G Model
RESUS-5744; No. of Pages 7

ARTICLE IN PRESS

Resuscitation xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Resuscitation

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

Clinical Paper

Chest compression depth and survival in out-of-hospital cardiac arrest☆

Tyler Vadeboncoeur[a,*], Uwe Stolz[b,1], Ashish Panchal[i,2], Annemarie Silver[c], Mark Venuti[d], John Tobin[e], Gary Smith[e], Martha Nunez[f], Madalyn Karamooz[g], Daniel Spaite[b,1], Bentley Bobrow[f,h,j,3]

[a] *Department of Emergency Medicine, Mayo Clinic Florida, 4500 San Pablo Road, Jacksonville, FL 32224, United States*
[b] *Department of Emergency Medicine, University of Arizona, PO Box 245057, 1501 N. Campbell, Tucson, AZ 85724-5057, United States*
[c] *ZOLL Medical, 269 Mill Road, Chelmsford, MA 01824, United States*
[d] *Guardian Medical Transport, 1200 N Beaver Street, Flagstaff, AZ 86001, United States*
[e] *Mesa Fire and Medical Department, 13 W First Street, Mesa, AZ 85201, United States*
[f] *Bureau of Emergency Medical Services, Arizona Department of Health Services, 150 N. 18th Avenue, #540, Phoenix, AZ 85007, United States*
[g] *Arizona State University, Phoenix, AZ, United States*
[h] *Maricopa Medical Center, Phoenix, AZ, United States*
[i] *Department of Emergency Medicine, The Ohio State University Wexner Medical Center ,760 Prior Hall 376 West 10th Avenue, Columbus, OH, 43210, United States*
[j] *University of Arizona College of Medicine, Phoenix, AZ, United States*

ARTICLE INFO

Article history:
Received 16 May 2013
Accepted 2 October 2013
Available online xxx

Keywords:
Cardiac arrest
Cardiopulmonary resuscitation
Compression depth

ABSTRACT

Aim: Outcomes from out-of-hospital cardiac arrest (OHCA) may improve if rescuers perform chest compressions (CCs) deeper than the previous recommendation of 38–51 mm and consistent with the 2010 AHA Guideline recommendation of at least 51 mm. The aim of this study was to assess the relationship between CC depth and OHCA survival.

Methods: Prospective analysis of CC depth and outcomes in consecutive adult OHCA of presumed cardiac etiology from two EMS agencies participating in comprehensive CPR quality improvement initiatives. Analysis: Multivariable logistic regression to calculate adjusted odds ratios (aORs) for survival to hospital discharge and favorable functional outcome.

Results: Among 593 OHCAs, 136 patients (22.9%) achieved return of spontaneous circulation, 63 patients (10.6%) survived and 50 had favorable functional outcome (8.4%). Mean CC depth was 49.8 ± 11.0 mm and mean CC rate was 113.9 ± 18.1 CC min^{-1}. Mean depth was significantly deeper in survivors (53.6 mm, 95% CI: 50.5–56.7) than non-survivors (48.8 mm, 95% CI: 47.6–50.0). Each 5 mm increase in mean CC depth significantly increased the odds of survival and survival with favorable functional outcome: aORs were 1.29 (95% CI 1.00–1.65) and 1.30 (95% CI 1.00–1.70) respectively.

Conclusion: Deeper chest compressions were associated with improved survival and functional outcome following OHCA. Our results suggest that adhering to the 2010 AHA Guideline-recommended depth of at least 51 mm could improve outcomes for victims of OHCA.

1. Introduction

Annually, EMS treats approximately 380,000 out-of-hospital cardiac arrests (OHCA) in the U.S.[1] Outcomes vary widely between communities with survival rates for ventricular fibrillation (VF) ranging from 3.3% to 45%.[2–4] The quality of CPR delivered (defined by rate, chest compression (CC) fraction, depth, and recoil) impacts outcomes and may be one modifiable variable contributing to this wide range of survival.[5–8] Prior to 2010, the European Resuscitation Council (ERC) and the American Heart Association (AHA) recommended a CC depth of 38–51 mm (1.5–2.0 inches) while the 2010 Guidelines recommend at least 51 mm.[9–12]

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at http://dx.doi.org/10.1016/j.resuscitation.2013.10.002.

* Corresponding author. Tel.: +1 904 953 1498; fax: +1 904 953 0007.
E-mail addresses: Vadeboncoeur.tyler@mayo.edu (T. Vadeboncoeur), ustolz@aemrc.arizona.edu (U. Stolz), apanchal@aemrc.arizona.edu (A. Panchal), asilver@zoll.com (A. Silver), mark.venuti@nahealth.com (M. Venuti), johntobin@arizona.edu (J. Tobin), garysmithmd@netscape.net (G. Smith), martha.nunez@azdhs.gov (M. Nunez), Madalyn821@gmail.com (M. Karamooz), dan@aemrc.arizona.edu (D. Spaite), bobrowb@azdhs.gov (B. Bobrow).
1 Tel.: +1 520 626 5032; fax: +1 520 626 2480.
2 Tel: +1 614-366-7880 (office) 614-293-3124.
3 Tel.: +1 602 364 3154; fax: +1 602 364 3568; mobile: +1 602 370 2861.

0300-9572/$ – see front matter © 2013 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.resuscitation.2013.10.002

Studies using pre-2010 data have shown that providers achieve the 2005 Guideline-recommended depth of 38–51 mm infrequently.[13–15] Despite this, evidence suggests that even deeper compressions might be necessary to produce optimal outcomes. Studies demonstrate that a coronary perfusion pressure (CPP) of 15 mmHg is required to achieve return of spontaneous circulation (ROSC) and others suggest that 38–51 mm is not deep enough to achieve this.[16–19] Finally, several reports demonstrate that CCs deeper than 51 mm are associated with improved short term outcomes[20–23] and this is the depth currently recommended by the 2010 AHA and ERC Guidelines.[11,12]

In this analysis we evaluate whether the depth of CCs provided by prehospital rescuers is independently associated with survival and favorable functional outcome.

2. Methods

2.1. Study setting

Data were collected from two EMS agencies in Arizona. The Mesa Fire and Medical Department responds to a suburban area (population: 439,000) with approximately 70,000 annual 911 calls. It is staffed by 373 emergency medical technicians (EMTs). A typical crew includes two EMT-Paramedics (EMT-P) and two EMT Basics (EMT-B).[5] Guardian Medical Transport (GMT) responds to a suburban and rural population (80,000) with 14,000 annual 911 calls. GMT is staffed by 80 EMTs with a minimal crew of one EMT-P and one EMT-B. Both agencies participate in a statewide cardiac resuscitation quality improvement program (SHARE – Save Hearts in Arizona Registry and Education), use minimally interrupted cardiac resuscitation (MICR) as their adult cardiac resuscitation protocol,[24] and submit OHCA data to an Utstein-style statewide registry which has been previously described.[24,25]

2.2. Study design and population

This is a prospective, before-after, observational cohort study of consecutive adult patients (aged ≥18 years) with OHCA of presumed cardiac cause and initiation of CPR between 10/7/2008 and 9/30/2011.[5] Cases were excluded from analysis if resuscitation was not initiated, the patient had a do-not-resuscitate order, arrest was witnessed by EMS, or the cause of the arrest was presumed to be non-cardiac.

Eighteen months of baseline CPR quality and outcome data (10/7/08–3/31/10) were collected during Phase 1 (P1) before a dedicated education initiative (described in detail previously)[5] and before the use of real-time audiovisual feedback (RTAVF) for CC quality metrics. The education included 2 h of didactic teaching and 2 h of team-centered psychomotor practice, termed "Scenario-Based Training" (SBT). SBT emphasizes a team approach to resuscitation and meticulous compliance with the parameters of high-quality CPR based upon the 2010 AHA Guidelines.[11] Phase 2 (P2) began on 5/27/10 after training was completed and the monitor-defibrillators RTAVF software was enabled (E-series, ZOLL Medical). This technology has been described in detail previously.[5]

2.3. Data collection

CC quality was measured during resuscitation including minute-by-minute rate and depth data. Interruptions in compressions were assessed using the CC fraction, the percentage of time compressions were performed (when indicated) throughout the entire resuscitation event.[11]

The SHARE program was implemented in 2005 by the Arizona Department of Health Services (ADHS) as a statewide quality improvement program in response to its declaration of OHCA as a major public health problem in Arizona.[25] SHARE includes a voluntary Utstein-style database with detailed OHCA data and linked hospital outcomes. Since SHARE is an ADHS-sponsored public health initiative, the Attorney General has determined that the program is exempt from the requirements of the Health Insurance Portability and Accountability Act (HIPAA). This allows linkage of EMS and hospital data, tracking of OHCA events, and evaluation of efforts to improve resuscitation care. The ADHS Human Subjects Review Board and the University of Arizona Institutional Review Board have determined that, by virtue of being a public health initiative, neither the interventions nor their evaluation constitute Human Subjects Research and have approved the publication of de-identified data. The project is registered at ClinicalTrials.gov #NCT01258244.

2.4. Statistical analysis

The primary outcomes for this study were survival to hospital discharge and survival with favorable functional status [Cerebral Performance Category (CPC) Score = 1 or 2]. CC depth was assessed (1) as a continuous variable using the mean depth of each patient in millimeters (mm), (2) as a categorical variable (mean depth <38.0 mm, 38.0–50.9 mm, or ≥51.0 mm), and (3) as a continuous variable using the percentage of CCs that were ≥51.0 mm. Demographic data are shown along with descriptive statistics (means ± SD, median with IQR, proportions). For univariate analyses, we used linear regression to calculate means, 95% confidence intervals (CIs), and mean differences for mean depth and mean rate. Quantile (median) regression was used to calculate median, 95% CIs, and median differences for dispatch-to-scene arrival interval, age, compression fraction, and percent of compressions ≥51 mm for study outcomes. Univariate analyses for categorical and binary data consisted of proportions and 95% CIs, as well as differences in proportions along with 95% CIs. Logistic regression was used to assess the association between the various CC depth variables and outcomes. Hierarchical (mixed effects) logistic regression models ("xtmelogit", Stata version 12.1; StataCorp, College Station, TX) were used to explore the effects of, and to control for, clustering by EMS agency, hospitals (patients not transported were a single cluster), and community. The analysis included known independent risk factors for OHCA survival and functional outcomes as well as potential confounders associated with the outcomes and CC depth. Confounders considered were initial cardiac rhythm, EMS dispatch-to-scene arrival interval, age, sex, location of arrest, witnessed vs. unwitnessed arrest, provision of bystander CPR, quality of EMS MICR (high quality vs. low quality),[24] use of therapeutic hypothermia during prehospital or hospital care, and post- vs. pre-CPR quality improvement intervention.[5]

Fractional polynomial regression was used to assess the linearity of all continuous variables in the logit scale. Multiple imputation was used to account for the high number of missing CPR metric data points. Missing CPR quality data fit a monotone missing pattern (i.e. if one CPR quality metric was missing, all of them were missing) and we used linear regression to impute missing values for mean CC depth, mean rate, CC fraction, and percent of CCs ≥51 mm. Linear regression was used to impute dispatch-to-scene arrival interval. Compression fraction and percent of CCs ≥51 mm were truncated to 0 and 100 if imputed values were outside this range. We used all demographic variables in Table 1 for multiple imputation as well as the responding EMS agency, receiving hospital, and community of occurrence. Twenty imputed data sets were generated. Model fit and diagnostics were evaluated as described previously.[5] Because the number of variables in our final model was greater than 1 per 10 outcomes, we conducted a sensitivity analysis by constructing logistic regression models for each outcome that only included

Please cite this article in press as: Vadeboncoeur T, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. Resuscitation (2013), http://dx.doi.org/10.1016/j.resuscitation.2013.10.002

Table 1
Characteristics of study population.

Characteristics	N = 593	
	n (%)	Missing, n (%)
Age, yrs-median (IQR)	67 (55 to 78)	0
Male sex	394 (66.4)	0
Witnessed arrest	241 (40.6)	0
Initial rhythm upon EMS arrival		0
V-fib/V-tach	170 (28.7)	
PEA	117 (19.6)	
Asystole	306 (51.6)	
Location of arrest		0
Residential	407 (68.6)	
Medical facility	77 (13.0)	
Public	109 (18.4)	
Provision of bystander CPR	238 (40.1)	0
Adequate MICR	466 (78.6)	0
Prehospital ROSC	136 (22.9)	1 (0.2)
EMS dispatch to arrival interval-median (IQR)	5 (4 to 6)	34 (5.7)
Use of therapeutic hypothermia	60 (10.2)	0
Post (vs. Pre) intervention	312 (52.6)	0
Transported to hospital (vs. called in the field)	394 (66.4)	0
City		0
Mesa	484 (81.6)	
Flagstaff	109 (18.4)	
All rhythms		
Survival to hospital discharge	63 (10.6)	1 (0.2)
Favorable functional outcome (CPC score = 1 or 2)	50 (8.4)	2 (0.3)
Witnessed arrests & shockable rhythms (n = 170)		
Survival to hospital discharge	49 (28.99)	1 (0.6)
Favorable functional outcome (CPC score = 1 or 2)	40 (23.8)	2 (1.2)
Mean compression depth, mm-mean (SD)	49.8 (11.0)	175 (29.5)
Mean compression depth categories		175 (29.5)
<38 mm	68 (16.3)	
38–50.9 mm	152 (36.4)	
≥51 mm	198 (47.4)	
Mean compression rate, compressions/minute-mean (SD)	113.9 (18.1)	175 (29.5)
Percent of compressions 51+ mm-median (IQR)	49.3 (13.5 to 77.4)	176 (29.7)
Percent of time in compressions-median (IQR)	79.2 (67.5 to 86.8)	175 (29.5)

CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; IQR, interquartile range; MICR, minimally interrupted cardiac resuscitation; mm, millimeters; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; SD, standard deviation; V-fib, ventricular fibrillation; V-tach, ventral tachycardia.

covariates that had a p-value of ≤0.1 or were judged significant confounders of the relationship between CC depth and outcome (e.g., inclusion of a confounder changed the regression coefficient for mean depth approximately 10% or more).[26] All analyses (univariate and multivariable) that included CPR quality metrics used the imputed data, accounting for the variance across imputed data sets using Rubin's rules ("mi estimate" in Stata).

3. Results

A total of 593 consecutive adult OHCAs met inclusion criteria. Two cases were missing functional outcome data and one case was missing survival data (Fig. 1). Cases with missing data as well as demographic data are shown in Table 1. Median age was 67 yrs (IQR 55–78) and 66.4% were male. Overall, 136 patients (22.9%) achieved ROSC and 63 patients (10.6%) survived; 50 (8.4%) with a CPC of 1 or 2. Of witnessed arrests with an initial shockable rhythm 49/170 (29.0%) survived; 40 (23.8%) with favorable functional outcome (Table 1).

Mean CC depth was 49.8 mm, mean rate was 113.9 CC min^{-1}, and the median CC fraction was 79.2% (IQR 67.5–86.8%) (Table 1). Sixty-eight (16.3%) cases had a mean depth <38 mm, 152 cases (36.4%) had a mean depth between 38 and 51 mm and 198 (47.4%) had a mean depth ≥51 mm (Table 1). Depth was inversely associated with the compression rate (Table 2). In cases with a mean depth <38 mm, the mean rate was 125 CC min^{-1} (95% CI 121.2–128.8), while in those with a mean depth ≥51 mm, the mean rate was 105.7 CC min^{-1} (95% CI 103.0–108.0).

Compared to non-survivors, survivors were more likely to have witnessed arrests, an initial shockable rhythm, and to be treated with therapeutic hypothermia (Table 3). Rate was similar for survivors 113.5 (95% CI 108.5–118.6) and non-survivors 112.7 (95% CI 110.9–114.4) (Table 3). Depth was significantly deeper in survivors (53.6 mm; 95% CI 50.5–56.7) than in non-survivors (48.8 mm; 95% CI 47.6–50.0). Notably, the median percent of CCs ≥51 mm was 64.0% (95% CI 47.0–81.0) for survivors and 45.0% (95% CI 39.6–50.4) for non-survivors (Table 3).

Hierarchical logistic regression modeling showed that only clustering by hospital had a significant random effect and that including EMS agency and/or community did not change any coefficients by more that 5%. Thus, our final model only included hospital as a random effect. Table 4 shows the final logistic regression models. The odds of survival increased 1.29 times for every 5 mm increase in mean compression depth (aOR = 1.29; 95% CI 1.00–1.65). Likewise, a favorable functional outcome had 1.30 times greater odds for each 5 mm increase in depth (aOR = 1.30 95% CI 1.00–1.70). The proportion of CCs that were ≥51 mm did show a statistically significant relationship with outcomes. The odds of survival increased by 1.21 for each ten percent increase in the percent of compressions that were ≥51 mm. The odds of a favorable functional outcome also increased by 1.21 for each ten percent increase in the percent of compressions that were ≥51 mm.

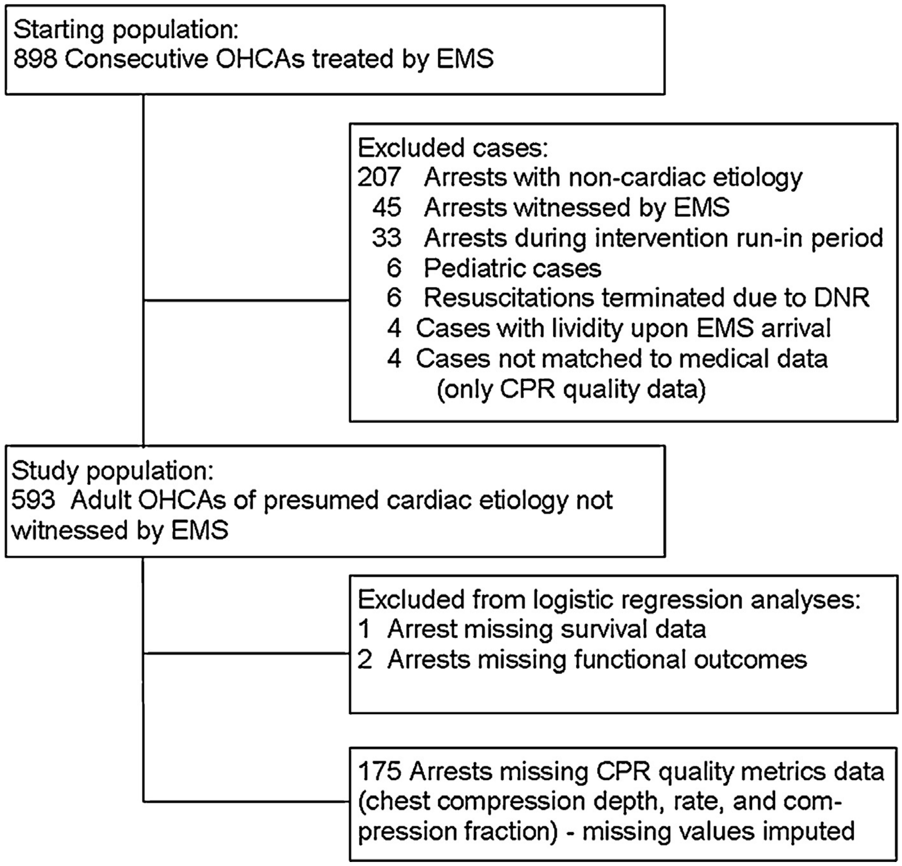

Fig. 1. Study participants.

Table 2
Relationship between mean chest compression rate and mean chest compression depth using imputed data.

Mean compression depth categories	Mean compression rate, mean (95% CI)*	Percent of compressions ≥51 mm, median (95% CI)**
<38.0 mm	125.0 (121.2 to 128.8)	0.6 (0 to 5.6)***
38–50.9 mm	115.6 (113.1 to 118.1)	29.4 (26.0 to 32.7)
≥51 mm	105.7 (103.0 to 108.0)	78.9 (76.0 to 81.9)
p-value for association	$p < 0.001$*	$p < 0.001$**

* Assessed using linear regression.
** Assessed using median regression.
*** Lower bound for 95% CI truncated at 0.

Sensitivity analysis showed that excluding variables from the final logistic regression model that were not significantly related to the outcomes or were not significant confounders between compression depth and outcomes (provision of bystander CPR, adequate MICR, location of arrest, dispatch-to-scene arrival interval) did not significantly change the results. The aORs per 5 mm increase in mean CC depth were 1.30 (95% CI: 1.03–1.65) and 1.33 (1.03–1.71) for survival and favorable functional outcome respectively. The aORs for the proportion of compressions ≥51 mm (per 10% increase) were 1.22 (1.03–1.44) for survival and 1.23 (1.02–1.47) for favorable functional outcome.

4. Discussion

High quality CPR impacts outcomes from OHCA and yet CPR quality remains highly variable in both the prehospital and in-hospital settings.[6–8,13,27–29] During resuscitations, healthcare providers frequently interrupt CCs, provide compressions of insufficient depth and rate, and over-ventilate patients.[13,14,30–33] We believe this is the first study using prospectively-collected prehospital CPR quality data showing a significant association between deeper compressions and both improved survival and favorable functional outcome from OHCA. This population of patients was part of a before/after intervention to improve EMS CPR quality. Our previous results showed that all CPR quality metrics and outcomes improved after our intervention.[5] This analysis shows that improved CC depth (mean and the proportion of compressions ≥51 mm) was independently associated with survival. This was not true of other metrics such as compression fraction or rate. In fact, after controlling for these other metrics as well as the intervention as a whole, depth remained a significant predictor of improved survival and favorable functional outcome (Table 4).

Given that the proportions for survival and favorable functional outcome were approximately 10% or less, the odds ratio is a good estimator of risk. The adjusted likelihood of survival increased by 29% (aOR = 1.29) and the likelihood of a favorable functional outcome, by 30% (aOR = 1.30) for every 5 mm increase in depth. Similarly, the likelihood of both survival and favorable functional outcome increased by 21% (aOR = 1.21) for each 10% increase in the percent of CCs ≥51 mm. Additionally, survivors were more likely to have been treated with mean compressions ≥51 mm than non-survivors (64% vs. 45%). While deeper compressions were positively

Table 3
Univariate analyses of various study characteristics for survival to hospital discharge and favorable functional outcome upon hospital discharge.

	Survival to hospital discharge			Functional outcome upon hospital discharge		
	Survived (*n* = 63)	Died (*n* = 529)	Difference (95% CI): survived–died	Favorable (CPC = 1 or 2, *n* = 50)	Unfavorable (CPC ≥3, *n* = 541)	Difference (95% CI): favorable–unfavorable
Age, yrs-median (95% CI)	62 (56 to 68)	68 (66 to 70)	-6 (−12 to 0)	60 (53 to 67)	68 (66 to 70)	−8 (−15 to −1)
Male sex, percent (95% CI)	61.9 (49.8 to 74.0)	67.1 (63.1 to 71.1)	−5.2 (−17.8 to 7.4)	66.0 (52.7 to 79.3)	66.7 (62.7 to 70.7)	−0.7 (−14.4 to 13.0)
Witnessed arrest, percent (95% CI)	77.8 (67.4 to 88.1)	36.1 (32.0 to 40.2)	41.7 (30.6 to 52.7)	78.0 (66.4 to 89.6)	37.0 (32.9 to 41.0)	41.0 (28.9 to 53.2)
Initial rhythm upon EMS arrival						
V-fib/V-tach, percent (95% CI)	77.8 (67.4 to 88.1)	22.7 (19.1 to 26.3)	55.1 (44.2 to 66.0)	80.0 (68.8 to 91.2)	23.7 (20.1 to 27.3)	56.3 (44.7 to 68.0)
PEA, percent (95% CI)	8.1 (12.2 to 14.9)	21.0 (17.5 to 24.5)	−12.9 (−20.5 to −5.3)	6.0 (−0.1 to 12.7)	20.9 (17.5 to 24.3)	−14.9 (−22.3 to 7.5)
Asystole, percent (95% CI)	12.9 (4.5 to 21.3)	56.3 (52.1 to 60.6)	−43.4 (−52.8 to −34.1)	12.0 (2.9 to 21.1)	55.5 (51.3 to 59.7)	−43.5 (−53.4 to −33.5)
Location of arrest						
Residential, percent (95% CI)	60.3 (48.1 to 72.5)	69.8 (65.8 to 73.7)	−9.4 (−22.1 to 3.3)	56.0 (42.1 to 69.9)	69.9 (66.0 to 73.7)	−13.9 (−28.2 to 0.4)
Medical facility, percent (95% CI)	9.5 (2.2 to 16.8)	13.4 (10.5 to 16.3)	−3.8 (−11.7 to 3.9)	8.0 (0.3 to 15.6)	13.5 (10.6 to 16.4)	−5.5 (−13.5 to 2.5)
Public, percent (95% CI)	30.2 (18.7 to 41.6)	16.8 (13.6 to 20.0)	13.3 (1.6 to 25.1)	36.0 (22.5 to 49.5)	16.6 (13.5 to 19.8)	19.3 (5.7 to 33.0)
Provision of Bystander CPR, percent (95% CI)	50.8 (38.3 to 63.3)	38.8 (34.6 to 42.9)	12.0 (−0.1 to 25.1)	48.0 (34.0 to 62.0)	39.2 (35.1 to 43.3)	8.8 (−5.6 to 23.3)
Adequate MICR, percent (95% CI)	84.1 (75.0 to 93.2)	78.1 (74.5 to 81.6)	6.1 (−3.6 to 15.7)	80.0 (68.8 to 91.2)	78.6 (75.1 to 82.0)	1.4 (−10.2 to 13.1)
EMS dispatch to arrival interval-median (95% CI)	5 (5 to 6)	5 (5 to 5)	0 (−1 to 1)	5 (4 to 6)	5 (5 to 5)	0 (−1 to 1)
Use of therapeutic hypothermia, percent (95% CI)	54.0 (41.5 to 66.4)	4.9 (3.1 to 6.8)	49.1 (36.6 to 61.5)	56.0 (42.1 to 69.9)	5.9 (3.9 to 7.9)	50.1 (36.2 to 64.0)
Post (vs. Pre) intervention, percent (95% CI)	61.9 (49.8 to 74.0)	51.5 (47.3 to 55.9)	10.3 (−2.4 to 23.0)	62.0 (48.4 to 75.6)	51.8 (47.5 to 56.0)	10.2 (−3.8 to 24.3)
Mean compression depth, mm-mean (95% CI)	53.6 (50.5 to 56.7)	48.8 (47.6 to 50.0)	4.8 (1.5 to 8.2)	53.5 (49.9 to 57.1)	48.9 (47.7 to 50.1)	4.6 (0.9 to 8.3)
Mean compression depth						
<38.0 mm, percent (95% CI)	5.8 (0 to 13.0)	18.5 (14.2 to 22.7)	−12.7 (−23.2 to −2.2)	6.8 (0 to 15.6)	18.1 (14.0 to 22.3)	−11.3 (−23.1 to 0.4)
38.0–50.9 mm, percent (95% CI)	35.5 (21.3 to 49.6)	38.1 (33.3 to 42.9)	−2.7 (−17.4 to 12.0)	32.9 (16.9 to 48.9)	38.4 (33.7 to 43.1)	−5.5 (−22.0 to 11.1)
≥51.0 mm, percent (95% CI)	58.7 (44.8 to 72.7)	43.4 (38.4 to 48.3)	15.4 (0.6 to 30.1)	60.3 (44.5 to 76.1)	43.5 (38.6 to 48.4)	16.8 (0.3 to 33.4)
Mean compression rate, compressions/minute-mean (95% CI)	113.5 (108.5 to 118.6)	112.7 (110.9 to 114.4)	0.8 (−4.6 to 6.3)	113.3 (107.6 to 119.0)	112.8 (111.1 to 114.5)	0.5 (−5.5 to 6.5)
Percent of compressions ≥51.0 mm-median (95% CI)	64.0 (47.1 to 81.0)	45.0 (39.6 to 50.4)	19.0 (1.0 to 37.1)	59.3 (49.3 to 69.4)	44.9 (41.6 to 48.1)	14.5 (4.0 to 25.0)
Percent of time in compressions-median (95% CI)	75.6 (69.6 to 81.7)	78.1 (76.0 to 80.2)	−2.5 (−8.7 to 3.8)	70.6 (66.0 to 75.1)	76.0 (74.5 to 77.5)	−5.4 (−10.1 to −0.8)

CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; CI, confidence interval; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation; mm, millimeters; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; V-fib, ventricular fibrillation; V-tach, ventral tachycardia.

Table 4
Logistic regression analyses for compression depth and survival to hospital discharge and favorable functional outcome upon hospital discharge.

	Survival to hospital discharge		Favorable functional outcome (CPC 1 or 2)	
	Adjusted OR**	95% CI	Adjusted OR***	95% CI
Mean compression depth (per 5 mm increase)*	1.29	(1.00 to 1.65)	1.30	(1.00 to 1.70)
Mean compression depth (categories)*				
<38.0 mm	1 (REF.)		1 (REF.)	
38.0–50.9 mm	5.92	(0.69 to 51.13)	5.00	(0.44 to 57.12)
≥51.0 mm	7.99	(0.87 to 73.17)	7.74	(0.63 to 94.69)
Mean compression 38 mm or greater*	6.66	(0.8 to 55.44)	5.97	(0.57 to 62.47)
Percent of compressions ≥51 mm (per 10% increase)*	1.21	(1.02 to 1.45)	1.21	(1.00 to 1.46)
Compression fraction (per 10% increase)	0.62	(0.39 to 1.00)	0.48	(0.28 to 0.82)
Mean compression rate (per 10 compressions/minute)	0.97	(0.71 to 1.32)	0.88	(0.62 to 1.26)
Post vs. pre intervention	3.93	(1.15 to 13.42)	5.09	(1.31 to 19.76)
Witnessed arrest	3.82	(1.64 to 8.91)	3.51	(1.35 to 9.14)
Shockable rhythm (V-fib/V-tach) on EMS arrival	7.68	(3.17 to 18.63)	8.04	(2.93 to 22.06)
Age (per year)	0.98	(0.95 to 1.00)	0.97	(0.94 to 0.99)
Male sex	0.38	(0.17 to 0.85)	0.53	(0.21 to 1.33)
Provision of TH (prehospital or hospital)	16.45	(6.81 to 39.71)	15.97	(5.8 to 43.97)
Provision of Bystander CPR	1.34	(0.62 to 2.92)	1.10	(0.46 to 2.63)
Dispatch to EMS arrival interval (per minute)	0.99	(0.97 to 1.01)	0.99	(0.97 to 1.02)
Location of arrest				
Residential	1 (REF.)		1 (REF.)	
Medical facility	1.32	(0.39 to 4.51)	1.29	(0.30 to 5.55)
Public area	1.31	(0.52 to 3.26)	1.83	(0.68 to 4.91)
Adequate MICR	1.63	(0.56 to 4.71)	1.07	(0.35 to 3.26)

CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; CI, confidence interval; EMS, emergency medical services; MICR, minimally interrupted cardiac resuscitation; mm, millimeters; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; TH, therapeutic hypothermia; V-fib, ventricular fibrillation; V-tach, ventral tachycardia.

* Adjusted for all other variables without "*".
** Hosmer–Lemeshow goodness-of-fit p-value = 0.76.
*** Hosmer–Lemeshow goodness-of-fit p-value = 0.74.

associated with improved outcomes, the optimal depth remains unknown.

Three human studies suggest that CCs ≥51 mm improve early outcomes. Babbs assessed 695 AED recordings and found that patients who were shocked >3 min after the initiation of CCs deeper than 50 mm had higher rates of ROSC than those with compressions <51 mm.[20] Edelson, using monitor/defibrillator measurement and real-time CPR feedback in 60 out-of-hospital and in-hospital arrests for which a shock was delivered, found that incremental increases in CC depth were associated with successful defibrillation.[21] As part of a study comparing out-of-hospital CPR quality with and without automated feedback, Kramer-Johansen found that, for each 1 mm increase in depth, the rate of survival to hospital admission increased significantly.[23]

Recently, Stiell reported on 1029 OHCA cases using data obtained prior to the release of the 2010 AHA and ERC Guidelines.[15] Fifty-three percent of cases had a median depth <38 mm and 91.6% had a median depth <50 mm. The authors found an inverse association between compression rate and depth, a finding also demonstrated in our analysis and by others.[34] Stiell reported a non-significant improvement in outcomes with deeper compressions. In addition, regression analysis revealed no survival advantage for those receiving the 2005 guideline range of 38–51 mm compared to the 2010 recommended depth of ≥51 mm. However, only 8.4% of victims received compressions meeting the 2010 recommendation for depth.

There are several plausible explanations for the differences between our study and Stiell's. First, the variation in depth was larger in our study. Second, the depth parameters themselves were much greater. Mean depth for our study population was 49.3 mm and standard deviation was 14. Mean depth in Stiell's report was only 37.9 mm and the standard deviation only 10. Additionally, 45% of our patients had mean depth of ≥51 mm while only 9% of those in Stiell's study were in this range. Thus, in Stiell's report, the compression depths among patients may have been too uniform to allow detection of a difference. In contrast, our study had a much greater variance in depth and this may have provided the ability to detect this association statistically. Furthermore, if the 2010 guidelines are in fact correct in recommending a depth ≥51 mm, then Stiell's study may simply have had too few patients receiving sufficient depth to show improved survival in this group. The differences in depths between the two reports may have been related to the fact that one of the explicit goals of our study was to increase depth to ≥51 mm.[21]

The results of our study, taken in context with the prior literature, suggest that deeper compressions have a positive impact on survival from OHCA. While this study cannot identify the optimal depth, our findings are consistent with the 2010 guideline-recommended depth of ≥51 mm.

4.1. Limitations

While this study demonstrated independent associations between increasing depth and improved outcomes, its observational design does not allow a firm determination of causality. In addition, the EMS agencies in this study use the MICR protocol (in contrast to ACLS) and the protocol differences could potentially impact the influence of depth on outcomes.[24] We used one type of CPR measurement and feedback device making the external validity and reproducibility of these results in other EMS systems using different devices unclear. Also, as is common in EMS evaluations, there were some missing CPR data points. We used multiple imputation to reduce the chance of bias that can occur from omitting cases with missing data. Finally, in this type of investigation, the effect of cluster sampling can impact the conclusions. Thus, unlike previous studies, we accounted for this effect in our analysis.

5. Conclusions

In this prospective study, deeper chest compressions performed by professional EMS rescuers were independently associated with improved survival and favorable functional outcome from OHCA. These findings are consistent with the 2010 AHA recommendation to compress the chest at least 51 mm (2 inches) in an effort to optimize the cardiopulmonary resuscitation provided to victims of OHCA.

Conflict of interest statement

Annemarie Silver, PhD, is an employee of Zoll Medical Corporation.

Funding source

Drs. Bobrow, Stolz, and Spaite disclose that the University of Arizona receives support from the Medtronic Foundation HeartRescue Program to help fund investigator time and projects involving community-based translation of resuscitation science.

Acknowledgements

The authors thank Guardian Medical Transport and the Mesa Fire and Medical Department for participating in the SHARE Program and for their efforts to improve survival from OHCA. We thank ZOLL Medical which assisted in the data collection for this study.

References

1. Roger VL, Go AS, Lloyd-Jones DM, et al. Heart disease and stroke statistics – 2012 update: a report from the American Heart Association. Circulation 2012;125:e2–220.
2. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. J Am Med Assoc 2008;300:1423–31.
3. Rea TD, Eisenberg MS, Sinibaldi G, White RD. Incidence of EMS-treated out-of-hospital cardiac arrest in the United States. Resuscitation 2004;63:17–24.
4. Sasson C, Rogers MA, Dahl J, Kellermann AL. Predictors of survival from out-of-hospital cardiac arrest: a systematic review and meta-analysis. Circ Cardiovasc Qual Outcomes 2010;3:63–81.
5. Bobrow BJ, Vadeboncoeur TF, Stolz U, et al. The influence of scenario-based training and real-time audiovisual feedback on out-of-hospital cardiopulmonary resuscitation quality and survival from out-of-hospital cardiac arrest. Ann Emerg Med 2013;62:47–56.
6. Gallagher EJ, Lombardi G, Gennis P. Effectiveness of bystander cardiopulmonary resuscitation and survival following out-of-hospital cardiac arrest. J Am Med Assoc 1995;274:1922–5.
7. Van Hoeyweghen RJ, Bossaert LL, Mullie A, et al. Quality and efficiency of bystander CPR. Belgian Cerebral Resuscitation Study Group. Resuscitation 1993;26:47–52.
8. Wik L, Steen PA, Bircher NG. Quality of bystander cardiopulmonary resuscitation influences outcome after prehospital cardiac arrest. Resuscitation 1994;28:195–203.
9. Handley AJ, Koster R, Monsieurs K, Perkins GD, Davies S, Bossaert L. European Resuscitation Council guidelines for resuscitation 2005. Section 2. Adult basic life support and use of automated external defibrillators. Resuscitation 2005;67:S7–23.
10. 2005 American Heart Association Guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2005;112:IV1–203.
11. Travers AH, Rea TD, Bobrow BJ, et al. Part 4: CPR overview: 2010 American Heart Association Guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010;122:S676–84.
12. Koster RW, Baubin MA, Bossaert LL, et al. European Resuscitation Council guidelines for resuscitation 2010 Section 2. Adult basic life support and use of automated external defibrillators. Resuscitation 2010;81:1277–92.
13. Wik L, Kramer-Johansen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. J Am Med Assoc 2005;293:299–304.
14. Olasveengen TM, Tomlinson AE, Wik L, et al. A failed attempt to improve quality of out-of-hospital CPR through performance evaluation. Prehosp Emerg Care 2007;11:427–33.
15. 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.
16. Martin GB, Carden DL, Nowak RM, Lewinter JR, Johnston W, Tomlanovich MC. Aortic and right atrial pressures during standard and simultaneous compression and ventilation CPR in human beings. Ann Emerg Med 1986;15:125–30.
17. Paradis NA, Martin GB, Rivers EP, et al. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. J Am Med Assoc 1990;263:1106–13.
18. 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.
19. Tomlinson AE, Nysaether J, Kramer-Johansen J, Steen PA, Dorph E. Compression force-depth relationship during out-of-hospital cardiopulmonary resuscitation. Resuscitation 2007;72:364–70.
20. Babbs CF, Kemeny AE, Quan W, Freeman G. A new paradigm for human resuscitation research using intelligent devices. Resuscitation 2008;77:306–15.
21. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137–45.
22. Edelson DP, Litzinger B, Arora V, et al. Improving in-hospital cardiac arrest process and outcomes with performance debriefing. Arch Intern Med 2008;168:1063–9.
23. 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.
24. Bobrow BJ, Clark LL, Ewy GA, et al. Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. J Am Med Assoc 2008;299:1158–65.
25. Bobrow BJ, Vadeboncoeur TF, Clark L, Chikani V. Establishing Arizona's statewide cardiac arrest reporting and educational network. Prehosp Emerg Care 2008;12:381–7.
26. Hosmer DWaL S, editor. Applied logistic regression. 2nd ed. Hoboken, NJ: John Wiley and Sons, Inc; 2005.
27. van Alem AP, Sanou BT, Koster RW. Interruption of cardiopulmonary resuscitation with the use of the automated external defibrillator in out-of-hospital cardiac arrest. Ann Emerg Med 2003;42:449–57.
28. Valenzuela TD, Kern KB, Clark LL, et al. Interruptions of chest compressions during emergency medical systems resuscitation. Circulation 2005;112:1259–65.
29. Aufderheide TP, Pirrallo RG, Yannopoulos D, et al. Incomplete chest wall decompression: a clinical evaluation of CPR performance by EMS personnel and assessment of alternative manual chest compression-decompression techniques. Resuscitation 2005;64:353–62.
30. Abella BS, Edelson DP, Kim S, et al. CPR quality improvement during in-hospital cardiac arrest using a real-time audiovisual feedback system. Resuscitation 2007;73:54–61.
31. Abella BS, Sandbo N, Vassilatos P, et al. Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. Circulation 2005;111:428–34.
32. Aufderheide TP, Sigurdsson G, Pirrallo RG, et al. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. Circulation 2004;109:1960–5.
33. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. J Am Med Assoc 2005;293:305–10.
34. Monsieurs KG, De Regge M, Vansteelandt K, et al. Excessive chest compression rate is associated with insufficient compression depth in prehospital cardiac arrest. Resuscitation 2012;83:1319–23.