invasive direct cardiac massage

Internal cardiac massage through an open chest is capable of producing much higher blood flow than external chest compressions [21]. Internal cardiac massage is rarely performed, however, because of the need for a formal thoracotomy. A technique called minimally invasive direct cardiac massage (MIDCM; TheraCardia, San Clemente, CA) has been developed that allows internal cardiac massage to be performed without the need for a formal thoracotomy [22].

The MIDCM device is approximately 400 cm long and 1.5 cm in diameter. It has a handle on one end that is connected by a shaft to a palm-sized, expandable pump head membrane (shaped like an umbrella when open), which is able to collapse and retract inside the device. The pump head membrane end of the device has a flange that prevents all but the very tip of the device from passing through the ribs. The technique is begun by making a 3- to 4-cm skin incision in the medial aspect of the left fourth or fifth intercostal space. This is followed by blunt dissection with a gloved finger through the intercostal muscles and fascia onto the pericardium. The MIDCM device is then inserted into the incision until the flange sits on top of the ribs. Depressing a button and pushing on the handle opens up the pump head membrane directly on top of the heart. Pumping the handle pushes the pump head membrane up and down, and this compresses the heart against the vertebrae behind. In most cases, the time from deciding to perform the procedure to deploying the pump head within the chest and beginning compressions is well under a minute (personal experience). The most recently developed model of the MIDCM device has defibrillation wires incorporated within the pump head membrane, which allow for internal defibrillation.

The MIDCM device produces higher perfusion pressures and flow than external chest compressions in both animals and humans [22–25]. In human patients who have failed to achieve return of spontaneous circulation despite prolonged advanced cardiac life support and external chest compressions (most of whom were receiving ACD-CPR), use of the MIDCM device was associated with return of spontaneous circulation in seven of 25 patients [26]. None of these seven patients survived to hospital discharge. Clinically impressive flows can be achieved using this technique. Most patients develop easily palpable pulses, capillary return, and a significant increase in end tidal carbon dioxide (personal experience). The technique can be taught to paramedic staff and is being successfully used by paramedics in Auckland, New Zealand, and Melbourne, Australia. However, the potential exists for damage to internal structures.

Cardiac laceration, cardiac rupture, lung laceration, and intercostal vessel laceration can all occur. The incidence of these serious complications appears, however, to be surprisingly low. For many physicians, use of this technique represents a relative contraindication to thrombolysis. The MIDCM device is relatively complex, significantly complicating resuscitation attempts, and requires significant additional training, hands-on supervision, and regular exposure to the technique to maintain competence. Nonetheless, the technique need not be confined to medically qualified personnel.

In my opinion, MIDCM is an interesting area of research. The evidence is not yet sufficient enough that I would recommend its use outside of a research trial, and I have not incorporated it into my ambulance service or my own practice (except in the setting of a research trial). A large, international, multicenter, randomized trial of MIDCM with internal defibrillation versus external chest compressions in out-of-hospital cardiac arrest is currently underway.

Phased chest and abdominal compression-decompression cardiopulmonary resuscitation

Interposed abdominal compression CPR involves the application of abdominal compression during the relaxation phase of chest compressions. In theory, this abdominal compression will (1) aid blood return to the thorax and enhance blood flow and (2) elevate aortic diastolic pressure and enhance perfusion pressures.

In both animals and humans, interposed abdominal compression increases perfusion pressures and blood flow compared with standard external chest compressions [27–31]. Two randomized studies of patients with in-hospital cardiac arrest have shown improved rates of return of spontaneous circulation and 24-hour survival in the group randomly selected to receive interposed abdominal compression CPR [32,33], and one of these studies [32] was able to demonstrate improved hospital survival. These studies encouraged the Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [16••] to recommend interposed abdominal compression CPR as an acceptable alternative to standard CPR for in-hospital resuscitation when sufficient personnel trained in the technique are available. Despite these results and recommendations, the technique is rarely used outside of centers with a research interest.

A device has been developed that combines interposed abdominal compression with chest compression-decompression CPR. The LifeStick (Datascope, Fairfield, NJ) is a rigid frame with two large adhesive pads. One pad is attached to the sternum, and one is attached to the epigastrium. CPR is performed with a rocking

seesaw motion. In animal studies, LifeStick CPR has been shown to improve coronary and cerebral perfusion pressures, blood flow, and short-term survival when compared with standard external chest compressions [34,35]. In a randomized study of 50 patients, LifeStick CPR was associated with a lower hospital discharge rate than standard external chest compressions [36]. This was, however, a very small study with a much higher incidence of ventricular fibrillation in the group randomized to standard external chest compressions, and little can be concluded from this study. The LifeStick device is simple, requires some additional training and exertion, and adds some complexity (particularly compression timing) to resuscitation attempts.

In my opinion, LifeStick CPR is an interesting area of research. The evidence is not yet sufficient enough that I would recommend its use outside of a research trial, and I have not incorporated it into my own ambulance service or my own practice.

Vest cardiopulmonary resuscitation

Vest CPR involves the application of a sealed vest around the thorax, which is then rhythmically inflated and deflated. The positive and negative pressures within the vest are transmitted to the thorax and utilize the thoracic pump theory to create blood flow. Most vest CPR devices are large (approximately 40–50 kg), cumbersome, and require a significant power source. A smaller device (approximately 10 kg) requiring less power that utilizes a hydraulic pneumatic band rather than a pneumatic vest has been used successfully in pigs [37].

In animal studies, vest CPR is associated with higher blood flow, blood pressure, and short-term survival than external chest compressions [38,39]. In one human study, vest CPR was associated with higher coronary perfusion pressure and short-term survival than external chest compressions [40]. This is a small study of 49 patients and is the only human study that I can find that has been published in anything more than abstract form. The Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [16••] suggested that vest CPR was an acceptable alternative to standard CPR in the hospital or during ambulance transport provided that adequate numbers of trained personnel were available. This is, in my opinion, a very remarkable recommendation given the paucity of available evidence. Vest CPR requires a substantial amount of additional equipment, additional training, and complicates resuscitation attempts.

In my opinion, vest CPR is an interesting area of research. The evidence is not yet sufficient enough that I would recommend its use outside of a research trial, and I have not incorporated it into my own ambulance ser-

vice or my own practice. I think that the technology is a long way away from being of practical use in resuscitation attempts.

Conclusions

The literature is dominated by studies that are either conducted in animals, are too small, or use surrogate measures of outcome. The literature is embarrassingly short of appropriately sized human studies with clinically meaningful outcomes such as long-term survival and neurologic outcome. All of the alternative CPR devices improve perfusion pressures and/or blood flow, require additional training and/or manpower, and complicate resuscitation attempts, some of them significantly. None of the devices have been shown to consistently improve long-term outcomes in out-of-hospital situations, in which the vast majority of cardiac arrests occur. If a device is to significantly change outcomes, it will need to work in the real world, out of the hospital, in the hands of the normal responders, and ultimately outside of the setting of a research trial. In my opinion, none of the current alternative CPR devices fulfill these requirements.

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