Resuscitation 86 (2015) 38–43

Contents lists available at ScienceDirect

Resuscitation

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

Clinical paper

The association between chest compression release velocity and outcomes from out-of-hospital cardiac arrest☆

Sheldon Cheskes[a,b,c,*], Matthew R. Common[c,d], Adam P. Byers[c], Cathy Zhan[c], Annemarie Silver[e], Laurie J. Morrison[b,c]

[a] Sunnybrook Centre for Prehospital Medicine, Toronto, ON, Canada
[b] University of Toronto, Department of Family and Community Medicine, Division of Emergency Medicine, Toronto, ON, Canada
[c] Rescu, Li Ka Shing Knowledge Institute, St. Michaels Hospital, Toronto, ON, Canada
[d] Institute of Medical Science, University of Toronto, Toronto, ON, Canada
[e] Zoll Medical, Chelmsford, MA, United States

ARTICLE INFO

Article history:
Received 2 September 2014
Received in revised form 8 October 2014
Accepted 28 October 2014

Keywords:
Cardiopulmonary resuscitation
Heart arrest
Resuscitation
Survival

ABSTRACT

Background: Previous studies have demonstrated significant relationships between cardiopulmonary resuscitation (CPR) quality metrics and survival to hospital discharge from out-of-hospital cardiac arrest (OHCA). Recently, it has been suggested that a new metric, chest compression release velocity (CCRV), may be associated with improved survival from OHCA.
Methods and results: We performed a retrospective review of all treated adult OHCA occurring over a two year period beginning January 1, 2012. CPR metrics were abstracted from accelerometer measurements during each resuscitation. Multivariable regression analysis was used to examine the impact of CCRV on survival to hospital discharge. Secondary outcome measures were the impact of CCRV on return of spontaneous circulation (ROSC) and neurologically intact survival (MRS ≤ 3). Among 1800 treated OHCA, 1137 met inclusion criteria. The median (IQR) age was 71.6 (60.6, 82.3) with 724 (64%) being male. The median (IQR) CCRV (mm/s) amongst 96 survivors was 334.5 (300.0, 383.2) compared to 304.0 (262.6, 354.1) in 1041 non survivors ($p < 0.001$). When adjusted for Utstein variables, the odds of survival to hospital discharge for each 10 mm/s increase in CCRV was 1.02 (95% CI: 0.98, 1.06). Similarly the odds of ROSC and neurologically intact survival were 1.01 (95% CI: 0.99, 1.03) and 1.02 (95% CI: 0.98, 1.06), respectively.
Conclusions: When adjusted for Utstein variables, CCRV was not significantly associated with outcomes from OHCA. Further research in other EMS systems is required to clarify the potential impact of this variable on OHCA survival.

1. Introduction

Improving survival from out-of-hospital cardiac arrest (OHCA) continues to challenge Emergency Medical Services (EMS) systems.[1–3] The 2010 American Heart Association-International Liaison Committee on Resuscitation (AHA-ILCOR) guidelines for cardiopulmonary resuscitation (CPR) suggest improvements in CPR quality may increase the chance of survival from OHCA.[4,5] CPR quality metrics of chest compression fraction (CCF), compression rate, compression depth and peri-shock pause duration have been independently associated with improved survival to hospital discharge from OHCA.[6–10]

The importance of minimizing provider leaning on the chest during CPR and allowing for complete chest recoil during chest compressions has been highlighted in an AHA consensus statement on CPR quality.[11] Leaning during chest compressions has been associated with both a decrease in venous return and cardiac output during CPR.[12] Animal studies have demonstrated deleterious effects on right atrial pressure as well as cerebral and coronary perfusion pressure when leaning occurs during resuscitation.[13,14] These observations suggest that decreasing leaning and improving the speed of chest recoil may improve hemodynamics during cardiac resuscitation. Recent animal studies have suggested that

☆ 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.2014.10.020.

* Corresponding author at: Sunnybrook Centre for Prehospital Medicine, 77 Brown's Line, Suite 100, Toronto, ON, Canada M8W 3S2.
E-mail address: Sheldon.Cheskes@sunnybrook.ca (S. Cheskes).

http://dx.doi.org/10.1016/j.resuscitation.2014.10.020
0300-9572/

a new CPR quality measure, chest compression release velocity (CCRV), may be associated with enhancements in both venous return and cardiac output.[15,16] Preliminary findings from a recent observational study by Bobrow et al., appear to corroborate these animal findings.[17] The authors reported that mean CCRV "recoil" (per 10 mm/s) was independently associated with survival to hospital discharge.

The theoretical benefit of an association between CCRV and clinical outcomes may be significant. If CCRV can be shown to be associated with improved clinical outcomes, optimization of this variable through real-time CPR feedback[18–20] to providers (manual CPR) and modification of mechanical CPR devices[21,22] (mechanical CPR) may impact OHCA survival.

The primary objective of this study was to explore the relationship between CCRV and survival to hospital discharge from OHCA. Secondary objectives were to determine the impact of CCRV on return of spontaneous circulation (ROSC) and neurologically intact survival (Modified Rankin Score ≤3).

2. Methods

2.1. Setting and design

This was a retrospective observational study of prospectively collected data to determine the relationship between CCRV and clinical outcomes following OHCA over a two year period beginning January 1, 2012. The study took place in the Regions of Peel and Halton in the province of Ontario, Canada. The regions cover an area of 2040 km^2 and have a combined population of 1.6 million people. Prehospital medical care is provided by advanced care paramedics (full advanced life support skills) and primary care paramedics (basic life support skills with the addition of a small number of medications and manual defibrillation). EMS in each region is predominately provided by a single EMS agency (Peel Regional Paramedic Service – Region of Peel, Ontario, Canada, Halton Emergency Medical Services – Region of Halton, Ontario, Canada). Both EMS agencies are part of the Resuscitation Outcomes Consortium (ROC), Toronto site, and participate in ROC Epistry,[23,24] as well as all ROC cardiac randomized controlled trials. Since 2006, both EMS providers have collected CPR process data (chest compression rate, compression depth, CCF and shock-pause duration). The new CPR metric of CCRV was not specifically collected by either service, but was extracted from the accelerometer signal collected from each cardiac arrest resuscitation. CCRV abstraction was performed by one of the co-investigators (A.S.) at Zoll Medical Corporation (Chelmsford, Massachusetts).

The study protocol was approved by the St. Michael's Hospital Research Ethics Board (REB) as an amendment to each agency's pre-existing ROC REB approval.

2.2. Study population

Patients were included in this study if they were ≥18 years of age and sustained non-traumatic OHCA of presumed cardiac etiology. Cases of public access defibrillation, EMS witnessed arrest and those missing any Utstein variable or discharge status data were excluded. Cases were also excluded if the time of CPR start was missing, no compression data was available for the first 5 min of EMS CPR or cases had less than 100 compressions for analysis.

2.3. Measurement

Compression data (maximum 10 min of data) from all eligible resuscitations were abstracted from the compression acceleration signal recorded by the defibrillator and assessed for duration of pre- and post-shock pauses, CCF, compression rate, compression depth and CCRV. Velocity (mm/s) was determined by taking the integral of the acceleration signal and CCRV was defined as the maximal value of release velocity measured during decompression.

2.4. Statistical analysis

Descriptive statistics were used to summarize the general characteristics of the study population. Differences in demographic characteristics, Utstein variables and CPR metrics between the survivors and non-survivors were evaluated using chi square statistics and *t*-tests for categorical and continuous variables where appropriate. Data elements were chosen with the intent of evaluating variables for model inclusion based on known (Utstein variables) and hypothesized relationships between potential independent variables (CCRV) and survival to hospital discharge from OHCA. Univariable analyses of all demographic characteristics, Utstein variables and CPR metrics were completed and clinically relevant variables with a p-value of 0.10 or less in the univariable analysis were considered for the multivariable logistic regression models. As noted in Table 1, these variables included age, gender, bystander CPR, bystander witnessed status, response time, public location, presenting rhythm, CPR quality metrics and CCRV.

Multivariable logistic regression analyses were performed to assess the relationship between CCRV and survival to hospital discharge (primary outcome). Secondary outcome measures investigated the association between CCRV, ROSC and neurologically intact survival to hospital discharge with Modified Rankin Score (MRS) ≤3. Secondary outcomes were assessed in 10 mm/s increments of CCRV to be consistent with published literature in this area.[17] A pre-specified secondary analysis was performed to investigate the association between CCRV and survival to hospital discharge in the subgroup of patients who presented in ventricular fibrillation/ventricular tachycardia (VF/VT). Likelihood ratio tests determined appropriate inclusion of variables in the multivariable logistic regression model. Linear regression analysis was used to determine if there was a correlation between age and CCRV as well as chest compression depth and CCRV. Results are reported as odds ratios with 95% confidence intervals. The Hosmer–Lemeshow goodness-of-fit statistic measured how well the final model described the response variable. Multiple imputation employing Markov Chain Monte Carlo methods was used to generate a range of plausible values (10 simulated complete datasets) for cases with missing CCRV data. All analyses were performed using SAS 9.3 software (SAS Institute, Cary, NC).

2.5. Sample size calculation

To estimate the required sample size for our primary multivariable regression model, we employed the formula by Peduzzi et al., $N = 10k/p$, where p is the estimated proportion of patients who survived to hospital discharge and k is the number of covariates (independent variables) to be included in the model.[25] We expected to include 9 covariates in the final multivariable model and estimated that 9% of patients would survive (based on combined survival rates from each agency for similar patient population over the previous 2 years) to hospital discharge, resulting in an estimated sample size of 1000 patients.

3. Results

Fig. 1 displays a CONSORT diagram of all cases included in the study. Of 1800 treated resuscitations, 1137 (63%) were included in the final analyses. Of those, 266 (23%) had a presenting rhythm of ventricular fibrillation or ventricular tachycardia (VF/VT), with 227 (20%) presenting in pulseless electrical activity (PEA) with the majority presenting in asystole. Of the 663 (37%) cases excluded

Table 1
Univariable associations between baseline characteristics, CPR quality metrics and CCRV for survivors and non-survivors.

Variable	Survivor group (n = 96)	Non-survivor group (n = 1041)	p value
Mean age (SD)[a]	59.4 (13.7)	71.2 (15.1)	<0.001
Male (%)[a]	78 (81.2%)	646 (62.1%)	<0.001
Bystander witnessed (%)[a]	70 (72.9%)	419 (40.3%)	<0.001
Bystander CPR (%)[a]	51 (53.1%)	373 (35.8%)	0.001
Mean response time (SD)[a]	5.5 (2.0)	6.0 (2.2)	0.02
Public location (%)	36 (37.5%)	133 (12.8%)	<0.001
Initial rhythm[a]			
VF/VT (%)	79 (82.3%)	187 (18.0%)	
PEA (%)	12 (12.5%)	215 (20.6%)	<0.001
Asystole (%)	5 (5.2%)	639 (61.4%)	
Median (IQR) compression fraction	0.85 (0.78, 0.92)	0.85 (0.77, 0.93)	0.89
Median (IQR) compression rate	108 (101, 115.5)	105 (101, 115)	0.21
Median (IQR) compression depth (mm)[a]	51.8 (47.5, 57.8)	49.8 (42.3, 56.2)	0.01
Median (IQR) pre-shock pause (s)	n = 71; 13.0 (8.0, 19.0)	n = 305; 12.0 (7.3, 18.0)	0.67
Median (IQR) post-shock pause (s)	n = 81; 4.0 (3.0, 4.5)	n = 314; 3.7 (3.0, 5.0)	0.89
Median (IQR) CCRV (mm/s)[a]	334.5 (300.0, 383.2)	304.0 (262.6, 354.1)	<0.001

SD, standard deviation; CPR, cardiopulmonary resuscitation, VF/VT, ventricular fibrillation/ventricular tachycardia, PEA, pulseless electrical activity; IQR, interquartile range; CCRV, chest compression release velocity.
[a] Considered in the multivariable model.

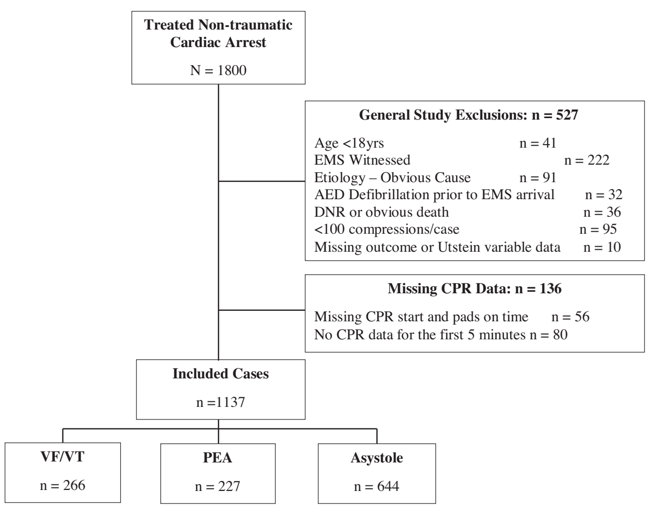

Fig. 1. Consort diagram of included cases.

from the study, 136 (21% of exclusions, 10.7% of study cohort) were excluded due to missing or insufficient CPR process data.

Univariable associations between baseline characteristics, CPR quality metrics and CCRV of survivors and non-survivors are noted in Table 1. As expected, OHCA survivors were more likely to demonstrate favorable Utstein characteristics than non-survivors. In terms of CPR metrics, chest compression depth and CCRV were found to be significantly associated with survival to hospital discharge. Shock pause durations are only assessed for cases in which shocks were actually delivered and are independent of presenting rhythm.

In Table 2 we assessed for selection bias by comparing baseline characteristics for those included in the study with 136 cases excluded due to missing CPR process data. Only presenting rhythm was significantly different between the two groups with the excluded group having a higher rate of asystole as a presenting rhythm. Surprisingly, survival was similar between the two groups despite the differences in presenting rhythm.

Table 3 shows the univariable association between categorical median CCRV (per 100 mm/s) and survival to hospital discharge employing CCRV of <300 mm/s (given the median CCRV in survivors and non survivors noted in Table 1) as our reference range. Significant improvements in survival to hospital discharge are noted with increasing median CCRV. Specifically cases with a median CCRV of 301–400 mm/s (OR = 2.62; 95% CI: 1.59, 4.32) and median CCRV of >400 mm/s (OR = 3.28; 95% CI: 1.72, 6.25) were associated with greater survival to hospital discharge when compared to the reference group.

Results from our multivariable logistic regression model assessing the association between CCRV and survival to hospital discharge for all variables in our model are noted in Table 4. Linear regression analysis was used to determine if there was a correlation between age and CCRV; no multicollinearity was detected so both variables were included in the final model. However, statistical analyses revealed significant correlation between chest compression depth and CCRV (variance inflation factor = 4.34), so we chose to exclude depth from the final multivariable regression model. Patient age, bystander witnessed status, response time and presenting rhythm of VF were found to be significantly associated with survival. When adjusted for all other variables, CCRV was not found to be independently associated with survival. Based on our univariable findings between CCRV and survival we explored the association between categorical CCRV (greater or lesser then 300 mm/s) in our multivariable regression model and found no association between CCRV and survival. We explored the inclusion of an interaction term (CCRV × depth) as a variable in our regression model but the interaction term was also not associated with survival (p = 0.85). We performed multiple imputation on the 136 patients excluded from our study for missing CCRV data. Using imputed data to include all patients, multivariable regression found no significant association between CCRV and survival to hospital discharge.

Table S1 displays our multivariable logistic regression model assessing the association between CCRV and survival to hospital discharge for patients presenting in VF/VT only. Although the variables of age and response time were associated with improved survival, CCRV was not found to be associated with improved survival, consistent with our regression model encompassing the full patient cohort.

The association between CCRV (per 10 mm/s increase) and clinical outcome measures of ROSC and neurologically intact survival (MRS $\leq$ 3) can be viewed in Table 5. No significant association was noted between CCRV and clinical outcomes.

4. Discussion

This study explored the relationship between CCRV and clinical outcomes in OHCA. In our univariable analysis of CPR quality metrics, CCRV was found to be significantly associated with survival

Table 2
Comparison of Utstein variables between those included in study and those excluded for missing CPR process data.

Variable	Included (n = 1137)	Excluded (n = 136)	p value
Survival to discharge	96 (8.4%)	13 (9.6%)	0.66
Mean age (SD)	70.2 (15.3)	68.1(14.4)	0.12
Male (%)	724 (63.7%)	93 (68.4%)	0.28
Bystander witnessed (%)	489 (43.0%)	64 (47.1%)	0.36
Bystander CPR (%)	424 (37.3%)	59 (43.4%)	0.17
Mean response time (SD)	6.0 (2.2)	6.1 (2.1)	0.49
Public location (%)	169 (14.9%)	27 (19.8%)	0.30
Initial rhythm			
VF/VT (%)	266 (23.4%)	30 (22.0%)	0.04
PEA (%)	227 (20.0%)	16 (11.8%)	
Asystole (%)	644 (56.6%)	90 (66.2%)	

SD, standard deviation; CPR, cardiopulmonary resuscitation; VF/VT, ventricular fibrillation/ventricular tachycardia; PEA, pulseless electrical activity.

Table 3
Univariable association between categorical median chest compression release velocity compared between survivors and non-survivors.

Variable	Survivors (n = 96)	Non-survivors (n = 1041)	Total	OR (95% CI)
CCRV ≤ 300 mm/s	24 (25%)	499 (48%)	523 (46%)	Reference
CCRV 301–400 mm/s	54 (56%)	428 (41%)	482 (42%)	2.62 (1.59, 4.32)
CCRV > 400 mm/s	18 (19%)	114 (11%)	132 (12%)	3.28 (1.72, 6.25)

CCRV, chest compression release velocity; OR, odds ratio; CI, confidence interval.

Table 4
Results from the multivariable logistic regression model (including multiple imputation cohort) for survival to hospital discharge.

Variable	Original cohort			MI cohort		
	OR	95% CI	p value	OR	95% CI	p value
Age	0.96	(0.95, 0.98)	<0.001	0.96	(0.95, 0.98)	<0.001
Gender – male	1.16	(0.62, 2.15)	0.65	1.04	(0.78, 1.38)	0.80
Bystander witnessed	1.93	(1.12, 3.33)	0.02	1.51	(1.17, 1.94)	0.002
Bystander CPR	1.02	(0.61, 1.71)	0.93	1.03	(0.81, 1.30)	0.83
Response time	0.86	(0.74, 0.99)	0.03	0.85	(0.74, 0.98)	0.02
Public location	1.29	(0.73, 2.26)	0.38	1.20	(0.93, 1.55)	0.16
Initial rhythm of VF/VT	13.22	(7.22, 24.20)	<0.001	3.21	(2.46, 4.18)	<0.001
CCRV (mm/s)	1.00	(0.99, 1.01)	0.37	1.00	(1.00, 1.01)	0.33

OR, odds ratio; CI, confidence interval; CPR, cardiopulmonary resuscitation; VF/VT, ventricular fibrillation/ventricular tachycardia; CCRV, chest compression release velocity; MI, multiple imputation. The Hosmer–Lemeshow chi-square test for the final model yields a p-value of 0.34 (χ^2 = 9.03, degrees of freedom = 7), thus suggesting a model with good predictive value.

Table 5
Association between chest compression release velocity (per 10 mm/s increase) and clinical outcome measures of return of spontaneous circulation and neurologically intact survival (MRS ≤ 3).

Outcome measure	Adjusted OR (95% CI) for each 10 mm/s increase in CCRV
Return of spontaneous circulation	1.01 (0.99, 1.03)
Neurologically intact survival (MRS ≤ 3)	1.02 (0.98, 1.06)

OR, odds ratio; CI, confidence interval; CCRV, chest compression release velocity; MRS, Modified Rankin Score.

to hospital discharge. As well, our analysis assessing the association between categorical CCRV and survival showed significant improvements in survival for CCRV > 300 mm/s. However, when Utstein variables and CPR quality metrics were adjusted for in our multivariable model, no independent significant association was found between CCRV and survival to hospital discharge from OHCA. A secondary analysis exploring the association between CCRV and survival to hospital discharge in the subgroup of patients presenting in VF/VT was also unable to demonstrate any significant relationship between CCRV and improved outcomes. Exploring our regression model findings more closely, suggests that in our data set a presenting rhythm of VF/VT was overwhelmingly associated with improved survival. Only in a post hoc exploratory analysis, removing presenting rhythm from the regression model did we note a significant finding (OR = 1.03; 95% CI: 1.00, 1.07) suggesting an association between improved survival and CCRV. As noted in Table 1, EMS providers delivered high quality CPR with median CPR fractions of >80% in both survivors and non-survivors. Median CPR rate, depth and shock pause durations were also consistent with established benchmarks[11] with minimal variability between survivors and non-survivors. Given the lack of variability between survivors and non-survivors with respect to CPR quality metrics, the co-linearity of compression depth and CCRV and the overall high CPR quality in the study cohort, it is possible that improvements in CCRV may not have had the expected impact on clinical outcomes.

Our findings would seem to contrast with the hope of improved outcomes through improved CCRV noted in both animal and preliminary human studies. In a swine model of cardiac arrest, Lampe et al., were able to demonstrate improvements in hemodynamic power (power = flow × pressure) during cardiac arrest through variations in CCRV with the greatest improvement found at higher CCRV.[15] Although hemodynamic power was found to be increased in the inferior vena cava, coronary perfusion pressure was not significantly improved, making the conclusion of questionable clinical significance. Similar findings related to flow in the inferior vena cava with improved CCRV, but not forward flow, were noted in subsequent swine models of cardiac arrest.[16]

Preliminary findings from an observational human study by Bobrow et al., have reported a significant relationship between

CCRV and survival to hospital discharge from OHCA.[17] Among 730 adult OHCA patients with CPR quality data, survival was greatest with CCRV > 400 mm/s (23%) compared to patients with CCRV 300–400 mm/s (12%) and those with CCRV < 300 mm/s (6%). Adjusted OR for survival were greatest for CCRV > 400 mm/s (OR = 3.86; 95% CI: 1.54, 9.66) and CCRV 300–400 mm/s (OR = 3.31; 95% CI: 1.50, 7.29) when compared to a reference group of CCRV ≤ 300 mm/s, which is consistent with our study findings. CCRV (per 10 mm/s) was noted to be an independent predictor of survival ($p < 0.05$) with a 5% increase in odds of survival for each 10 mm/s increase in CCRV (OR = 1.05; 95% CI: 1.00, 1.10). Further data from this study (variables included in regression model, CPR quality and system characteristics) may help us better understand the association between CCRV and survival in other EMS systems.

Real-time CPR feedback to providers during cardiac arrest resuscitation appears to show promise in improving the performance of CPR. Hostler et al., were able to demonstrate improvements in CPR quality metrics, but not clinical outcomes, in a randomized controlled trial exploring the impact of CPR feedback during OHCA.[18] Bobrow et al., reported an increase in both CPR quality metrics and survival to hospital discharge through implementation of CPR feedback in a "before" and "after" observational study.[19] The authors reported that compression rate, compression depth, CPR fraction, shock pause duration and CCRV were all improved by CPR feedback. Specifically, mean CCRV improved by 29.7 mm/s through the use of CPR feedback. Similar findings related to CCRV were noted by Barash et al., in a mannequin model assessing the impact of CPR feedback on CCRV.[20] Future research should attempt to elucidate whether improvements in real-time CPR feedback technology results in further improvements in CCRV during resuscitation.

Alternatives to conventional manual CPR have been developed in an effort to minimize compression inconsistencies and interruptions and enhance perfusion during resuscitation from cardiac arrest. If mechanical chest compression devices have the potential to pre-program CCRV, venous return and cardiac output may be improved. Wik et al., were able to demonstrate equivalent survival to hospital discharge for patients treated with mechanical CPR (automatic load-distributing band) when compared to high quality manual CPR in a randomized control trial of CPR quality in OHCA.[21] Rubertsson et al., reported similar findings using a suctional cup mechanical CPR device, although CPR quality metrics were only measured in 10% of cases.[22] CCRV was not measured in any of these cases. Given the quality of mechanical CPR in these studies, extrapolation to improving CCRV via mechanical CPR seems plausible. Further study is warranted to determine the impact of mechanical CPR devices on CCRV.

Our study has several limitations. Our study took place in regions with heavily monitored EMS systems with rapid response times and overall high CPR quality. Survival from OHCA is impacted by system characteristics (bystander CPR, bystander witnessed status, public location of arrest, EMS response time, patient age and gender), CPR quality metrics (CCF, chest compression rate, compression depth and shock-pause duration) and differences in presenting rhythms. The applicability of our findings to other EMS systems without similar system response optimization and CPR quality characteristics is uncertain. The measurement of CCRV by the accelerometer may be impacted by the release of other compressible surfaces (bed/EMS stretcher) beneath the patient. Although we believe the vast majority of the CPR provided by our EMS agencies occurred on a firm surface (backboard) minimizing the potential impact on our CCRV data, we were unable to determine how often this happened. CPR process data was missing for 136 (10.7%), cases which were excluded from the main analyses. Given that the baseline characteristics (including overall survival) between the included and excluded cases were similar, we believe our study findings were not impacted by missing CCRV data. Additionally, our regression model with imputed CCRV data for 136 cases did not differ from our regression model without imputed data, confirming the veracity of our study findings. Our data is abstracted from an observational registry and as such causality cannot be inferred from our study's findings.

5. Conclusion

When adjusted for Utstein variables and CPR quality metrics, CCRV was not significantly associated with outcomes from OHCA. Further research in other EMS systems is required to clarify the potential impact of this variable on OHCA survival.

Conflict of interest statement

This study was funded in part by an unrestricted research grant from Zoll Medical Inc. Dr. Cheskes has received speaking honoraria from Zoll Medical. Dr. Cheskes has received salary support from U.S. National Institute of Health as Co PI, Toronto site, Resuscitation Outcomes Consortium. Dr. Morrison has received salary support from U.S. National Institute of Health as PI, Toronto site, Resuscitation Outcomes Consortium. Drs. Cheskes and Morrison have ongoing research grant support from Heart and Stroke Foundation of Canada and Canadian Institutes of Health Research in cardiac arrest research. Annemarie Silver is an employee of Zoll Medical. No other grant disclosures.

Acknowledgements

We would like to acknowledge the hard work and dedication of all paramedics of both the Region of Peel Paramedic Service and Halton EMS. Research in the prehospital setting would not be possible without the tireless efforts of their paramedics. As well we would like to thank Zoll Medical Corporation for their funding support of this research.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2014.10.020.

References

1. Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. JAMA 2008;300:1423–31.
2. Sans S, Kesteloot H, Kromhout D. Task Force of the European Society of Cardiology on Cardiovascular Morbidity and Mortality Statistics in Europe. The burden of cardiovascular diseases mortality in Europe. Eur Heart J 1997;18:1231–48.
3. Becker LB, Ostrander MP, Barret J, Kondos GT. Outcome of CPR in a large metropolitan area: where are the survivors? Ann Emerg Med 1991;20:355–61.
4. Ornato JP, Peberdy MA. Measuring progress in resuscitation: it's time for a better tool. Circulation 2006;114:2754–6.
5. Nadkami VM, Nolan JP, Billi JE, et al. Part 2: International Collaboration in Resuscitation Science: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 2010;122:S276–82.
6. 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.
7. Idris AH, Guffey D, Aufderheide TP, et al. Relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004–12.
8. Christenson J, Andrusiek D, Everson-Stewart S, et al. Chest compression fraction determines survival in patients with out-of-hospital ventricular fibrillation. Circulation 2009;120:1241–7.
9. Cheskes S, Schmicker RH, Christenson J, et al. Peri-shock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. Circulation 2011;124:58–66.
10. 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 ROC PRIMED trial. Resuscitation 2014;85:336–42.

11. Meaney PA, Bobrow BJ, Mancini ME, et al. CPR quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. Circulation 2013;128:417–35.
12. Zuercher M, Hilwig RW, Ranger-Moore J, et al. Leaning during chest compressions impairs cardiac output and left ventricular myocardial blood flow in piglet cardiac arrest. Crit Care Med 2010;38:1141–6.
13. Sutton RM, Niles D, Nysaether J, et al. Effect of residual leaning force on intrathoracic pressure during mechanical ventilation in children. Resuscitation 2010;81:857–60.
14. Niles DE, Sutton RM, Nadkarni VM, et al. Prevalence and hemodynamic effects of leaning during CPR. Resuscitation 2011;82:S23–6.
15. Lampe JW, Yin T, Bratinov G, et al. Importance of release velocity for improved hemodynamic power at varying chest compression depths. Circulation 2013;128:A144.
16. Lampe JW, Garcia JD, Yin T, Bratinov G, Kaufman CL, Becker LB. Chest compression release velocity does not affect net forward flow but does affect hydrodynamic power in the inferior vena cava. Circulation 2012;126:A114.
17. Bobrow B, Silver A, Stolz U, et al. Chest compression release velocity is independently associated with improved survival from out-of-hospital cardiac arrest. Resuscitation 2014;85:S1–2.
18. Hostler D, Everson-Stewart S, Rea TD, et al. Effect of real-time feedback during cardiopulmonary resuscitation outside hospital: prospective, cluster-randomised trial. BMJ 2011;342:d512.
19. 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.
20. Barash DM, Kerley CJ, Silver AE. Chest compression release is improved with novel visual chest compression release feedback. Resuscitation 2010;81: S13.
21. Wik L, Olsen JA, Persse D, et al. Manual vs. integrated automatic load-distributing band CPR with equal survival after out of hospital cardiac arrest. The randomized CIRC trial. Resuscitation 2014;85:741–8.
22. Rubertsson S, Lindgren E, Smekal D, et al. Mechanical chest compressions and simultaneous defibrillation vs. conventional cardiopulmonary resuscitation in out-of-hospital cardiac arrest. The LINC randomized trial. JAMA 2014;311:53–61.
23. Davis DP, Garberson LA, Andrusiek DL, et al. A descriptive analysis of Emergency Medical Services participating in the Resuscitation Outcomes Consortium (ROC) network. Prehosp Emerg Care 2007;11:369–82.
24. Morrison LJ, Nichol G, Rea TD, et al. Rationale, development and implementation of the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest. Resuscitation 2008;78:161–9.
25. Peduzzi P, Concato J, Kemper E, Holford TR, Feinstein AR. A simulation study of the number of events per variable in logistic regression analysis. J Clin Epidemiol 1996;49:1373–9.