Mechanical devices for cardiopulmonary resuscitation

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Purpose of the review

For over 40 years, manual chest compressions have been the foundation of cardiopulmonary resuscitation and recent studies have clearly reconfirmed the hemodynamic significance of delivering consistent, high-quality, infrequently-interrupted chest compressions. However, there remain multiple inadequacies in the actual delivery of manual chest compressions during cardiopulmonary resuscitation. One potential solution is use of adjunct mechanical devices.

Recent findings

Two different methods of accessory chest compression techniques recently have demonstrated enhanced short-term survival. The active compression–decompression device is a hand-held, manually operated suction device applied to the center of the chest wall. In tandem with an impedance threshold (airway) device, active compression–decompression has shown a 65% improvement in 24-hour survival rates (compared with standard cardiopulmonary resuscitation) in a randomized out-of-hospital clinical trial ($n = 210$). The second device, called Auto-Pulse CPR is an automated machine that uses a load-distributing, broad compression band that is applied across the entire anterior chest. A recent out-of-hospital retrospective case-control study ($n = 162$) also revealed improved short-term survival.

Summary

High quality chest compressions during cardiopulmonary resuscitation are critical elements in effecting successful resuscitation following a cardiac arrest. Recent studies utilizing adjunct mechanical devices have not only revealed significant increases in the effectiveness of chest compressions, including improved hemodynamics in both animal models and human studies, but also improvements in short-term human survival in the clinical setting. It is hoped that these promising findings will eventually be corroborated in terms of improved neurologically intact, long-term patient survival. Clinical trials are currently underway to validate such efficacy.

Keywords

cardiac arrest, cardiopulmonary arrest, cardiopulmonary resuscitation, chest compressions, coronary perfusion pressure, hemodynamics, mechanical devices, return of spontaneous circulation, survival

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Abbreviations

ACD	active compression–decompression
ACLS	advanced cardiac life support
AP-CPR	Auto-Pulse CPR
BSR	bellows on sternum resuscitation
CPR	coronary perfusion pressure
ITD	impedance threshold device
ROSC	return of spontaneous circulation
SST-CPR	sterno–thoracic cardiopulmonary resuscitation
VF	ventricular fibrillation

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Introduction

While traditional basic cardiopulmonary resuscitation (CPR) using manual chest compressions is generally considered to be a simple, quick, inexpensive and 'always available' technique for creating artificial blood flow during cardiac arrest, it is not without limitations and inconsistencies. Even when performed optimally and immediately, it does not generate the same level of coronary artery and cerebral perfusion that one achieves with spontaneous circulation. Also, few of the actual rescuers performing the CPR, be they laypersons or professionals, get the opportunity to practice or regularly train in the technique and thus will often perform it inadequately.

Regardless of the training or experience of the individual performing chest compressions, manual CPR also fully pre-occupies the services of one rescuer during the resuscitative effort; even with alternating rescuers, it can induce user fatigue. In the actual clinical situation, these factors can result in inconsistent rates and depths of compression. In addition, chest compressions induce positive intrathoracic pressures during the compression phases (and only slight negative pressure swings during the recoil phase). In turn, return of venous blood flow to the chest is relatively inhibited through much of the CPR cycle and particularly when accompanied by the positive pressure breaths provided by rescuers. Adding to this problem, many rescuers lean on the chest and do not fully release their chest compressions, thus inhibiting full chest wall recoil and the potential positive effect that the recoil might have on venous return. Finally, when circumstances require patient movement, proper manual CPR can be quite difficult to perform during those transfers and during vehicular transport.

Recent studies have documented that during both in-hospital and out-of–hospital resuscitation efforts, manual chest compressions were much slower and shallower than the specifications recommended by the European Resuscitation Council (ERC) and the American Heart Association (AHA). More worrisome perhaps, these studies demonstrated that a substantial amount of resuscitation time is spent without chest compressions being performed at all [1,2]. Considering the evolving body of data that repeatedly stresses the critical detrimental effects of interrupting chest compressions during cardiac arrest, these findings emphasize the need to improve the quality, monitoring, and re-tooling of our current standardized techniques.

In hope of improving the effectiveness of CPR, a variety of alternative compression devices are now being studied to improve not only the techniques and hemodynamics in resuscitative efforts, but, ultimately, the long-term outcomes of patients with cardiac arrest.

Active compression-decompression and the impedance threshold device

The active compression–decompression (ACD) device (Fig. 1) is a hand-held human-powered plunger device that transforms the chest of a cardiac arrest victim into a bellows. This mechanism acts to draw blood into the chest during the decompression phase by generating negative intrathoracic pressure, and then forces the blood out of the chest during the compression phase. There are multiple animal and human studies that have demonstrated that correctly performed ACD-CPR provides superior hemodynamic parameters such as arterial blood pressure and coronary perfusion compared with manual CPR. ACD-CPR

Figure 1. Active compression–decompression (ACD) device

Figure 2. Impedance threshold device

Figure 3. The simultaneous sterno-thoracic cardiopulmonary resuscitation (SST-CPR) device (mannequin simulation)

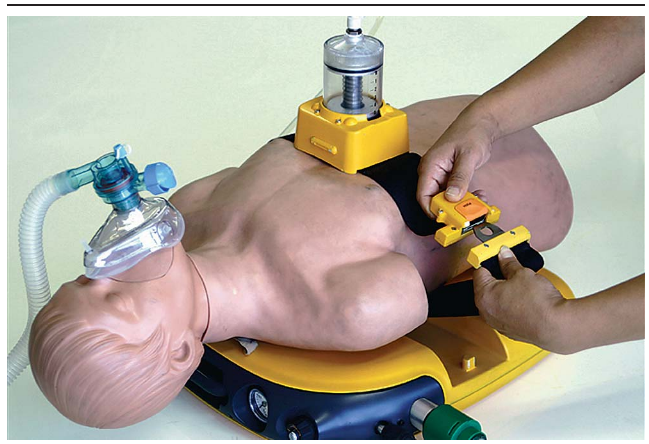


Figure 4. CardioVent bellows on sternum resuscitation (BSR-CPR)

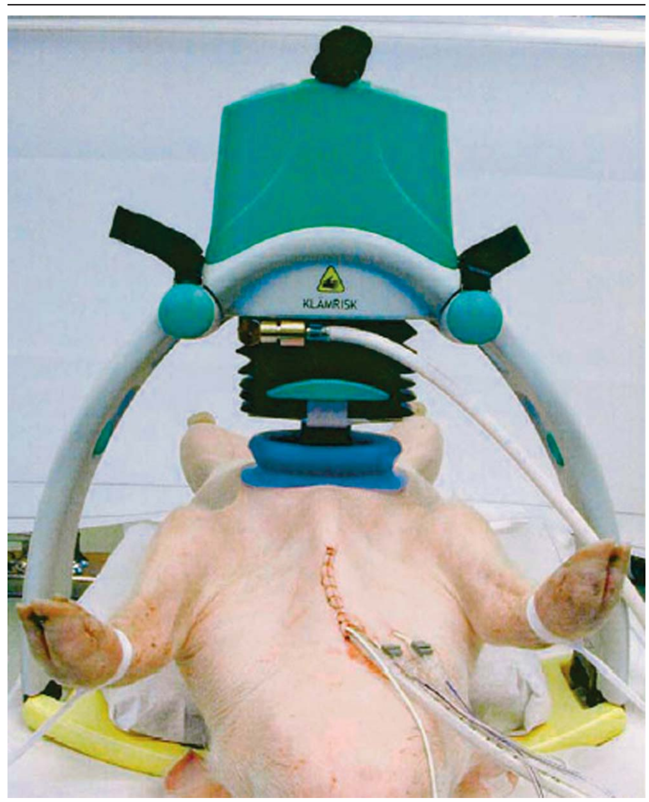
Patient simulation showing a bird's-eye view of the device and a lateral view of use.

has also provided at least similar, and, in some studies, significantly improved short- and long-term human survival rates [3–22]. It has been suspected that differences in results of various clinical trials may be due to differences in training and monitoring, as ACD-CPR is very physically demanding and requires frequent rotation of rescuers.

Most recently, the ACD device has been the subject of human studies in conjunction with another device, the impedance threshold device (ITD) (Fig. 2). The ITD is a small, disposable, lightweight plastic device which prevents full passive air movement during chest decompression. This translates into more negative intrathoracic pressure than can be generated by the re-expansion of the chest wall with the ACD device or standard chest compressions alone. In a recent study from Paris, Plaisance *et al*. showed that the ITD, which can be used with an

Figure 5. The AutoPulse device

Figure 6. The LUCAS device



The LUCAS device with a swine model.

endotracheal tube or facemask [23], significantly improves 24-h survival rates when used in conjunction with ACD-CPR (*32%*), as opposed to ACD–CPR alone (*22%*) (P = 0.02) [24,25]. Another recent study from Mainz, Germany found that 24-h survival rates were *37%* in patients receiving ACD + ITD CPR, compared with *22%* in those receiving standard CPR (P = .033) [26].

Simultaneous sterno–thoracic cardiopulmonary resuscitation

Simultaneous sterno–thoracic cardiopulmonary resuscitation (SST-CPR) (Fig. 3) is a potentially promising technique for chest compressions. The technique of SST–CPR was conceived to exploit both the 'cardiac pump' as well as the 'thoracic pump' models during CPR. Studies in experimental models have shown that SST–CPR results in improved mean aortic and coronary perfusion pressure as well as improved pulmonary perfusion and end-tidal CO_2 in mongrel dogs compared with standard CPR [27].

Animal studies also showed improved 12-h survival after cardiac arrest without increasing the frequency of complications compared with standard CPR [28]. Human studies are planned comparing SST–CPR with standard CPR. SST–CPR is not currently available for clinical use.

CardioVent bellows on sternum resuscitation CPR

The CardioVent (Kendall CardioVent™, Kendall Medizinische Erzeugnisse GMBH, Neustadt/Donau, Germany) bellows on sternum resuscitation (BSR) CPR (Fig. 4) adjunct is a cylindrical plastic human-powered mechanical device with a soft but firm interface that fits over the sternum to deliver closed chest compressions. It is configured such that, when the BSR is attached to an endotracheal tube or other similar device a single rescuer can deliver ventilations followed by multiple chest compressions without changing their position with respect to the victim.

During the upstroke of chest compressions, the main reservoir fills with air (or oxygen) which is then used to ventilate the patient prior to subsequent chest compressions. Tidal volume can be adjusted to deliver 200–1500 ml volume.

There is a flexible tube to provide ventilation through an endotracheal tube, esophageal obturator airway, combitube, or face mask.

In the one available study simulating CPR on a mannequin, it was found that CPR with the BSR device is as effective with one operator as two-person standard CPR in all measured and calculated variables including tidal volume, compression depth, minute volume, ventilation rate, and error in compression depth. There was one exception, compression rate, which was significantly lower with the BSR device and fell below the recommended rate of compression in standard CPR [29]. It is unknown at this time if the slower CPR rate can be corrected with further teaching and practice, or by a more frequent rotation of rescuers.

This device could ultimately require fewer rescuers in an intubated patient, or free up other available rescuers to perform other tasks.

The AutoPulse

The CPR vest was an early attempt to take advantage of the thoracic pump mechanism of blood flow. Vest CPR used a circumferential thoracic vest, analogous to a large blood pressure cuff, which was cyclically inflated and deflated; alternately producing rapid positive and negative swings in intrathoracic pressure. Vest CPR was shown to improve myocardial and cerebral blood flow in animals and improve peak aortic and coronary perfusion pressures during CPR in animals and humans.

The size and energy requirements for operation of the device were substantial barriers for its widespread use, and required that it be used for patients who could undergo vest CPR in either the hospital or emergency vehicle settings.

The AutoPulse (Revivant, Sunnyvale, CA, USA) (Fig. 5), a refinement of the vest CPR, is a relatively lightweight and easily portable electromechanical device that uses an automated wide compression band attached to a small backboard that squeezes the anterior and anterior-lateral chest. Studies have shown superior hemodynamics compared with the Thumper or manual CPR in animal and clinical studies. It does not substantially delay starting CPR, presents no significant known disadvantages (except cost over standard CPR), decreases interruptions in chest compression during transport, creates uniform compression depth across a broader area of the thorax, and it does not interfere with defibrillation efforts. The manufacturer of the AutoPulse device has obtained FDA permission for its distribution and sale.

LUCAS

LUCAS (Jolife, Lund, Sweden) (Fig. 6) is a chest compression device that uses a gas-driven mechanism to provide automated active compression–decompression CPR. It consists of a plunger device similar to the CardioPump driven by a two-legged pneumatic cylinder that is attached to a stiff back plate, and is preset to deliver 100 cycles per minute.

The only article published to date on this device actually represents multiple distinct studies involving LUCAS. In a set of pig studies the most important observation was that diastolic and mean arterial pressures were significantly higher with LUCAS than with standard CPR; moreover, end tidal CO_2, and myocardial and coronary artery perfusion pressures were higher with the LUCAS device. In a ventricular fibrillation (VF) cardiac arrest model, no animals in the standard CPR group had return of spontaneous circulation (ROSC), however 5 of 6 in the LUCAS group had ROSC [30].

In the human pilot component of this study, 20 patients were enrolled after standard advanced CPR proved futile. One patient was found to be in asystole after a witnessed in-hospital cardiac arrest. He was refractory to aggressive advanced cardiac life support (ACLS) measures, but was noted to have ROSC after 3 minutes of LUCAS-CPR. He was subsequently discharged from the hospital, and at 1-year follow-up was noted to be fully neurologically intact [30].

Conclusion

A growing body of evidence suggests that the standard current practices of applying manual chest compressions during CPR are not often optimal or effective as they could be in the actual clinical setting. However, recent laboratory and clinical investigations of adjunct mechanical or automated compression devices have demonstrated improved hemodynamic effects, enhanced coronary perfusion, and, in turn, an increased frequency of return of spontaneous circulation and short-term survival in preliminary human studies. These effects may be more pronounced in patients with longer periods of cardiac arrest, a group traditionally perceived as the most difficult to resuscitate. It must be recognized that while none of these chest compression devices have yet to be identified definitively as being superior in terms of long-term, neurologically intact survival, these technologies clearly hold significant promise and further research and development are strongly encouraged.

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