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Clinical paper

Out-of-hospital cardiac arrest in children in Norway: A national cohort study, 2016–2021

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Abstract

Aim: Children constitute an important and distinct subgroup of out-of-hospital cardiac arrest (OHCA) patients. This population-based cohort study aims to establish current age-specific population incidence, precipitating causes, circumstances, and outcome of paediatric OHCA, to guide a focused approach to prevention and intervention to improve outcomes.

Methods: Data from the national Norwegian Cardiac Arrest Registry was extracted for the six-year period 2016–21 for persons aged <18 years. We present descriptive statistics for the population, resuscitation events, presumed causes, treatment, and outcomes, alongside age-specific incidence and total paediatric mortality rates.

Results: Three hundred and eight children were included. The incidence of OHCA was 4.6 per 100 000 child-years and markedly higher in children <1 year at 20.9 child-years. Leading causes were choking, cardiac and respiratory disease, and sudden infant death syndrome. Overall, 21% survived to 30 days and 18% to one year.

Conclusion: A registry-based approach enabled this study to delineate the characteristics and trajectories of OHCA events in a national cohort of children. Precipitating causes of paediatric OHCA are diverse compared to adults. Infants aged <1 year are at particularly high risk. Mortality is high, albeit lower than for adults in Norway. A rational community approach to prevention and treatment may focus on general infant care, immediate first aid by caretakers, and identification of vulnerable children by primary health providers. Cardiac arrest registries are a key source of knowledge essential for quality improvement and research into cardiac arrest in childhood.

Keywords: Cardiac arrest, Paediatric cardiac arrest, Paediatric emergency, Cardiac arrest registry, Pre hospital care, Epidemiology

Introduction

Cardiac arrest in a child is a dramatic event with a high associated morbidity and mortality.[1–4] Studies of paediatric out-of-hospital cardiac arrest (OHCA) from Scandinavian countries have reported incidence rates ranging from 3.3 to 4.2 per 100 000 child-years.[5,6] This is significantly lower than overall population OHCA incidence at 56 per 100 000 person-years in Norway.[7] Reported thirty-day survival rates for paediatric OHCA in Scandinavia range from five to 40%.[5,6,8,9]

Paediatric OHCA differs from adult OHCA, notably in terms of incidence, underlying aetiology and first recorded rhythm.[9] Furthermore, characteristics may vary within the paediatric population according to the child's age and associated physiology. In children, triggers of OHCA are heterogeneous compared to the adult population, where cardiac and other medical causes underlie the majority of events. Choking, injuries, drowning, and sudden infant death

Abbreviations: AED, automated external defibrillator, CPC, cerebral performance category, CPR, cardiopulmonary resuscitation, ECMO, extracorporeal membrane oxygenation, EMCC, emergency medical communication centre, EMS, emergency medical service, OHCA, out-of-hospital cardiac arrest, PEA, pulseless electrical activity, NorCAR, Norwegian Cardiac Arrest Registry, ROSC, return of spontaneous circulation, SIDS, sudden infant death syndrome, VF, ventricular fibrillation, VT, ventricular tachycardia

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syndrome (SIDS) predominate.[9] This difference is reflected in paediatric resuscitation guidelines emphasising ventilation.[10,11] However, the scientific basis of such guidance is weak and primarily based on consensus statements from expert panels, extrapolation from adult studies, observational studies, and animal studies.[12]

In Norway, cardiac arrest data are collected in the Norwegian Cardiac Arrest Registry (NorCAR), where registration is mandated by law.[7] Founded in 2002 and established as a national medical quality registry in 2013, NorCAR provides a foundation for quality improvement in resuscitation and medical research.

Knowledge of population incidence underlies resource allocation and optimisation of the resuscitation chain, from first aid via prehospital and hospital care, to community support following discharge. The national constellation of precipitating causes, circumstances, and characteristics of OHCAs specific to children, is an important benchmark to establish as a starting point for improving outcomes. In this population-based cohort study, we aim to utilise NorCAR data to present the first comprehensive picture of current paediatric OHCA epidemiology in Norway.

Materials and methods

Setting

Norway has a population of 5.5 million, inhabiting 384 483 km^2.[13] On average, the group aged <18 years numbered 1.1 million (19.0%) during the study period. Population density varies considerably, ranging from 3 inhabitants per km^2 in the northernmost county of Troms and Finnmark to 1643 inhabitants per km^2 in Oslo County.[14,15]

The population is served by a public health care system. Secondary care is organised into four regional health authorities, subdivided into 19 local health trusts. The emergency medical service (EMS) is accessed through the national emergency telephone number 113. Sixteen Emergency Medical Communications Centres (EMCCs) provide telephone-guided first aid and cardiopulmonary resuscitation (CPR) instructions. An algorithm guides dispatch of EMS services. Depending on time and location, a multi-tiered EMS response with increasingly advanced resuscitation and airway measures may include first responders (fire brigade), ambulances, on-call general practitioners, and anaesthetist-staffed cars or helicopters.[16] Patients successfully resuscitated are admitted to an intensive care unit following initial stabilisation and managed according to standard protocols. Advanced resuscitative measures such as extracorporeal membrane oxygenation (ECMO) are centralised to regional university hospitals.

Data sources

Norwegian law has mandated registration of every resuscitation attempt in NorCAR since 2013. The proportion of health trusts reporting to NorCAR has steadily increased, reaching full national coverage for OHCA in May 2016[7] and data from all hospitals in 2023. A high degree of case completeness in the registry has been demonstrated.[17]

NorCAR records all patients resuscitated outside of and in hospital. For OHCA, all EMS assessed cardiac arrests are registered, including patients receiving bystander CPR only. Dispatch assisted CPR is initiated for patients unresponsive with absent or abnormal breathing, as advised by national resuscitation guidelines.[18] Neonates receiving resuscitation at birth are excluded.[7] Variables include the Utstein dataset[19] and describe the resuscitation pathway from cardiac arrest to 1 year post event. In addition, key characteristics of the event and treatment given by bystanders and health professionals are recorded.[7]

Official population and mortality data used to calculate incidences and total paediatric mortality were obtained from Statistics Norway.[14,20]

Inclusion and exclusion criteria

Cases of NorCAR registered OHCA from 01.01.2016 to 31.12.2021 for children aged <18 years at the time of arrest were retrieved, excluding patients aged <3 days. We included cardiac arrest cases confirmed by EMS or treated by automated external defibrillator (AED) (i.e. those successfully defibrillated before EMS arrival), excluding patients receiving no EMS treatment (Fig. 1).

Definitions

In line with the legal definition in Norway, a child was defined as a person aged <18 years. Age categories of <1, 1–4, 5–12, and 13–17 years were chosen as per available paediatric Utstein guidance.[21]

Sustained return of spontaneous circulation (ROSC) was defined as lasting at least 20 min or until handover to hospital.[22] For assigned causes, NorCAR defines choking as oxygenation failure or obstruction of airways and SIDS as sudden, unexpected death in children aged <2. The registry has no “unknown” category and codes cases of unclear precipitating cause as ”presumed cardiac“.

Arrests were defined as “daytime” if reported to EMS between 06:00 and 22:00.

For data protection purposes, categories of $n < 5$ are not presented. Similarly, in the presentation of the “presumed cause” variable, the category of “non-traumatic haemorrhage” was added to “presumed cardiac” due to small case number.

Clinical outcomes in survivors were stratified using Cerebral Performance Categories (CPC),[23] defining a score of 1 or 2 as “good”, and 3 or 4 as “poor”.

Statistical analysis

Data were processed and analysed using IBM SPSS Statistics, version 26.0, NY, USA. Categorical variables are stated as frequencies and incidences; continuous variables as means with standard deviation or median with interquartile range. Missing data were assumed missing at random and removed when calculating proportions.

Incidence rates per 100 000 child-years with corresponding confidence intervals were calculated using population data for persons aged <18 from Statistics Norway for 2016-21[14]. Age-specific incidence rate calculations used population data for each age group during the study period in the denominator. The number of deaths for one-year age cohorts from 0 to 17 was obtained for calculation of total child mortality as the incidence of death in the period for each cohort.[14]

Arrests witnessed by EMS were excluded when calculating telephone and bystander CPR rates, and proportions of bystander CPR techniques.

User involvement

The Norwegian SIDS and Stillbirth Society contributed user involvement. The society supports bereaved families and works to prevent unexpected deaths in pregnancy and infancy, promoting infant

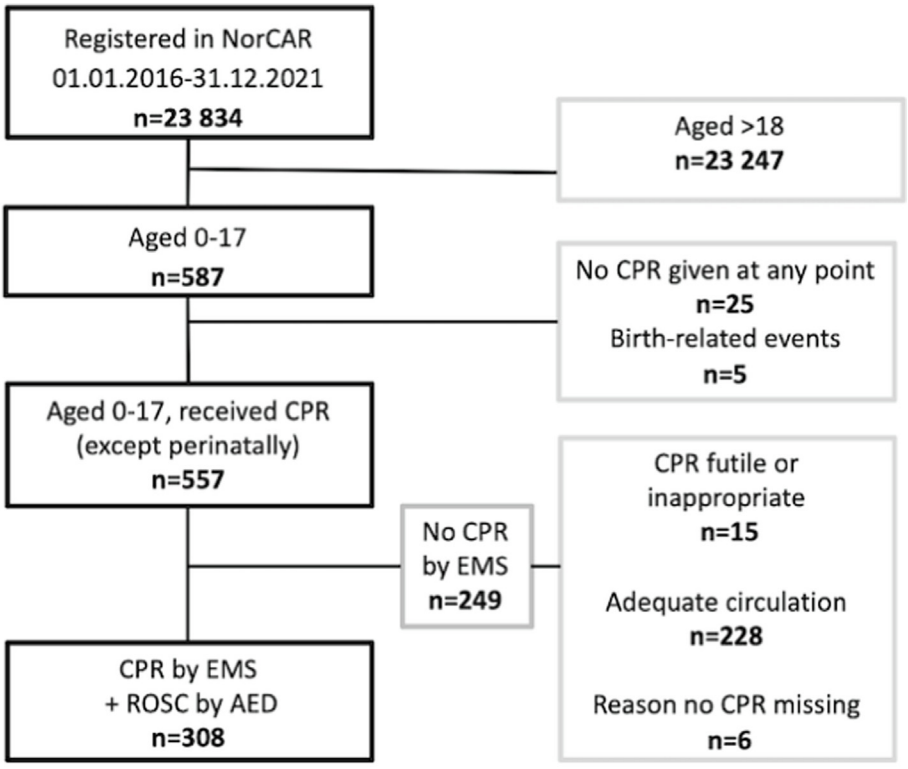

Fig. 1 – Flow chart describing the selection of cases from the Norwegian Cardiac Arrest Registry (NorCAR) for inclusion in the study. Abbreviations – CPR: cardiopulmonary resuscitation, EMS: emergency medical service, NorCAR: Norwegian cardiac arrest registry, ROSC: return of spontaneous circulation.

health and psychosocial health of bereaved families.[24] The association was consulted during the project planning stage, particularly regarding the application for ethical approval.

Ethical approval and data protection

The Regional Ethics Committee granted ethical approval (Ref. no. 2018-7163), including exemption from consent and duty of information. The Data Protection Officer for Oslo University Hospital approved the data management and storage plan (Case Registration Number 22/16211).

Results

Study cohort

Of 23 834 NorCAR registered OHCA cases during the study period, 587 (2.5%) were aged <18 and eligible for inclusion (Fig. 1). Exclusion of cases identified as "no CPR" or perinatal resuscitation yielded 557 potential cases. A further 249 (45%) cases received no CPR by EMS and were excluded. Reasons CPR was not continued in the latter group are given in Fig. 1. Ultimately, cases receiving CPR by EMS or ROSC by AED were included (*n* total = 308).

Characteristics of the study population and cardiac arrest

Table 1 summarises baseline characteristics, stratified by age. Most cases were found at the extremes of age, with 71 (23%) aged <1 year and 133 aged 13–17 years (43%). Overall, 171 cases (56%) were registered as male. Most events occurred in a private home (65%). The proportion occurring at home was highest in the youngest, declining successively with age.

Most arrests were unwitnessed (*n* = 157, 53%), with bystander-witnessed arrests dominating only in the 5–12-year age group (*n* = 27, 56%). All exercise-related arrests occurred in children aged five to 17. The overall bystander CPR rate was 88% (*n* = 247), ranging from 84% (*n* = 101) in the 13–17-year age group to 94% (*n* = 61) in the group aged <1 year. Telephone-assisted CPR was offered in 79% of cases (*n* = 193).

Non-shockable initial rhythms predominated across all age groups. Overall, 73% and 14% of rhythms were documented as asystole or pulseless electrical activity (PEA), respectively (Table 1). However, the proportion of shockable rhythms increased with age to 15% in the 13–17-year group with 19 cases of initial ventricular fibrillation (VF) recorded.

Causes of cardiac arrest, assigned during resuscitation, were dominated by triggers of hypoxia. Choking, SIDS, respiratory failure and drowning made up 67% of cases (Table 1, Fig. 2). The leading cause shifted with age, from SIDS in 0–4 year olds, to respiratory failure in children aged 5–12, and choking in the oldest group (Appendix A1a–d).

Out-of-hospital cardiac arrest and total child mortality

Total child mortality during the study period was highest for patients <1 year, at 206 per 100 000 child-years, near nine-fold that of the group aged 17 (Appendix A2, Fig. 3). Plotting total child mortality with incidence rates of OHCA and 30-day survival for one-year cohorts showed a similar pattern for mortality and OHCA incidence, with

Table 1 – Baseline characteristics.

	Overall *n* = 308	<1 yrs *n* = 71	1–4 yrs *n* = 52	5–12 yrs *n* = 52	13–17 yrs *n* = 133
Incidence, (95% CI)	4.6 (4.3–4.9)	20.9 (18.4–23.4)	3.6 (3.1–4.1)	1.7 (1.5–1.9)	7.0 (6.8–7.2)
Age (median, IQR)	11 yrs (1–15)	71 days (43–142)	1 yr (1–4)	10 yrs (7–12)	16 yrs (14–17)
Sex, *n* female (%)	137 (44)	31 (44)	23 (44)	26 (50)	57 (43)
Location of arrest, *n* (%)					
Home	198 (65)	64 (90)	40 (77)	26 (51)	68 (51)
Public place*	87 (28)	–	–	18 (35)	57 (43)
Healthcare facility[#] or ambulance*	17 (5.5)	–	–	–	–
Educational institution*	5 (1.6)	–	–	–	–
Missing, *n* (% of category)	1 (0.3)	0	0	1 (1.9)	0
Exercise-related arrest, *n* (%)*	11 (3.8)	–	–	–	–
Daytime arrest 06:00–22:00, *n* (%)	243 (81)	53 (75)	40 (77)	46 (88)	104 (78)
Bystander CPR, *n* (%)/Incidence	247 (88)/3.7	61 (94)/18	42 (88)/2.9	43 (88)/1.4	101 (84)/5.3
Missing, *n* (% of category)	8 (2.6)	2 (2.8)	1 (1.9)	2 (3.8)	3 (2.3)
Witnessed collapse, *n* (%)					
Unwitnessed	157 (53)	33 (50)	26 (50)	20 (43)	78 (59)
Bystander-witnessed	119 (40)	28 (42)	22 (43)	27 (56)	42 (32)
EMS-witnessed*	18 (15)	–	–	–	10 (7.7)
Other/missing, *n* (%)	14 (4.5)	5 (7.0)	1 (1.9)	5 (9.6)	3 (2.3)
Offered telephone-guided CPR, *n* (%)	193 (79)	49 (92)	31 (82)	36 (82)	77 (71)
Missing, *n* (% of category)	46 (15)	14 (20)	11 (21)	7 (13)	14 (11)
Initial rhythm, *n* (%)/Incidence					
Asystole	210 (73)/3.1	45 (71)/13.3	39 (81)/2.7	38 (79)/1.2	88 (69)/4.6
PEA*	40 (14)/0.59	12 (19)/0.83	–	–	19 (15)/0.62
VF/VT*	30 (10)/0.45	–	–	6 (13)/0.20	19 (15)/1.0
Perfusing rhythm *	7 (2.4)/0.10	–	–	–	–
Missing	22 (7,1)	8 (11)	4 (7.7)	4 (7.7)	6 (4.5)
Presumed cause, *n* (%)					
Presumed cardiac*	55 (18)	–	–	14 (28)	28 (21)
Respiratory	51 (17)	19 (27)	11 (21)	15 (29)	6 (4.5)
Neurological*	9 (2.9)	–	–	–	5 (3.8)
SIDS	51 (17)	37 (52)	14 (27)	0	0
Trauma/fire	29 (9.4)	0	6 (11)	5 (9.8)	18 (14)
Choking*	67 (22)	–	10 (19)	–	47 (35)
Drowning*	37 (12)	–	–	8 (16)	21 (16)
Overdose/poisoning	8 (2.6)	0	0	0	8 (6.0)
Missing	1 (0.3)	0	0	1 (1.9)	0

Incidences are given per 100 000 child-years for the relevant age group (see "Statistics" in method). Missing data are excluded when calculating proportions. EMS-witnessed events are excluded when calculating bystander CPR rates. "*" indicates less than 5 cases, not displayed in order to comply with privacy regulations. [#]Excluding hospitals. Abbreviations – CI: confidence interval, CPR: cardiopulmonary resuscitation, EMS: emergency medical service, IQR: interquartile range, PEA: pulseless electrical activity, SIDS: sudden infant death syndrome, VF: ventricular fibrillation, VT: ventricular tachycardia.

peaks in the younger and older age groups. Overall, 25% of children who died received CPR, suggesting their deaths were unexpected.

Life support measures

Table 2 summarises prehospital interventions. Most commonly, the type of CPR provided by bystanders complied with guideline recommendations, comprising combined chest compressions and ventilations (*n* = 163, 68% overall).

Advanced airway management was commonest, with more patients undergoing endotracheal intubation (49% of total) than supraglottic airway insertion (16%).

Fifty-four patients were defibrillated (18%), of which six received a shock before EMS arrived (2.0% of all cases). The youngest patients were least likely to receive defibrillation during resuscitation (*n = 9*, 7.8% of all 0–4-year olds), contrasted with approximately one quarter of 5–12- and 13–17-year olds. A minority of shockable rhythms were refractory, i.e. requiring more than three shocks (*n* = 7, 15%). These occurred predominantly in the oldest group (*n* = 6, 21% of defibrillations in this age cohort).

Mechanical CPR using LUCAS™ or AutoPulse® devices was applied in 35 cases aged 11–17 yrs.

Adrenaline was the medication given most frequently during resuscitation (*n* = 167, 56%). Use of Amiodarone was limited to the two oldest age groups, corresponding with the occurrence of refractory VT/VF and current guidelines.

Mechanical circulatory support was established in 7.8% of all cases (*n* = 24), most often ECMO (*n* = 19). The nature of circulatory support for the remaining five cases is not available in NorCAR. Active temperature control was provided in 36 cases (12% of total), and therapeutic hypothermia in a further 30 cases (9.7% of total).

Outcomes

A third of patients had sustained ROSC before hospital arrival (Table 2). Whereas 105 patients (34%) survived 24 hours, 64 were

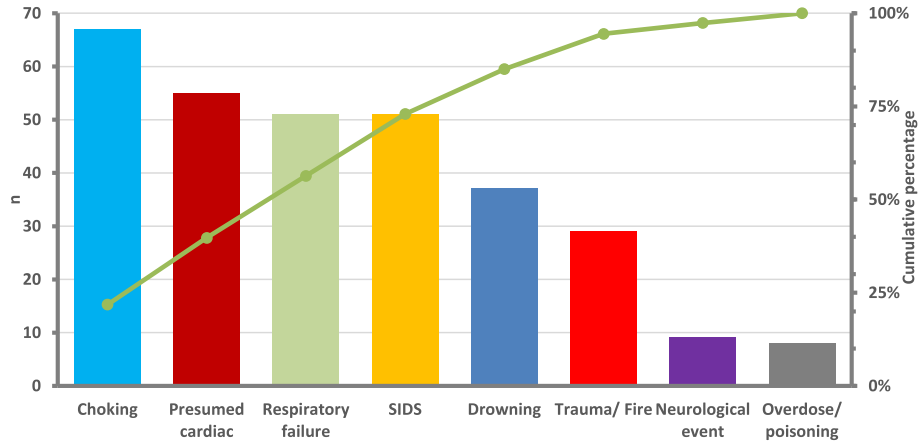

Fig. 2 – Pareto chart of presumed causes of cardiac arrest at the time of resuscitation in the overall cohort, illustrating the great diversity of causes. Abbreviations – SIDS: sudden infant death syndrome All cases of SIDS in the 1–4 age group were aged <2.

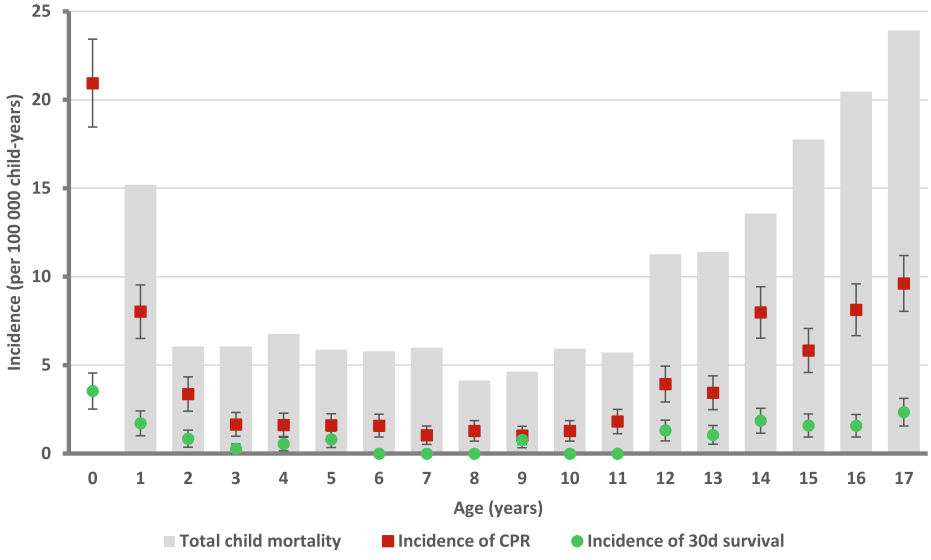

Fig. 3 – Total child mortality (grey columns) with yearly incidence rates of CPR (red squares) and 30-day survival (green dots) for ages 1–17 (per 100 000 children in age cohort). Error bars show 95% confidence intervals. For the group aged <1, total paediatric mortality is not displayed for graphical purposes due to its large value of 206 per 100 000 child-years. Abbreviations – CPR: cardiopulmonary resuscitation, EMS: emergency medical service, OHCA: out-of-hospital cardiac arrest. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

alive at 30 days (21%) and 56 at one year (18%). One-year survival was lowest in those aged <1 ($n = 8$, 11%) and highest in 13–17-year olds ($n = 26$, 20%). Fig. 4 depicts patient status at different stages of the resuscitation chain, illustrating trajectories and outcomes.

Forty-three survivors (15% overall) had Cerebral Performance Category (CPC) scores classed as "good".

Discussion

In this first national population-based report of OHCA in children aged <18 years in Norway, data from the "Utstein" based NorCAR registry enabled description of cardiac arrest events, the resuscitation pathway, and outcome up to 1-year post-arrest. The overall incidence of OHCA was 4.6 per 100 000 during the study period, and markedly higher among the youngest children at 20.9 per 100 000. A similar overall incidence of 4.2/100 000 aged <17 years was recently reported from the Danish cardiac arrest registry by Holgersen et al.[6] This Danish study also found a higher incidence in children aged <1 year, in line with previous and recent international literature reporting age distribution or age-specific incidence of OHCA.[5,25–27]

Non-shockable rhythms dominated, while shockable rhythms increased in proportion with age. Low rates of shockable rhythms have been found consistently in studies of paediatric OHCA.[1,5,8,9,25–28] Hypoxia as the commonest driving mechanism fits with the rate of non-shockable rhythms. A possible explanation for higher rates of shockable rhythms in older children could be cardiac

Table 2 – Prehospital treatment and outcomes.

	Overall *n* = 308	<1 yrs *n* = 71	1–4 yrs *n* = 52	5–12 yrs *n* = 52	13–17 yrs *n* = 133
PREHOSPITAL TREATMENT					
Type of bystander CPR performed[#], *n* (% of those receiving bystander CPR)					
Chest compressions and ventilations	163 (67)	40 (73)	31 (74)	31 (70)	61 (60)
Chest compressions only	77 (32)	15 (27)	11 (26)	11 (25)	40 (40)
Missing, % of non-EMS witnessed	48 (17)	12 (18)	7 (14)	7 (14)	22 (18)
Type of airway management, *n* (%)					
Bag mask ventilation	99 (22)	31 (45)	17 (34)	15 (31)	36 (28)
Supraglottic airway*	46 (16)	–	–	–	34 (26)
Endotracheal tube	145 (49)	32 (46)	27 (54)	28 (57)	58 (45)
Missing, *n* (%)	14 (4.5)	3 (4.2)	2 (3.8)	4 (7.7)	5 (3.8)
Capnography used, *n* (%)	198 (64)	39 (55)	33 (63)	35 (67)	91 (68)
Defibrillation, any, *n* (%)*	54 (18)	–	–	12 (24)	33 (25)
Prior to EMS arrival, *n* (%)*	6 (2.0)	–	–	–	–
Missing, *n* (% of total)	13 (4.2)	5 (7.0)	3 (5.8)	2 (3.8)	3 (2.3)
Drugs given during CPR, *n* (%)					
Adrenaline	167 (54)	32 (45)	32 (62)	32 (62)	71 (53)
Amiodarone*	6 (1.9)	0	0	–	–
OUTCOME					
Sustained ROSC prehospital, *n* (%)	101 (33)	24 (34)	18 (35)	14 (27)	45 (34)
Missing, *n* (% of total)	4 (1.2)	1 (1.4)	1 (1.9)	1 (1.9)	1 (0.8)
Survival, *n* (%)/					
Incidence (95% CI)					
At 24 hours	105(34)/	21 (30)/	18 (35)/	15 (29)/	51 (38)/
	1.6 (1.4–1.7)	6.2 (4.8–7.5)	1.3 (1.0–1.5)	0.49 (0.36–0.62)	2.7 (2.3–3.1)
At 30 days	64 (21)/	12 (17)/	11 (21)/	11 (21)/	30 (23)/
	0.95 (0.83–1.07)	3.5 (2.5–4.6)	0.77 (0.53–1.00)	0.36 (0.25–0.47)	1.6 (1.3–1.9)
At 1 year	56 (18)/	8 (11)/	11 (21)/	11 (21)/	26 (20)/
	0.83 (0.72–0.94)	2.4 (1.5–3.2)	0.77 (0.53–1.0)	0.36 (0.25–0.47)	1.4 (1.1–1.6)
Missing, *n* (%)	2 (0.6)	1 (1.4)	0	0	1 (0.8)
CPC score at discharge, *n* (% of total)					
CPC 1–2	43 (15)	5 (7.5)	9 (18)	5 (10)	24 (18)
CPC 3–5*	8 (2.8)	–	–	–	–
Missing	13 (4.2)	4 (5.6)	2 (3.8)	4 (7.7)	3 (2.3)

Incidences are given per 100 000 child-years. Missing data are excluded when calculating proportions. #EMS-witnessed events are excluded when calculating type of bystander CPR rates. "*" indicates less than 5 cases, not displayed in order to comply with privacy regulations. Abbreviations – CI: confidence interval, CPC: cerebral performance category, CPR: cardiopulmonary resuscitation, EMS: emergency medical service, ECMO: extracorporeal membrane oxygenation, ROSC: return of spontaneous circulation

diseases, such as cardiomyopathies, manifesting in adolescence as the heart grows. However, with more than half of events unwitnessed, some of these cases could represent initial shockable rhythms degenerating to non-shockable forms by the time the child is found. We noted seven cases with an initial cardiac arrest rhythm recorded as "perfusing rhythm". Without further details available, we speculate these may represent bradycardias, which is currently not a separate category in NorCAR.

Precipitating causes, evaluated by treating personnel, were diverse, with conditions causing hypoxia predominating in all age groups. Mirroring the tendency observed for shockable rhythms, the proportion of arrests attributed to cardiac causes increased successively with age. This corresponds with the existing picture of hypoxia as a key driver of cardiac arrest in children, and previous studies finding relatively low proportions of precipitating cardiac causes.[8] However, the literature shows local variations, e.g. for traumatic causation, which was low in our study at 9.4% overall. Studies from Europe and North America report proportions of traumatic cardiac arrest ranging from 20% to 40%.[28,29] This difference may reflect societal factors including population density, gun control, and local traffic regulations including the legal age for driving. Surprisingly, choking was the leading assigned cause of cardiac arrest, accounting for 22% of cases overall and 35% of teenage cases. Further details were not available, but we hypothesise many such cases may unfortunately represent strangulation with suicidal intent.

The bystander CPR rate of 88%, consistent across age groups, was encouraging. Two in three bystanders employed a technique combining chest compressions and ventilations, compliant with guidelines,[11] suggesting a high degree of CPR awareness. High bystander CPR rates have consistently been shown in Norway, with reasons including telephone-assisted CPR and CPR training in schools and workplaces previously cited.[7] Half the patients were endotracheally intubated before hospital arrival, implying involvement of prehospital anaesthetists. Notably, 7.8% of patients received mechanical circulatory support, procedures centralised to four regional hospitals in Norway. Further analyses of patient trajectories including use of these specialised resources may facilitate adaptation of the resuscitation chain to meet future population demands.

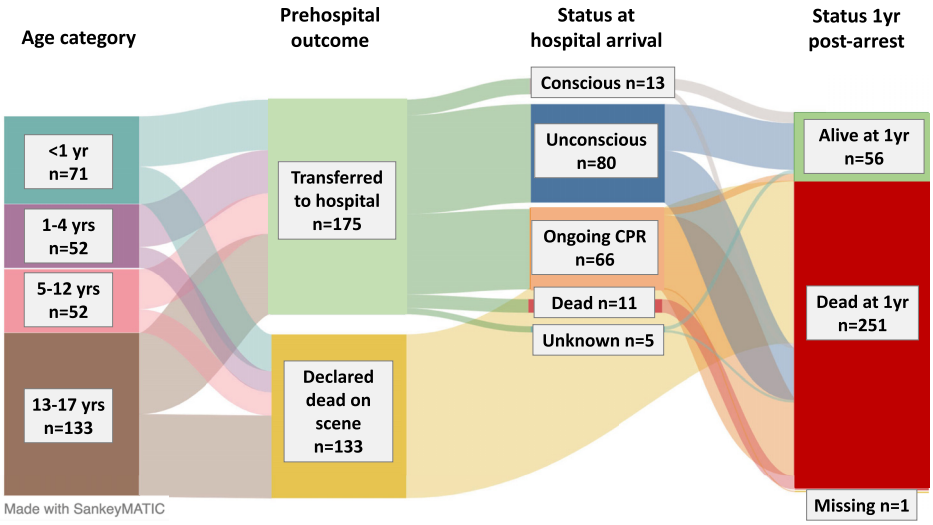

Fig. 4 – Sankey diagram of patient trajectories and outcomes. Summary flowchart showing how patient status progresses at two key stages of resuscitation through to 1 year following cardiac arrest. Abbreviations – CPR: cardiopulmonary resuscitation.

Our reported one-year survival of 18% is higher than in most studies. A meta-analysis by Phillips et al. showed a survival rate of 5.8% after OHCA.[4] Meanwhile, Holgersen et al. reported 30-day survival of 40% in the Danish national registry.[6] Of note, the Danish dataset had a higher rate of shockable rhythms at 23% vs 10% in our study. The known association of shockable rhythms with better outcomes may contribute to this difference. Other factors, such as EMS response intervals could play in, given the relative sizes of Denmark and Norway.

Interestingly, in 45% of screened cases, CPR commenced by a bystander or first responder was not continued by EMS personnel. Typically, the reason was presence of spontaneous circulation. It is possible there were cases of ROSC after bystander CPR alone which were not captured in this study. "Over-triage" by EMCC to telephone-guided CPR is an alternative explanation. Episodes of unconsciousness, triggered by underlying pathology, may resolve spontaneously yet render patients at risk of future cardiac arrest. Such conditions (e.g., inherited arrhythmias, epilepsy) may be amenable to risk modification, warranting further investigation of the "bystander CPR only" group.

A key strength of this study is use of data from a population-based registry with mandatory registration and high case completeness. In our view, this suggests results highly representative of Norway's paediatric population. However, in an observational study it is impossible to eliminate all selection bias, e.g. from differing registration practices. Although NorCAR captures pre- and in-hospital variables, this study was limited to its dataset, meaning paediatric outcome measures, e.g. the paediatric CPC score, as well as AED rhythm traces, were unavailable.[30] Equally, presumed causes assigned during resuscitation with limited information do not capture later investigations or post-mortem findings, limiting accuracy. Cases of unknown cause are coded as "cardiac" in NorCAR, potentially biasing towards more cases of cardiac origin. "Provider's prejudice" may also affect registered causes, e.g. hypoxia is an accepted mechanism triggering cardiac arrest in children, meaning treating personnel could be more prone to assigning e.g. "respiratory" aetiology. Detailed studies of underlying causes, combining information from multiple sources including post-mortems, may provide future insights.

Moving forward, a multi-pronged approach combining ongoing efforts to optimise resuscitation quality with a search for prevention strategies will be crucial.[31] This will require multidisciplinary cooperation and may involve evaluating and applying new technology such as apnoea monitoring for infants, parent and carer education, screening of at-risk populations (e.g. families with inherited arrhythmias, suicide prevention in teenagers with mental health conditions) and public policy (incl. swimming safety).

Future studies assessing interventions will rely on high-quality epidemiological data. The "Utstein style" framework for uniform reporting of OHCA data, first agreed in 1991, has underpinned the creation of regional and national cardiac arrest registries with comparable datasets.[32] International collaborations synthesising registry data have since greatly improved knowledge of OHCA epidemiology.[33–35] However, the discrepant sizes of the adult and paediatric OHCA populations mean that adults dominate findings. Larger studies and international collaborations focusing on OHCA in children could improve our understanding of these events. Furthermore, collaborations can build and strengthen research networks needed for future interventional studies. However, cardiac arrest registries require tailoring to better capture specific aspects of paediatric cardiac arrests. A "Paediatric Utstein Style" was published in the wake of the first Utstein guidelines,[21] yet research carried out since has inconsistently adhered to this, limiting the comparability of studies.[36]

Conclusions

This study aligns with existing literature depicting paediatric OHCA as an entity distinct from adult OHCA, characterised by heterogenous, most often non-cardiac, precipitating causes and a paucity of shockable rhythms. Infants aged <1 year are at particular risk.

The NorCAR registry allowed detailed description of paediatric OHCA epidemiology in Norway, providing an important benchmark against which to assess future progress, and a guide to strategies for prevention, pre- and inhospital resource allocation. With only one in five children surviving to one year, reduction of morbidity and mortality from paediatric OHCA should be a priority, continuing emphasis on high-quality resuscitation in parallel with a search for primary prevention strategies.

CRediT authorship contribution statement

Inga K. Kelpanides: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stephan Katzenschlager:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Eirik Skogvoll:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Ingvild Beathe Myrhaugen Tjelmeland:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Guro Grindheim:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Kristin Alm-Kruse:** Writing – review & editing, Methodology, Investigation, Conceptualization. **John-Petter Liberg:** Writing – review & editing, Methodology, Conceptualization. **Thomas Kristiansen:** Writing – review & editing, Methodology, Funding acquisition. **Jan Wnent:** Writing – review & editing, Methodology. **Jan-Thorsten Gräsner:** Writing – review & editing, Methodology. **Jo Kramer-Johansen:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declared the following financial interests/personal relationships which may be considered as potential competing interests. IBMT received an unrestricted grant from the Laerdal foundation for an unrelated research project. JKJ has no conflict of interest for the current research work, but has received an unrestricted grant from the Laerdal foundation for an unrelated research project. All other authors have no conflicts of interest.

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Appendix A. Supplementary material

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