Outcomes of children admitted to intensive care after out-of-hospital cardiac arrest in Victoria, Australia

Anri Forrest, Warwick W Butt and Siva P Namachivayam

ABSTRACT

Objectives: Paediatric out-of-hospital cardiac arrest (OHCA) is an uncommon event but is associated with high mortality and severe neurological sequelae among survivors. Most studies of paediatric OHCA are population-based, with very few reports on the cohort admitted to the paediatric intensive care unit (PICU). We sought to determine outcomes and predictors of neurologically intact survival in these children admitted to the PICU.

Design and setting: Retrospective analysis of data prospectively collected from the PICU and emergency department (ED) databases and cross-checked with medical records and coronial reports for January 2005 to December 2014. Neurological outcome was assessed using the Paediatric Cerebral Performance Category scale.

Main outcome measure: Survival with a favourable neurological outcome at hospital discharge.

Results: In the 10 years, 283 children presented with OHCA. After 16 study exclusions (because of cardiopulmonary resuscitation [CPR] duration < 1 min or age > 16 years), there were 121 children who died in the ED and 146 admitted to the PICU. Among the PICU cohort, hospital survival with favourable neurological outcome was 42% (60 of 143), and at 1 year after arrest it was 41% (59 of 143). The following factors were associated with the primary outcome: bystander CPR (odds ratio [OR], 4.74 [95% CI, 1.49–15.05]); cardiac aetiology (OR, 6.40 [95% CI, 1.65–24.76]); male sex (OR, 0.32 [95% CI, 0.12–0.84]); and CPR duration: ≥ 20 min v 0–5 min (OR, 0.05 [95% CI, 0.01–0.16]) and 6–20 min v 0–5 min (OR, 0.45 [95% CI, 0.16–1.28]).

Conclusions: Bystander CPR and primary cardiac aetiology had strong associations with survival with a favourable neurological outcome after paediatric OHCA. Maximising CPR education for the community, and targeting people most likely to witness a paediatric OHCA may further improve outcomes.

Crit Care Resusc 2017; 19: 150-158

Paediatric out-of-hospital cardiac arrest (OHCA) is an uncommon event but is associated with high mortality and severe neurological sequelae among survivors.[1] Globally, the incidence of OHCA in children is eight per 100 000 person-years,[2] and in Melbourne, Australia, the reported incidence is around three per 100 000.[3] Recent population-based studies conducted outside Australia have reported survival rates between 4.7% and 6.4%,[4,5] and a previous population-based study from Melbourne reported survival of 7.7%.[3] In 2014, OHCAs were only 0.9% of admissions to Australian and New Zealand paediatric intensive care units (PICUs)[6] but accounted for about 15%–20% of intensive care mortality.[7]

The five links in the OHCA "chain of survival" are prevention, early cardiopulmonary resuscitation (CPR), prompt access to emergency medical services (EMS), rapid paediatric advanced life support (ALS) and aggressive post-resuscitation care in the PICU.[8] In Victoria, the pre-hospital cardiac arrest protocols follow the guidelines of the Australian Resuscitation Council, and if the child fails to respond to ALS at the scene, transport to hospital with continued CPR is recommended.[9] Once stabilised, children are admitted to the PICU for ongoing post-resuscitation care. Survival outcomes following in-hospital cardiac arrest (IHCA) have improved (from 25% to 43% between 2001 and 2013) over the past decade,[10] but improvements in outcomes from OHCA appear to have been modest, at best.[11]

Previous studies of paediatric OHCA are predominantly community-based,[2] with very few studies conducted among the cohort admitted to the PICU. Information on outcomes and factors that influence survival with favourable neurological outcome will be most useful in the approach to management of children presenting to the PICU after OHCA in the future, and for counselling the families of these children. Additionally, factors associated with intact survival in this PICU cohort could be useful for the approach to a child experiencing an OHCA in the community. The aims of this study were to report the hospital survival, 1-year survival and neurological outcomes of children admitted to the PICU following an OHCA, and to report factors associated with survival with a favourable neurological outcome.

Methods

Study design and setting

A retrospective cohort study was undertaken of children aged between 1 day and 16 completed years who were admitted to the PICU at the Royal Children's Hospital (RCH), Melbourne, following an OHCA between 1 January 2005 and 31 December 2014. The

RCH is the major specialist paediatric hospital in Victoria. Patients were identified by the diagnostic code 'out-of-hospital cardiac arrest' from the PICU and emergency department (ED) databases. Children were excluded if they received < 1 minute of CPR, suffered a cardiac arrest after arrival at the ED or other hospital setting (classified as IHCA), or were over 16 full years of age, due to the possibility of being taken to an adult intensive care unit in Victoria. This study was approved by the RCH Human Research and Ethics Committee (data access approval number DA004-2015-11) and conforms to the provisions of the World Medical Association Declaration of Helsinki.

Data collection

Information was obtained from the RCH PICU and ED, and verified using hospital medical records and coroner reports. Utstein-style definitions and data collection[12] were used (Appendix 1, online at cicm.org.au/Resources/Publications/Journal) to ensure the uniform reporting of cardiac arrest data, thus permitting comparability of results with other OHCA reports.

Demographics

Demographic information collected included data on age, sex and pre-existing comorbidities. Children were classified as having a comorbidity if they had a pre-existing illness within these categories: neuromuscular, cardiovascular, respiratory, renal, gastrointestinal, haematological or immunological, metabolic, other congenital or genetic defect, and malignancy.[13]

Aetiology

The following major aetiological categories, as diagnosed by clinical, radiological, pathology and coroner reports, were assigned: asphyxia, respiratory, neurological, submersion, cardiac, trauma (motor vehicle accident, non-accidental injury and other trauma), and other (including sudden infant death syndrome [SIDS] and malignancy). Children were also further classified as having an OHCA of either cardiac or non-cardiac aetiology if the arrest was caused by a primary cardiac event (including dysrhythmias, congenital heart disease and myocarditis).

Event characteristics

Event characteristic data collected included witnessed arrest (including EMS-witnessed OHCA), bystander CPR, first monitored cardiac rhythm (initial rhythm), total duration of CPR (bystander and EMS CPR), and administration of epinephrine and return of spontaneous circulation before hospital arrival. The initial rhythm, as documented in the EMS notes, was categorised by EMS personnel as sinus rhythm, shockable rhythm (pulseless ventricular tachycardia [VT] or ventricular fibrillation [VF]), pulseless electrical activity (PEA) or asystole.

Hospital and intensive care factors

Data relating to hospital and intensive care factors included first systolic blood pressure (SBP) and pupil size and response on initial contact by PICU team member, blood gases (pH, base excess and lactate level), Paediatric Index of Mortality 2 (PIM2) score, use of therapeutic hypothermia, duration of mechanical ventilation, administration of inotropes calculated using a vasoactive–inotrope score (VIS), and PICU and hospital lengths of stay. The VIS is a marker of illness severity and has been shown to predict mortality and morbidity in children admitted to intensive care.[14] It is calculated from the doses of vasoactive and inotropic agents administered to children in intensive care, according to the following formula:

VIS = *dopamine* (μg/kg/min) + *dobutamine* (μg/kg/min) + 100 × *epinephrine* (μg/kg/min) + 10 × *milrinone* (μg/kg/min) + 10 000 × *vasopressin* (U/kg/min) + 100 × *norepinephrine* (μg/kg/min)

Outcome measures

The primary outcome was hospital survival with a favourable neurological outcome. The secondary outcomes were PICU survival and 1-year survival with a favourable neurological outcome. Neurological outcome was assessed using the Paediatric Cerebral Performance Category (PCPC) scale. The PCPC scale is a validated way to uniformly determine a child's functional status and independence, and quantifies the degree of functional outcome from 1 to 6 (Appendix 2).[15] A favourable neurological outcome was classified as a PCPC score of 1–3 (all categories in which the individual maintains independent activities of daily living). The PCPC score was determined from a retrospective review of discharge and outpatient notes.

Statistical analysis

Continuous variables are presented as medians with interquartile ranges (IQRs), and categorical variables as frequencies and percentages. Continuous variables were compared using the Kruskal–Wallis test, and categorical variables were compared using the χ^2 test or Fisher exact test, as appropriate. Study characteristics were compared between the four initial rhythm types (sinus rhythm, shockable rhythm, PEA and asystole).

Two logistic regression models were developed. Model 1 checked the association between pre-hospital variables and the primary outcome. The following variables were used in the model: age, sex, bystander CPR, and CPR duration. The cardiac and submersion aetiological categories were also included in Model 1, because of previous evidence indicating superior outcomes.[16] Model 2 checked the association between variables from the time of PICU admission and the primary outcome. The following variables were used: age, sex and VIS score at 4 hours after PICU admission. Model 2 was controlled for the PIM2 score. Age was categorised (< 1 year or ≥ 1 year) based on data that demonstrated poor outcomes for the < 1-year age group.[17] CPR duration and VIS were categorised into three categories using the 50th and 75th centile values (CPR duration: < 5 min, 6–20 min, > 20 min; VIS: 0, 1–12.5, > 12.5).

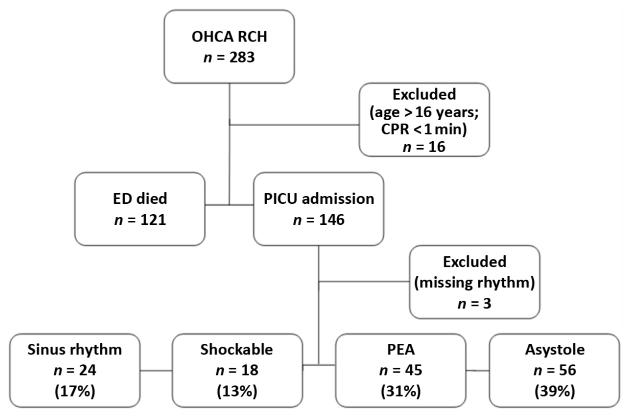
The final multivariable model was created by a stepwise elimination of variables in which only variables with a $P < 0.2$ were retained. Explanatory variables where a high degree of collinearity was suspected were assessed using the Spearman rank correlation coefficient or χ^2 test. If a high correlation was identified, the variable of least clinical importance was dropped from the multivariable model. In this way, bystander CPR and initial rhythm were correlated, and bystander CPR was included as it was more likely to have influenced initial rhythm. Because admission SBP, lactate level, pupillary responses and VIS score at admission (0 hours) were highly correlated with PIM2 score, they were not included in the model. Goodness-of-fit of the final model was assessed using the Hosmer–Lemeshow statistic. All analyses were performed using Stata, version 14.0 (StataCorp).

Results

Out-of-hospital cardiac arrest presentations over 10 years

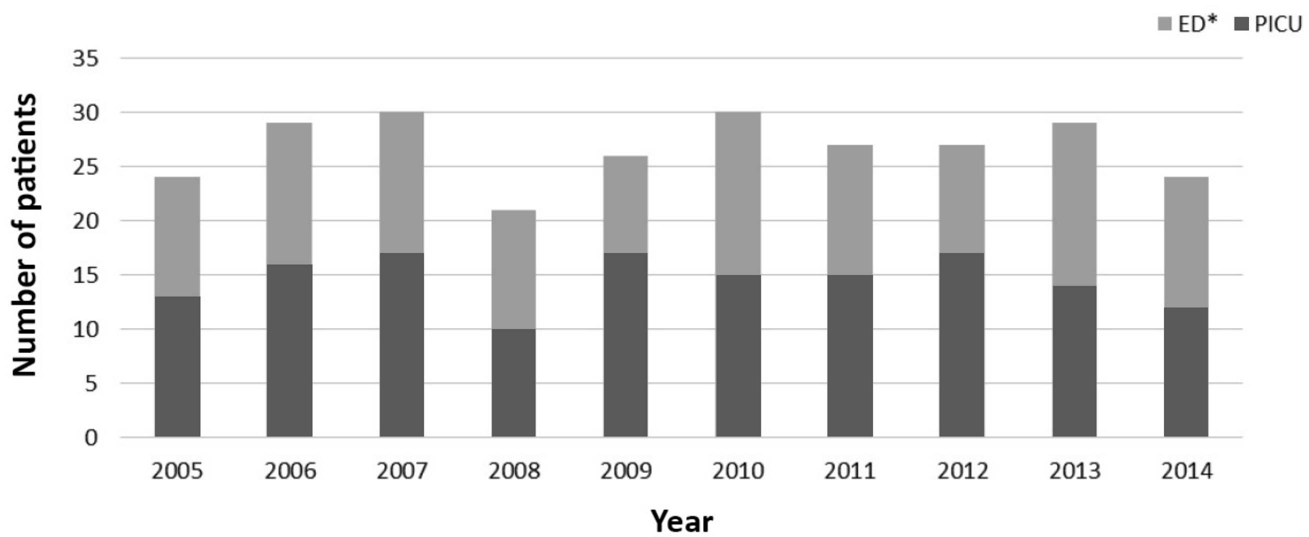
During the study period (2005–2014), 283 children presented with OHCA to the RCH. The number per year varied between 21 and 30, with an average of 28 (Figure 1). Of the 283 presentations, 16 children were excluded as they did not meet the study inclusion criteria (CPR duration > 1 minute or age < 16 years), and 121 children were dead on arrival or died in the ED (Figure 2) (Appendix 3). A total of 146 children were admitted to the PICU through the RCH ED or as paediatric emergency transport retrievals from a different hospital. Over the 10-year study period, children with OHCA accounted for 1% of total admissions (146 of 14 159) to the PICU. Initial cardiac rhythm was not available for three children, so they were excluded from our analyses. Of the remaining 143 children, 24 (17%) presented with an initial sinus rhythm, 18 (13%) with a shockable rhythm (VT/VF), 45 (31%) with PEA, and 56 (39%) with asystole.

Figure 2. Overview of out-of-hospital cardiac arrest presentations to the Royal Children's Hospital over a 10-year period, 2005–2014



OHCA = out-of-hospital cardiac arrest. RCH = Royal Children's Hospital. CPR = cardiopulmonary resuscitation. ED = emergency department. PICU = paediatric intensive care unit. PEA = pulseless electrical activity.

Figure 1. Annual number of out-of-hospital cardiac arrest presentations to the Royal Children's Hospital over a 10-year period, 2005–2014



ED = emergency department. PICU = paediatric intensive care unit. * ED presentations indicate children who did not survive to be admitted to the PICU.

Baseline characteristics of study population

Demographic data showed that 67% of the children (96 of 143) were male, with a median age of 50 months (IQR, 13–136 months), and that 39% (56 of 143) had a pre-existing comorbidity (Table 1). The various OHCA aetiologies are shown in Table 2. The most common causes were trauma (19%), respiratory (17%), other (17%), submersion (16%) and cardiac (14%). Among children with an initial sinus rhythm, 54% had an OHCA secondary to submersion, and 72% of those with a shockable rhythm had an OHCA caused by a primary cardiac event. Two children had SIDS as their aetiology; they presented with asystole and both died in the PICU.

Of the 143 children, 59% (84 of 143) presented after a witnessed arrest; these children were more likely to present with a shockable rhythm (17 of 18; 94%) or PEA (34 of 45; 76%) compared with other groups (Table 1). Overall, 107 children (75%) presented after bystander CPR; these children were more likely to present with sinus rhythm (all 24 children) and shockable rhythm (all 18 children) compared with other groups.

For hospital and intensive care factors (Table 3), no children with initial sinus rhythm had pupils fixed and dilated (PFAD) on PICU admission, compared with 41% with asystole, 31% with PEA and 6% with a shockable rhythm. Children with sinus rhythm had a median lactate level of 1.3 mmol/L (IQR, 1.0–1.7 mmol/L), and those with asystole had a median lactate level of 8.3 mmol/L (IQR, 4.7–12.8 mmol/L).

Outcomes of study population

Overall hospital survival with favourable neurological outcome was 42% (Table 4). This was highest for children

Table 1. Demographic and pre-hospital characteristics of children presenting to the paediatric intensive care unit after out-of-hospital cardiac arrest*

Variable	Sinus rhythm (*n* = 24)	Shockable (VF/VT) (*n* = 18)	Pulseless electrical activity (*n* = 45)	Asystole (*n* = 56)	*P*
Age group, *n* (%)					0.38
< 12 months	3 (13%)	4 (22%)	14 (31%)	13 (23%)	
≥ 12 months	21 (88%)	14 (78%)	31 (69%)	43 (77%)	
Male, *n* (%)	18 (75%)	11 (61%)	24 (53%)	43 (77%)	0.07
Pre-existing comorbidity, *n* (%)	8 (33%)	6 (33%)	21 (47%)	21 (38%)	0.63
Arrest characteristics					
Witnessed, *n* (%)	9 (38%)	17 (94%)	34 (76%)	24 (43%)	< 0.001
Bystander CPR performed, *n* (%)	24 (100%)	18 (100%)	28 (62%)	37 (66%)	< 0.001
Epinephrine administered before hospital admission, *n* (%)	2 (8%)	8 (44%)	24 (53%)	41 (73%)	< 0.001
Median number of epinephrine doses, (IQR)	0 (0–0)	0 (0–2)	0 (0–3)	2 (1–5)	< 0.001
Median CPR duration, minutes (IQR)	4 (2–10)	14 (10–24)	18 (5–32)	23 (18–40)	< 0.001
Return of spontaneous circulation before hospital admission, *n* (%)	22 (92%)	16 (89%)	30 (67%)	42 (75%)	0.03

VF = ventricular fibrillation. VT = ventricular tachycardia. CPR = cardiopulmonary resuscitation. IQR = interquartile range. * Percentages may not total 100% because of rounding.

Table 2. Aetiology of out-of-hospital cardiac arrest

Aetiology	Sinus rhythm (*n* = 24)	Shockable (VF/VT) (*n* = 18)	Pulseless electrical activity (*n* = 45)	Asystole (*n* = 56)
Asphyxia	3 (13%)	0	4 (9%)	8 (15%)
Cardiac	0	13 (72%)	6 (14%)	1 (2%)
Neurological	1 (4%)	0	4 (9%)	3 (6%)
Respiratory	4 (17%)	0	10 (23%)	10 (18%)
Submersion	13 (54%)	0	2 (5%)	8 (15%)
Trauma	2 (8%)	1 (6%)	12 (27%)	12 (22%)
Other	1 (4%)	4 (22%)	6 (14%)	13 (23%)

VF = ventricular fibrillation. VT = ventricular tachycardia.

Table 3. Hospital and intensive care unit variables, from time of admission after out-of-hospital cardiac arrest*

Variable	Sinus rhythm (*n* = 24)	Shockable (VF/VT) (*n* = 18)	Pulseless electrical activity (*n* = 45)	Asystole (*n* = 56)	*P*
Median SBP, mmHg (IQR)	105 (90–115)	105 (85–125)	90 (80–115)	100 (65–115)	0.35
PFAD, *n* (%)	0	1 (6%)	14 (31%)	23 (41%)	< 0.001
Median pH (IQR)	7.30 (7.25–7.36)	7.27 (7.03–7.28)	7.20 (7.06–7.31)	7.11 (7.00–7.22)	< 0.001
Median base excess, mEq/L (IQR)	–4 (–5 to –2)	–9 (–12 to –4)	–8.5 (–14 to –5)	–15 (–21 to –9)	< 0.001
Median lactate concentration, mmol/L (IQR)	1.3 (1.0–1.7)	3.3 (1.9–7.6)	4.2 (1.8–7.4)	8.3 (4.7–12.8)	< 0.001
Median PIM2 POD (IQR)	16 (14–22)	17 (16–22)	22 (15–78)	47 (22–86)	< 0.001
Median intubation duration, hours (IQR)	89 (24–126)	122 (48–159)	78 (24–150)	55 (10–145)	0.31
Treated with therapeutic hypothermia, *n* (%)	14 (58%)	15 (83%)	27 (60%)	37 (66%)	0.29
Median VIS at PICU, 0 hours (IQR)	0 (0–0)	0 (0–0)	0 (0–10)	2 (0–45)	0.004
Median VIS at PICU, 4 hours (IQR)	0 (0–0)	0 (0–5)	0 (0–10)	0 (0–45)	0.02
Median PICU LOS, days (IQR)	5 (2–6)	6 (4–8)	4 (1–7)	2 (0–7)	0.08
Median hospital LOS, days (IQR)	9 (4–12)	19 (12–26)	5 (1–11)	2 (0–8)	< 0.001

VF = ventricular fibrillation. VT = ventricular tachycardia. SBP = systolic blood pressure. IQR = interquartile range. PFAD = pupils fixed and dilated. PIM2 POD = Paediatric Index of Mortality 2 probability of death. VIS = vasoactive–inotrope score. PICU = paediatric intensive care unit. LOS = length of stay. * Percentages may not total 100% because of rounding.

Table 4. Outcome of children admitted to the paediatric intensive care unit after out-of-hospital cardiac arrest, *n* (%)*†

Outcome	Total (*n* = 143)	Sinus rhythm (*n* = 24)	Shockable (VF/VT) (*n* = 18)	Pulseless electrical activity (*n* = 45)	Asystole (*n* = 56)
Primary outcome					
Hospital survival with favourable neurological outcome	60 (42%)	22 (92%)	15 (83%)	18 (40%)	5 (9%)
Secondary outcomes					
PICU survival	71 (50%)	23 (96%)	15 (83%)	20 (44%)	13 (23%)
1-year survival with favourable neurological outcome	59 (41%)	22 (92%)	15 (83%)	17 (38%)	5 (9%)

VF = ventricular fibrillation. VT = ventricular tachycardia. PICU = paediatric intensive care unit. * Percentages may not total 100% because of rounding. † Due to difficulties in assessing the Paediatric Cerebral Performance Category score in children with pre-morbid neurodevelopmental disabilities, results for these children were removed from analysis.

with initial sinus rhythm (92%), then shockable rhythm (83%), PEA (40%) and asystole (9%). Of the 20 children with OHCA of cardiac aetiology, 65% (13 of 20) survived with a favourable neurological outcome, compared with 39% of children (48 of 123) with OHCA of non-cardiac aetiology. There was one additional death at the 1-year follow-up, which brought the overall 1-year survival with favourable neurological outcome to 41%. No major difference in primary outcome was observed (Table 5) between the first and second 5 years of the study period (2005–2009 v 2010–2014: 39% v 44%, *P* = 0.54).

Factors associated with primary outcome

Table 6 shows the multivariable logistic regression models for factors associated with survival with a favourable neurological outcome. Among the pre-hospital variables

Table 5. Primary outcome, 2005–2009 versus 2010–2014

Primary outcome	Total (*n* = 143)	2005–2009 (*n* = 71)	2010–2014 (*n* = 72)
Hospital survival with favourable neurological outcome			
Normal	37	17	20
Mild disability	18	8	10
Moderate disability	5	3	2
Hospital survival with unfavourable neurological outcome			
Severe disability	5	3	2
Coma or vegetative state	2	2	0

Table 6. Univariable and multivariable logistic regression analyses for predictors of hospital survival with a favourable neurological outcome after paediatric out-of-hospital cardiac arrest

	Univariable		Multivariable	
Variable	OR (95% CI)	*P*	OR (95% CI)	*P*
Model 1: demographics and pre-hospital factors				
Cardiac aetiology	2.34 (0.94–6.00)	0.07	6.40 (1.65–24.76)	0.007
Bystander CPR	2.70 (1.12–6.51)	0.03	4.74 (1.49–15.05)	0.008
Total duration of CPR, min				
0–5	Reference		Reference	
6–20	0.68 (0.28–1.67)	0.40	0.45 (0.16–1.28)	0.134
≥ 20	0.94 (0.34–0.26)	< 0.001	0.05 (0.01–0.16)	< 0.001
Male	0.48 (0.24–0.96)	0.04	0.32 (0.12–0.84)	0.021
Age ≥ 12 months	1.12 (0.52–2.44)	0.76	ns	
Submersion aetiology	3.14 (1.24–8.00)	0.02	ns	
Model 2: hospital and intensive care factors*				
Male	0.48 (0.24–0.96)	0.04	0.39 (0.16–0.96)	0.041
VIS at 4 hours				
0	Reference		Reference	
1–12.5	0.33 (0.11–1.03)	0.06	0.18 (0.05–0.64)	0.008
> 12.5	0.10 (0.33–0.31)	< 0.001	0.19 (0.54–0.67)	0.009
Age ≥ 12 months	1.12 (0.52–2.44)	0.76	ns	

OR = odds ratio. CPR = cardiopulmonary resuscitation. ns = not significant. VIS = vasoactive–inotrope score. * Controlled for Paediatric Index of Mortality 2 probability of death score.

(Model 1), bystander CPR had a strong association with survival with a favourable neurological outcome, with an OR of 4.74 (95% CI, 1.49–15.05). Other factors associated with the outcome in this model were male sex (OR, 0.32 [95% CI, 0.12–0.84]; OHCA of cardiac v non-cardiac aetiology (OR, 6.40 (95% CI, 1.65–24.76); and CPR duration ≥ 20 min v 0–5 min (OR, 0.05 [95% CI, 0.01–0.16]) and 6–20 min v 0–5 min (OR, 0.45 [95% CI, 0.16–1.28]). Model 2 looked at hospital and intensive care factors from the time of admission and their association with survival with a favourable neurological outcome. The associations were: 4-hour (post-admission) VIS, 1–12.5 (OR, 0.18 [95% CI, 0.05–0.64]) and VIS > 12.5 (OR, 0.19 [95% CI, 0.54–0.67]), using a VIS of 0 as the reference value, and after controlling for age, sex and PIM2 score.

Discussion

Overall, 42% of children admitted to the PICU after OHCA survived to hospital discharge with a favourable neurological outcome. At 1-year follow up, one child had subsequently died and 41% were alive and functioning independently. Among children who were asystolic at presentation, five (9%) were alive with independent function at 1 year. There are limited studies that report on the cohort of children admitted to the PICU following OHCA. Moler and colleagues reported in 2015 that survival after OHCA was 33%, and survival with a favourable neurological outcome was 16.2%.[18] Despite dissimilarities in methodological design and method of functional assessment exclusion criteria, the difference in outcome suggests that survival with favourable neurological outcome is higher in Victoria, Australia, compared with the United States and Canada.

Our results showed that children with OHCA of cardiac (v non-cardiac) aetiology were more likely to survive with favourable neurological outcome. Akahane and colleagues reported that junior high school children were more likely to have an OHCA of cardiac aetiology and present with a shockable rhythm, compared with infants and pre-school-aged patients in their community OHCA study.[19] The lower rate of shockable rhythms in infants and pre-school children was postulated to be due to a lower rate of witnessed arrests, as bystander CPR rates were comparable and the interval between EMS call and arrival on the scene was shortest for these children. Our results also showed that 72% of children who presented with a shockable rhythm had an OHCA of cardiac aetiology, and 94% of children with a shockable rhythm had a witnessed arrest. However, it must be recognised that although the higher rate of shockable rhythms in children with an underlying cardiac aetiology may be contributing to improved outcomes, it may also be due to better preparedness and systems for CPR and management of cardiac complications compared with the "unexpected" non-cardiac arrests such as drowning, SIDS and asphyxia.

Among children admitted to the PICU after OHCA, bystander CPR was associated with survival with a favourable neurological outcome. This is consistent with animal studies,[20] epidemiological evidence of adult OHCA[21,22] and previous studies in children.[17,23] The literature attributes this improved survival to early bystander CPR increasing the likelihood of an initial shockable rhythm.[24] Interestingly, our results showed that all children with initial sinus rhythm and shockable rhythm received bystander CPR, compared with 62% with PEA and 66% with asystole. A previous community study from Melbourne, however, did not show an association between bystander CPR and outcome. This is likely to be related to the high proportion of infants with SIDS (19% of the study population v 1% in our current study), the relatively smaller study size and the lower rate of bystander CPR (49%) in the community cohort versus 75% in the current PICU cohort.[3] Certain aetiological scenarios for OHCA were more likely to have involved bystander CPR (eg, an adolescent child participating in sports having a primary cardiac event, and a child in a swimming pool with a submersion event) and were associated with a positive outcome. However, even after controlling for cardiac and submersion aetiology, bystander CPR had a strong association with survival with favourable neurological outcome among the OHCA cohort in the PICU.

Our results showed that other pre-hospital factors associated with outcome among the PICU cohort were male sex and duration of CPR; this was consistent with previous studies. The reasons for the association between males and negative outcome are not entirely clear and are beyond the scope of this study, but it is important to note that boys are more likely to be involved in aggressive and risk-taking activities. Biological and other environmental factors may also be involved in this association.[25,26] Finally, our results support previous findings that CPR duration > 20 min is a negative predictor of survival with a favourable neurological outcome.[27]

Study implications and future directions

The impact of bystander CPR on survival with a favourable neurological outcome demonstrates the importance of maximising community awareness and education about bystander CPR for children. In Victoria over the past decade, bystander CPR rates increased from 35% in 2005–2006 to 64% in 2013–2014, and the use of automated external defibrillators has increased 10-fold.[28] This indicates the success of basic life support education for adults in the community. Similarly, our study shows that bystander CPR rates among the PICU OHCA cohort in Victoria (75%) are higher than in PICU cohorts in the US and Canada (66%),[18] but the benefit of bystander CPR on outcome justifies further paediatric CPR education in the community. This is particularly relevant to the most effective types of bystander CPR in children, as Kitamura and colleagues showed that conventional CPR (chest compressions with rescue breathing) or compression-only CPR is effective for children with sudden OHCA caused by a primary cardiac event, but conventional CPR is more effective for OHCA secondary to asphyxia.[17] Additionally, the current study identified 39% of children who were admitted to the PICU after OHCA with pre-existing comorbidities. Therefore, we propose targeting CPR education among those most likely to witness an OHCA, which includes families with children, particularly families with swimming pools and with children with pre-existing disease conditions and comorbidities.

In addition to the potential increase in education for CPR in children, preventive measures undertaken to minimise the chances of an OHCA occurring are of utmost importance. There have therefore been several societal and public health initiatives introduced over the past decade to reduce paediatric mortality in Victoria, such as the Red Nose Safe Sleeping campaign,[29] Kidsafe Victoria Don't go if you Don't Know driveway safety campaign,[30] the Asthma Cycle of Care initiative (Medicare),[31] and amendments to pool fencing requirements,[32] that may have altered trends in paediatric OHCA. It also remains to be seen whether the increasing prevalence of children living with chronic disease[33] and complex congenital cardiac defects,[34] as well as changes in pre-hospital OHCA management, such as the public access defibrillation project,[35] have had an impact on trends in paediatric OHCA over time. This information may present important public health and clinical information to guide future planning for children presenting with OHCA, and is therefore an area for future research.

Study limitations

There are important limitations to our study that must be recognised. First, we did not capture all children admitted to the PICU after OHCA in Victoria, as some children may have been transported to other tertiary centres. However, we recognise that, because the RCH is the largest specialist paediatric hospital in Victoria, most children are transferred there, which will have minimised this potential limitation. Second, the retrospective nature of the study means that information potentially valuable to our findings was not available in the data sources. For example, data on the type of bystander CPR given (ie, conventional or chest compression-only CPR) were not included. We also did not have information on the time interval between OHCA and commencement of bystander CPR. Despite this, core Utstein data elements[12] were collected, which allowed results to be compared with other paediatric cardiac arrest reports.

Inherent in all retrospective OHCA studies is the potential uncertainty about whether an OHCA occurred, particularly for events that were not witnessed by health care personnel. We accounted for this limitation by excluding cases in which CPR lasted < 1 minute, and having all children identified as having had an OHCA event by treating medical teams. Finally, the utility of the PCPC score was limited, as it may not have reflected subtle changes in cognitive function. Previous literature has suggested that a decline in PCPC score of 1 may represent a huge burden in terms of family adjustment, school performance and long-term functioning.[16] Also, we note that the method of obtaining the PCPC score by means of medical chart review is an important limitation to the accuracy of the data, compared with clinical follow-up methods or telephone follow-up. We recognise that a more age-appropriate and extensive neurobehavioural assessment tool would have been optimal, but the PCPC score nonetheless provided a quick way of identifying a child's ability to live and function independently.[3]

Conclusions

This observational study of children admitted to the PICU after OHCA showed that 42% survived to hospital discharge with a favourable neurological outcome. At 1-year follow-up, most of these children (41%) were alive and functioning independently. Those with an OHCA caused by a primary cardiac event had a much higher survival rate than those with a non-cardiac aetiology. Receiving bystander CPR had a strong association with survival with a favourable neurological outcome. This justifies further increasing awareness of and education and training for CPR for the community in general, and particularly targeting people who are more likely to witness a child having an OHCA. Future studies are needed to evaluate population trends in demographic patterns of paediatric OHCA, with potential to present important public health and clinical information to guide future management of these children.

Acknowledgements

We thank Meredith Allen and the medicolegal team at Royal Children's Hospital, Melbourne, for providing coronial data, and the ED and PICU for access to OHCA databases. We thank Trevor Duke for useful suggestions. We also thank Carmel Delzoppo and Jenny Thompson for supplying information and contributing to the PICU database. Finally, we thank the EMS personnel and bystanders who made the survival of many of these children possible.

Competing interests

None declared.

Author details

Anri Forrest, Medical Intern[1,2]

Warwick W Butt, Director of Intensive Care[1,2,3]

Siva P Namachivayam, Intensive Care Specialist[1,2,3]

1 Intensive Care Unit, Royal Children's Hospital, Melbourne, VIC, Australia.

2 Department of Paediatrics, University of Melbourne, Melbourne, VIC, Australia.

3 Murdoch Childrens Research Institute, Melbourne, VIC, Australia.

Correspondence: siva.namachivayam@rch.org.au

References

1 Donoghue AJ, Nadkarni V, Berg RA, et al. Out-of-hospital pediatric cardiac arrest: an epidemiologic review and assessment of current knowledge. *Ann Emerg Med* 2005; 46: 512-22.

2 Atkins DL, Berger S. Improving outcomes from out-of-hospital cardiac arrest in young children and adolescents. *Pediatr Cardiol* 2012; 33: 474-83.

3 Deasy C, Bernard SA, Cameron P, et al. Epidemiology of paediatric out-of-hospital cardiac arrest in Melbourne, Australia. *Resuscitation* 2010; 81: 1095-100.

4 Atkins DL, Everson-Stewart S, Sears GK, et al. Epidemiology and outcomes from out-of-hospital cardiac arrest in children: the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest. *Circulation* 2009; 119: 1484-91.

5 Park CB, Shin SD, Suh GJ, et al. Pediatric out-of-hospital cardiac arrest in Korea: a nationwide population-based study. *Resuscitation* 2010; 81: 512-7.

6 Straney L, Schlapbach L, Yong G, et al. Trends in PICU admission and survival rates in children in Australia and New Zealand following cardiac arrest. *Pediatr Crit Care Med* 2015; 16: 613-20.

7 Australian and New Zealand Intensive Care Society Centre for Outcome and Resource Evaluation. Report of the Australian and New Zealand Paediatric Intensive Care Registry 2014. Melbourne: ANZICS-CORE, 2015. http://www.anzics.com.au/Pages/CORE/CORE-Reports.aspx (accessed Feb 2017).

8 Berg MD, Schexnayder SM, Chameides L, et al. Pediatric basic life support: 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Pediatrics* 2010; 126: e1345-60.

9 Tibballs J, Aickin R, Nuthall G, et al. Basic and advanced paediatric cardiopulmonary resuscitation — guidelines of the Australian and New Zealand Resuscitation Councils 2010. *J Paediatr Child Health* 2012; 48: 551-5.

10 Girotra S, Spertus J, Li Y, et al. Survival trends in pediatric in-hospital cardiac arrests: an analysis from Get With the Guidelines-Resuscitation. *Circ Cardiovasc Qual Outcomes* 2013; 6: 42-9.

11 Sutton RM, Case E, Brown SP, et al. A quantitative analysis of out-of-hospital pediatric and adolescent resuscitation quality

— a report from the ROC epistry-cardiac arrest. *Resuscitation* 2015; 93: 150-7.

12 Jacobs I, Nadkarni V, Bahr J, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries. A statement for healthcare professionals from a task force of the international liaison committee on resuscitation. *Resuscitation* 2004; 63: 233-49.

13 Feudtner C, Christakis DA, Connell FA. Pediatric deaths attributable to complex chronic conditions: a population-based study of Washington state, 1980–1997. *Pediatrics* 2000; 106: 205-9.

14 Gaies M, Jeffries H, Niebler R, et al. Vasoactive-Inotropic Score (VIS) is associated with outcome after infant cardiac surgery: an analysis from the Pediatric Cardiac Critical Care Consortium (PC4) and virtual PICU system registries. *Pediatr Crit Care Med* 2014; 15: 529-37.

15 Fiser D, Long N, Roberson P, et al. Relationship of pediatric overall performance category and pediatric cerebral performance category scores at pediatric intensive care unit discharge with outcome measures collected at hospital discharge and 1- and 6-month follow-up assessments. *Crit Care Med* 2000; 28: 2616-20.

16 Moler FW, Donaldson AE, Meert K, et al. Multicenter cohort study of out-of-hospital pediatric cardiac arrest. *Crit Care Med* 2011; 39: 141-9.

17 Kitamura T, Iwami T, Kawamura T, et al. Conventional and chest-compression-only cardiopulmonary resuscitation by bystanders for children who have out-of-hospital cardiac arrests: a prospective, nationwide, population-based cohort study. *Lancet* 2010; 375: 1347-54.

18 Moler F, Silverstein F, Holubkov R, et al. Therapeutic hypothermia after out-of-hospital cardiac arrest in children. *N Engl J Med* 2015; 372: 1898-908.

19 Akahane M, Tanabe S, Ogawa T, et al. Characteristics and outcomes of pediatric out-of-hospital cardiac arrest by scholastic age category. *Pediatr Crit Care Med* 2013; 14: 130-6.

20 Berg RA, Hillwig RW, Kern KB, et al. Simulated mouth-to-mouth ventilation and chest compressions (bystander cardiopulmonary resuscitation) improves outcome in a swine model of prehospital pediatric asphyxial cardiac arrest. *Crit Care Med* 1999; 27: 1893-9.

21 Iwami T, Kawamura T, Hiraide A, et al. Effectiveness of bystander-initiated cardiac-only resuscitation for patients with out-of-hospital cardiac arrest. *Circulation* 2007; 116: 2900-7.

22 SOS-KANTO study group. Cardiopulmonary resuscitation by bystanders with chest compression only (SOS-KANTO): an observational study. *Lancet* 2007; 369: 920-6.

23 Naim M, Burke R, McNally B, et al. Characteristics and impact of bystander cardiopulmonary resuscitation following pediatric out of hospital cardiac arrest in the United States: a study from the Cardiac Arrest Registry to Enhance Survival (CARES) [abstract]. *Circulation* 2015; 132: A16428.

24 Fridman M, Barnes V, Whyman A, et al. A model of survival following pre-hospital cardiac arrest based on the Victorian Ambulance Cardiac Arrest Register. *Resuscitation* 2007; 75: 311-22.

25 Kalben B. Why men die younger. *N Am Actuar J* 2000; 4: 83-111.

26 Sidebotham P, Fraser J, Covington T, et al. Understanding why children die in high-income countries. *Lancet* 2014; 384: 915-27.

27 Lopez-Herce J, Garcia C, Dominguez P, et al. Outcome of out-of-hospital cardiorespiratory arrest in children. *Pediatr Emerg Care* 2005; 21: 807-15.

28 Lijovic M. Victorian Ambulance Cardiac Arrest Registry annual report 2013–2014. Melbourne: VACAR, 2014. http://ambulance.vic.gov.au/about-us/research/research-publications (accessed Feb 2017).

29 Red Nose. Safe Sleeping. Melbourne: Red Nose, 2016. http://www.sidsandkids.org/safe-sleeping (accessed Feb 2017).

30 Kidsafe Victoria. The Child Accident Prevention Foundation of Australia. 'Don't go if you Don't Know' driveway safety campaign. Melbourne: Kidsafe Victoria, 2011. https://www.kidsafevic.com.au/road-safety/driveway-safety/don-t-go-if-you-don-t-know-driveway-safety-campaign (accessed Feb 2017).

31 National Asthma Council Australia. Asthma Cycle of Care. https://www.nationalasthma.org.au/living-with-asthma/resources/health-professionals/reports-and-statistics/asthma-cycle-of-care (accessed Feb 2017).

32 Victorian Building Authority. Swimming pools, spas and their safety barriers. Melbourne: VBA, 2014. http://www.vba.vic.gov.au/__data/assets/pdf_file/0009/19386/Swimming-pools,-spas-and-their-safety-barriers.pdf (accessed Feb 2017).

33 Odetola F, Gebremariam A, Davis M. Comorbid illnesses among critically ill hospitalized children: impact on hospital resource use and mortality, 1997–2006. *Pediatr Crit Care Med* 2010; 11: 457-63.

34 Erikssen G, Liestøl K, Seem E, et al. Achievements in congenital heart defect surgery. *Circulation* 2015; 131: 337-46.

35 Campbell Research and Consulting. An evaluation of the public access defibrillation (PAD) PAD demonstration. Melbourne: Campbell Research and Consulting, 2008. http://www.health.gov.au/internet/main/publishing.nsf/content/14ECB83A6CBA80EBCA257BF0001D3A58/$File/padev.pdf (accessed Feb 2017). ❑

Appendix

This appendix was part of the submitted manuscript and has been peer reviewed. It is posted as supplied by the authors.

APPENDICES

Appendix I: Utstein definitions for the uniform collection and reporting of data on cardiac arrest (Jacobs et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: Update and simplification of the Utstein templates for resuscitation registries. A statement for healthcare professionals from a task force of the international liaison committee on resuscitation. Resuscitation. 2004;63(3):233-49)

Core Data Element	Definition
Cardiac arrest	The cessation of cardiac mechanical activity as confirmed by the absence of signs of circulation. If an EMS provider of physician did not witness the cardiac arrest, he/she may be uncertain as to whether a cardiac arrest actually occurred.
CPR	An attempt to restore spontaneous circulation by performing chest compressions with or without ventilations.
Cause of arrest/aetiology	An arrest is presumed to be of cardiac aetiology unless it is known or likely to have been caused by trauma, submersion, drug overdose, asphyxia, exsanguination, or any other non-cardiac cause as best determined by rescuers.
Emergency medical services	EMS personnel respond to a medical emergency in an official capacity as part of an organised medical response team. By this definition, physicians, nurses or paramedics who witness a cardiac arrest and initiate CPR but are not part of the organised rescue team are characterized as bystanders and not part of the EMS team.
Witnessed	One that is seen or heard by another person or an arrest that is monitored
Bystander CPR	Cardiopulmonary resuscitation performed by a person who is not responding as part of an organised emergency response system to a cardiac arrest. Physicians, nurses and paramedics may be described as performing bystander CPR is they are not part of the emergency response system involved in the victim's resuscitation.
First monitored rhythm	The first cardiac rhythm present when the monitor or defibrillator is attached to the patient after a cardiac arrest.
Shockable/non-shockable	Shockable cardiac arrest rhythms are further divided into ventricular fibrillation and pulseless ventricular tachycardia. Nonshockable cardiac arrest rhythms can be categorized as either asystole or

	PEA. Although a very specific definition of asystole is desirable, no consensus agreement was reached on either a specific duration (e.g. 30 seconds) or heart rate (e.g. <5 beats per minute) to define asystole versus bradycardia/PEA.
Return of spontaneous circulation (ROSC)	Signs of return of spontaneous circulation include breathing (more than an occasional gasp), coughing or movement. For healthcare personnel, signs of ROSC may also include evidence of a palpable pulse or a measurable blood pressure. ROSC is defined for all rhythms as the restoration of a spontaneous perfusing rhythm that results in more than an occasional gasp, fleeting palpated pulse, or arterial waveform.
Sustained ROSC	Sustained ROSC is deemed to have occurred when chest compressions are not required for 20 consecutive minutes and signs of circulation persist (or sustained ROC if extracorporeal circulatory support is applied).
Neurological outcome at discharge from hospital	Documentation of the patient’s neurological status at many specific points is desirable (e.g. on discharge from the hospital, at 1 year). Survival without higher neurological function is suboptimal; therefore, it is important to attempt to assess neurological outcome at discharge. A simple validated neurological score such as the cerebral performance category (CPC) should be recorded if available.

Appendix II: The Paediatric Cerebral Performance Category (PCPC) scale

(Fiser D, Long N, Roberson P, Hefley G, Zolten K, Brodie-Fowler M. Relationship of Pediatric Overall Performance Category and Pediatric Cerebral Performance Category scores at pediatric intensive care unit discharge with outcome measures collected at hospital discharge and 1- and 6-month follow-up assessments. Crit Care Med. 2000;28(7):2616-20)

Scale	Category	Description
1	Normal	Normal: at age-appropriate level; school-age child attending regular school classroom
2	Mild disability	Conscious, alert, and able to interact at age-appropriate level; school-age child attending regular school classroom but grade perhaps not appropriate for age; possibility of mild neurologic deficit (e.g. seizure disorder).
3	Moderate disability	Conscious. Below age-appropriate functioning; neurologic disease that is not controlled and severely limits activities. Sufficient cerebral function for age-appropriate independent activities of daily life; school age child attending special education classroom and//or learning deficit present.
4	Severe disability	Conscious; dependent on others for daily support because of impaired brain function. School-age child may be so impaired as to be unable to attend school.
5	Coma or vegetative state	Any degree of coma without the presence of all brain death criteria unawareness, even if awake in appearance, without interaction with environment; cerebral unresponsiveness and no evidence of cortex function (not roused by verbal stimuli); possibility of some reflexive response, spontaneous eye-opening, and sleep-wake cycles.
6	Brain death	Apnoea, areflexia, and/or electroencephalographic silence.

Appendix III. Baseline variables of paediatric out-of-hospital cardiac arrest presentations to Royal Children's Hospital Emergency Department

Variable	**Total (n = 121)**
Age, months, *median (IQR)*	6 (2,20)
Male sex, *n (%)*	77 (64)
Aetiology, *n (%)*	
Asphyxia	3 (3)
Cardiac	7 (6)
Neurological	6 (5)
Other	17 (14)
Respiratory	8 (7)
SIDS	50 (41)
Submersion	4 (3)
Trauma	4 (3)
Unknown	22 (18)