Resuscitation 80 (2009) 773–777

Contents lists available at ScienceDirect

Resuscitation

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

Clinical paper

Defibrillation probability and impedance change between shocks during resuscitation from out-of-hospital cardiac arrest☆

Robert G. Walker[a,*], Rudolph W. Koster[b], Charles Sun[c,1], George Moffat[c,2], Joseph Barger[d], Pamela P. Dodson[d], Fred W. Chapman[a]

[a] Physio-Control Inc. A Division of Medtronic, 11811 Willows Road NE, Redmond, WA 98052, USA
[b] Department of Cardiology, F3-239, Academic Medical Center, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands
[c] British Columbia Ambulance Service, Victoria, BC, Canada
[d] Contra Costa County EMS, 1340 Arnold Drive, Suite 126, Martinez, CA 94553, USA

ARTICLE INFO

Article history:
Received 3 October 2008
Received in revised form 21 March 2009
Accepted 1 April 2009

Keywords:
Automated external defibrillator (AED)
Cardiac arrest
Defibrillation
Transthoracic impedance

ABSTRACT

Objective: Technical data now gathered by automated external defibrillators (AEDs) allows closer evaluation of the behavior of defibrillation shocks administered during out-of-hospital cardiac arrest. We analyzed technical data from a large case series to evaluate the change in transthoracic impedance between shocks, and to assess the heterogeneity of the probability of successful defibrillation across the population.
Methods: We analyzed a series of consecutive cases where AEDs delivered shocks to treat ventricular fibrillation (VF) during out-of-hospital cardiac arrest. Impedance measurements and VF termination efficacy were extracted from electronic records downloaded from biphasic AEDs deployed in three EMS systems. All patients received 200 J first shocks; second shocks were 200 J or 300 J, depending on local protocols. Results presented are median (25th, 75th percentiles).
Results: Of 863 cases with defibrillation shocks, 467 contained multiple shocks because the first shock failed to terminate VF ($n = 61$) or VF recurred ($n = 406$). Defibrillation efficacy of subsequent shocks was significantly lower in patients that failed to defibrillate on first shock than in patients that did defibrillate on first shock (162/234 = 69% vs. 955/1027 = 93%; $p < 0.0001$). The failed VF terminations were distributed heterogeneously across the population; 5% of patients accounted for 71% of failed shocks. Shock impedance decreased by 1% [0%, 4%] and peak current increased by 1% [0%, 4%] between 200 J first and 200 J second shocks. Shock impedance decreased 4% [2%, 6%] and current increased 27% [25%, 29%] between 200 J first and 300 J second shocks. In all 499 pairs of same-energy consecutive shocks, impedance changed by less than 1% in 226 (45%), increased >1% in 124 (25%) and decreased >1% in 149 (30%).
Conclusions: Impedance change between consecutive shocks is minimal and inconsistent. Therefore, to increase current of a subsequent shock requires an increase of the energy setting. Distribution of failed shocks is far from random. First shock defibrillation failure is often predictive of low efficacy for subsequent shocks.

1. Introduction

Cardiac arrest remains a leading cause of mortality. Of the hundreds of thousands of patients that suffer out-of-hospital cardiac arrest each year, many initially present with ventricular fibrillation (VF) and many others experience VF during resuscitation attempts. Since VF must be terminated in these patients before spontaneous circulation can resume, defibrillation remains an important link in their chain of survival.

Data on technical details of out-of-hospital defibrillation has, until recent years, been extremely difficult to gather and is correspondingly scarce. In the absence of such data, defibrillation practices have been based largely on presumptions informed by animal experiments and very limited sets of clinical data. However, modern defibrillators have made it feasible to gather technical data from large cohorts, allowing more careful evaluation of these presumptions.

Until 2005, protocols for resuscitation from out-of-hospital cardiac arrest prescribed delivery of defibrillation countershocks in

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at doi:10.1016/j.resuscitation.2009.04.002.

* Corresponding author. Tel.: +1 425 867 4484; fax: +1 425 867 4462.
E-mail address: rob.walker@medtronic.com (R.G. Walker).
[1] University of British Columbia, and Island Medical Program, University of Victoria, 2127 Gourman Place, Victoria, BC V9B 6C5, Canada.
[2] British Columbia Ambulance Service, PO Box 9600 Stn Prov Govt, Victoria, BC V8W 9P1, Canada.

0300-9572/$ – see front matter © 2009 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.resuscitation.2009.04.002

"stacks" of up to three shocks prior to initiating or resuming CPR. Part of the rationale for delivering shocks in stacks had been an expected decrease in transthoracic impedance between consecutive shocks; a decrease in impedance caused by delivery of a first shock would result in higher current flow, and thus a higher probability of defibrillation success, for a subsequent shock.[1] However, clinical evidence supporting this presumption has been limited to two small studies conducted with monophasic waveform shocks in settings other than out-of-hospital cardiac arrest.[2,3] Recent guidelines have moved away from stacked shocks, but the fact that there was limited data supporting the original rationale for stacked shocks makes it desirable to determine whether the change in guidelines is further supported by the more extensive clinical data now available.[4,5]

Definitive evidence has been lacking over the years on whether, when one countershock fails to terminate VF, it is better to increase the dose or to keep the same dose for the next countershock. The rationale for repeating the same dose has been based, in part, on the expectation that impedance will decrease meaningfully from one shock to the next. Another part of the rationale is the presumption of "constant defibrillation probability". This is the presumption that the same defibrillation probability obtained for a particular countershock dose across the general population will also be obtained in the subset of patients left in VF after a failed first shock or after failed first and second shocks.[6] This presumption has not been evaluated.

In the current investigation, we analyzed technical data collected by automated external defibrillators (AEDs) in a large consecutive case series of out-of-hospital cardiac arrests. We used these data to test two presumptions: the presumption that transthoracic impedance decreases between shocks, and the presumption of "constant defibrillation probability".

2. Methods

A retrospective review was performed on electronic records downloaded from biphasic waveform AEDs (LIFEPAK 500, Medtronic Inc.) deployed with first-responding BLS teams in three EMS systems. Ethical approval for this retrospective review was obtained in each of the three participating systems. For each system, we analyzed a consecutive series of downloaded records where one or more shocks were delivered for treatment of ventricular fibrillation (VF) during out-of-hospital cardiac arrest.

All AEDs were configured per local protocols to an energy sequence of either 200 J–200 J–360 J, or 200 J–300 J–360 J. Thus first shocks were always delivered at 200 J, and second shocks were delivered at either 200 J or 300 J depending on the configured energy protocol. In accordance with the then current guidelines, stacks of up to three shocks were delivered prior to initiating or resuming CPR.

Electronic device records were reviewed to determine VF termination efficacy and extract impedance values for each delivered shock. Defibrillation efficacy was determined from manual review of ECG records, and was defined per commonly accepted convention as termination of VF for at least 5 s after shock delivery.[1] Peak current was calculated for all shocks based on the recorded impedance values and knowledge of the design of the energy delivery circuit of these AEDs.

Two different types of impedance measurements were extracted from the AED records. The first type, "high-frequency impedance", was an estimate made prior to the countershock by delivery of a very low intensity, high frequency (62.5 kHz) carrier signal across the thorax. This impedance estimation technique was first described by Geddes et al.,[7] and has been shown to correlate well with impedance measurements made during shock discharge. The second type, "shock impedance", was a direct measurement made during shock discharge. Due to non-linear behavior of the thorax, the shock impedance naturally decreases with increasing shock intensity.[7] Therefore, we analyzed the change in shock impedance for the cases with two shocks at the same energy setting (200 J–200 J) separately from the cases with a higher energy setting for the second shock (200 J–300 J). On the other hand, the high-frequency impedance is measured before shock delivery and is not influenced by shock intensity. Therefore, data from all cases, regardless of second shock setting, could be combined for analysis of impedance change using this high-frequency impedance value.

Descriptive statistics for impedance and current are reported as median [25th, 75th percentiles] unless otherwise indicated. Differences between proportions were tested with Chi-square statistics.

3. Results

A total of 863 AED cases containing defibrillation shocks were available for analysis. VF was terminated by the initial 200 J shock in 802 (93%) cases. Due to failed VF termination with the first shock ($n = 61$) or refibrillation ($n = 406$), 467 cases contained at least two defibrillation shocks, and thus could be analyzed for impedance and defibrillation trends.

3.1. Impedance change between consecutive shocks

Among the 467 cases with at least two shocks, the median shock impedance for the initial 200 J shock was 86 Ω [73,103], and the median peak current was 17.4 A [14.8, 20.1]. In patients receiving second shocks at the same energy as the first shock (200 J), shock impedance decreased by a median of 1% and peak current thus increased by 1% between first and second shocks (Table 1). In patients receiving larger (300 J) second shocks, second-shock impedance decreased only 4% while second-shock peak current increased 27%, primarily as a consequence of the higher energy setting.

Across all 467 cases with at least two shocks, the median change in high-frequency impedance between first and second shocks was 0% [−3%, 2%]. The median change between first and second-shock impedance was not influenced by whether the second shock was delivered immediately after the first as a part of a shock stack (0% [−3%, 2%]) or delivered later after an interval of CPR (0% [−3%, 2%]). Neither the change in shock impedance nor the change in high-frequency impedance was correlated to the impedance of the first shock (shock impedance $R^2 = 0.05$; high-frequency impedance $R^2 = 0.04$).

Table 1
Impedance and peak current change between first and second shocks.

	Second shock at same energy (200 J, $n = 109$)	Second shock at higher energy (300 J, $n = 358$)
Decrease in shock impedance	1 Ω [0, 3]	3 Ω [2, 5]
% shock impedance decrease	1% [0%, 4%]	4% [2%, 6%]
Increase in peak current	0.2 A [0.0, 0.7]	4.7 A [3.7, 5.5]
% peak current increase	1% [0%, 4%]	27% [25%, 29%]
Decrease in high-frequency impedance	0 Ω [−2, 2]	
% high-frequency impedance decrease	0% [−3%, 2%]	