Resuscitation 87 (2015) 86–90

Contents lists available at ScienceDirect

Resuscitation

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

Clinical paper

Cardiopulmonary resuscitation duty cycle in out-of-hospital cardiac arrest☆

Bryce V. Johnson[a], Jason Coult[a], Carol Fahrenbruch[b], Jennifer Blackwood[b], Larry Sherman[a], Peter Kudenchuk[a,b], Michael Sayre[a,b], Thomas Rea[a,b,*]

[a] University of Washington, United States
[b] Division of Emergency Services, Public Health-Seattle & King County, United States

ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 2 November 2014
Accepted 10 November 2014

Keywords:
CPR
Duty cycle
Human
Ventricular fibrillation
Resuscitation

ABSTRACT

Background: Duty cycle is the portion of time spent in compression relative to total time of the compression–decompression cycle. Guidelines recommend a 50% duty cycle based largely on animal investigation. We undertook a descriptive evaluation of duty cycle in human resuscitation, and whether duty cycle correlates with other CPR measures.

Methods: We calculated the duty cycle, compression depth, and compression rate during EMS resuscitation of 164 patients with out-of-hospital ventricular fibrillation cardiac arrest. We captured force recordings from a chest accelerometer to measure ten-second CPR epochs that preceded rhythm analysis. Duty cycle was calculated using two methods. Effective compression time (ECT) is the time from beginning to end of compression divided by total period for that compression–decompression cycle. Area duty cycle (ADC) is the ratio of area under the force curve divided by total area of one compression–decompression cycle. We evaluated the compression depth and compression rate according to duty cycle quartiles.

Results: There were 369 ten-second epochs among 164 patients. The median duty cycle was 38.8% (SD = 5.5%) using ECT and 32.2% (SD = 4.3%) using ADC. A relatively shorter compression phase (lower duty cycle) was associated with greater compression depth (test for trend <0.05 for ECT and ADC) and slower compression rate (test for trend <0.05 for ADC). Sixty-one of 164 patients (37%) survived to hospital discharge.

Conclusions: Duty cycle was below the 50% recommended guideline, and was associated with compression depth and rate. These findings provider rationale to incorporate duty cycle into research aimed at understanding optimal CPR metrics.

© 2014 Elsevier Ireland Ltd. All rights reserved.

1. Introduction

Cardiopulmonary resuscitation (CPR) – characterized by repeated chest compressions sometimes interspersed with rescue breathing – is a key link in the chain of survival designed to improve outcomes following cardiac arrest. Increasing evidence indicates that the specific composition of CPR can influence the likelihood of successful resuscitation. CPR characteristics such as compression depth, rate, extent of release (chest recoil), and timing (CPR interruptions) vary substantially in resuscitation, and this variability has been associated with the likelihood of survival and neurological recovery.[1] This evidence has formed the basis of resuscitation guidelines which provide specific goals for the different metrics of CPR (depth, rate, release, and timing).[2] This understanding has produced efforts directed toward training, CPR feedback (depth, rate, recoil), and mechanical CPR; all with the goal of improving outcomes following cardiac arrest.

Resuscitation guidelines also provide specific goals for the chest compression metric of "duty cycle". The CPR duty cycle is the proportion of time spent in compression relative to the total time of the compression plus decompression cycle.[2] Current CPR guidelines recommend a 50:50 duty cycle, where the time spent in compression and decompression is equal.[2] The recommendation is based on modest evidence derived largely from experimental and animal studies.[3–9] Little is known about duty cycle in human resuscitation

☆ A Spanish translated version of the abstract of this article appears as Appendix in the final online version at http://dx.doi.org/10.1016/j.resuscitation.2014.11.008.

* Corresponding author at: 401 5th Ave, Suite 1200, Seattle, WA 98104, United States.
E-mail address: rea123@u.washington.edu (T. Rea).

http://dx.doi.org/10.1016/j.resuscitation.2014.11.008
0300-9572/© 2014 Elsevier Ireland Ltd. All rights reserved.

and its relationship to other CPR metrics. We hypothesized that duty cycle would vary across individual arrests and would be correlated with other CPR metrics such as compression depth and rate.

2. Methods

2.1. Design, population, and setting

The study was a retrospective observational investigation of 164 persons who suffered non-traumatic, out-of-hospital ventricular fibrillation cardiac arrest between January 1, 2007 and December 31, 2011 and were treated by King County Emergency Medical Services (EMS) agencies equipped with specific recording equipment that monitored CPR performance. Cases were excluded if no defibrillator recording was available or the recording did not include measures of CPR throughout the resuscitation event. The investigation was approved by both the University of Washington and Public Health Review Boards. The study communities have a population of approximately 600,000 persons. The EMS is a 2-tier system activated by calling a central emergency dispatch (9-1-1) number. The first tier is comprised of EMT-firefighters equipped with automated external defibrillators. The second-tier is comprised of paramedics trained in advanced cardiac life support including ECG rhythm interpretation, drug administration, and endotracheal intubation. The EMS personnel generally follow the American Heart Association guidelines for cardiac arrest resuscitation.

2.2. Data collection and variables

The EMS system maintains a registry that includes every treated out-of-hospital cardiac arrest. Patient, circumstance, care, and outcome characteristics are abstracted from a range of sources including dispatch, EMS, hospital, vital statistics, and defibrillator records and organized according to the Utstein definitions.[10] The defibrillator information gathered for this particular study included a recording of the ECG rhythm tracing, the transthoracic impedance measurements, data from an accelerometer placed on the patient's chest, and the audio recording. The accelerometer data included measurements of acceleration and force which were used to compute chest compression rate and depth.

Chest compression duty cycle was calculated using the force recordings from the chest accelerometer, Philips MRx-Event Review Pro©, using two different previously reported methods termed the effective compression time (ECT) and area duty cycle (ADC). The force accelerometer can distinguish forces of compression from decompression. The ECT is a first-order measure that is the time from the beginning to the end of the compression divided by the total period for that compression–decompression event.[2] The ADC is a second-order measure that is the ratio between the area under the force curve and the total area of one rectangle outlining the compression–decompression curve (Fig. 1).[11] Thus the ECT is more intuitive measure of duty cycle but we also assessed the ACD in an effort to explore how different measures of force might compare to one another and to the compression metrics of depth and rate. The time period defining each compression period for ECT and ADC was defined as the time between the two absolute minima on either side of the compression peak in the force trace. Both measures are reported as percentages. These measures of duty cycle were derived using the ten-second CPR epochs that immediately preceded each scheduled defibrillator rhythm analysis set to occur at 2 min intervals per American Heart Association resuscitation guidelines. We calculated the median value of ECT and ADC for all compressions within the 10-s epoch.

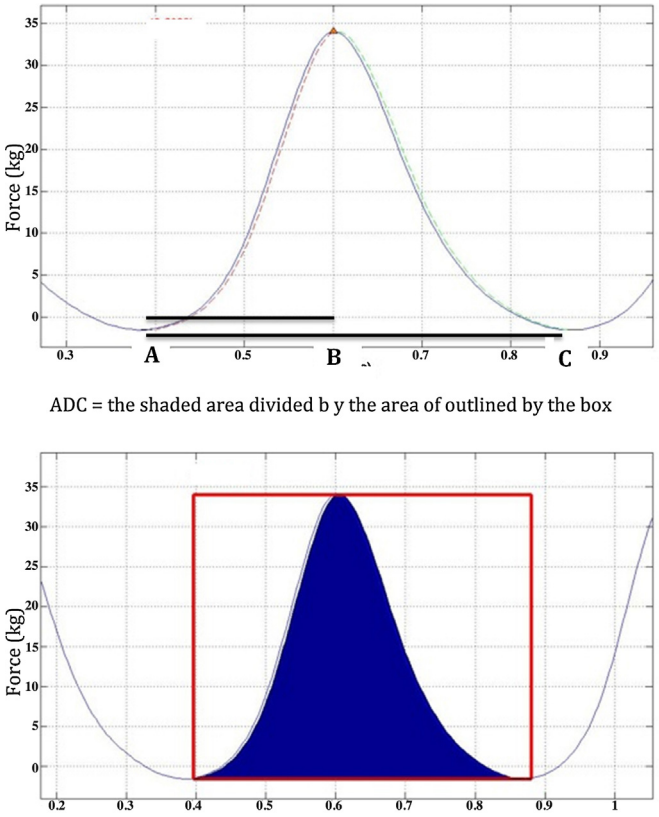

Fig. 1. Graphic depiction of duty cycle as derived from the ECT and ADC. The *y*-axis is the force and the *x*-axis is time.

Median depth values for each ten-second epoch were obtained directly from the MRx defibrillator download files, which record the depth for each CPR compression by estimating the position of the puck based on the acceleration measurements. Median chest compression rate was also calculated based on the force trace.

2.3. Statistical analysis

We used descriptive statistics to evaluate the distribution of the duty cycle. To characterize the relationships between duty cycle and the other CPR metrics parameters, we divided the duty cycle into quartiles. We then calculated compression depth and compression rate according to duty cycle quartiles. CPR metrics were calculated in MATLAB© and SPSS© statistics. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Patients

Of the 558 persons who suffered out-of-hospital ventricular fibrillation arrests and were treated by the study EMS agencies, 164 (29%) had complete defibrillator download information for the entire resuscitation event. Demographic, circumstance, care, and outcome characteristics were similar between cases included and excluded in the study (Table 1). Among study cases, most arrests were witnessed; more than half received bystander CPR; nearly two-thirds had spontaneous circulation at the end of EMS care, and about a third survived to hospital discharge with good neurological outcome (Table 1). Among witnessed ventricular fibrillation arrest due to presumed cardiac etiology (as designated by the Utstein

Table 1
Characteristics according to defibrillator record status.

Characteristic	Defibrillator record status	
	Eligible, available (n = 164)	Eligible, unavailable (n = 394)
Average age, years (SD)	63.4 (16.6)	63.6 (15.6)
Male, % (n)	78% (128)	76% (298)
Cardiac etiology, % (n)	88% (144)	89% (391)
Bystander witnessed, % (n)	74% (121)	71% (181)
Bystander CPR, % (n)	70% (114)	69% (270)
EMS response interval, min (SD)	5.3 (2.0)	4.9 (2.1)
ROSC at the end of EMS care, % (n)	63%(104)	66% (259)
Survival to discharge, % (n)	37% (61)	42% (167)
Favorable neurological status, % (n)	32% (53)	37% (147)

Return of spontaneous circulation is abbreviated ROSC.
All comparisons result in $p > 0.05$.

template), 43% survived to hospital discharge, and 37% survived with favorable neurological status.

3.2. Duty cycle measures

There were 369 epochs for evaluation, collectively constituting 3690 s of CPR. The mean duty cycle per epoch was 38.8% (SD = 5.5%) using the ECT method and 32.2% (SD = 4.3%) using the ADC method (Fig. 2a and b). Duty cycle did not significantly vary during the course of resuscitation. For example, the average duty cycle using the ECT method was 38.7% prior to the 1st shock, 37.2% prior to the 2nd shock, 37.8% prior to the 3rd shock, 36.8% prior to the 4th shock, and 37.3% prior to the 5th shock. Regardless of the derivation method or time point during resuscitation, the vast majority of duty

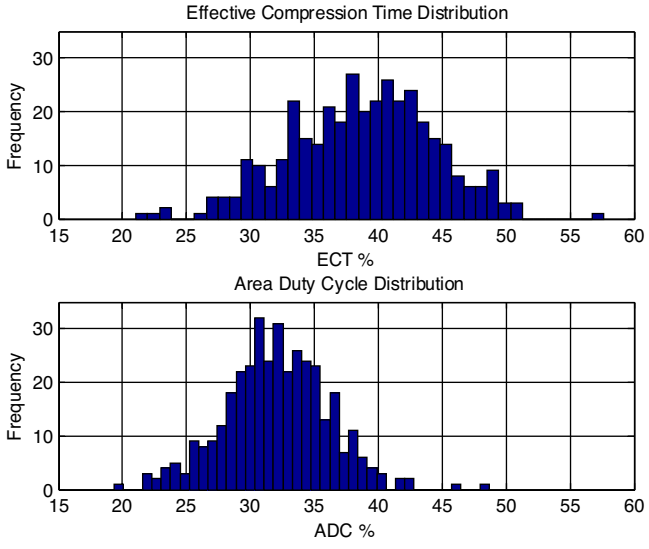

Fig. 2. Distribution of the duty cycle according to the effective compression time and area duty cycle methods. The y-axis is the number of epochs and the x-axis is the median value of the duty cycle for a given epoch. ADC, area duty cycle; ECT, effective compression time.

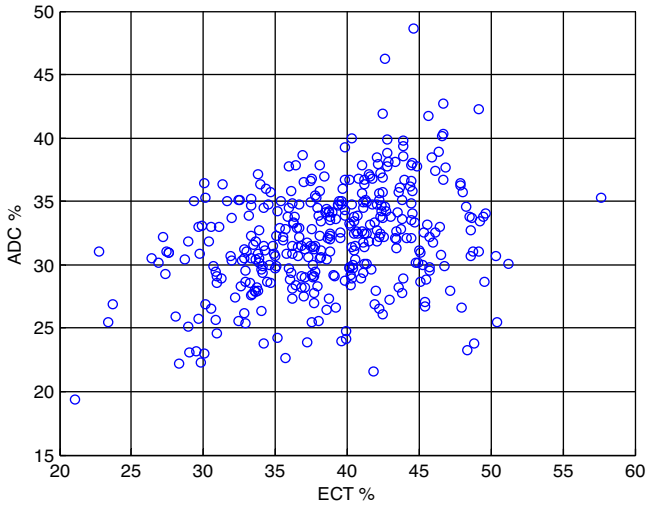

Fig. 3. Scatter plot of area duty cycle versus effective compression time. ADC, area duty cycle; ECT, effective compression time.

cycle measures were <50%. The ECT and ADC were only moderately correlated (R = 0.35) (Fig. 3).

3.3. Correlation with other CPR parameters

The duty cycle was inversely associated with compression depth by both methods used to derive the duty cycle (Table 2) (test for trend <0.05 for ECT and ADC). For example when stratified according to duty cycle quartile using the ADC method, the average compression depth was 43.9 mm for quartile 1 (median duty cycle = 32.4%), 44.6 mm for quartile 2 (median duty cycle = 37.1%), 42.6 mm for quartile 3 (median duty cycle = 41.0%), and 37.9 mm for quartile 4 (median duty cycle = 45.2%). Conversely, increasing ADC quartile – but not ECT quartile – was associated with greater compression rate (Table 2).

4. Discussion

In this investigation of out-of-hospital ventricular fibrillation cardiac arrest, we observed a duty cycle during clinical resuscitation that averaged 32–38%, depending on the method used to derive the measure. Regardless of the measurement approach, the duty cycle was inversely associated with compression depth such that relatively shorter compression phase (lower duty cycle) corresponded to greater compression depth. In addition, a relatively shorter compression phase corresponded to slower compression rate using the ADC method. Taken together, the findings involving duty cycle indicate that actual field care in a high-performing EMS system differs substantially from guideline recommendations, and that the duty cycle and its variation likely influence other important CPR metrics.

Previous animal experimental studies indicate that duty cycle can influence hemodynamics and potentially resuscitation outcome, but have provided conflicting results regarding optimal ratios.[3–9] Many – though not all – of these investigations demonstrate higher blood flow and better outcomes when the compression phase is less than 50%. Conversely, in a small case series of 8 in-hospital human arrests treated with mechanical compressions during the very terminal phase of care, a duty cycle of 50–60% achieved greater arterial blood flow during CPR compared to shorter compression phase duty cycles (30–40%).[12] We observed that the active compression phase in clinical resuscitation comprised about a third of the typical compression–decompression cycle, and nearly all duty cycles were less than 50%.

Table 2
Compression depth and rate according to duty cycle quartile.

Characteristic	Measure								Total
	ECT quartile				ADC quartile				
	1 (*n* = 92)	2 (*n* = 92)	3 (*n* = 93)	4 (*n* = 92)	1 (*n* = 92)	2 (*n* = 92)	3 (*n* = 93)	4 (*n* = 92)	
Median duty cycle	32.4	37.1	41.0	45.2	27.5	30.8	33.4	36.7	–
Compress rate (SD)	109.1 (8.9)	112.7 (13.1)	112.2 (12.5)	109.6 (12.5)	108.8 (9.1)	109.3 (9.8)	110.1 12.0	115.4 (14.9)	110.9 (11.9)
Compress depth (SD)	43.8 (8.4)	43.9 (8.2)	41.2 (7.2)	40.1 (9.1)	43.9 (8.3)	44.6 (7.2)	42.6 (7.9)	37.9 (8.5)	42.2 (8.4)

Compression rate and depth associated with ADC quartile (test for trend $p < 0.05$).
Compression depth associated with ECT quartile (test for trend $p < 0.05$).

What are the implications of these results? The study does not demonstrate that a relatively shorter compression phase is associated with better clinical outcomes. Nonetheless and speculative, the findings suggest that "high-impulse" compressions with a shorter compression phase constituted the characteristic compression in an EMS system with a very high survival rate.[13] The finding – in the context of experimental studies – is provocative and questions whether the duty cycle is typical of other systems and importantly whether the 50% duty cycle recommended by guidelines is optimal? For example, recent randomized trials of mechanical CPR have not demonstrated clinical benefits compared to manual CPR despite potential mechanistic advantages related to traditional CPR metrics.[14,15] The duty cycle of these mechanical devices is 50%, and may differ from the duty cycle of manual CPR. This difference in duty cycle may undermine any potential benefit of mechanical CPR.

We also observed that relatively shorter compression phase was associated with greater compression depth and slower compression rate (for the ADC measure). Evidence indicates that greater compression depth is associated with better clinical outcome.[16,17] Compression rate may also influence clinical prognosis.[18] However these investigations have not incorporated duty cycle. Whether the primary benefit is due to depth, rate, duty cycle, or some combination is not known, but the current study results provide a strong rationale for future prognostic studies of CPR metrics to include duty cycle in order to clarify how these metrics independently or synergistically affect outcome.

We used two different methods to derive the duty cycle: the effective compression time and the area duty cycle. Although the two methods used to derive duty cycle both indicated an average duty cycle far below 50% and a consistent correlation between shorter compression phase and deeper chest compression, the two approaches were only moderately correlated. The lack of correlation likely reflects the essential differences in derivation: the ECT is a first-order equation that that depends on the change in direction of the chest as determined by the accelerometer while the ADC incorporates the area under the force curve. The ECT is a more intuitive measure but the ADC may also be useful. The imperfect agreement suggests that efforts to achieve an optimal duty cycle should consider the method (or methods) used to derive the measure to best inform resuscitation stakeholders how to consider duty cycle.

The investigation has limitations. We used a convenience sample of ventricular fibrillation arrest that provided for recording the duty cycle and other CPR metrics. Those cases that were not available for the study could have been different with regard to duty cycle; however clinical characteristics and outcome were similar between cases that were and were not included (Table 1). Moreover, an evaluation of non-shockable arrest was not included and could also provide distinct results. We used two methods to derive the duty cycle, and other derivations may provide different results. There is no reporting standard for duty cycle. We chose to derive duty cycle from ten-second CPR epochs prior to defibrillation. We focused on this CPR segment among ventricular fibrillation arrest given the potential importance of care during the perishock period.[19] A more comprehensive assessment throughout resuscitation could produce different results. However, we did not observe a substantial change in duty cycle over the course of a resuscitation. For example, the duty cycle prior to the first shock was similar to the duty cycle prior to the fifth shock. We evaluated the relationship between duty cycle and compression depth and rate, but not completeness of chest recoil. Incorporating all these CPR measures including duty cycle simultaneously may be required to optimally understand how measures are related and may interact to influence clinical outcomes. The study was not designed to evaluate if and how duty cycle may affect clinical outcome. Such a study would require larger sample and ideally a randomized trial design. The study occurred in a community with a high-performing EMS system and may not be generalizable. Subsequent studies should characterize the duty cycle in other EMS systems.

5. Conclusion

The characteristic duty cycle comprised only about a third of the compression–decompression cycle, and was well below the recommended guideline. A relatively shorter compression phase (lower duty cycle) was associated with greater compression depth and slower compression rate (by the ADC method). These findings provider rationale to incorporate duty cycle into future research aimed at understanding optimal CPR metrics.

Conflict of interest statement

The investigators have no conflicts.

Acknowledgements

We appreciate the EMS providers and emergency telecommunicators dedicated to improving resuscitation care.

The investigation was supported in part by the Laerdal Foundation, the NIH (T32 EB001650 for JC) and Philips Inc. The funding sources had no role in the study design; in the collection, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.

References

1. Meaney PA, Bobrow BJ, Mancini ME, et al. Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the

hospital: a consensus statement from the American Heart Association. Circulation 2013;128:417–35.
2. Berg RA, Hemphill R, Abella BS, et al. Part 5: adult basic life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122:S685–705.
3. Koeken Y, Aelen P, Noordergraaf GJ, Paulussen I, Woerlee P, Noordergraaf A. The influence of nonlinear intra-thoracic vascular behaviour and compression characteristics on cardiac output during CPR. Resuscitation 2011;82:538–44.
4. Jung E, Babbs CF, Lenhart S, Protopopescu VA. Optimal strategy for cardiopulmonary resuscitation with continuous chest compression. Acad Emerg Med 2006;13:715–21.
5. Sunde K, Wik L, Naess PA, Ilebekk A, Nicolaysen G, Steen PA. Effect of different compression–decompression cycles on haemodynamics during ACD-CPR in pigs. Resuscitation 1998;36:123–31.
6. Swart GL, Mateer JR, DeBehnke DJ, Jameson SJ, Osborn JL. The effect of compression duration on hemodynamics during mechanical high-impulse CPR. Acad Emerg Med 1994;1:430–7.
7. Betz AE, Menegazzi JJ, Logue ES, Callaway CW, Wang HE. A randomized comparison of manual, mechanical and high-impulse chest compression in a porcine model of prolonged ventricular fibrillation. Resuscitation 2006;69:495–501.
8. Dean JM, Koehler RC, Schleien CL, et al. Improved blood flow during prolonged CPR with 30% duty cycle in infant pigs. Circulation 1991;84:896–904.
9. Halperin HR, Tsitlik JE, Guerci AD, et al. Determinants of blood flow to vital organs during cardiopulmonary resuscitation in dogs. Circulation 1986;73:539–50.
10. Jacobs I, Nadkarni V, Bahr J, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries: a statement for healthcare professionals from a task force of the International Liaison Committee on Resuscitation. Circulation 2004;110:3385–97.
11. Laerdal Medical. Description of PC Skillreporter Exported Data; 2005.
12. Taylor GJ, Tucker WM, Greene HL, Rudikoff MT, Weisfeldt ML. Importance of prolonged compression during cardiopulmonary resuscitation in man. N Engl J Med 1977;30:1515–7.
13. Becker L, Gold LS, Eisenberg M, White L, Hearne T. Rea T Ventricular fibrillation in King County, Washington: a 30-year perspective. Resuscitation 2008;79:22–7.
14. Lucas Specifications. http://www.physio-control.com/uploadedFiles/products/cpr-assist-devices/product_data/instructions_for_use/LUCAS2_InstructionsForUse_100666-00_Rev_E.pdf [accessed 24.03.14].
15. AutoPulse Specifications. http://www.zoll.com/uploadedFiles/Public_Site/Products/AutoPulse/AutoPulse_Product_Manual(1).pdf [accessed 24.03.14].
16. Stiell IG, Brown SP, Christenson J, et al. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? Crit Care Med 2012;40:1192–8.
17. Vadeboncoeur T, Stolz U, Panchal A, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. Resuscitation 2014;85:182–8.
18. Idris AH, Guffey D, Aufderheide TP, et al. Relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004–12.
19. Cheskes S, Schmicker RH, Verbeek PR, et al. The impact of peri-shock pause on survival from out-of-hospital shockable cardiac arrest during the Resuscitation Outcomes Consortium PRIMED trial. Resuscitation 2014;85:336–42.