RESUSCITATION 140 (2019) 209–210

Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Editorial

Shocking insights on double defibrillation: How, when and why not?

Alongside CPR, rapid defibrillation is the foremost life-saving intervention for cardiac arrest caused by ventricular fibrillation and pulseless ventricular tachycardia (VF/VT). In recent years a number of technological advances, most notably development of the biphasic waveform, have reduced the energy requirements for successful defibrillation, thereby enhancing the procedure's efficacy and safety[1–3] Unfortunately, biphasic defibrillation is not always successful. Although shock failure is often attributed to inadequate shock energy, other factors such as electrode positioning and poor skin contact are usually more common and readily correctable culprits when this is thought to be the case.[4,5] Notably, defibrillation is itself probabilistic and involves an element of chance. Defibrillation success (even at an identical energy) can change from one moment to the next, depending on the electrical state of the heart at the time of shock administration.[6] Regardless of reason, repeated shock failures typically prompt incrementing defibrillator energy settings, when this is possible. When the perceived need for more energy exceeds the capacity of a single defibrillator, some emergency medical services (EMS) have resorted to administering double shocks during out-of-hospital cardiac arrest (OHCA), using two defibrillators in combination.

Double defibrillation (also called double sequential defibrillation) involves placing two separate sets of electrodes on a patient, to which two defibrillators are attached and manually activated to shock near-simultaneously or sequentially, usually at their maximum energy setting. This results in a higher net output than that of either defibrillator alone. While well intentioned, the practice of double defibrillation is largely empiric, with little or no uniformity in how the procedure is performed clinically. Double defibrillation is in fact often attempted with a degree of naivety as to its complexity, potential risks and unintended consequences for which a more scientifically informed approach is desperately needed. While scientific studies involving animals, like the one to be discussed here, have limitations and incomplete applicability to humans, the lessons learned can be invaluable before advancing such experimentation into clinical practice. What can we learn from such science that might encourage, alter or deter the growing use of this technique?

This animal-based study of double defibrillation entailed two experiments to help answer these questions.[7] The first experiment addressed the positioning of shock electrodes and the resulting risk of lethal damage to the defibrillators themselves used for the procedure. For this experiment, transthoracic voltages were measured from a set of shock electrodes when a corresponding pair was placed either in parallel or in orthogonal orientation to the other and used to administer a shock. In this manner, the "risk" of high voltage exposure from one defibrillator to another depending on how and where these electrodes were placed could be tested.

The study found a 10-fold difference in measured peak voltage between electrode configurations, with exposure to high voltage being significantly higher when electrode pairs from the two defibrillators lay "in-line" (parallel), than when perpendicular to each other – thereby exposing one or the other defibrillator to potentially damaging energy from double shocks. Notably, this was the precise configuration of the shock electrodes in a recent clinical report describing nonfunction of a defibrillator after its use for administering double shocks.[8] Not mentioned in the animal experiment is the ideal separation between double sets of defibrillation electrodes needed to prevent possible electrical "arcing" between them or whether misdirecting a shock to adjacent patches via a potentially lower impedance pathway might result in the shock missing the patient entirely.

In the second experiment, the efficacy of double defibrillation was evaluated (using the "safer" orthogonal configuration between the two sets of defibrillation electrodes) by varying the precise time interval between the dual shocks, as compared with giving two separate "stacked" shocks (one followed by the other, if necessary, after 10 s) from a single set of electrodes. The programmed energy for each of the double shocks and each of the stacked shocks was identical, and chosen to be one arbitrary step below that required for successful defibrillation (from earlier testing using a single biphasic shock). This allowed for seeing potential improvement (or worsening) in shock success when double shocks were compared against two stacked shocks. Apart from the single versus double shock technique, the two approaches only differed by the time interval between the double shocks and not by any differences in the total combined energy administered using either approach.

The study findings underscore the supreme importance of timing and the tight precision required when administering double shocks. When dual shocks overlapped (i.e. each shock given within 7 ms of the other) or were delivered precisely 10 ms or 100 ms apart, shock success was significantly improved compared to two stacked single shocks. Conversely, when the inter-shock interval was 50 ms the efficacy of double shocks was significantly worse than single shocks. And, when the interval between dual shocks exceeded 200 ms, single shocks performed just as well as double shocks without any differences in efficacy and arguing against the double shock's necessity. Of note, the results of this experiment using external (transthoracic) biphasic defibrillation replicated those from independent but similarly-designed work using internal (epicardial) biphasic defibrillation, reinforcing the validity of each study's findings.[9] The implications of these studies are sobering given the precision in timing required for double shock efficacy (allowing for at most a <50–100 ms margin of error). When compared to the typical human reaction time of 250 ms for "button pushing,"[10,11] this degree of precision needed to confer benefit rather than harm from double defibrillation is not only daunting but is actually unachievable by human hands. Another concern that was not assessed in this animal experiment is the added risk of "shock toxicity" when the heart is exposed to greater currents resulting from high energy shocks, which can themselves result in recurrent arrhythmias, myocyte injury and impairment of cardiac contractile function.[12–14]

Beyond the questions concerning the safety and efficacy of dual defibrillation addressed by this study lies a bigger question, is it even necessary? In studies in which detailed analyses of defibrillator recordings during resuscitation of OHCA were performed, the vast majority of VF/VT episodes were found to have been successfully terminated by shock but recurred during the ensuing period of CPR.[15,16] That these were in fact recurrences rather than ongoing VF/VT was understandably not recognized by EMS providers due to the artifact created by chest compressions, suggesting that, more often than not, so-called "shock refractory" (or shock resistant) VF/VT is a case of mistaken identity. The distinction is critical since the recurrence of VF/VT after successful shock does not implicate defibrillation failure nor the need for more power, but should rather direct providers to other avenues of therapy for which double defibrillation can all-too-easily become a distractor. On uncommon occasions where more power may actually be needed, lessons from the current study and others suggest the technology for double shocks is perhaps best built into a single device, with precise timing by an internal microprocessor, along with safety measures to insure protection of internal components during shock administration and specific directives as to optimal patch placement. We are not there yet.

Funding

The work for this editorial was not funded.

Conflicts of interest

None.

REFERENCES

1. Jones JL, Jones RE. Improved defibrillator waveform safety factor with biphasic waveforms. Am J Physiol 1983;245:H60.
2. Jones JL, Jones RE. Decreased defibrillator-induced dysfunction with biphasic rectangular waveforms. Am J Physiol 1984;247:H792.
3. Jones JL, Jones RE. Determination of safety factor for defibrillator waveforms in cultured heart cells. Am J Physiol 1982;242:H662.
4. Esibov A, Chapman FW, Melnick SB, et al. Minor variations in electrode pad placement impact defibrillation success. Prehosp Emerg Care 2016;20(2):292–8.
5. Sado DM, Deakin CD. How good is your defibrillation technique? J R Soc Med 2005;98:3–6.
6. Yashima M, Kim YH, Armin S, et al. On the mechanism of the probabilistic nature of ventricular defibrillation threshold. Am J Physiol Heart Circ Physiol 2003;284:H249–255.
7. Taylor TG, Melnick SB, Chapman FW, Walcott GP. An investigation of inter-shock timing and electrode placement for double sequential defibrillation. Resuscitation 2019;140:194–200, doi:http://dx.doi.org/10.1016/j.resuscitation.2019.04.042 pii: S0300-9572(19)30158-3. [Epub ahead of print].
8. Gerstein NS, McClean AR, Stecker EC, Schulman PM. External defibrillator damage associated with attempted synchronized dual-dose cardioversion. Ann Emerg Med 2018;71:109–12.
9. Johnson EE, Alfernes CA, Wolf PD, Smith WM, Ideker RE. Effect of pulse separation between two sequential biphasic shocks given over different lead configurations on ventricular defibrillation efficacy. Circulation 1992;85:2267–74.
10. Eckner JT, Richardson JK, Kim H, Lips DB, Ashton-Miller JA. A novel clinical test of recognition reaction time in healthy adults. Psychol Assess 2012;24:249–54.
11. Anstey KJ, Dear K, Christensen H, Jorm AF. Biomarkers, health, lifestyle and demographic variables as correlates of reaction time performance in early, middle and late adulthood. Q J Exp Psychol A 2005;58:5–21.
12. Jones JL, Jones R. Postshock arrhythmias-A possible cause of unsuccessful debrillation. Crit Care Med 1980;8:167–71.
13. Tung L, Tovar O, Neunlist M, Jain SK, O'Neill RJ. Effects of strong electrical shock on cardiac muscle tissue. Ann N Y Acad Sci 1994;720:160–75.
14. Xie J, Weil MH, Sun S, Tang W, Sato Y, Jin X. Bisera. High energy defibrillation increases the severity of postresuscitation myocardial dysfunction. Circulation 1997;96:683–8.
15. Kudenchuk PJ, Cobb LA, Copass MK, Olsufka M, Maynard C, Nichol G. Transthoracic incremental monophasic versus biphasic defibrillation by emergency responders (TIMBER). Circulation 2006;114:2010–8.
16. van Alem AP, Chapman FW, Lank P, Hart AA, Koster RW. A prospective, randomized and blinded comparison of First shock success of monophasic and biphasic waveforms in out-of-hospital cardiac arrest. Resuscitation 2003;58(1):17–24.

Peter J. Kudenchuk
Department of Medicine, Division of Cardiology, Electrophysiology Services, University of Washington and King County Emergency Medical Services, Public Health, Seattle and King County, WA, USA

E-mail address: kudenchu@u.washington.edu (P. Kudenchuk).

Received 19 May 2019

http://dx.doi.org/10.1016/j.resuscitation.2019.05.022