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Clinical paper

Evaluation of hospital management of paediatric out-of-hospital cardiac arrest

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Abstract

Introduction: Pediatric out of hospital cardiac arrest (POHCA) is rare, with high mortality and neurological morbidity. Adherence to Pediatric Advanced Life Support guidelines standardizes in-hospital care and improves outcomes. We hypothesized that in-hospital care of POHCA patients was variable and deviations from guidelines were associated with higher mortality.

Methods: POHCA patients in the London-Middlesex region between January 2012 and June 2020 were included. The care of children with ongoing arrest (intra-arrest) and post-arrest outcomes were reviewed using the Children's Hospital, London Health Sciences Centre (LHSC) patient database and the Adverse Event Management System.

Results: 50 POHCA patients arrived to hospital, with 15 (30%) patients admitted and 2 (4.0%) surviving to discharge, both with poor neurological outcomes and no improvement at 90 days. Deviations occurred at every event with intra-arrest care deviations occurring mostly in medication delivery and defibrillation (98%). Post-arrest deviations occurred mostly in temperature monitoring (60%). Data missingness was 15.9% in the intra-arrest and 1.7% in the post-arrest group.

Discussion: Deviations commonly occurred in both in-hospital arrest and post-arrest care. The study was under-powered to identify associations between DEVs and outcomes. Future work includes addressing specific deviations in intra-arrest and post-arrest care of POHCA patients and standardizing electronic documentation.

Keywords: Pediatrics, Cardiac arrest, Pediatric Advanced Life Support, CPR, Guidelines, Deviations

Introduction / background

Pediatric out of hospital cardiac arrest (POHCA) is a rare, life-threatening event, with 2–24% of POHCA patients surviving to hospital discharge.[1–5] Of survivors, many are left with devastating neurological injury.[3,6] A recent epidemiological study by Fink et al. found no change in incidence or survival rates of POHCA events in North America over time, highlighting the need for further investigation into this field.[5]

Adherence to the Pediatric Advanced Life Support (PALS) guidelines, which outlines best practices in resuscitation and post-resuscitation care, may help standardize the care of POHCA patients and may improve outcomes.[7,8] POHCA patients require rapid interventions early on including high-quality CPR, airway control, early epinephrine, and rapid defibrillation, as needed.[7,9–13] Emphasis is also placed on post cardiac arrest care (PCAC), specifically, targeted temperature management (TTM), oxygen (O2) and carbon dioxide (CO2) targeting, hemodynamic monitoring, and prognostication, among other factors.[8] However, the in-hospital management of ongoing arrest in POHCA patients has not been investigated.

Due to the rarity and complexities of POHCA events, deviations (DEV) in care from the PALS guidelines may occur. Wolfe et al. investigated DEVs from the American Heart Association (AHA) guidelines for in-hospital cardiac arrest (IHCA) patients and found that DEVs in chest compressions, defibrillation, medications or vascular access led to a lower chance of achieving return of spontaneous circulation (ROSC).[14] McKenzie et al. also found common DEVs in the pre-hospital care of POHCA patients in Ontario's Middlesex-London region, but the study was underpowered to estab-

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lish an association with outcomes.[15] Pitetti et al. showed that survival was higher in POHCA patients if ROSC was achieved prior to emergency department (ED) arrival.[16] In the Middlesex-London POHCA cohort, paramedics were able to achieve higher-than-average rates of ROSC prior to ED arrival (35.3%), but these patients had a low survival rate (5.8%) with neurological morbidity for all survivors.[15]

The current study investigated the in-hospital management for POHCA patients in the Middlesex-London region between the years of 2012–2020. We hypothesized that in-hospital intra-arrest and post-arrest care at Children's Hospital – London Health Sciences Centre (CH-LHSC) is highly variable and DEVs in care are associated with poor patient outcomes.

Methods

We performed a retrospective cohort study, for POHCA patients in the Middlesex-London region between January 1, 2012 and June 30, 2020. Patients were identified for inclusion using the Canadian Resuscitation Outcomes Consortium (CanROC) registry, a national de-identified OHCA registry. Ambulance call records were used to collect data on pre-hospital patient management and transport to hospital. In-hospital management and patient outcomes were collected using hospital records from the Children's Hospital, London Health Sciences Centre (CH-LHSC) Electronic Medical Records (EMR). The Adverse Event Management System (AEMS) was used to identify equipment unavailability, malfunction or failure. The study was approved by Western University Health Science Research Ethics Board (ID: 119460).

Patient population

Pediatric patients, one day old to less than 18 years of age, in the Middlesex-London region were included into the study if they had an OHCA event between January 1, 2012 and June 30, 2020, and were transported to CH-LHSC via ambulance. Patients were excluded if they had a traumatic OHCA, or if their outcome variables were not retrievable. Comorbidities were recorded into the following categories: cardiac (e.g., congenital heart deformities, cardiomyopathy), respiratory (e.g., asthma, recurrent pneumonia, congenital lung malformations) neurological (e.g., cerebral palsy, epilepsy, hydrocephalus, tumors) or other conditions (e.g., mental illness, developmental disorders, non-cardiac/neurological conditions). Ability to perform all age-appropriate activities of daily living prior to arrest was also recorded. Pediatric Overall Performance Category (POPC) was collected at discharge and at 90 days by chart review as a measure of neurological morbidity. The primary outcome was survival to hospital discharge. Secondary outcomes were survival to hospital admission, survival at 90 days post event, and neurological status at discharge and at 90 days.

Process of care Deviation definitions

DEVs were defined as any departure from the most recent resuscitation and post-resuscitation guidelines outlined by PALS AHA and the Heart and Stroke Foundation Canada (HSFC).[7,8] The 2010 guidelines were used to assess for DEVs for patients from January 1, 2012 - November 3, 2015, whereas the 2015 guidelines were used for patients from November 4, 2015 - June 30, 2020 (the 2015 guidelines were published on November 4th, 2015). McKenzie et al.'s deviation categories and definitions were modified for this study.[15] Eleven categories of DEVs were developed: 1) Airway management, 2) Vascular access, 3) CPR/Chest compressions, 4) Defibrillation, 5) Medications, 6) Leadership/Teamwork, 7) Equipment function, 8) Temperature management, 9) Hemodynamic monitoring, 10) Prognostication and 11) General Monitoring. Specific definitions are listed in Appendix 1. In total, this study investigated 32 potential DEVs, with 24 being intra-arrest specific, and 8 being post-arrest specific. DEVs were recorded for the number and frequency per patient and were analyzed according to the aforementioned categories and individual DEVs. Hyperkalemia was defined as a value greater than 5.5 mmol/L. Definitive airway management was defined as insertion of either an endotracheal tube, supraglottic airway or surgical airway. We defined a time of initial epinephrine delivery of two minutes or greater from arrival to hospital with ongoing arrest a DEV.

Intra-Arrest and Post-Arrest care group definitions

Because our study aim was to better understand the in-hospital management of POHCA patients, we needed to distinguish between the two stages of care provided in the hospital: intra-arrest (i.e., the resuscitation), and post-arrest (i.e., post-arrest care). Patients were subdivided into these 2 groups according to the stage of their arrest while in the ED. These groups are not distinct. The intra-arrest group included all patients who received cardiac arrest care in the ED, including those who presented with ROSC and those who re-arrested in the ED. The intra-arrest group only included data regarding resuscitative efforts in the ED, as performed by pediatric ED staff. The post-arrest group included all patients who survived to have an admit-to-hospital order and received PCAC in the ED and/or the Pediatric Critical Care Unit (PCCU) by either ED staff or PCCU staff respectively. The post-arrest group included data only surrounding PCAC. The primary survival outcome for the intra-arrest group was survival to admission, whereas the primary survival outcome for the post-arrest group was survival to discharge.

Data analysis

Descriptive statistics were performed on cardiac arrest management variables, DEVs, and outcomes for each group. Medians and interquartile ranges (IQR) were used to summarize continuous variables, whereas percentages and frequencies summarized categorical variables. DEVs were analyzed individually and in categories, using logistic regression for dichotomous outcomes and Pearson correlations for continuous outcomes. Data missingness to patient outcomes was analyzed using Pearson correlations and chi-square tests for continuous and categorical outcomes, respectively. Relevancy of missingness was considered for the applicability of data points to each patient (e.g., if epinephrine was not given, then specific dosages of epinephrine and dosing intervals would be irrelevant data points). Missing data were not included as a DEV. SPSS version 29 (IBM Corporation, Armonk, NY, USA) was used for all statistical analyses, and p-values < 0.05 were considered statistically significant.

Results

From January 1st, 2012 to June 30th, 2020, a total of 51 atraumatic POHCA patients were transported to CH-LHSC. One patient was excluded due to missing hospital records, making the cohort analyzed in this study $N = 50$. Patient characteristics are included in Table 1a, with event specific characteristics in Table 1b. Pre-hospital ROSC was achieved in six (12%) patients and lost in five

Table 1a – Patient Characteristics.

Characteristic	Total (n = 50) *n (%)*
Age (years) (median, IQR)	2 (0–14)
Infant (1 day to 12 months)	20 (40.0%)
Child (1 year to 11 years)	13 (26.0%)
Adolescent (12 years to < 18 years)	17 (34.0%)
Male Sex	26 (52.0%)
Weight (kg) (median, IQR)	14 (6.55–43.75)
Pre-Existing Comorbidities	
Cardiac	7 (14.0%)
Neurological	6 (12.0%)
Respiratory	10 (20.0%)
Other	14 (28.0%)
None	23 (46.0%)
Baseline POPC Category	
1	40 (80.0%)
2	≤5
3	≤5
4	7 (14.0%)
5	≤5
Unknown	≤5
Age-appropriate independent living prior to arrest (yes)	41 (83.7%)

Table highlighting the patient characteristics of the cohort and the percentage of patients associated with each descriptor.

of these in the ED. In-hospital ROSC was achieved in nine (18%) patients. Forty-nine (98%) patients were included into the intra-arrest group, and 15 (30%) patients were included in the post-arrest group (Fig. 1). Two (4%) patients survived to discharge with new neurological impairments, with POPC scores of four, and no improvement at 90 days.

Intra-Arrest group deviations

Within the intra-arrest group, all patients (n = 49) had at least one DEV per event, with a median (IQR) of six (5.0–9.0) DEVs per event. The greatest number of DEVs occurring for one patient was 13. Medication delivery and defibrillation were the most frequent categorical DEV groups, occurring in 48 out of 49 patients (98%), with a median (IQR) of three (2–4) and one (1–2) DEVs per patient respectively. DEVs in airway management and chest compression occurred in 61% and 53% of patients, respectively. Vascular access DEVs occurred in 39% of patients, while no DEVs occurred in the Equipment Function category. No data were collectable surrounding Leadership DEVs. The most frequent individual DEVs were: rhythm check intervals, fluid bolus dose, ETCO2 monitoring use for airway placement, and epinephrine delivery intervals occurring in 65%, 61%, 53%, and 51% of patients respectively. Total DEVs and categorical DEVs were not associated with survival to admission (p > 0.05) or secondary outcomes.

Post-Arrest group deviations

Most patients in the post-arrest group (n = 12, 80%) had at least one DEV per event with a median (IQR) of two (1–2.5). The maximum number of DEVs per event was three. Temperature management was the most frequent categorical DEV occurring in 9 out of 15 patients (60%). The next most frequent categorical DEVs were: airway management, general monitoring, hemodynamic monitoring and prognostication occurring in 40%, 40%, 20% and 13% of patients respectively. No DEVs occurred in the medication delivery category. The most common individual DEVs were: disruption in continuous temperature monitoring, echocardiography not performed, and failure to target O2 saturation of 94–99% (or child's normal O2 saturation level), which occurred in 60%, 40% and 40% of patients, respectively. Total DEVs were not associated with survival to discharge or the secondary outcomes (p > 0.05). There were no instances of equipment malfunction, unavailability or misuse.

Intra-Arrest group missingness

All patients in the intra-arrest group had missing data, with a mean (SD) of 15.9% (±6.2%) of all relevant data missing per patient. The following data were missing for all patients: CPR rate, compression fraction, frequency of CPR compressor change, and reassessments following fluid bolus administration. The next most frequent missing data points were ventilation rate (n = 30, 97%), if team roles were well defined (n = 38, 78%), and ETCO2 monitoring during airway placement (n = 19, 61%). Total missingness and categorical missingness were not associated with outcomes (p > 0.05).

Post-arrest group missingness

For the post-arrest group, a mean (SD) of 1.7% (±1.7%) of all relevant data were missing per patient. No data were available on disruptions during continuous electroencephalography (cEEG) use. The next most frequent missing data points were TTM used (n = 4, 27%) and cEEG used (n = 1, 11%). Total missingness was not associated with outcomes (p > 0.05).

Discussion

Our study investigated the in-hospital care of POHCA patients in the Middlesex-London region. Our main findings were: 1) DEVs from current resuscitation and/or PCAC guidelines were frequent, and 2) missingness in data recording was especially present in the ED. We have identified areas for improvement with potential solutions that are applicable to other hospitals.

Our cohort's survival to discharge rate (4%) was lower than other cohorts reported in the literature.[1–5] Paramedics achieved higher-than-average rates of ROSC prior to ED arrival, 35.3% compared to 16.2% in a large North American multicenter POHCA study.[5,15] ROSC upon ED arrival (14%) was similar to that same study (16.7%).[5] The inability to obtain a sustained ROSC in the pre-hospital setting may be due to DEVs in PCAC and should be an area of future inquiry.

Intra-arrest group deviations

All intra-arrest group patients had at least three DEVs per event, with a median (IQR) of six (5.0–9.0) DEVs per event. This high rate of DEVs may be explained by the rarity of POHCA events at CH-LHSC, which averaged 5.5 events per year during the study period. Care providers do not have the opportunity to manage POHCA regularly and not all providers have PALS training as it is not mandated for employment. Multi-disciplinary simulation training is being used more regularly but POHCA is only one of many potential emergencies involved.

Table 1b – Event Specific Characteristics.

Characteristic	Total (*n* = 50) *n (%)*
Year of event (median, IQR)	
2012–2014	18 (36.0%)
2015–2017	12 (24.0%)
2018–2020	20 (40.0%)
Time of arrival	
00:01–06:00	9 (18.0%)
06:01–12:00	11 (22.0%)
12:01–18:00	16 (32.0%)
18:01–24:00	14 (28.0%)
ROSC present on arrival	6 (12.0%)
ROSC status in hospital	
ROSC upon ED arrival, sustained to discharge	1 (2.0%)
ROSC upon ED arrival, lost in hospital, not regained	5 (10.0%)
CPR upon ED arrival, ROSC achieved in hospital/sustained to discharge	1 (2.0%)
CPR upon ED arrival, ROSC achieved in hospital, lost and not regained	8 (16.0%)
CPR upon ED arrival, ROSC never achieved in hospital	35 (70.0%)
Initial presenting rhythm on ED arrival	
VF	1 (2.0%)
PEA	8 (16.0%)
Asystole	30 (60.0%)
Sinus rhythm	2 (4.0%)
Not recorded	9 (18.0%)
Pupillary response upon ED arrival	
Fixed/Non-Reactive	43 (86.0%)
Sluggish	1 (2.0%)
Reactive	1 (2.0%)
Not recorded	5 (10.0%)
Systolic BP upon ED arrival	
Normal BP	5 (10.0%)
Hypotension	12 (24.0%)
Hypertension	5 (10.0%)
Not recorded	22 (44.0%)
Temperature upon ED arrival	
Normothermia	5 (10.0%)
Hypothermia	31 (62.0%)
Hyperthermia	1 (2.0%)
Not recorded	13 (26.0%)
Heart rate upon ED arrival	
Normal HR	6 (12.0%)
Bradycardia	2 (4.0%)
Tachycardia	7 (14.0%)
Not recorded	35 (70%)
Definitive airway management obtained prior to hospital arrival	18 (36.0%)
Oropharyngeal airway	17 (35.0%)
Endotracheal Tube	21 (42.0%)
Surgical airway	3 (6.0%)
Definitive airway management obtained in hospital	26 (52.0%)
Endotracheal Tube	26 (52.0%)
IV access achieved by Paramedic Teams	8 (16.0%)
IO access achieved by Paramedic Teams	32 (64.0%)
IV access achieved in hospital	28 (56.0%)
IO access achieved in hospital	19 (38.0%)
Defibrillation in ED	4 (8.0%)
Medication Delivery in ED	
Epinephrine	45 (90.0%)
Amiodarone	1 (2.0%)
Lidocaine	0 (0.0%)
Dopamine	2 (4.0%)
Fluid bolus	39 (78.0%)
Reversible Causes Identified in ED	
Hypovolemia	37 (74.0%)

Table 1b (continued)

Characteristic	Total (*n* = 50) *n (%)*
Acidosis	29 (58.0%)
Hypoglycemia	2 (4.0%)
Hyperkalemia	17 (34.0%)
Hypokalemia	2 (4.0%)
Toxins	1 (2.0%)
Survival to hospital admission	15 (30.0%)
Survival to hospital discharge	2 (4.0%)
Type of death (*n* = 48)	
TOR in ED	35 (70.0%)
WLST	12 (24.0%)
Physiological death	1 (2.0%)
Patient alive at day 90 following hospital discharge	2 (4.0%)

Table highlighting the percentage of POHCA events in the Middlesex-London region with the following event specific characteristics. Acronyms: Termination of Resuscitation (TOR), Withdrawal of Life Sustaining Therapy (WLST). Physiologic death is defined as death occurring in the absence of the removal of life sustaining therapies.

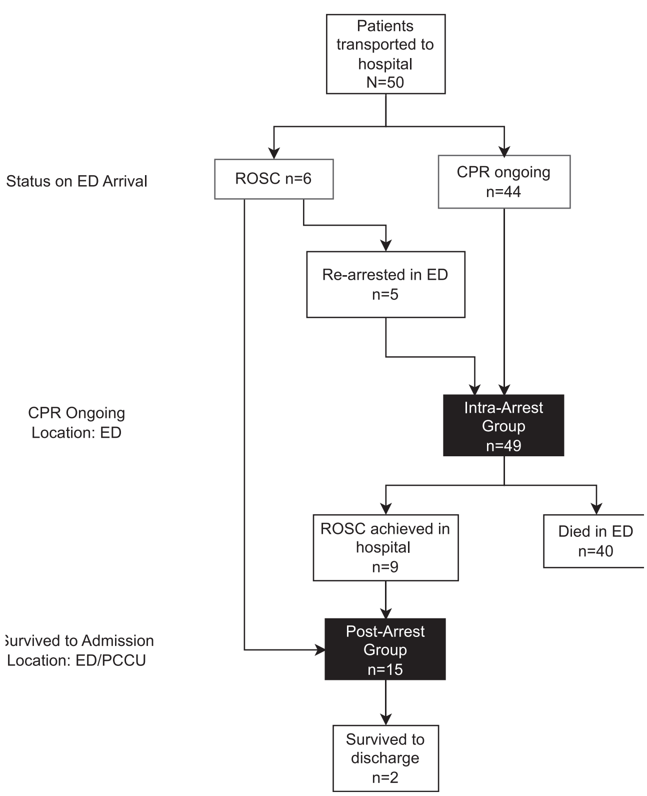

Fig. 1 – Summary of group allocation based on ROSC status.

The frequency of in-hospital, intra-arrest DEVs was much higher than the pre-hospital frequency of DEVs, which had a median (IQR) of three (2–5) for the same cohort.[15] Though the Middlesex-London Paramedic Services teams do not have PALS mandated for employment, they have annual mandatory arrest simulation training. The regional paramedic teams respond to over 500 adult cardiac arrest events per year, with each paramedic attending 2–50 arrests per year. Frequent exposure to adult arrests and annual arrest training may contribute to effective pre-hospital teams and their ability to achieve high rates of ROSC with low DEVs from guidelines. Replicating these factors in the in-hospital setting should be considered and may be feasible for children's hospitals that are situated within or beside adult hospitals.

Nearly all patients in the intra-arrest group had a DEV in both the medication delivery (98.0%) and defibrillation (83.7%) category, with airway management (61.2%) being the next most frequent. A similar pediatric IHCA study by Wolfe et al. found airway management was the most frequent categorical DEV (38.8%).[14] Our results showed a much higher frequency of our top three categorical DEVs than comparable IHCA studies.[14,17] This may be due to differences in OHCA and IHCA in-hospital response teams, despite treatment of cardiac arrest for these two settings being the same. Hence, our results must be taken into context with local protocols and rarity of regional POHCA.

The most common individual DEV within medication delivery was incorrect epinephrine dosing intervals in 25 (51.0%) patients, with the majority of DEVs (65.0%) being dosages greater than five minutes apart. Emerging evidence suggests more frequent dosing of epinephrine may be beneficial.[18–22] Additionally, delay to initial epinephrine delivery (greater than two minutes after arrival/onset of cardiac arrest) occurred in 23 (46.9%) patients. Delayed epinephrine has been associated with a lower likelihood of ROSC, survival to discharge and favorable neurological outcomes at discharge.[11,23–25] Both of these DEVs may have contributed to the low survival rate, even though our study was underpowered to show this. These are important interventions to focus future training and quality improvement initiatives.

Post-Arrest group deviations

Most patients in the post-arrest group (80%) had at least one DEV per event, with the most frequent DEVs occurring in disruptions in continuous temperature monitoring (60%). Continuous temperature monitoring allows care providers to initiate TTM and reactively respond to fluctuations in temperature, specifically fever, which is associated with poorer neurological outcomes.[26] The post-arrest group experienced a lower frequency of DEVs than the intra-arrest group. Fewer DEVs may also reflect the feasibility of guideline compliance in a non-arrest situation; the situation becomes more controlled due to less urgency, less personnel, and less stress. One solution to reducing DEVs during PCAC is to formally order PCAC protocol in the patient's chart. Guideline non-compliance is multifactorial. Barriers include lack of guideline awareness, ineffective communication, workload, and adaptability to guideline changes, and can be explained at the provider and system levels.[27–29] Site specific evaluations of factors contributing to guideline DEVs can help create focused, reliable change in both the acute care and inpatient settings.

Documentation & missing data

The intra-arrest group had a higher percent missingness of relevant data than the post arrest group (15.9% vs 1.7%). ED notes were exclusively written by hand, introducing the potential for omissions and inaccuracies in recording time and dose-specific information. EMRs could improve these inherent limitations of hand-written documentation. Regional paramedic teams have protected time for documentation and utilize a standardized EMR. Additionally, Root et al. found improved guideline compliance and documentation with the implementation of weekly audits using visual and physiological parameters of NICU resuscitation events.[30]

CPR quality data such as compression fraction, CPR rate, and change in compressors, were not available for this study. Quality of CPR is associated with survival and is dependent on factors such as rapid initiation of CPR, minimal interruptions, and optimal chest compression, among other factors.[31–44] Assumptions cannot be made regarding the quality of CPR in the absence of information, as studies have found it can often deviate from suggested guidelines.[45–49] Further efforts to improve data collection for quality of CPR for POHCA patients have been achieved by implementing defibrillator pads that monitor and automatically record CPR parameters for future interpretation, as recommended by PALS guidelines.[46] In the case of the Middlesex-London Paramedic Services, these data are analyzed and feedback is provided about resuscitation performance to promote guideline compliance.

Recording of resuscitation parameters can also help improve the accuracy and reliability of documentation.[47–49] Jiang et al. demonstrated that use of audio-visual recording of CPR in regular feedback sessions post-arrest can help highlight DEVs in CPR delivery and improve aspects of CPR quality.[50] Debriefs are valuable for improving resuscitation team performance. Hunt et al. found improved AHA CPR guideline compliance by developing a resuscitation quality bundle formed from weekly IHCA debriefs that identified strengths, barriers to compliance, and quality improvement solutions.[51] Currently, debriefs are not standardized in the ED following cardiac arrest events at our centre, whereas they are mandatory for our region's paramedic teams.

Our study was not without limitations. Local protocols and regional demographics may limit the generalizability of our findings. However, our study site is very similar to many other hospitals where cardiac arrest resuscitation and post-cardiac arrest care have not yet been addressed by a focused quality improvement initiative. There was considerable missingness in patient records; we controlled for this by ensuring that missing data were not interpreted as actions or inactions with respect to care delivery.

Conclusion

DEVs from guidelines occurred at every event in both the arrest and post-arrest care of POHCA patients in a hospital setting. Medication delivery and disruptions in continuous temperature monitoring were the most frequent DEVs. Given our study's lack of power we could not draw associations between DEVs and our outcomes of interest. Data missingness was common; we suggest that standardized electronic documentation, quality of CPR data acquisition, documentation audits, and directed feedback on CPR quality and team performance may improve our team's performance and survival outcomes.

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Color Requirements

No color needed for figures.

CRediT authorship contribution statement

Dhruv Gupte: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Maysaa Assaf:** Methodology, Software, Resources, Data curation, Writing – review & editing. **Michael R. Miller:** Formal analysis, Writing – review & editing. **Katie McKenzie:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – review & editing. **Jay Loosley:** Writing – review & editing. **Janice A. Tijssen:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1 Intra-arrest group deviations

Category	Deviation
Airway Management	Airway insertion delay
	Delay recognition of airway misplacement
	Aspiration related to provision of airway
	Intubation attempted; not achieved
	Advanced airway placed; incorrect ventilation rate (breath every 6–8 s)
	Bag-mask ventilation; wrong flow (10–15 L/min in peds bag, > or = 15 L/min in adult bag)
	Use of uncuffed ETT (not recommended)
	Incorrect ETT ID size (cuffed: age < 1 – 3.0 mm, 1-2y 3.5 mm, >2 = 3.5+(age/4))
	Inappropriate oxygen during resuscitation (100%)
	0 ETCO2 monitoring if available for proper airway placement
Vascular Access	Delay in obtaining access (should be right after rhythm interpretation and CPR 2 min)
	IV not used as initial attempt for access
	Infiltration or inadvertent disconnection of IV line
	Inadvertent arterial cannulation
	IO indicated; insertion delay (after 2 IV attempts or < 90 s for IV then IO)
CPR / Chest Compressions	Chest compression delay (>10 s)
	Wrong compression and ventilation rate without advanced airway (15:2 or 30:2)
	Chest compressions not on hard surface
	Optimal depth chest compressions not achieved (infant 4 cm, children 5 cm, puberty 5–6 cm)
	Wrong compression rate (100 to 120/min for infants and children)
	Disruptions to CPR greater than 10 s, or </= 10 s with intervals < 2 min
	Compressor not changed every 2 minutes
Defibrillation	Initial monitored rhythm delay (>2 min from arrival to ED)
	Rhythm check; inappropriate intervals (q2min)
	Manual defibrillation incorrect energy INITIAL dose (2–4 J/kg infants and children)
	Manual defibrillation incorrect energy subsequent dose (4 J/kg)
	Manual defibrillation incorrect energy, exceeded maximal dosage (>10 J / kg, >maximal adult dose)
	Manual defibrillation incorrect dosing interval (2–3 min)
	Defibrillation given; not indicated
	Defibrillation delay; incorrect pad placement
	Defibrillation delay; incorrect pad size (largest ones that will fit without touching)
	Defibrillation delay; defibrillator not immediately available
	Defibrillation delay; personnel not available
	Defibrillation not given; indicated
Medications	Epinephrine not given
	Incorrect epinephrine dose (0.01 mg/kg (0.1 ml/kg of 1:10000), max 1 mg)
	Initial epinephrine delay (asystole and PEA; should be given once IV/IO access)
	Epinephrine interval delay (3–5 min)
	Amiodarone not given; indicated
	Wrong amiodarone dose (loading – 5 mg/kg bolus, max 3 total doses (15 mg/kg/day), max 300 mg / dose)
	Incorrect timing of amiodarone (after 2 shocks)
	Excess amiodarone given (>3 total doses)
	Lidocaine not given; indicated
	Wrong lidocaine dose – (initial dose: 1 mg/kg loading)
	Incorrect dosing interval (2–4 mins)
	Incorrect timing of lidocaine (after 2 shocks)
	Fluid bolus given; not indicated (indication: shock)
	Inappropriate fluid dose (IV 10–20 ml/kg, max vol 2000 ml)
	Failure to reassess after every fluid bolus infusion
	Fluid bolus not given; indicated
	Wrong medication selection
	Hypovolemia: 0 IV fluids given
	Acidosis: 0 sodium bicarbonate when necessary
	Hypoglycemia: 0 IV dextrose given
	Hyperkalemia: 0 sodium bicarb, glucose + insulin, calcium chloride or calcium gluconate, kayexalate, dialysis given
	Hypokalemia: 0 diluted IV K + given
	Tension pneumothorax: 0 needle decompression given
	Toxins: 0 reversing agent given (when applicable)
Leadership	Delay in identifying team leader
	Too many team members
Equipment Function	Equipment not available
	Equipment malfunction

Appendix 2. Post-arrest group deviations

Category	Deviation
Airway Management	Failure of pCO2, ETCO2 to target 35–45 mmHg, or appropriate to child's condition
	Failure to target O2 saturation of 94–99%
Medication Delivery	Fluid bolus given; not indicated (SBP >/90 mmHg)
	If hypotension (SBP < 60 for < 1 m, <70 for 1 m-1y, 70 + 2x age for > 1y- 10 yo, <90 for > 10yo) persists beyond 2–3 20 ml/kg fluid boluses, inotropes not started (dopamine, epinephrine, norepinephrine)
	Sedation and analgesia not addressed; indicated (ie. ETT placed)
	Sedatives provided, contraindicated
	Sedatives provided, wrong dose
Temperature Management	TTM indicated, not performed
	TTM contraindicated, performed
	Failure to maintain central temperature within acceptable range (36–37.5 or 32–34 degrees)
	Disruption in continuous monitoring of temperature
	Fever not identified / treated immediately
Hemodynamic Monitoring	Continuous arterial pressure monitoring not used (where available) – 2015 Specific DEV
	Hemodynamic goals not set
	Disruption in hemodynamic monitoring
	Failure to reassess for HR, rales, resp distress, hepatomegaly after each bolus
	Antibiotics not started, indicated (sepsis as etiology to ROSC)
Prognostication	Disruption in continuous EEG (where available)
	Continuous EEG not used; available, indicated – 2015 Specific DEV
	Clinical seizure; no treatment
	Clinical seizure; delayed treatment
	Clinical seizure; anticonvulsant inappropriate dosage
	Glucose not measured
General Monitoring	Lactate not measured
	MAP not measured
	ECG not performed; indicated
	Echo not performed
	Head CT not performed; indicated

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