Mechanical CPR

Leong S H B

ABSTRACT

Mechanical devices for cardiopulmonary resuscitation have been in use for decades. Significant advances in the understanding of cardiac arrest physiology have led to improvements and new devices. Piston, load distribution band, active compression decompression and the impedance threshold device are discussed.

Keywords: active compression decompression, impedance threshold device, load distribution band, mechanical CPR, piston compression

Singapore Med J 2011;52(8):592-595

Emergency Medicine Department, National University Hospital Singapore, 5 Lower Kent Ridge Road, Singapore 119074

Leong SHB, MBBS, MMed, MRCSE
Consultant

Correspondence to:
Dr Leong Siew Hon Benjamin
Tel: (65) 6772 5002
Fax: (65) 6775 8551
Email: leong_benjamin @yahoo.com.sg

INTRODUCTION

Although modern cardiopulmonary resuscitation (CPR) was only introduced in 1960,[1] man has been trying to resuscitate the cardiac arrest victim for thousands of years. Mechanical aids of yore that have been tried for resuscitation included bellows, whips, barrels and trotting horses, among various other adjuncts. The aim of CPR is to restore circulation to the vital organs and the heart itself. However, standard CPR has been shown to restore only about 30% of cardiac output.[2] Additionally, manual CPR is frequently limited by the poor performance of chest compressions by CPR providers.[3,4]

Mechanical CPR devices, on the other hand, offer the promise of consistent, high-quality CPR. Also, the engineering of such devices may target additional physiological mechanisms to improve circulatory output. Over the years, manufacturers have incorporated ventilation into these devices and also programmed the recommended compression ventilation ratios. However, despite promising animal data and clinical studies demonstrating improved haemodynamics, return of spontaneous circulation (ROSC) and short-term survival, no device to date has been conclusively proven to be superior to standard CPR in improving survival to hospital discharge.[5-7] The 2010 International Consensus Conference reviewed several devices and concluded that there was insufficient data to support or refute their use.[8]

MECHANICAL PISTON CPR

Within a year of the introduction of closed chest cardiac massage, a mechanical CPR device was described,[9] recognising the limitations of manual CPR. Mechanical piston CPR essentially replaces the human hands with a piston mounted on an arm that is connected to a backboard or spine board that directly causes anterior-posterior compression on the sternum. The physiological mechanism employed was originally thought to be the 'cardiac pump' theory, where the heart was directly squeezed between the sternum and the thoracic vertebrae.[1] Subsequently, the 'thoracic pump'[10] and the 'lung pump'[11] theories have also been proposed. Results from studies have found that mechanical piston CPR improved haemodynamic parameters,[12-14] but not survival.[15] The main piston device that is familiar to many is the Thumper, which has been renamed Life-Stat.

LOAD DISTRIBUTING BAND CPR

In the 'thoracic pump' theory, it is the change in intrathoracic pressures that drives the flow of blood. An early mechanical device that employed this principle was the Vest CPR, which utilised a pneumatic vest resembling a very large blood pressure cuff, worn around the patient's chest and cyclically inflated with a pneumatic pump.[16]

The Autopulse device may be considered an evolution of the Vest CPR. It uses a load distributing band that is wrapped around the patient's chest and connected to a motor built into a firm backboard. The band is then rhythmically tightened to compress the entire chest, distributing the force evenly to generate changes in intrathoracic pressure. Initial studies of the device had found improved haemodynamic parameters and coronary perfusion pressures[17-20] as well as improved pre-hospital survival to the emergency department.[21] Subsequently, a before-and-after study found significant improvements in ROSC and survival compared with manual CPR (34.5% vs. 20.2% and 9.7% vs. 2.9%, respectively).[22] However a multi-site cluster-randomised trial was terminated early due to a lack of benefit and apparent harm.[23] It is believed that site-specific factors had led to the poorer results,[24] and further clinical research is still ongoing.[25]

ACTIVE COMPRESSION DECOMPRESSION CPR (ACD-CPR)

Interest and research in ACD-CPR began after an elderly man was reported to have been resuscitated by his son using a toilet plunger on the chest.[26] The physiological basis is believed to be due to the generation of a negative intrathoracic pressure in diastole, thus increasing venous return to the heart.[27]

The first ACD-CPR device (the Active Compression Decompression Resuscitator) is a manual hand-held device that comprised a suction cup fitted to a large disc-shaped handle. The suction cup is attached to the chest of the patient, and the operator then holds the handle using both hands, manually pushing down to compress and pulling up to decompress the chest. Several trials have found some mixed, although promising results,[28-31] but a meta-analysis[32] found no difference in ROSC or survival between ACD-CPR and standard CPR.

The Lund University Cardiac Arrest System (LUCAS) also employs ACD-CPR to re-expand the chest wall back to the initial uncompressed state, but not beyond that. By combining a mechanical piston with a suction cup that is applied onto the chest, it provides both active compression and decompression to the chest. It is mounted on two legs that straddle the patient and attached to the sides of a firm backboard.

Animal studies have demonstrated improved cardiac outputs, coronary perfusion pressures and end-tidal CO_2, as well as increased survival over manual CPR.[33] Clinical experience has been favourable,[34] although one study in the setting of emergency medical services has found no difference in ROSC or survival.[35] There have been no randomised controlled trials to date, but trials are being planned.[36]

IMPEDANCE THRESHOLD DEVICE (ITD) OR IMPEDANCE THRESHOLD VALVE

By itself, the ITD is not strictly a CPR device. It is a device with a system of valves that is attached in-line with the endotracheal tube and the ventilator or manual resuscitator-bag. The valves impede airflow into the chest when air is drawn in by negative pressure during re-expansion of the chest. Air that is pushed in by positive pressure is not impeded. Air may also be expelled during chest compression. Physiologically, by slowing the inflow of air into the chest during chest re-expansion, blood is then preferentially drawn into the chest to equilibrate the pressure. Venous return, and thus cardiac output, is improved. By extension, the ITD and ACD-CPR are naturally synergistic to each other, both acting to increase venous return to the thorax together.[37]

Studies combining the two have found some promising but mixed results,[38-40] although a meta-analysis[41] did not show any survival benefit. A recent randomised study published after the 2010 Consensus Conference pairing the ITD with manual ACD-CPR[42] found that 9% of patients treated with this combination survived to discharge with favourable neurological function, compared with 6% in the control group. This effect persisted for one year, demonstrating long-term efficacy as well.

SPECIAL SITUATIONS

Despite the overall lack of strong survival benefit, there are several situations where mechanical CPR offers the advantage of relieving the human provider of performing the chest compressions. These include medical transport[43-45] and during coronary intervention.[46-48] One group has even evaluated the feasibility of mechanical CPR while acquiring brain computed tomography images for reversible causes of cardiac arrest.[49]

COMPLICATIONS OF MECHANICAL CPR

Mechanical CPR devices are not a panacea. Complications have been described, particularly trauma to the patient.[50-52] However, some might argue that manual CPR also causes injury, and that saving lives is more important. The time it takes to set up the device also leads to delays in CPR and increased the no-flow time fractions.[53, 54]

CONCLUSION

The search for an effective and safe device for resuscitation is still ongoing. The devices reviewed here are already in common use or available commercially. It is important that healthcare providers understand the physiological mechanisms that these devices are based on as well as their respective limitations, in order to maximise the benefits afforded by them.

REFERENCES

1. Kouwenhoven WB, Jude JR, Knicherbocker GG. Closed-chest cardiac massage. JAMA 1960; 173:1064-7.
2. Delguercio LR, Feins NR, Cohn JD, et al. Comparison of blood flow during external and internal cardiac massage in man. Circulation 1965; 31 Suppl 1:171-80.
3. Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. Resuscitation 2006; 71:283-92.
4. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 2005; 293:305-10.
5. Perkins GD, Brace S, Gates S. Mechanical chest-compression devices: current and future roles. Curr Opin Crit Care 2010; 16:203-10.
6. Brooks SC, Bigham BL, Morrison LJ. Mechanical versus manual chest compressions for cardiac arrest. Cochrane Database Syst Rev 2011;1:CD007260.
7. Jacobs I. Mechanical chest compression devices--will we ever get the evidence? Resuscitation 2009; 80:1093-4.
8. Lim SH, Shuster M, Deakin CD, et al. Part 7: CPR techniques and devices: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Resuscitation 2010; 81 Suppl 1:e86-92.

9. Harkins GA, Bramson ML. Mechanized external cardiac massage for cardiac arrest and for support of the failing heart. A preliminary communication. J Surg Res 1961; 1:197-200.
10. Rudikoff MT, Maughan WL, Effron M, Freund P, Weisfeldt ML. Mechanisms of blood flow during cardiopulmonary resuscitation. Circulation 1980; 61:345-52.
11. Shaw DP, Rutherford JS, Williams MJ. The mechanism of blood flow in cardiopulmonary resuscitation--introducing the lung pump. Resuscitation 1997; 35:255-8.
12. McDonald JL. Systolic and mean arterial pressures during manual and mechanical CPR in humans. Ann Emerg Med 1982; 11:292-5.
13. Ward KR, Menegazzi JJ, Zelenak RR, Sullivan RJ, McSwain NE Jr. A comparison of chest compressions between mechanical and manual CPR by monitoring end-tidal PCO2 during human cardiac arrest. Ann Emerg Med 1993; 22:669-74.
14. Dickinson ET, Verdile VP, Schneider RM, Salluzzo RF. Effectiveness of mechanical versus manual chest compressions in out-of-hospital cardiac arrest resuscitation: a pilot study. Am J Emerg Med 1998; 16:289-92.
15. Taylor GJ, Rubin R, Tucker M, et al. External cardiac compression. A randomized comparison of mechanical and manual techniques. JAMA 1978; 240:644-6.
16. Halperin HR, Tsitlik JE, Gelfand M, et al. A preliminary study of cardiopulmonary resuscitation by circumferential compression of the chest with use of a pneumatic vest. N Engl J Med 1993; 329:762-8.
17. Timerman S, Cardoso LF, Ramires JA, Halperin H. Improved hemodynamic performance with a novel chest compression device during treatment of in-hospital cardiac arrest. Resuscitation 2004; 61:273-80.
18. Halperin HR, Paradis N, Ornato JP, et al. Cardiopulmonary resuscitation with a novel chest compression device in a porcine model of cardiac arrest: improved hemodynamics and mechanisms. J Am Coll Cardiol 2004; 44:2214-20.
19. Halperin H, Berger R, Chandra N, et al. Cardiopulmonary resuscitation with a hydraulic-pneumatic band. Crit Care Med 2000; 28(11 suppl):N203-6.
20. Duchateau FX, Gueye P, Curac S, et al. Effect of the AutoPulse automated band chest compression device on hemodynamics in out-of-hospital cardiac arrest resuscitation. Intensive Care Med 2010; 36:1256-60.
21. Casner M, Andersen D, Isaacs SM. The impact of a new CPR assist device on rate of return of spontaneous circulation in out-of-hospital cardiac arrest. Prehosp Emerg Care 2005; 9:61-7.
22. Ong ME, Ornato JP, Edwards DP, et al. Use of an automated, load-distributing band chest compression device for out-of-hospital cardiac arrest resuscitation. JAMA 2006; 295:2629-37.
23. Hallstrom A, Rea TD, Sayre MR, et al. Manual chest compression vs use of an automated chest compression device during resuscitation following out-of-hospital cardiac arrest: a randomized trial. JAMA 2006; 295:2620-8.
24. Paradis NA, Young G, Lemeshow S, Brewer JE, Halperin HR. Inhomogeneity and temporal effects in AutoPulse Assisted Prehospital International Resuscitation--an exception from consent trial terminated early. Am J Emerg Med 2010; 28:391-8.
25. Lerner EB, Persse D, Souders CM, et al. Design of the Circulation Improving Resuscitation Care (CIRC) Trial: a new state of the art design for out-of-hospital cardiac arrest research. Resuscitation 2011; 82:294-9.
26. Lurie KG, Lindo C, Chin J. CPR: the P stands for plumber's helper. JAMA 1990; 264:1661.
27. Cohen TJ, Tucker KJ, Redberg RF, et al. Active compression-decompression resuscitation: a novel method of cardiopulmonary resuscitation. Am Heart J 1992; 124:1145-50.
28. Stiell IG, Hébert PC, Wells GA, et al. The Ontario trial of active compression-decompression cardiopulmonary resuscitation for in-hospital and prehospital cardiac arrest. JAMA 1996; 275:1417-23.
29. Mauer D, Schneider T, Dick W, et al. Active compression-decompression resuscitation: a prospective, randomized study in a two-tiered EMS system with physicians in the field. Resuscitation 1996; 33:125-34.
30. Skogvoll E, Wik L. Active compression-decompression cardiopulmonary resuscitation: a population-based, prospective randomised clinical trial in out-of-hospital cardiac arrest. Resuscitation 1999; 42:163-72.
31. Plaisance P, Adnet F, Vicaut E, et al. Benefit of active compression-decompression cardiopulmonary resuscitation as a prehospital advanced cardiac life support. A randomized multicenter study. Circulation 1997; 95:955-61.
32. Lafuente-Lafuente C, Melero-Bascones M. Active chest compression-decompression for cardiopulmonary resuscitation. Cochrane Database Syst Rev 2004:CD002751.
33. Steen S, Liao Q, Pierre L, Paskevicius A, Sjöberg T. Evaluation of LUCAS, a new device for automatic mechanical compression and active decompression resuscitation. Resuscitation 2002; 55:285-99.
34. Steen S, Sjöberg T, Olsson P, Young M. Treatment of out-of-hospital cardiac arrest with LUCAS, a new device for automatic mechanical compression and active decompression resuscitation. Resuscitation 2005; 67:25-30.
35. Axelsson C, Nestin J, Svensson L, Axelsson AB, Herlitz J. Clinical consequences of the introduction of mechanical chest compression in the EMS system for treatment of out-of-hospital cardiac arrest-a pilot study. Resuscitation 2006; 71:47-55.
36. Perkins GD, Woollard M, Cooke MW, et al. Prehospital randomised assessment of a mechanical compression device in cardiac arrest (PaRAMeDIC) trial protocol. Scand J Trauma Resusc Emerg Med 2010;18:58.
37. Lurie KG, Coffeen P, Shultz J, et al. Improving active compression-decompression cardiopulmonary resuscitation with an inspiratory impedance valve. Circulation 1995; 91:1629-32.
38. Plaisance P, Lurie KG, Payen D. Inspiratory impedance during active compression-decompression cardiopulmonary resuscitation: a randomized evaluation in patients in cardiac arrest. Circulation 2000; 101:989-94.
39. Plaisance P, Lurie KG, Vicaut E, et al. Evaluation of an impedance threshold device in patients receiving active compression-decompression cardiopulmonary resuscitation for out of hospital cardiac arrest. Resuscitation 2004; 61:265-71.
40. Aufderheide TP, Pirrallo RG, Provo TA, Lurie KG. Clinical evaluation of an inspiratory impedance threshold device during standard cardiopulmonary resuscitation in patients with out-of-hospital cardiac arrest. Crit Care Med 2005; 33:734-40.
41. Cabrini L, Beccaria P, Landoni G, et al. Impact of impedance threshold devices on cardiopulmonary resuscitation: a systematic review and meta-analysis of randomized controlled studies. Crit Care Med 2008; 36:1625-32.
42. Aufderheide TP, Frascone RJ, Wayne MA, et al. Standard cardiopulmonary resuscitation versus active compression-decompression cardiopulmonary resuscitation with augmentation of negative intrathoracic pressure for out-of-hospital cardiac arrest: a randomised trial. Lancet 2011; 377:301-11.
43. Slattery DE, Silver A. The hazards of providing care in emergency vehicles: an opportunity for reform. Prehosp Emerg Care 2009; 13:388-97.
44. Tsou JY, Chi CH, Hsu RM, Wu HF, Su FC. Mechanical loading of the low back during cardiopulmonary resuscitation. Resuscitation 2009; 80:1181-6.

45. Jones AY. Can cardiopulmonary resuscitation injure the back? Resuscitation 2004; 61:63-7.
46. Larsen AI, Hjørnevik AS, Ellingsen CL, Nilsen DW. Cardiac arrest with continuous mechanical chest compression during percutaneous coronary intervention. A report on the use of the LUCAS device. Resuscitation 2007; 75:454-9.
47. Larsen AI, Hjørnevik A, Bonarjee V, et al. Coronary blood flow and perfusion pressure during coronary angiography in patients with ongoing mechanical chest compression: a report on 6 cases. Resuscitation 2010; 81:493-7.
48. Grogaard HK, Wik L, Eriksen M, Brekke M, Sunde K. Continuous mechanical chest compressions during cardiac arrest to facilitate restoration of coronary circulation with percutaneous coronary intervention. J Am Coll Cardiol 2007 ; 50:1093-4.
49. Wirth S, Körner M, Treitl M, et al. Computed tomography during cardiopulmonary resuscitation using automated chest compression devices--an initial study. Eur Radiol 2009; 19:1857-66.
50. Krischer JP, Fine EG, Davis JH, Nagel EL. Complications of cardiac resuscitation. Chest 1987; 92:287-91.
51. Baubin M, Sumann G, Rabl W, et al. Increased frequency of thorax injuries with ACD-CPR. Resuscitation 1999; 41:33-8.
52. Wind J, Bekkers SC, van Hooren LJ, van Heurn LW. Extensive injury after use of a mechanical cardiopulmonary resuscitation device. Am J Emerg Med 2009; 27:1017.e1-2.
53. Ong ME, Annathurai A, Shahidah A, et al. Cardiopulmonary resuscitation interruptions with use of a load-distributing band device during emergency department cardiac arrest. Ann Emerg Med 2010; 56:233-41.
54. Wang HC, Chiang WC, Chen SY, et al. Video-recording and time-motion analyses of manual versus mechanical cardiopulmonary resuscitation during ambulance transport. Resuscitation 2007; 74:453-60.

Singapore Medical Journal
Honour Roll of Editors

Honorary Editor	Term of Service
Dr Gwee Ah Leng	1960 – 1971
Dr Tan Kheng Khoo	1971 – 1975
Prof Lim Pin	1975 – 1978
Prof Feng Pao Hsii	1978 – 1987
Prof Chee Yam Cheng	1988 – 1995
Prof Tan Choon Kim	1995 – 1996
Prof Kua Ee Heok	1996 – 1999
Prof C Rajasoorya	2000 – 2003
Prof Wilfred CG Peh	2004 – 2009
Prof Teo Eng Kiong	From 2010