What Is the Optimal Chest Compression Depth During Out-of-Hospital Cardiac Arrest Resuscitation of Adult Patients?

Ian G. Stiell, MD; Siobhan P. Brown, PhD; Graham Nichol, MD; Sheldon Cheskes, MD; Christian Vaillancourt, MD; Clifton W. Callaway, MD; Laurie J. Morrison, MD; James Christenson, MD; Tom P. Aufferheide, MD; Daniel P. Davis, MD; Cliff Free, EMT-P; Dave Hostler, PhD; John A. Stouffer, EMT-P; Ahamed H. Idris, MD; and the Resuscitation Outcomes Consortium Investigators

Background—The 2010 American Heart Association guidelines suggested an increase in cardiopulmonary resuscitation compression depth with a target >50 mm and no upper limit. This target is based on limited evidence, and we sought to determine the optimal compression depth range.

Methods and Results—We studied emergency medical services–treated out-of-hospital cardiac arrest patients from the Resuscitation Outcomes Consortium Prehospital Resuscitation Impedance Valve and Early Versus Delayed Analysis clinical trial and the Epistry-Cardiac Arrest database. We calculated adjusted odds ratios for survival to hospital discharge, 1-day survival, and any return of circulation. We included 9136 adult patients from 9 US and Canadian cities with a mean age of 67.5 years, mean compression depth of 41.9 mm, and a return of circulation of 31.3%, 1-day survival of 22.8%, and survival to hospital discharge of 7.3%. For survival to discharge, the adjusted odds ratios were 1.04 (95% CI, 1.00–1.08) for each 5-mm increment in compression depth, 1.45 (95% CI, 1.20–1.76) for cases within 2005 depth range (>38 mm), and 1.05 (95% CI, 1.03–1.08) for percentage of minutes in depth range (10% change). Covariate-adjusted spline curves revealed that the maximum survival is at a depth of 45.6 mm (15-mm interval with highest survival between 40.3 and 55.3 mm) with no differences between men and women.

Conclusions—This large study of out-of-hospital cardiac arrest patients demonstrated that increased cardiopulmonary resuscitation compression depth is strongly associated with better survival. Our adjusted analyses, however, found that maximum survival was in the depth interval of 40.3 to 55.3 mm (peak, 45.6 mm), suggesting that the 2010 American Heart Association cardiopulmonary resuscitation guideline target may be too high.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT00394706.

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Key Words: cardiopulmonary resuscitation ■ emergency medical services ■ heart arrest

Out-of-hospital cardiac arrest (OHCA) leads to an estimated 330,000 deaths each year in the United States and Canada. Although overall survival for treated OHCA is low, hospital discharge rates vary from 3.0% to 16.3%. This variation in survival can be partly attributed to local differences in the 5 key links in the chain of survival: rapid emergency medical services (EMS) access, early cardiopulmonary resuscitation (CPR), early defibrillation, early advanced cardiac life support, and effective postresuscitation care. Considerable efforts by communities and hospitals to strengthen these links have led to only modestly better survival rates in recent years.

Clinical Perspective on p 1970

In recent years, those involved in cardiac resuscitation have recognized that the quality, quantity, and timeliness of CPR are key determinants for survival from cardiac arrest and that
delivery of chest compressions is often poor. Recent technological advances now allow for the detailed measurement and review of key compression parameters. Using this technology, Christenson et al and Vaillancourt et al demonstrated an association between outcomes of OHCA patients and the proportion of each resuscitation minute during which compressions were delivered (chest compression fraction). Cheskes et al found that longer perishock and preshock pauses were independently associated with a decrease in survival to hospital discharge in patients presenting in a shockable rhythm. Idris et al described an association between chest compression rate and return of spontaneous circulation.

Chest compression depth is another aspect of CPR for which data are limited. Current CPR guidelines for compression rate and depth have been published, with no upper limit specified. For compression depth, clinicians recommended a depth range of 38 to 50 mm, whereas protestations of impedance-based CPR machines recommended a depth range of 50 mm (2 in). This review found that shorter perishock and preshock pauses were independently associated with a decrease in survival to hospital discharge in patients presenting in a shockable rhythm. Idris et al described an association between chest compression rate and return of spontaneous circulation.

We included all individuals from the ROC PRIMED trial or the ROC Epistry, ≥18 years of age, who experienced nontraumatic cardiopulmonary arrest outside of the hospital within the catchment area of a participating ROC EMS agency and were treated with defibrillation or delivery of chest compressions by EMS providers. We included patients with any initial cardiac rhythm. We excluded patients who did not have attempts at resuscitation by EMS, with an obvious cause of arrest, whose arrests were EMS witnessed, who received a shock from a bystander-applied automated external defibrillator, and anyone who had ≥5 minutes of EMS CPR before the pads were applied. We also excluded patients for who ≥1 minute of electronic CPR compression depth data were not available. These data may have been unavailable because some EMS agencies do not use defibrillators with accelerometers capable of measuring compression depth or because of inadvertent failure to capture and transmit the data.

The ROC PRIMED trial and the ROC Epistry were reviewed and approved by the appropriate local institutional review boards (United States) or research ethics boards (Canada) without the need for informed consent from subjects. Strict confidentiality was maintained at all times, and no personal identifiers were retained in the database.

Data Collection
The characteristics of chest compressions were measured via an accelerometer interface between the rescuer and the patient’s chest using commercially available defibrillators. Tracings were acquired and downloaded from Phillips (N=1869; Andover, MA) and ZOLL (N=7246; Chelmsford, MA) defibrillators. CPR process measures, including compression rate, chest compression fraction, and compression depth, were calculated by proprietary automated external defibrillator analytic software. Chest compression fraction was defined as the proportion of resuscitation time without spontaneous circulation during which chest compressions were administered. Compression depth was defined as the posterior depression of the anterior chest wall in millimeters. The mean compression values for all minute intervals were averaged for each patient using all available minutes in the first 10 minutes after pads were placed. For compression depth, we defined depth within the recommended range as per the 2005 international guidelines, with an average depth of ≥38 mm. We described the case as being within the recommended depth if the mean depth was ≥38 mm for >60% of the minutes recorded.

Patient and clinical data were abstracted from EMS and hospital records using standardized definitions for patient characteristics, EMS process, and outcome at hospital discharge. Data were abstracted locally, coded without personal health information, and transmitted to the data coordinating center electronically. Site-specific quality assurance included initial EMS provider training in data collection and continuing education of EMS providers. The data coordinating center assured the quality of the data by a variety of techniques.

Outcome Measures
The primary outcome was survival to hospital discharge, defined as discharged alive from hospital after the index OHCA. Patients who were transferred to another acute care facility (eg, to undergo implantable cardioverter defibrillator placement) were considered to still be hospitalized. Patients were considered discharged if transferred to a nonacute ward or facility. The secondary outcomes were survival to the next calendar day and return of spontaneous circulation (ROSC). Survival for 1 day meant that the patient was still alive 1 day past the date of the event. ROSC refers to the presence of a palpable pulse for any duration of time before arrival at the hospital. Data were abstracted from collated EMS and hospital source documents.

Statistical Analysis
All of the statistical analyses were performed with commercially available statistical packages (SAS version 9.1.3; SAS Institute, Cary, NC; R version 2.14.1; R Foundation for Statistical Computing, Vienna, Austria). Summary results are presented as mean ±SD or median (interquartile range). To test differences in baseline characteristics between subjects who did and did not survive to discharge, likelihood ratio χ² tests or t tests were used as appropriate. ANOVA

Methods
Design and Setting
The Resuscitation Outcomes Consortium (ROC) is composed of 10 US and Canadian universities and their regional EMS systems and has a mandate to conduct large controlled trials of prehospital interventions for cardiac arrest and trauma. This study represents an analysis of consecutive OHCA cases prospectively gathered in the recent ROC Prehospital Resuscitation Impedance Valve and Early Versus Delayed Analysis (PRIMED) trial or in the ROC Epistry-Cardiopulmonary Arrest.24 The ROC PRIMED trial used a partial factorial design, whereby most patients were randomly assigned to 2 concurrent protocols. The first protocol compared early rhythm analysis versus later rhythm analysis, and the second protocol compared use of an impedance threshold device versus use of a sham impedance threshold device. The ROC Epistry is a prospective multicenter observational registry of OHCA in EMS agencies and receiving institutions and includes patient outcomes and electronic data on the CPR process.25

The ROC EMS network consists of 36000 EMS professionals within 260 EMS agencies; provides coverage to an estimated 24 million people from urban, suburban, and rural communities; and transports patients to 287 different hospitals.20 This analysis included OHCA patients treated by EMS and for whom electronic compression depth data were available. Sites that did not have the technical capacity to measure compression depth were not included, and, hence, this study included data from 95 participating EMS agencies affiliated with 9 US and Canadian ROC sites. At the time of data collection, OHCA patients were being treated according to the 2005 guideline standards for compression depth (38–50 mm).

Population
We included all individuals from the ROC PRIMED trial or the ROC Epistry, ≥18 years of age, who experienced nontraumatic cardiopulmonary arrest outside of the hospital within the catchment area of a participating ROC EMS agency and were treated with defibrillation or delivery of chest compressions by EMS providers.
was used to compare mean compression depths across study sites. The association between depth and rate categories was tested with a likelihood ratio $\chi^2$ test. The association between compression depth (evaluated separately with 4 approaches) and outcomes of interest was quantified using multivariate logistic regression with the Huber-White sandwich SE. The key covariates/potential confounders assessed were age, sex, public location, bystander witnessed arrest, bystander CPR, EMS response time, CPR fraction, compression rate, site, and device manufacturer. We did not include cardiac rhythm, because this is potentially a path variable. Smoothing splines were creating by including the b-spline used to explore the relationship between average compression depth and outcome, with a goal of finding the optimal 15-mm interval for depth. Smoothing splines were creating by including the b-spline basis for a natural cubic spline of depth in a logistic regression model in place of the other depth measures. Four degrees of freedom were used in the unadjusted models and 5 in the adjusted.

**Results**

During the study period from June 2007 to December 2010, EMS agencies in the 10 participating ROC sites treated 27,986 cases of cardiac arrest. Of these patients, all but 9266 were excluded for the reasons indicated in Figure 1; another 130 cases had missing data, leaving a final study group of 9136 patients. The most common reason for exclusion was missing time from 911 telephone call to EMS arrival (65 cases); missing subject age was the next most common (n=35). The other 30 subjects were missing various covariates used in the regression models. The patients in the final study cohort were similar in terms of clinical significance for characteristics and outcomes to those excluded, except that none were from British Columbia, more were from Toronto, and they had a lower survival rate (Table I in the online-only Data Supplement).

The patients in the study were typical of OHCA cases, with only 13% from a public location, 44% bystander witnessed, 42% receiving bystander CPR, and 99% having an advanced life-support EMS crew in attendance (Table 1). The mean values for CPR process measures were compression rate of 108 (SD, 16) per minute and chest compression fraction of 0.68 (SD, 0.15). Of all patients, 31.3% had ROSC, 22.8% survived 1 day, and 7.3% survived to hospital discharge.

Table 2 displays compression depth data, which was available per case for a median of 7 minutes (interquartile range, 5–10). The overall median chest compression depth was 41 mm (interquartile range, 35–48 mm), and 36% of cases had a mean value <38 mm. In addition, we calculated that 40% of cases were not within the 2005 recommended range for depth. We also found (Table II in the online-only Data Supplement) that compression rate and depth were inversely related ($P<0.001$), such that 53% of cases with a compression rate >120 also had depth <38 mm.

Figure 2 shows the distribution of survival to hospital discharge by compression depth categories with unadjusted smoothed spline plots and shows much poorer outcomes for patients with the lowest mean compression depth values. There is a gradual increase in the probability of survival as average depth increases, but this appears to fall off again at the greater depth levels, with a similar pattern for both men and women. See also Figure I in the online-only Data Supplement.

We compared the univariate characteristics of the 666 patients who survived to discharge with those who did not (Table 3) and found many correlates with better outcome, including whether the compression depth was greater and within the recommended range ($P<0.001$). We conducted 4 multivariate analyses (Table 4) to evaluate the association of compression depth and other covariates on the 3 survival measures. Not unexpectedly, the factors most strongly associated with good outcomes were arrest in a public location and bystander witnessed cases (odds ratios not shown). All 4 of the depth measures (mean values, categories, and within recommended range) were independently associated with better outcomes for all 3 of the survival measures. For survival to discharge, the adjusted odds ratios were 1.04 (95% CI, 1.00–1.08) for each 5-mm increment in compression depth, 1.45 (95% CI, 1.20–1.76) for cases within depth range, and 1.05 (95% CI, 1.03–1.08) for percentage of minutes in depth range (10% change). Sensitivity analyses adjusted for initial rhythm and duration of CPR and found similar results except for little association between compression depth and survival for patients with a nonshockable rhythm (Table III in the online-only Data Supplement).

Finally, we created a covariate-adjusted smoothed spline plot with 95% CIs of the probability of survival versus compression depth. Inspection of Figure 3A reveals that survival peaks at 45.6 mm (15-mm interval with highest survival between 40.3 and 55.3 mm). The survival curves are very similar for men and women (Figure 3B).

![Figure 1. Patient enrollment.](image-url)
Interpretation of Findings

This large ROC data set allowed us to accurately evaluate the role of CPR compression depth in the outcomes of OHCA patients. We found that adequate compression depth was often not provided according to the 2005 guidelines and usually not provided according to the 2010 guidelines. We also found a significantly deleterious effect on compression depth when the mean compression rate was faster than recommended. We demonstrated that increased depth, using a variety of measures, is strongly associated with short-term outcomes, as well as better survival to hospital discharge. A covariate-adjusted spline analysis further shows that the maximum survival in this sample was observed in the mean depth interval of 40.3 to 55.3 mm (peak, 45.6 mm). Finally, despite a large presumed difference in weight between men and women, their optimal compression depth appears to be the same. These findings do not support recent guideline changes that recommend compression depth exceed 50 mm (2 in) with no upper limit specified.

Previous Studies

The 2010 CPR guidelines significantly increased the recommended minimum compression depth from 38 to 50 mm but acknowledged insufficient evidence to indicate a specific upper limit.3,16 Although there have been some animal30–32 and human data suggesting better outcomes with increased compression depth, the evidence for depth >50 mm is very sparse. Most clinical studies have tended to evaluate overall CPR performance or feedback, usually in patients with shockable rhythms, and have not focused on the independent impact of compression depth.7,17–21 These studies have been relatively small, with insufficient power to evaluate clinically important outcomes or to compare different levels of depth. Edelson et al18 found an association between greater compression depth and shock success in 60 cases but had only 5 patients with depth >50 mm.22 A subsequent larger study of in-hospital cardiac arrest debriefing demonstrated better ROSC with better overall CPR performance but did not isolate specific compression depth levels as a factor.21 Kramer-Johansen et al20 evaluated 284 patients and found better hospital admission rates with increased compression depth, but very few cases had depth >50 mm. Babbs et al22 examined a library of...
prehospital CPR process data and found, in 101 patients with depth >51 mm, a higher rate of electric conversion but no difference in ROSC or other clinical outcomes.

Subsequent to the 2010 CPR guidelines, our group published a specific compression depth analysis of 1029 OHCA cases from the ROC Epistry. We found a strong association...
between survival outcomes and increased compression depth but had insufficient power to identify the optimal compression depth for adult men or women.

Limitations and Strengths
The study population represents a consecutive sample of cases from sites where compression depth could be measured and during a period when the 2005 guideline standards were in use. Regardless, we could detect no selection bias in our cases compared with those not included. Our records could not capture CPR data before the placement of accelerometer pads, a time period estimated to be <30 seconds (median, 16 seconds; mean, 29 seconds), and we did not examine data beyond 10 minutes of CPR. We did not have data for body size, firmness of the surface under the patient, leaning, or duty cycle, all possible confounders to the interpretation of compression depth data. We did, however, adjust for sex, which may be considered a crude proxy for weight, and found no difference between men and women. We had no measurements for children under age 18 years. We did not reliably capture data on whether device feedback was provided to providers.

The major strengths of the study include a large sample of patients with all initial rhythms, from 9 geographically disparate locations in the US and Canada, and receiving use of
devices from 2 different manufacturers. The overall survival-to-discharge proportion of 7.3% is quite reasonable, considering that we excluded cases witnessed by EMS or that received bystander AED shocks. With 1668 patients who received an average compression depth >50 mm, we were able to conduct robust analyses on clinically important outcomes and evaluate depth in a variety of ways.

Clinical Implications

This study has a number of important implications for those performing CPR. Our data clearly indicate that ROSC, short-term survival, and survival to discharge are better when compression depth is greater. Compared with the 2010 guideline recommendation depth of >50 mm, however, we found a peak effect at 45.6 mm within an interval of 40.3 to 55.3 mm, with similar results for both men and women. Hence, we believe that professional CPR providers must be mindful of achieving adequate compression depth but without going too deep. In the absence of other large studies, we anticipate that future recommendations for optimal compression depth for adults may be in the range of 40 to 55 mm. Providers must be cognizant of achieving proper compression depth along with other CPR process measures, such as rate, fraction, and perishock pauses. Of note is that depth and rate are inversely related, such that exceeding the target for one will likely lead to underperformance for the other. How best to assist EMS responders in providing excellent CPR is unknown, but presumably this includes a combination of good training, CPR process debriefing, and possibly real-time feedback.

Research Implications

Clinical studies of the CPR process are difficult to conduct but are essential if we are to know the optimal targets and interplay

### Table 4. Adjusted Odds Ratios for Association of 4 Separate Depth Measures With 3 Survival Outcomes

<table>
<thead>
<tr>
<th>Compression Depth Measure</th>
<th>Prehospital ROSC</th>
<th>Survival to Day After Arrest</th>
<th>Survival to Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adjusted OR (CI)*</td>
<td>P Value</td>
<td>Adjusted OR (CI)*</td>
</tr>
<tr>
<td>Compression depth (5-mm increments)</td>
<td>1.06 (1.04–1.08)</td>
<td>&lt;0.001</td>
<td>1.05 (1.03–1.08)</td>
</tr>
<tr>
<td>Compression depth category, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;38</td>
<td>0.70 (0.60–0.80)</td>
<td>0.71 (0.61–0.83)</td>
<td>0.69 (0.53–0.90)</td>
</tr>
<tr>
<td>38–51</td>
<td>0.86 (0.75–0.97)</td>
<td>0.88 (0.76–1.01)</td>
<td>1.03 (0.82–1.31)</td>
</tr>
<tr>
<td>&gt;51 Reference</td>
<td>&lt;0.001†</td>
<td>Reference</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Within depth range‡</td>
<td>1.27 (1.15–1.40)</td>
<td>&lt;0.001</td>
<td>1.25 (1.11–1.39)</td>
</tr>
<tr>
<td>Percentage of minutes in depth range (10% change)</td>
<td>1.04 (1.02–1.05)</td>
<td>&lt;0.001</td>
<td>1.04 (1.02–1.05)</td>
</tr>
</tbody>
</table>

The ORs for each of the depth measures were estimated from a separate multivariable logistic regression model. The estimates and CIs for the other covariates come from the model that includes depth as a linear variable. CI indicates confidence interval; CPR, cardiopulmonary resuscitation; OR, odds ratio; and ROSC, return of spontaneous circulation.

*Data were adjusted for age, sex, public location, bystander witnessed, bystander CPR, CPR fraction, chest compression rate, time from 911 call to emergency medical services at scene, device manufacturer, and study site.

†Data show the type III test of the association between depth and outcome.

‡Average depth was ≥38 mm for ≥60% of minutes with CPR process measures available.

![Figure 3. A. Covariate-adjusted survival to discharge by compression depth with 95% confidence intervals (CIs). B. Covariate-adjusted survival to discharge by compression depth for men and women separately.](http://circ.ahajournals.org/)

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among compression depth, compression rate, ventilations, compression fraction, duty cycle, and recoil. In addition, more data for children are required to understand the best CPR process parameters to optimize survival. Ultimately we need randomized intervention trials that evaluate the impact of different combinations of CPR process targets on patient survival.

Conclusions
This large study of OHCA patients from a variety of settings demonstrated that increased CPR compression depth is strongly associated with better survival to hospital discharge. An adjusted analysis, however, found that maximum survival was in the mean depth interval of 40.3 to 55.3 mm (peak, 45.6 mm), suggesting that the 2010 American Heart Association CPR guideline target may be too high. We encourage the use of all validated strategies for prehospital and in-hospital cardiac arrest resuscitations to assist rescuers to stay within range for key CPR parameters.

Acknowledgments
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Disclosures
None.

References


### CLINICAL PERSPECTIVE

The 2010 American Heart Association cardiopulmonary resuscitation (CPR) guidelines recommended a CPR compression depth for adults of ≥50 mm (2 in), with no upper limit specified, although this was based on limited human data. This study of 9136 adult out-of-hospital cardiac arrest patients from 9 US and Canadian cities in the Resuscitation Outcomes Consortium found that adequate compression was often not provided, particularly when the compression rate was faster than recommended. The study clearly demonstrated that increased CPR compression depth is strongly associated with better survival to hospital discharge. In addition, however, analyses showed that the maximum survival was observed in the mean depth interval of 40.3 to 55.3 mm (peak, 45.6 mm). Finally, despite a large presumed difference in weight between men and women, their optimal compression depth appeared to be the same. The authors conclude that the 2010 American Heart Association CPR guideline target for compression depth may be too high. They encourage the use of all validated strategies for prehospital and in-hospital cardiac arrest resuscitations to assist rescuers to stay within range for key CPR parameters, including compression depth and rate.
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The online version of this article, along with updated information and services, is located on the
World Wide Web at:
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Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2014/09/24/CIRCULATIONAHA.114.008671.DC1
Summary results are presented as mean (±SD) or median (IQR). To test differences in baseline characteristics between subjects who were included in the analysis and those excluded due to missing data, likelihood ratio chi-squared tests or t-tests were used as appropriate. The association between compression depth (evaluated separately with four approaches) and outcomes of interest was quantified using multivariate logistic regression with the Huber-White sandwich standard error. The key covariates/potential confounders assessed were age, sex, public location, bystander witnessed arrest, bystander CPR, EMS response time, CPR fraction, compression rate, site, and device manufacturer. Additional sensitivity analyses adjusted for initial cardiac rhythm and duration of CPR. Smoothing splines were used to explore the relationship between average compression depth and outcome. Unadjusted smoothing splines were creating by including the b-spline basis with four degrees of freedom for a natural cubic spline of depth in a logistic regression model in place of the other depth measures.

Supplemental References


### Appendix Table 1. Comparison of Analysis Cohort with Patients Excluded Due to Missing Compression Depth or Covariates

<table>
<thead>
<tr>
<th></th>
<th>Analyzed Cohort</th>
<th>Excluded Patients</th>
<th>p-value from Chi-squared or t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=9,136</td>
<td>N=13,727</td>
<td></td>
</tr>
<tr>
<td>Age - mean (SD)</td>
<td>67.5 (16.4)</td>
<td>66.3 (16.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male - n (%)</td>
<td>5857 (64%)</td>
<td>8744 (64%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Public location – n (%)</td>
<td>1161 (13%)</td>
<td>2026 (15%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bystander witnessed – n (%)</td>
<td>4065 (44%)</td>
<td>5854 (43%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bystander CPR – n (%)</td>
<td>3633 (42%)</td>
<td>5916 (45%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Site - n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARC</td>
<td>22 (0%)</td>
<td>512 (4%)</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>0 (0%)</td>
<td>2601 (19%)</td>
<td></td>
</tr>
<tr>
<td>DFW</td>
<td>272 (3%)</td>
<td>1403 (10%)</td>
<td></td>
</tr>
<tr>
<td>MLW</td>
<td>936 (10%)</td>
<td>515 (4%)</td>
<td></td>
</tr>
<tr>
<td>OTT</td>
<td>1389 (15%)</td>
<td>2068 (15%)</td>
<td></td>
</tr>
<tr>
<td>PGH</td>
<td>596 (7%)</td>
<td>295 (2%)</td>
<td></td>
</tr>
<tr>
<td>PTL</td>
<td>168 (2%)</td>
<td>1499 (11%)</td>
<td></td>
</tr>
<tr>
<td>SDG</td>
<td>842 (9%)</td>
<td>643 (5%)</td>
<td></td>
</tr>
<tr>
<td>SKC</td>
<td>837 (9%)</td>
<td>1901 (14%)</td>
<td></td>
</tr>
<tr>
<td>TOR</td>
<td>4074 (45%)</td>
<td>2290 (17%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EMS Response</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time from 911 call to scene – mean (SD)</td>
<td>5.9 (2.5)</td>
<td>6.1 (3.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Time from 911 call to first EMS shock assessment – mean (SD)</td>
<td>10.5 (3.5)</td>
<td>10.4 (4.8)</td>
<td>0.028</td>
</tr>
<tr>
<td>ALS first on scene – n (%)</td>
<td>3274 (36%)</td>
<td>5492 (41%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ALS on scene – n (%)</td>
<td>9049 (99%)</td>
<td>13105 (95%)</td>
<td>0.028</td>
</tr>
<tr>
<td>Number of responding EMS units</td>
<td>2.6 (0.8)</td>
<td>2.5 (0.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>-------------------------------</td>
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</tr>
<tr>
<td>EMS Interventions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intubation attempted - n (%)</td>
<td>6747 (74%)</td>
<td>9450 (69%)</td>
<td>0.133</td>
</tr>
<tr>
<td>Shocks delivered - n (%)</td>
<td>3647 (40%)</td>
<td>5002 (37%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Epinephrine use noted - n (%)</td>
<td>7956 (87%)</td>
<td>10715 (79%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPR process measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPR prior to first analysis – n (%)</td>
<td>8409 (92%)</td>
<td>13018 (95%)</td>
<td>0.552</td>
</tr>
<tr>
<td>CPR fraction – mean (SD)</td>
<td>0.68 (0.15)</td>
<td>0.76 (0.16)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Chest compression rate – mean (SD)</td>
<td>108.3 (16.0)</td>
<td>118.7 (18.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Initial cardiac rhythm – n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF/VF</td>
<td>2181 (24%)</td>
<td>3255 (24%)</td>
<td></td>
</tr>
<tr>
<td>PEA</td>
<td>1845 (20%)</td>
<td>2378 (17%)</td>
<td></td>
</tr>
<tr>
<td>Asystole</td>
<td>4513 (49%)</td>
<td>6109 (45%)</td>
<td></td>
</tr>
<tr>
<td>AED no shock, no strip</td>
<td>583 (6%)</td>
<td>1703 (12%)</td>
<td></td>
</tr>
<tr>
<td>Cannot Determine/Missing</td>
<td>14 (0%)</td>
<td>282 (2%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Device - n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philips</td>
<td>1869 (20%)</td>
<td>739 (6%)</td>
<td></td>
</tr>
<tr>
<td>Zoll</td>
<td>7246 (79%)</td>
<td>3760 (29%)</td>
<td></td>
</tr>
<tr>
<td>Medtronic/Other</td>
<td>21 (0%)</td>
<td>8627 (66%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Outcomes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any pre-hospital ROSC – n (%)</td>
<td>2861 (31.3%)</td>
<td>4583 (33.4%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Survived at least one day – n (%)</td>
<td>2081 (22.8%)</td>
<td>3450 (25.2%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Survived to hospital discharge – n (%)</td>
<td>666 (7.3%)</td>
<td>1210 (8.9%)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
## Appendix Table 2. Compression Rate versus Compression Depth

<table>
<thead>
<tr>
<th>Average Compression Depth</th>
<th>0 to 80</th>
<th>81 to 120</th>
<th>121+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;38 mm</td>
<td>45% (109)</td>
<td>32% (2256)</td>
<td>53% (969)</td>
<td>36% (3334)</td>
</tr>
<tr>
<td>38-51 mm</td>
<td>30% (73)</td>
<td>48% (3405)</td>
<td>36% (656)</td>
<td>45% (4134)</td>
</tr>
<tr>
<td>&gt;51 mm</td>
<td>24% (58)</td>
<td>20% (1418)</td>
<td>11% (192)</td>
<td>18% (1668)</td>
</tr>
<tr>
<td>Total</td>
<td>100% (240)</td>
<td>100% (7079)</td>
<td>100% (1817)</td>
<td>100% (9136)</td>
</tr>
</tbody>
</table>

Chi-square test for association: $p < 0.001$
## Appendix Table 3: Sensitivity Analyses - Survival to Discharge

<table>
<thead>
<tr>
<th>Compression Depth Category</th>
<th>VT/VF Adjusted OR (CI)¹</th>
<th>p-value</th>
<th>Non-shockable Adjusted OR (CI)¹</th>
<th>p-value</th>
<th>Adjusted for First Rhythm Adjusted OR (CI)³</th>
<th>p-value</th>
<th>Adjusted for Duration of CPR Adjusted OR (CI)⁴</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression Depth (5mm increments)</td>
<td>1.04 (0.98, 1.09)</td>
<td>0.178</td>
<td>1.01 (0.96, 1.06)</td>
<td>0.770</td>
<td>1.02 (0.99, 1.05)</td>
<td>0.264</td>
<td>1.03 (0.99, 1.07)</td>
<td>0.092</td>
</tr>
<tr>
<td>&lt;38 mm</td>
<td>0.73 (0.53, 1.02)</td>
<td>0.88 (0.53, 1.45)</td>
<td>0.81 (0.62, 1.07)</td>
<td>0.77 (0.56, 1.04)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38-51 mm</td>
<td>1.08 (0.81, 1.44)</td>
<td>0.91 (0.56, 1.48)</td>
<td>1.06 (0.83, 1.36)</td>
<td>1.17 (0.89, 1.54)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;51 mm</td>
<td>reference</td>
<td>0.019</td>
<td>reference</td>
<td>0.878</td>
<td>reference</td>
<td>0.054</td>
<td>Reference</td>
<td>0.005</td>
</tr>
<tr>
<td>Within Depth Range²</td>
<td>1.35 (1.05, 1.73)</td>
<td>0.019</td>
<td>1.15 (0.81, 1.64)</td>
<td>0.443</td>
<td>1.27 (1.04, 1.56)</td>
<td>0.021</td>
<td>1.48 (1.18, 1.85)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Percent of minutes in depth range (10% change)</td>
<td>1.04 (1.00, 1.07)</td>
<td>0.029</td>
<td>1.02 (0.98, 1.07)</td>
<td>0.320</td>
<td>1.03 (1.00, 1.06)</td>
<td>0.020</td>
<td>1.05 (1.02, 1.08)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

¹Adjusted for age, sex, public location, bystander witnessed, bystander CPR, CPR fraction, chest compression rate, time from 911 call to EMS at scene, device manufacturer, and study site.

²Average depth at least 38 mm for at least 60% of minutes with CPR process measures available.

³Adjusted for age, sex, public location, bystander witnessed, bystander CPR, CPR fraction, chest compression rate, time from 911 call to EMS at scene, device manufacturer, study site, and first recorded rhythm.
Adjusted for age, sex, public location, bystander witnessed, bystander CPR, CPR fraction, chest compression rate, time from 911 call to EMS at scene, device manufacturer, study site, and duration of CPR. Excludes 97 subjects who are missing duration of CPR.

The odds ratios for each of the depth measures was estimated from a separate multivariable logistic regression model.
Appendix Figure 1. Unadjusted Smoothing Spline of Different Survival Outcomes by Depth

2a. ROSC

2b. One Day Survival

2c. Survival to Hospital Discharge
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Dallas Center for Resuscitation Research, University of Texas Southwestern Medical Center, Dallas, TX: Ahamed H. Idris, MD, Principal Investigator

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Participating EMS Agencies: Cudahy Fire Dept, Franklin Fire Dept, Greendale Fire Dept, Greenfield Fire Dept, Hales Corners Fire Dept, Milwaukee County Airport Fire Dept, Milwaukee Fire Dept, North Shore Fire Dept, Oak Creek Fire Dept, South Milwaukee Fire Dept, Wauwatosa Fire Dept, West Allis Fire Dept

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**BC Health Authorities**: Fraser Health Authority, Vancouver Island Health Authority, Vancouver Coastal Health Authority and Providence Health Care

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