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Controversies

Is this the next step for CPR?

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Abstract

The author observes that an incremental approach to improving basic life support (BLS) has met with limited success. Rather than continuing to optimize each of the broadly different techniques for increasing forward blood flow, we should evaluate a combination of techniques. Because human providers would likely be unable to apply such a combination, the next generation in the chain of survival, after immediate manual BLS, should be a machine. As envisioned, this machine would incorporate optimized circumferential constriction, anteroposterior compression with forceful decompression, and partial airway obstruction into one system—a combination of combinations. This may enhance both forward flow and venous return. Incorporation into a single device appears straightforward, and the mechanisms of action have the potential of additive, or even synergistic, efficacy when combined.

The modern age of resuscitation was ushered in by Kouwenhoven, Jude, and Knickerbocker's report that application of anteroposterior compression to an intact chest was associated with restoration of circulation [1].

In retrospect, it is possible that their inclusion of patients with halothane-associated loss of blood pressure may have overestimated the efficacy of external chest compression in comparison to classical internal cardiac massage [2,3]. But that did not matter. The remarkable fact that no equipment was required to immediately initiate some perfusion to the brain and heart made it reasonable to widely promulgate the technique without clinical trial validation. Unquestionably, BLS has saved countless lives.

Although the last decade may have seen improvements in the neurological outcomes of initially unconscious survivors of cardiac arrest—possibly because of hypothermia—there is general frustration that a large fraction of patients in cardiac arrest never achieve sustained return of spontaneous circulation. We must ask if there are major changes in the initial components of the chain of survival that might dramatically increase the probability that return of spontaneous circulation will be achieved.

Going forward, BLS based on hands and mouths will continue to be widely used in the first moments after sudden death, whereas the definitive technique in health care settings and on the arrival of advanced providers will likely be some type of extracorporeal assisted circulation [4]. Between these two ends of the resuscitative spectrum, there continues to be a need for something innovative in the middle: BLS that is more than hands and mouths but less than invasive technologies.

Since its initial adoption, multiple improvements to BLS have been proposed. While incremental changes in parameters such as the rates of rescue breathing and chest compression have been widely adopted, qualitatively different techniques have not become routine. Although it has been possible to demonstrate some improvement in outcome in animal models with techniques such as abdominal counterpulsation [5], circumferential constrict [6], and active decompression [7], the degree of improvement has been insufficient to result in widespread adoption. In almost all cases, truly innovative changes to BLS have not been evaluated in clinical trials, have failed in clinical trials, or have had only modest effectiveness when used clinically.

Our inability to significantly improve BLS has been both surprising and disappointing. It is almost as if there is a limit to the amount of forward flow that can be created noninvasively, and simply applying vigorous compression to the chest as early as possible gets us close to that limit. Alternative techniques or alteration of the standard technique just doesn't seem to be associated with improvements in perfusion sufficient to merit widespread clinical adoption.

What about optimizing every component of the standard technique? Force, depth, duration, downstroke, upstroke, release pattern, hands-off time, and the fraction of time spent in interruptions could all be optimized based on preclinical and theoretical data. Wouldn't that give us our best shot at a major improvement in rate of return of spontaneous circulation and hospital discharge with good neurological outcome?

Yes, but the benefits of such optimization may already have occurred, as evidence-based changes have been made at each of the recent guideline revisions [8].

And truth be told, improvements in the rate of return of spontaneous circulation have been modest at best and may principally reflect increases in the fraction of time patients actually receive quality BLS. The overall prognosis for patients suffering sudden death remains poor. While the increased perfusion associated with invasive extracorporeal technologies will likely lead to demonstrable improvements in return of spontaneous circulation, it is hard to imagine that this will be the case for BLS tweaks in parameters such as rate, depth, and hands-off patterns.

The litany of disappointing clinical trials leads me to believe that further optimizing "plain-vanilla" BLS may be a dry hole. What is needed is innovation that improves outcome sufficiently that the number needed to treat for a survivor with good neurological outcome is low enough that adoption would be worthwhile in the challenging environment of resuscitation medicine.

So, if we have gotten about as much as possible from incremental optimization of classic BLS, what about completely new approaches?

Here too, the news has been mostly disappointing.

When it comes to truly new techniques of BLS, a pattern has developed that is now decades old. Single innovations appear promising in the hands of early innovators and enthusiasts but then fail when examined independently [9–12]. Even when they survive the rigors of

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prospective randomized clinical trials [13], the effectiveness is deemed insufficient to drive widespread acceptance.

Why?

I believe the explanation for this frustrating pattern is straightforward: the incremental gain in efficacy with single innovations is just not of sufficient magnitude.

So what is to be done?

Rather than continuing to incrementally optimize BLS or trying alternative techniques in a univariate manner, I propose that we consider combining multiple techniques. Their efficacy may be at least partially additive, and it is possible (if we are lucky) that such a combination might even be synergistic.

But a combination of what?

Both the basic techniques and the innovations in BLS fall into 2 broad groups: (1) techniques to directly create forward flow and (2) techniques that enhance venous return. It is reasonable to assume that enhanced venous return primes the pump of the forward flow.

Examples of forward flow techniques include standard anteroposterior chest compression and circumferential constriction [1,6]. Examples of techniques that may enhance venous return include active decompression of the chest [7], abdominal counterpulsation [14], and partial airway obstruction during inhalation—the so-called impedance threshold device [15].

The idea of combinations is not new. The impedance threshold device has been combined with active decompression. Such a combination is among the very few CPR techniques associated with improved long-term survival [13] and is the only BLS technique that has received a modern FDA indication for use in the treatment of cardiac arrest.

And once we decide to incorporate multiple different techniques into one enhanced form of BLS, we must consider doing so using a machine because human beings would likely be incapable of such combinations.

The promise of machine-based CPR has been around since Michigan Instruments first developed their "Thumper" device in the 1960s. Unlike human providers, machines allow combination and optimization of multiple techniques and do not fatigue.

Unfortunately, in a pattern remarkably similar to clinical trials of manual CPR, the clinical trials of mechanical devices have been disappointing [12,16–18]. Similarly, once the initial innovation has been made mechanical, further effort has been limited to incremental optimization or adaptations necessary to remain compliant with current American Heart Association guidelines. Beyond the combination of the impedance threshold device and active decompression already mentioned, the possibilities for combining techniques has rarely been investigated. This may reflect the intellectual property challenges inherent in commercial development.

If we are going the route of machines incorporating multiple innovations, which ones should we include?

In answering this question, it must be kept in mind that, although mechanical and electrical innovations can occur quickly, the clinical trials to evaluate efficacy are difficult and time consuming. The time from completion of prototype to clinical trial results can easily be 5 to 10 years. So we must choose wisely and test aggressively during preclinical evaluation in laboratory models.

Of particular importance, we should choose techniques that are likely to fit together in a single coherent device without adding to the complexity of getting that device on the patient. The underlying mechanisms, to the extent they are understood, should potentially be additive. If we are lucky (something the field of resuscitation research tends not to be), there may be a component of synergy between the techniques.

It goes without saying that we do not have the option of choosing multiple techniques whose efficacy is robustly better than standard CPR. Such a list would essentially be empty. But at least, we should limit ourselves to innovations whose performance has been reproducible—a list that is also remarkably short:

1. Anteroposterior chest compression [1]
2. Circumferential constriction, either fully circumferential via pneumatic vest or partially circumferential via a band [6]
3. Anteroposterior active decompression [19]
4. Transient inspiratory occlusion [20]

Two of the techniques, anteroposterior compression and circumferential constriction, are basic forms of CPR and likely induce forward blood flow by thoracic or cardiac pump mechanisms. The other two techniques, active decompression and transient inspiratory occlusion, likely augment venous return.

Particularly intriguing, none of these techniques is mechanistically, or even mechanically, exclusive. All four techniques could be combined and would not of necessity interfere with each other. The combination of anteroposterior compression and circumferential constriction into one device holds the promise of a more effective forward pump. Addition of both active anteroposterior decompression and transient inspiratory occlusion into the same system may enhance the priming of that pump to a greater degree than either technique alone.

And, at least at a superficial level, the design and construction of a next-generation device incorporating these techniques seem straightforward. Such a system would likely include:

1. A backboard of sorts to maintain the patient in the optimal configuration with respect to the other components.
2. A pistonlike device for provision of anteroposterior compression and active decompression.
3. A mechanism to attach the piston to the patient's chest for provision of active decompression. This may be a suction cup device.
4. A gantry or arch anterior and above the patient for holding the piston in position.
5. A circumferential or semicircumferential band or bladder for provision of circumferential constriction, possibly applied to the gantry and backboard.

Imagine, if you will, an archlike gantry that semisurrounds the chest and is easily placed on the patient. At the center of this arch can be a piston mechanism attached to the patient by a suction cup. A bladder or band on the inside of the arch can provide partial circumferential compression, whereas the piston can provide standard compression and active decompression. Nearly full circumferential compression of the chest might be accomplished by including a component of the circumferential mechanism into the backboard. The impedance threshold device is separate and may be inserted into the airway.

Like all mechanical devices, such a system has the advantage of not fatiguing. Incorporation of the electrode pads on the patient-side surface of the piston, circumferential constriction band, or backboard would be relatively straightforward and would allow anteroposterior electrical countershock without interruption of chest compression [21]. If, in the future, it is demonstrated that synchronization of CPR with pseudo-pulseless electrical activity is effective [22], such synchronization could also be incorporated into the device.

Clinical application of devices has generally been associated with prolonged interruptions in CPR [23]. This may be addressed by applying the device before any CPR-related reperfusion or the minimization of the interruption by use of "pit stop" approaches. Regardless, the design of the next-generation device should try to address the interruption issue comprehensively from the beginning.

A prototype of this device would be relatively easy to construct and test in the laboratory. For it to be worthwhile to proceed with clinical development and randomized clinical trials, I would propose that the system should consistently raise coronary perfusion pressure and return of spontaneous circulation at least 50% in porcine models with prolonged downtime and minimal epinephrine. This result should be sufficiently robust that it is easily replicated in laboratories not directly involved in the initial development and completely free of intellectual and financial bias.

When death occurs without warning in the midst of life, it is clear that BLS performed with hands will remain the first-line therapy, at least in the near future. The big question is what will be done when more advanced resources have arrived. I propose a machine-based combination-of-combinations as a bridge to extracorporeal therapies.

Disclosure

The author has intellectual property in the area of mechanical CPR and is a consultant to companies that sell mechanical CPR devices.

References

[1] Kouwenhoven WB, Jude JR, Knickerbocker GG. Closed chest cardiac massage. JAMA 1960;173:1064–7.
[2] Sanders AB, Kern KB, Ewy GA, Atlas M, Bailey L. Improved resuscitation from cardiac arrest with open-chest massage. Ann Emerg Med 1984;13(9 Pt 1):672–5.
[3] Stephenson HE, Corsan Reed L, Hinton JW. Some common denominators in 1200 cases of cardiac arrest. Ann Surg 1953;137:731–44.
[4] Shinar Z, Bellezzo J, Paradis N, et al. Emergency department initiation of cardiopulmonary bypass: a case report and review of the literature. J Emerg Med 2012;43(1):83–6.
[5] Ralston SH, Babbs CF, Niebauer MJ. Cardiopulmonary resuscitation with interposed abdominal compression in dogs. Anesth Analg 1982;61:645–51.
[6] 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.
[7] 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.
[8] Chan PS, McNally B, Tang F, Kellermann A. Recent trends in survival from out-of-hospital cardiac arrest in the United States. Circulation 2014;130(21):1876–82.
[9] Cave DM, Gazmuri RJ, Otto CW, et al. Part 7: CPR techniques and devices: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010;122(18 Suppl. 3):S720–8.
[10] Hostler D, Everson-Stewart S, Rea TD, et al. Effect of real-time feedback during cardiopulmonary resuscitation outside hospital: prospective, cluster-randomised trial. BMJ 2011;342:d512.
[11] Stiell IG, Nichol G, Leroux BG, et al. Early versus later rhythm analysis in patients with out-of-hospital cardiac arrest. N Engl J Med 2011;365(9):787–97.
[12] 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(22):2620–8.
[13] Plaisance P, Lurie KG, Vicaut E, et al. A comparison of standard cardiopulmonary resuscitation and active compression-decompression resuscitation for out-of-hospital cardiac arrest. French Active Compression-Decompression Cardiopulmonary Resuscitation Study Group. N Engl J Med 1999;341(8):569–75.
[14] Voorhees WD, Niebauer MJ, Babbs CF. Improved oxygen delivery during cardiopulmonary resuscitation with interposed abdominal compressions. Ann Emerg Med 1983;12:128–35.
[15] Wolcke BB, Mauer DK, Schoefmann MF, et al. Comparison of standard cardiopulmonary resuscitation versus the combination of active compression-decompression cardiopulmonary resuscitation and an inspiratory impedance threshold device for out-of-hospital cardiac arrest. Circulation 2003;108(18):2201–5.
[16] Rubertsson S, Lindgren E, Smekal D, et al. Mechanical chest compressions and simultaneous defibrillation vs conventional cardiopulmonary resuscitation in out-of-hospital cardiac arrest: the LINC randomized trial. JAMA 2014;311(1):53–61.
[17] Wik L, Olsen JA, Persse D, et al. Manual vs. integrated automatic load-distributing band CPR with equal survival after out of hospital cardiac arrest. The randomized CIRC trial. Resuscitation 2014;85(6):741–8.
[18] Esibov A, Banville I, Chapman FW, Boomars R, Box M, Rubertsson S. Mechanical chest compressions improved aspects of CPR in the LINC trial. Resuscitation 2015;91:116–21.
[19] Cohen TJ, Tucker KJ, Lurie KG, et al. Active compression-decompression. A new method of cardiopulmonary resuscitation. Cardiopulmonary Resuscitation Working Group [see comments]. JAMA 1992;267:2916–23.
[20] 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(9):989–94.
[21] Neumann T, Gruenewald M, Lauenstein C, Drews T, Iden T, Meybohm P. Hands-on defibrillation has the potential to improve the quality of cardiopulmonary resuscitation and is safe for rescuers-a preclinical study. J Am Heart Assoc 2012;1(5):e001313.
[22] Paradis NA, Halperin HR, Zviman M, Barash D, Quan W, Freeman G. Coronary perfusion pressure during external chest compression in pseudo-EMD, comparison of systolic versus diastolic synchronization. Resuscitation 2012;83(10):1287–91.
[23] 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(3):233–41.