

Mechanical CPR devices

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ABSTRACT

It is recognized that the quality of cardiopulmonary resuscitation (CPR) is an important predictor of outcome from cardiac arrest. Mechanical chest-compression devices provide an alternative to manual CPR. Physiological and animal data suggest that mechanical chest-compression devices are more effective than manual CPR. Consequently, there has been much interest in the development of new techniques and devices to improve the efficacy of CPR. This review will consider the evidence and current indications for the use of some of the more common mechanical devices developed to increase the safety and efficacy of CPR administration.

Key words: cardiac arrest, chest compression, automatic mechanical devices, piston chest compression, LUCAS, vest CPR, Autpulse – load distributing band CPR, cost effectiveness, outcome, survival

Introduction

The rhythmic application of force to the body of the patient is fundamental to the process of generating blood flow in cardiopulmonary resuscitation (CPR), but there is little agreement as to the optimal technique for applying that force. There is a great need for improved external chest compression techniques, since only an average of 5-15% of patients treated with standard CPR survive cardiac arrest, (1) and it is widely agreed that increasing the blood flow generated by chest compression will improve survival. (2)

Chest compressions are often done incorrectly, (3) and incorrect chest compression can compromise survival. (4) One way of potentially improving the quality of chest compression is with automatic mechanical devices, which can potentially apply compression more consistently than manually. Automatic mechanical devices can provide

high quality chest compressions in a moving ambulance, which is very difficult to accomplish with manual CPR, and may allow a reduction in the number of emergency medical systems (EMS) personnel needed to perform resuscitation.

Piston chest compressions

Early automatic mechanical devices used a pneumatic piston (figure 1) to administer external chest compressions at a specified rate, compression depth, and duty cycle (percent of time compression is held during each cycle). The piston is located at the end of an arm that extends over the patient's chest, and is based on a board which provides a firm surface under the patient's back. In addition, a ventilation circuit can be integrated into the device, which allows for continuous CPR with minimal operator input once the device is set up. While there are some differences between mechanical and manual external chest compression in the time course of application of force which may affect hemodynamics, 5 small studies have showed no difference in survival using the two techniques, 5 and have

also shown a slight hemodynamic benefit to CPR performed by the pneumatic piston. (5,6)

Trauma is the major complication from piston CPR. The reported incidence of trauma from piston CPR can be as high as 65%. (7) Despite the substantial amount of trauma, however, the detrimental effects of trauma are unclear, since most research on the incidence of CPR-related trauma has focused on non-survivors of CPR, who might have died even if no trauma had occurred.

The piston system was modified to perform chest compressions simultaneously with high pressure ventilation (60-100 cm H₂O). (8) This system was named Simultaneous Compression and Ventilation CPR (SCV-CPR). In human studies of SCV-CPR, there was no consistent hemodynamic benefit reported for SCV-CPR. (9) In addition, a major clinical trial of SCV-CPR used during out-of-hospital cardiac arrest showed no benefit for patients treated with SCV-CPR, compared with those treated with standard CPR. (10) That latter trial was criticized, however, for its potential for adding bias, since ambulance crews, rather than patients, were randomized. Because of the lack of

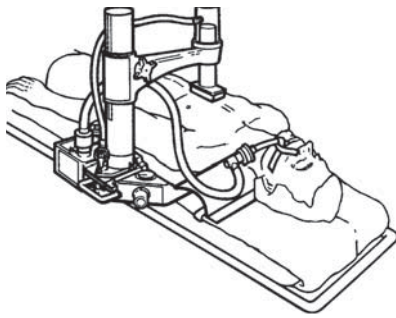


Figure 1. Piston device used for performing mechanical external chest compressions. (Thumper, Courtesy of Michigan Instruments, Grand Rapids, MI.)

significant resuscitation survival benefit in any study, there is little active research on this technique.

Lund University cardiac arrest System (LUCAS)

This piston technique was further modified by the addition of an integral suction cup (figure 2). The suction cup allows for active return of the chest to the neutral, uncompressed position, and was an evolution of a technique that used both active chest compression and active chest decompression (ACD-CPR). With ACD-CPR, the active decompression, beyond the uncompressed position, was thought to generate negative intrathoracic pressure that would augment venous return, and thereby, enhance forward blood flow. ACD-CPR research began with a report of an elderly man resuscitated by his uninitiated son with a bathroom plunger. (11) Extensive subsequent research showed variable benefit for the ACD technology, (12-15) but the system evolved into the currently-available LUCAS device, where the chest is returned to the neutral, uncompressed position rather than beyond it.

The current LUCAS device (figure 2) uses an electrically actuated piston for chest compression and decompression. In a series of 100 consecutive patients with witnessed cardiac arrest, treated with the LUCAS device, if compressions were started < 15 minutes

after the ambulance call, the 30 day survival was 25% if the patients were in ventricular fibrillation, and 5% if they were in asystole. (16) If the device was placed > 15 minutes after the ambulance call, there were no 30 day survivors. In a retrospective study of 508 patients in Sweden, survival to discharge was assessed for patients treated with the LUCAS device as well as manual CPR. (17) A majority of the survivors had return of spontaneous circulation (ROSC) before application of the LUCAS device, making interpretation of that trial problematic. Further research to determine the clinical utility of the LUCAS device is ongoing.

Vest CPR

With vest CPR, a bladder-containing vest (analogous to a large blood pressure cuff) is placed circumferentially around the patient's chest (figure 3) and cyclically inflated and deflated by an automated pneumatic system. Adherent defibrillation pads are placed on the chest before applying the vest to allow for defibrillation without having to remove the vest or interrupt CPR.



Figure 2. LUCAS Device. (Courtesy Jolife corporation). The device is positioned around the patient. The suction cup (at the lower end of the piston) adheres to the chest and is used to return the anterior chest to the neutral, uncompressed position, in between chest compressions.

Vest CPR was designed to maximize the force applied to the chest during compression. (18-20) By encircling the chest (figure 3), force can be distributed over the chest, thereby reducing local stresses on the chest wall and allowing high forces to be safely applied. This distributed compression allows for large increases in intrathoracic pressure without the trauma inherent in applying force to a single point, as with standard chest compression.

With an improved vest CPR system, which incorporated a vest that covered more of the chest than previous systems, (20) hemodynamics in humans were significantly improved over those of standard external chest compression, and there was a trend toward improved initial resuscitation with vest CPR, but that latter trial was too small to show a statistically significant benefit. The vest device, however, was too large, and consumed too much power to be easily portable, and has not been tested in large clinical trials.

Autopulse – load distributing band (LDB) CPR

An improved device, based on an electromechanically-actuated-band that distributed the compression load over the entire anterior chest (load distributing band – LDB) was subsequently developed (figure 4).

Initial trials with LDB CPR showed improved hemodynamics, (21) with coronary perfusion pressures raised above the level generally associated with improved survival, (22) as well as improvement in survival to arrival at the emergency department, when compared to manual CPR. (23)

A prospective trial (ASPIRE) compared resuscitation outcomes following out-of-hospital cardiac arrest when an automated LDB-CPR device was added to standard emergency medical services (EMS) care with manual CPR. The trial included 5 centers and enrolled 1071 patients. Block randomization was done where a specific EMS crew would perform either LCD-CPR or manual CPR

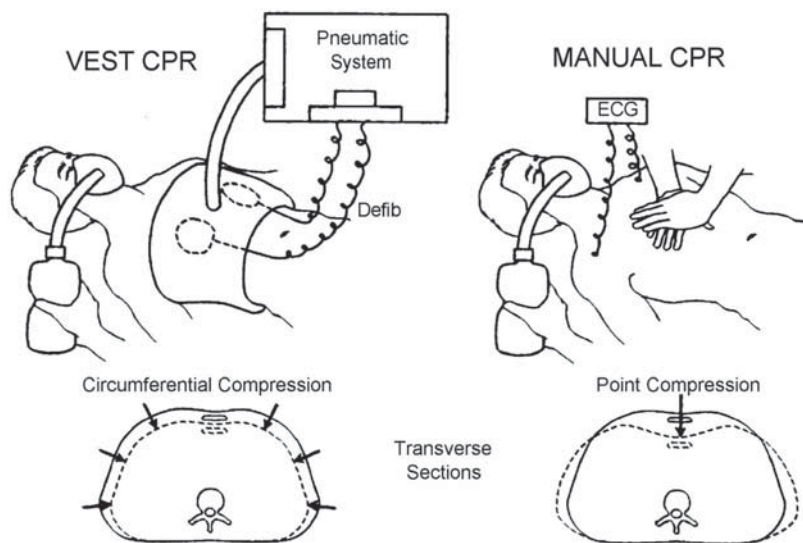


Figure 3. Comparison of vest CPR and manual CPR. The vest compresses most of the circumference of the chest (lower panels), compared with a point compression of standard CPR. (From Halperin, et al, N Engl J Med 1993;29:762-8. Copyright 1993, New England Journal of Medicine.)

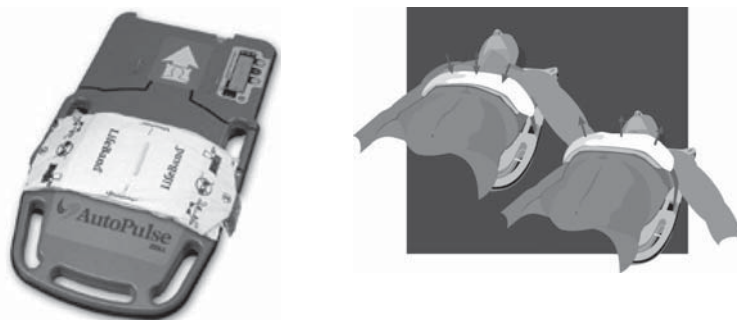


Figure 4. Autopulse - Load Distributing Band Device (left). The white band is fastened around the patient's chest. During compression (right-inward arrows) the band is tightened by a motor, and compression force is directed inward. During relaxation (right-outward arrows), the band is released, and the chest expands.

on a specific number of patients (block size), then perform the other type on a subsequent block of patients. In addition, the crews had the discretion of whether or not to enroll specific patients. The primary end point was survival to 4 hours after the 911 call. Following the first planned interim monitoring conducted by an independent data and safety monitoring board, study enrollment was terminated. No difference existed in the primary end point of survival to 4 hours

between the manual CPR group and the LDB-CPR group overall (N = 1071; 30% vs 29%; P = .74). However, among the patients that were felt to have primary cardiac arrests, survival to hospital discharge was 9.9% in the manual CPR group and 5.8% in the LDB-CPR group (P = .06, adjusted for covariates and clustering). (24)

There were a number of issues that makes interpretation of the results of the ASPIRE trial problematic. (25) Sta-

tistical analysis showed that the study sites were not statistically homogeneous, since one site was statistically different from the other four sites. (25) The statistically different site had much higher survival rates for both manual CPR and LCD CPR than the other 4 sites, prior to a protocol change that occurred in the middle of the trial. (25) The survival with LCB-CPR and manual CPR were similar prior to the protocol change, but the survival with LDB-CPR decreased dramatically after the protocol change. The one statistically different site was responsible for the overall decrease in survival noted in the study, likely due to substantial delays in applying the LDB-CPR device after the protocol change. (25)

A prospective and retrospective trial was conducted in Richmond, Virginia, comparing LDB-CPR with manual CPR after the Richmond emergency medical services system switched from manual CPR to LDB-CPR. A total of 499 patients were included in the retrospective manual CPR phase, and 284 patients in the prospective LDB-CPR phase. Rates for ROSC were increased with LDB-CPR compared with manual CPR (34.5% vs 20.2%, $p < 0.05$); and survival to hospital discharge was also increased with LDB-CPR (9.7% vs 2.9%, $p < 0.05$). (26) A weakness of the Richmond trial is that there was a historical control group. A major strength is that all patients treated for cardiac arrest were included. Minimal trauma was reported to be attributed to the use of LDB CPR.

A large scale prospectively randomized trial (CIRC) is currently ongoing comparing survival outcomes for Autopulse - LDB CPR vs standard manual CPR. A number of issues that arose in the ASPIRE trial, such as block randomization and study site heterogeneity, were addressed in this new trial.

Cost effectiveness of mechanical CPR

Mechanical CPR has a number of advantages over manual CPR for use in EMS vehicles. Cost effectiveness may be increased by using mechani-

cal CPR, by reducing the risk of injury to ambulance crews. It has been reported that ambulance personnel that perform CPR in a moving ambulance do so without being restrained by seatbelts or other protection devices. These ambulance personnel are

at least 4 times more like to have a fatal or incapacitating injury than personnel that are restrained. Mechanical CPR also allows high quality CPR to be performed while the personnel are restrained, reducing risk to the crew, (27,28) and thereby saving valuable

EMS resources. Finally, mechanical devices can improve cost effectiveness of EMS systems by reducing the number of personnel needed to be present during resuscitative efforts, since separate personnel are no longer needed to perform manual CPR.

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