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Original Article

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Summary

The 7th National Audit Project of the Royal College of Anaesthetists studied peri-operative cardiac arrest. An activity survey estimated UK paediatric anaesthesia annual caseload as 390,000 cases, 14% of the UK total. Paediatric peri-operative cardiac arrests accounted for 104 (12%) reports giving an incidence of 3 in 10,000 anaesthetics (95%CI 2.2–3.3 per 10,000). The incidence of peri-operative cardiac arrest was highest in neonates (27, 26%), infants (36, 35%) and children with congenital heart disease (44, 42%) and most reports were from tertiary centres (88, 85%). Frequent precipitants of cardiac arrest in non-cardiac surgery included: severe hypoxaemia (20, 22%); bradycardia (10, 11%); and major haemorrhage (9, 8%). Cardiac tamponade and isolated severe hypotension featured prominently as causes of cardiac arrest in children undergoing cardiac surgery or cardiological procedures. Themes identified at review included: inappropriate choices and doses of anaesthetic drugs for intravenous induction; bradycardias associated with high concentrations of volatile anaesthetic agent or airway manipulation; use of atropine in the place of adrenaline; and inadequate monitoring. Overall quality of care was judged by the panel to be good in 64 (62%) cases, which compares favourably with adults (371, 52%). The study provides insight into paediatric anaesthetic practice, complications and peri-operative cardiac arrest.

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Introduction

Cardiac arrest in the paediatric peri-operative population is incompletely studied but existing research indicates it is a rare event with rates reported of approximately 1 in 1900 anaesthetic interventions and an associated mortality of 18% [1]. Much of our understanding of peri-operative cardiac arrest in children is based on single-centre studies, case reports and US-based multicentre registries [2, 3]. These studies are largely outcome orientated, rather than focussed on the events leading to, and management of, peri-operative cardiac arrest.

Paediatric anaesthesia is a subspecialty in the United Kingdom with approximately 40% of cases undertaken in district general hospitals and the remainder in tertiary settings [4]. The Royal College of Anaesthetists has published comprehensive guidelines for the provision of anaesthetic services with specific recommendations for paediatric services [5].

All UK anaesthetists receiving a certificate of completion of training will have undertaken paediatric anaesthesia training and are expected to be competent to provide safe peri-operative care for common non-complex elective and emergency procedures in children aged ≥ 1 y. In many district general hospitals, consultants without regular paediatric anaesthetic sessions are required to provide an on-call service that includes the stabilisation and treatment of sick children.

The 7th National Audit Project of the Royal College of Anaesthetists (NAP7) studied peri-operative cardiac arrest in the four nations of the United Kingdom. The project provided an opportunity to study institutional structures and processes related to paediatric anaesthesia provision in the UK and to examine the incidence, risk factors and complications associated with paediatric peri-operative cardiac arrest.

Methods

The methods of NAP7 are described in detail elsewhere [6]. In brief, all NHS hospitals and a subset of independent sector hospitals undertaking anaesthesia care in the UK were invited to take part. A network of local co-ordinators was established to provide leadership and oversight in each hospital. The project was divided into three key phases: a baseline survey of anaesthetists and departments; an activity survey of the anaesthetic case load across all participating sites; and the case registry of peri-operative cardiac arrests. The baseline survey had two components. The first phase assessed knowledge, training and personal experiences of anaesthetists in relation to cardiac arrest. The second studied the preparedness of departments for managing peri-operative cardiac arrest by examining case mix; staff mix; procedures for summoning help; access to emergency guidelines; availability of emergency airway and resuscitation equipment; and governance structures [7, 8]. The activity survey looked at anaesthetic activity across all sites over a 4-day period. Any case under the care of an anaesthetist, including general or regional anaesthesia, sedation or monitored anaesthesia care were included. Reporters were asked to include details of any complications during each of the cases. The activity survey data were extrapolated to provide overall and specialty-specific denominator data for NAP7 [9]. The registry of case reports of peri-operative cardiac arrest formed the core of the project with cases collected over 12 months from 16 June 2021 to 15 June 2022. Collation of reports enabled quantitative analysis and extensive multispecialty peer review of cases [6], and qualitative exploration of events, causes, patterns and themes.

A paediatric patient was defined as being aged ≤ 18 y. We examined the following cohorts individually to explore potential differences in these subpopulations: neonates aged < 28 d; infants aged 28 d to < 1 y; children aged > 1 y; children with congenital heart disease; and children undergoing interventions that were neither cardiac surgery nor a cardiological intervention.

In addition to studying peri-operative care, the study included a special inclusion criterion to capture cardiac arrests in children who were critically ill and anaesthetised before retrieval by specialist transport teams. These cases were analysed and reported separately to the paediatric peri-operative cardiac arrest cases. The full results [10, 11] and project report are published separately [12].

Results

The baseline survey reported that 165 (84%) hospitals admitted children and 154 (78%) anaesthetic departments performed paediatric surgery. Of the 165 hospitals admitting children, 78 (47%) had a paediatric high dependency unit and 21 (13%) had a paediatric intensive care unit. A total of 864 (8%) responding anaesthetists reported that they did not treat children, whereas 1163 (17%) consultant/staff and associate specialist anaesthetists specialised in paediatric anaesthesia. Provision of emergency paediatric equipment in areas where anaesthesia care was delivered was more commonly deficient than adult equipment: 23 (15%) responding departments reported not having immediate access to advanced paediatric airway equipment in all locations where anaesthesia took place. The survey of individual anaesthetists identified that, across all grades of training, up-to-date training in paediatric advanced life support was less common than adults, and respondents were notably more likely to be out of date with, or never trained in, paediatric advanced life support than adults. Of 4664 anaesthetists reporting their most recent attendance at a cardiac arrest, 321 (7%) involved a child and 155 (3%) an infant.

The activity survey collected data from 3455 (14%) anaesthetic interventions in infants and children, giving an approximate denominator of 390,000 procedures annually [9]. The full results of the activity survey are available in the NAP7 report [12] and a further analysis will be published separately.

There were 104 paediatric cardiac arrests reported to NAP7, representing 12% of all peri-operative arrests reported (Table 1). The incidence of peri-operative cardiac arrest in all children was 1 in 3724 or approximately 3 in 10,000 anaesthetics (95%CI 2.2–3.3 per 10,000), which is similar to that in adults. Excluding two cases that met the Emergency Department special inclusion criterion [6] affects this incidence minimally (3 in 10,000, 95% CI 2.2–3.2 per 10,000). Of the 104 cases, 86 (83%) survived the initial event (sustained return of spontaneous circulation > 20 min); 43 (41%) survived to hospital discharge; and 34 (33%) were still admitted at the time of reporting. There were 27 (26%) children who had died at the point of reporting to NAP7. Overall, more children survived the initial event and more were alive at the time of reporting compared with adults reported to NAP7.

Most cardiac arrests occurred in infants and neonates (36, 35% and 27, 26%, respectively) and more than half of these were patients with congenital heart disease. Eighty-eight (85%) case reports were from tertiary paediatric centres. Of the remaining 16 cases, three were recorded as `teaching hospitals´; three major trauma centres; three cardiac centres; one `stand-alone´ paediatric hospital; four district general hospitals; and two did not answer this specific question.

The 104 children reported to the NAP7 registry, when compared with the 3429 paediatric cases in the NAP7 activity survey, were more often: male (68, 65% vs. 2023, 59%); younger (Fig. 1); sicker and more comorbid (ASA physical status 1–2: 13, 13%, vs. 2908, 85%); and of non-White ethnicity (Fig. 2). They also had higher rates of urgent or immediate surgery (52, 50% vs. 573, 17%); non-elective surgery (74, 71% vs. 1023, 30%); major or complex surgery (66, 63% vs. 298, 9%); and general anaesthesia (99, 97% vs. 2982, 90%). Cardiac surgery was the most prevalent specialty (30, 29%) followed by ear, nose and throat surgery (14, 13%), interventional cardiology (12, 12%) and lower gastrointestinal surgery (11, 11%). Most cardiac arrests presented with a non-shockable rhythm and sustained return of spontaneous circulation was achieved after < 20 min of resuscitation (Tables 2 and 3).

On review, the panel assigned one or more causes of cardiac arrest to each case. The most frequent precipitants of cardiac arrest in non-cardiac surgery cases included severe hypoxaemia (20, 22%); bradycardia (10, 11%); and major haemorrhage (9, 8%). These causes also featured prominently for cardiac surgical cases, but the most frequently cited causes were isolated severe hypotension (10, 16%) and cardiac tamponade (7, 11%) (online Supporting Information Appendix S1).

A consultant was present at induction of anaesthesia in 98 (94%) cases, with two or more present in 16 (15%). In reports of patients aged < 1 y, 10 (15%) had two consultants present at induction, and in one case, three consultants were present. Supervision of trainees and the involvement of senior clinicians in resuscitation attempts were almost universal.

Of 25 children who died, 11 deaths were judged the result of an inexorable process, four partially and 10 not. The panel judged that of those who survived, 13 patients experienced severe harm and 66 experienced moderate harm.

Table 1 Incidence of peri-operative cardiac arrest in patient subgroups.

Patient group	Incidence
All; n = 104	1 in 3724 (95%CI 3058–4525)
Neonate; n = 27	1 in 195 (95%CI 132–290)
Aged 28 d to 1 y; n = 36	1 in 613 (439–862)
Aged 1–18 y; n = 41	1 in 8778 (95%CI 6406–12,077)
Elective; n = 28	1 in 9291 (95%CI 6337–13,717)
Non-elective; n = 74	1 in 1549 (95%CI 1227–1961)
ASA physical status 1–2; n = 13	1 in 25,072 (95%CI 14,245–45,045)
ASA physical status 3–5; n = 91	1 in 642 (95%CI 521–794)

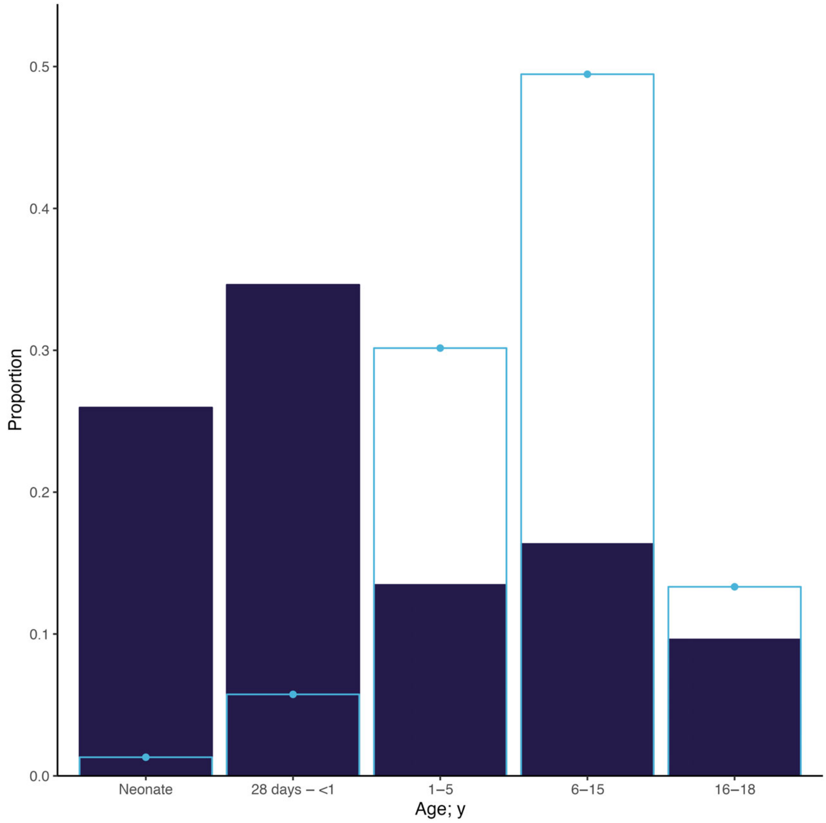

Figure 1 Age distribution among patients in the NAP7 activity survey and who had a cardiac arrest reported to the registry. For results in tabular form, see online Supporting Information Appendix S2.

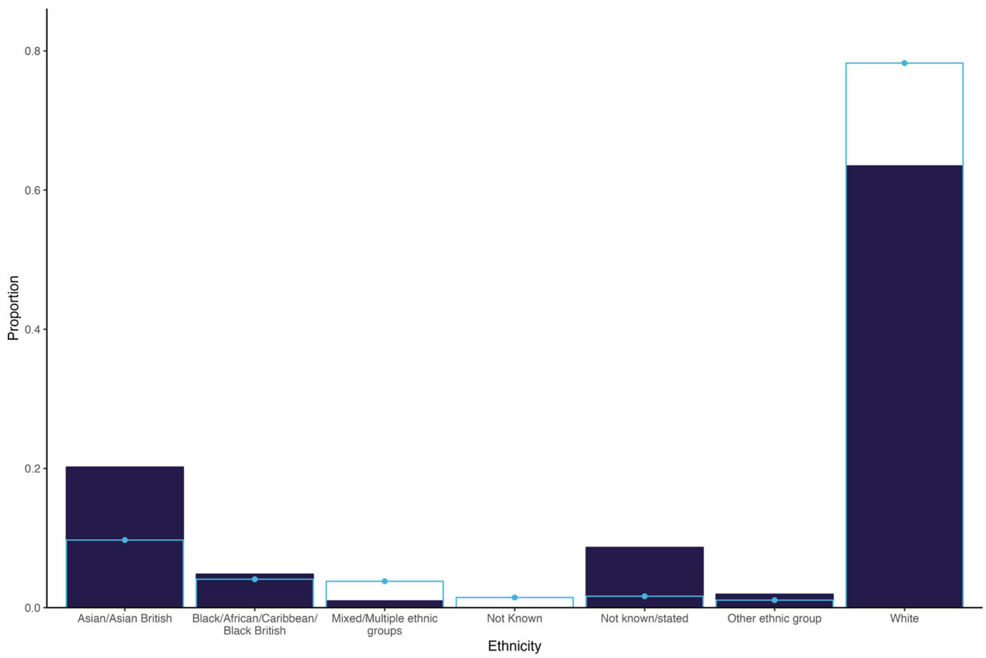

Figure 2 Distribution of ethnicity among patients in the NAP7 activity survey and who had a cardiac arrest reported to the registry. For results in tabular form, see online Supporting Information Appendix S2.

Table 2 Patient and case characteristics by age group. Neonate, aged < 28 d; Infant, aged 28 d to 1 y. Values are number (proportion).

	Neonate n = 27	Infant n = 36	1–18 y n = 41	All n = 104
Sex				
Male	22 (81%)	21 (58%)	25 (61%)	68 (65%)
Ethnicity				
White	17 (63%)	21 (58%)	28 (68%)	66 (63%)
Mixed/multiple ethnic groups	1 (4%)	0	0	1 (1%)
Asian/Asian British	5 (19%)	8 (22%)	8 (20%)	21 (20%)
Black/African/Caribbean/Black British	0	2 (6%)	3 (7%)	5 (5%)
Other ethnic group	1 (4%)	1 (3%)	0	2 (2%)
Not known/stated	3 (11%)	4 (11%)	2 (5%)	9 (9%)
ASA physical status				
1	0	0	8 (20%)	8 (8%)
2	1 (4%)	1 (3%)	3 (7%)	5 (5%)
3	9 (33%)	25 (69%)	15 (37%)	49 (47%)
4	14 (52%)	9 (25%)	11 (27%)	34 (33%)
5	3 (11%)	1 (3%)	4 (10%)	8 (8%)
Day of the week				
Weekday	21 (78%)	35 (97%)	32 (78%)	88 (85%)
Weekend	6 (22%)	1 (3%)	5 (12%)	12 (12%)
Public holiday	0	0	2 (5%)	2 (2%)
Unknown	0	0	2 (5%)	2 (2%)
Time of case start				
Daytime (08.00–17.59)	22 (81%)	35 (97%)	30 (73%)	87 (84%)
Evening (18.00–23.59)	4 (15%)	0	5 (12%)	9 (9%)
Night (00.00–07.59)	1 (4%)	1 (3%)	4 (10%)	6 (6%)
Unknown	0	0	2 (5%)	2 (2%)
Surgical priority				
Immediate	7 (26%)	1 (3%)	5 (12%)	13 (13%)
Urgent	12 (44%)	13 (36%)	14 (34%)	39 (38%)
Expedited	6 (22%)	12 (33%)	4 (10%)	22 (22%)
Elective	2 (7%)	10 (28%)	16 (39%)	28 (27%)
Unknown	0	0	2 (5%)	2 (2%)
Grade of surgery				
Minor	3 (11%)	3 (8%)	9 (22%)	15 (15%)
Intermediate	5 (19%)	8 (22%)	8 (20%)	21 (21%)
Major or complex	19 (70%)	25 (69%)	22 (54%)	66 (65%)
Unknown	0	0	2 (5%)	2 (2%)
Mode of anaesthesia				
GA	26 (96%)	35 (97%)	38 (93%)	99 (97%)
GA + neuraxial	0	0	1 (2%)	1 (1%)
GA + RA	0	1 (3%)	0	1 (1%)
Intravenous analgesia only	1 (4%)	0	0	1 (1%)
Unknown	0	0	2 (5%)	2 (2%)

GA, general anaesthesia; RA, regional anaesthesia.

Table 3 Peri-operative cardiac arrest characteristics by age group. Neonate, aged < 28 d; infant, aged 28 d to 1 y. Values are number (proportion).

	Neonates n = 27	Infants n = 36	1–18 y n = 41	All n = 104
Key cause				
Anaesthesia	7 (26%)	11 (31%)	15 (37%)	33 (32%)
Organisation	3 (11%)	3 (8%)	0	6 (6%)
Patient	25 (93%)	32 (89%)	35 (85%)	92 (88%)
Postoperative care	2 (7%)	6 (17%)	3 (7%)	11 (11%)
Surgery	12 (44%)	17 (47%)	15 (37%)	44 (42%)
Phase				
Pre-induction	0	0	0	0
Induction	3 (11%)	4 (11%)	6 (15%)	13 (13%)
Transfer to theatre	0	0	0	0
After induction, before surgery	2 (7%)	3 (8%)	6 (15%)	11 (11%)
During surgery – GA	12 (44%)	8 (22%)	16 (39%)	36 (35%)
During surgery – LA/RA	1	0	0	1 (1%)
Conversion to GA	0	0	0	0
Emergence/tracheal extubation	0	2 (6%)	0 (0%)	2 (2%)
Transfer to recovery	0	0	1 (2%)	1 (1%)
Postoperative – in PACU	0	0	2 (5%)	2 (2%)
Postoperative – after PACU	9 (33%)	19 (53%)	10 (24%)	38 (37%)
Arrest location				
Anaesthetic room	2 (7%)	4 (11%)	4 (10%)	10 (10%)
Cardiac catheter laboratory	3 (11%)	4 (11%)	2 (5%)	9 (9%)
Critical care area	8 (30%)	16 (44%)	8 (20%)	32 (31%)
CT scanner	0	0	1 (2%)	1 (1%)
Emergency Department	1 (4%)	0	2 (5%)	3 (3%)
Interventional radiology	1 (4%)	1 (3%)	1 (2%)	3 (3%)
Other	0	0	1 (2%)	1 (1%)
Recovery	0	0	1 (2%)	1 (1%)
Theatre: day surgery unit	0	1 (3%)	1 (2%)	2 (2%)
Theatre: main theatre suite	11 (41%)	7 (19%)	18 (44%)	36 (35%)
Theatre: other	0	0	1 (2%)	1 (1%)
Ward	1 (4%)	3 (8%)	1 (2%)	5 (5%)
Rhythm				
Asystole	1 (4%)	1 (3%)	6 (15%)	8 (8%)
Bradycardia	13 (48%)	20 (56%)	8 (20%)	41 (39%)
Pulseless electrical activity	6 (22%)	9 (25%)	16 (39%)	31 (30%)
Pulseless ventricular tachycardia	0	0	3 (7%)	3 (3%)
Ventricular fibrillation	1 (4%)	1 (3%)	2 (5%)	4 (4%)
Unknown	6 (22%)	5 (14%)	6 (15%)	17 (16%)
Duration				
< 10 min	13 (48%)	25 (69%)	26 (63%)	64 (62%)
10–20 min	6 (22%)	4 (11%)	5 (12%)	15 (14%)
20–30 min	3 (11%)	4 (11%)	2 (5%)	9 (9%)
30–40 min	1 (4%)	1 (3%)	0	2 (2%)

(continued)

Table 3 (*continued*)

	Neonates n = 27	Infants n = 36	1–18 y n = 41	All n = 104
40–50 min	2 (7%)	1 (3%)	1 (2%)	4 (4%)
50–60 min	0	1 (3%)	5 (12%)	6 (6%)
1–2 h	0	0	2 (5%)	2 (2%)
> 2 h	2 (7%)	0	0	2 (2%)
Initial outcome of event				
Died	9 (33%)	2 (6%)	7 (17%)	18 (17%)
Survived	18 (67%)	34 (94%)	34 (83%)	86 (83%)
Hospital outcome				
Alive	9 (33%)	14 (39%)	20 (49%)	43 (41%)
Dead	11 (41%)	6 (17%)	10 (24%)	27 (26%)
N/A – still admitted	7 (26%)	16 (44%)	11 (27%)	34 (33%)

GA, general anaesthesia; LA, local anaesthesia; RA, regional anaesthesia; PACU, post-anaesthesia care unit; CT, computed tomography.

Of the 41 reports including children aged > 1 y, patients of ASA physical status 1–2 were more prevalent than other age groups. The most common causes of cardiac arrest were major haemorrhage (8, 20%); severe hypoxaemia (7, 17%); and bradyarrhythmia (7, 17%). Of the 36 cardiac arrests in infants, 19 (53%) occurred postoperatively after discharge from recovery, which was a higher proportion than in other age groups. The most common causes of cardiac arrest were severe hypoxaemia (15, 42%); bradyarrhythmia (9, 25%); and isolated severe hypotension (6, 17%). Of the 27 reports in neonates, in contrast with other age groups, surgery was elective in only two cases. The most common causes of cardiac arrest were isolated severe hypotension (5, 19%); severe hypoxaemia (4, 15%); and bradyarrhythmia (3, 11%). Longer durations of cardiac arrest were more common, with two patients receiving > 2 h of cardiopulmonary resuscitation. Initial event (18, 67%) and hospital survival rates (16, 59%) were lower.

Forty-four cardiac arrests were in children with congenital heart disease undergoing cardiac surgery or catheter laboratory interventions, all of whom were ASA physical status ≥ 3 (25, 57% ASA 3; 18, 41% ASA 4; 1, 2% ASA 5). The most common causes of cardiac arrest were similar to the wider cohort but additionally included cardiac tamponade in seven (16%) cases. Cardiac arrests in operating theatre suites were more common in the anaesthetic room than in theatre (7 vs. 5).

Of the 60 cardiac arrests in children not undergoing either cardiac surgery or interventional/diagnostic cardiology procedures, 14 (23%) were related to ear, nose and throat surgery; 14 (23%) to abdominal surgery; and six (10%) to anaesthesia for radiological procedures. This was the only paediatric group in which anaesthesia was judged a key cause of cardiac arrest more commonly than surgical factors (23, 38% vs. 20, 33%). In 14 (23%) cases, anaesthesia was judged to be the sole key factor.

Of all the cardiac arrests, 15 (14%) were airway related. Of these, six resulted from misplaced or obstructed tracheal tubes on paediatric or neonatal ICU postoperatively. Accidental tracheal extubation also occurred in paediatric and neonatal ICU during patient repositioning or tracheal tube manipulation. Capnography was in place for all of these cases; however, in all instances, tracheal intubation was known to be difficult. A common theme was failure to plan for tracheal tube displacement and rapid and challenging tracheal reintubation. For the remaining nine cases, the precipitant or causative events varied but included failed tracheal intubation; endobronchial intubation; postoperative airway swelling; and `cannot intubate, cannot oxygenate´ situations. Among these cases, one patient died (as a result of an inexorable process), one experienced severe harm and 13 survived with moderate harm.

There were 10 cases of bradycardic cardiac arrest in non-cardiac surgery. In four of these cases, atropine or glycopyrronium was used as the first-line drug. Calcium and bicarbonate were used in 32 (31%) and 20 (19%) paediatric cardiac arrests, respectively. This was noted particularly during the resuscitation of patients in cardiac settings and in paediatric critical care.

There were eight reports where monitoring inadequacy was judged to have contributed to unrecognised deterioration and cardiac arrest. The majority of these related to the lack of invasive arterial blood pressure monitoring, particularly in patients undergoing cardiac catheterisation.

The ASA physical status was recorded to be lower than it should have been in six (6%) reports. All these cases were in children presenting for emergency non-cardiac surgery or cardiac interventions and the ASA physical status was based on the child's pre-morbid status rather than their current physiological condition.

Care before the cardiac arrest was judged by the panel to be good in 65 (63%) and poor in seven (7%) patients, whereas overall care was judged to be good in 64 (62%) and poor in one (1%). Among 39 cases of severe harm or death, some aspect of care was rated as poor in five (13%). There was only one case reported where the level of supervision was judged to be inadequate based on the initial clinical condition of the patient. Debriefs were performed in 44 (42%) reports and more frequent where the initial event outcome was death (14, 78%) than when the patient survived (30, 35%).

Discussion

In the first UK-wide prospective audit of peri-operative cardiac arrest, we found an incidence of peri-operative cardiac arrest in children of approximately 3 per 10,000 with an immediate mortality rate of 17%. The overall incidence was lower than a previous report [2] which identified 5.3 per 10,000 paediatric anaesthetics, including cardiac arrests within 24 h of surgery, although the mortality rate of 18% was similar. The incidence was significantly higher in neonates and infants at 50 per 10,000 cases and 20 per 10,000 cases, respectively. The rate of initial successful resuscitation was also lower in neonates than in other paediatric age groups and only 59% had survived when reported to NAP7. The neonatal population (which includes a large proportion of patients undergoing non-elective surgery for congenital heart disease) had a higher risk of cardiac arrest, lower rate of return of spontaneous circulation and higher mortality. This has been identified in several studies and is related to congenital anomalies, reduced physiological reserve and requirement for emergency high-risk surgery [13]. Rates of cardiac arrest in children with congenital heart disease have been shown to be reduced by quality improvement programmes, such as the cardiac arrest prevention bundle introduced by the Paediatric Cardiac Critical Care Consortium collaborative [14].

The majority of paediatric cases reported to NAP7 were from tertiary paediatric centres. Reassuringly, only 4% of reports were from a district general hospital. This likely reflects an effective triage system within paediatric anaesthesia care, with escalation of complex cases to specialist centres. Overall quality of care was judged to be good in approximately two-thirds of cases. Compared with judgements in adults, children were somewhat more likely to be judged to have received good care. As with adults, more poor care was judged to have occurred before the cardiac arrest [11]. Underestimation of ASA physical status grading was common and is also seen in adult practice [9]. The ASA physical status grading system now includes paediatric-specific examples for each grade to address the long-standing issues presented by the original adult-based definitions [15].

Cardiac arrests occurred in 44 children undergoing cardiac surgery or catheter laboratory procedures which was 42% of the paediatric data set, with an 18% mortality. Notably, the most common location in which cardiac arrest occurred was on paediatric ICU, highlighting the vulnerability of this population in the postoperative period. Of the cardiac arrests reported to NAP7 in children with congenital heart disease, 77% were in neonates and infants. Importantly, 31% of cases occurred during diagnostic or interventional procedures in the cardiac catheter laboratory. The National Institute for Cardiovascular Outcomes Research (NICOR) audits all activity in children with congenital heart disease having surgical or cardiac catheter procedures in the UK. The overall outcomes after paediatric cardiac surgery continue to improve, with a 30-day survival rate of 98% [16]. Measurement of complication rate variables is an area of continuing development, but NICOR does not report the cardiac arrest rate in these children. These NAP7 data add important understanding relating to peri-operative cardiac arrest in this population.

More than 50% of the paediatric cardiac arrests reported to NAP7 occurred in children with congenital heart disease. This complex group is recognised to be at risk of cardiac arrest and specific guidelines have been formulated to reflect this [17]. In several reports, the NAP7 panel judged that invasive blood pressure monitoring was not present when it would likely have been beneficial, especially during procedures in the cardiac catheter laboratory. A problem in this environment is that children with critical cardiac lesions have invasive lines inserted by the cardiology team during the procedure. Critical deterioration may occur either at the time of anaesthetic induction, before the cardiologists establish access or during the procedure when the monitoring or access needed for the anaesthetist to adequately manage sudden cardiovascular deteriorations are unavailable to them. High-risk interventional cardiac catheter procedures should be set up by the anaesthetist as for high-risk surgery, with the insertion of invasive blood pressure monitoring as early as possible. Pre-procedural team briefings should heighten awareness of the phases during an intervention where no invasive monitoring is available to the anaesthetist, and if these are prolonged, a separate line placed. An open and frank discussion of the risk profile of each child and their planned procedure should be conducted by the team and during the consent process.

In several cases, the choice and dose of intravenous induction drug was judged to have contributed to hypotensive cardiac arrest in patients who were haemodynamically unstable. This was not exclusive to the paediatric subset but represents a common theme seen throughout NAP7 [10]. If propofol is used in such settings, a `standard´ dose of 4–5 $mg.kg^{-1}$ is excessive in patients who are clinically compromised. Similarly, there were examples of severe bradycardia requiring cardiopulmonary resuscitation resulting from excessive concentrations of inhalational anaesthetic agents at induction. The application of monitoring to distressed children is not always possible so a balance must be sought between achieving anaesthesia and monitoring physiological variables. Very high concentrations of volatile anaesthetic agents may not represent safe practice, so the practice of adding nitrous oxide to the inhaled gas mixture should be considered in selected cases [18].

Airway events were relatively prevalent as a cause of cardiac arrest. Excluding patients undergoing cardiac surgery, severe hypoxaemia and resulting bradycardia secondary to airway and respiratory events were the most common precipitants. As with the adult cohort, ear, nose and throat surgery was a prominent surgical population in these reports [19]. Airway events also occurred with positioning or manipulation of a tracheal tube on paediatric or neonatal ICUs. Initial correct tracheal tube placement may reduce the need for readjustment; however, this can be difficult and further guidance on the role of imaging is needed. Meticulous preparation for airway repositioning, exchange or physiotherapy is necessary to avoid adverse events relating to tracheal tube displacement [14].

Bradycardia was a precipitant of cardiac arrest in one in six non-cardiac cases and is a well-documented adverse effect of many interventions (e.g. airway manipulation, anaesthetic drugs) in children. Choice of drugs used to treat bradycardic cardiac arrest was often not consistent with international guidelines. In cases where bradycardia prompts chest compressions (heart rate $< 60\ min^{-1}$), adrenaline is the recommended drug rather than atropine or glycopyrronium [20]. In situations in which bradycardia is associated with hypotension rather than cardiac arrest, atropine or glycopyrronium may be appropriate choices. The Royal College of Anaesthetists Guidelines for Provision of Anaesthetic Services (GPAS) recommends that all anaesthetists who provide care to children should have training in advanced life support that covers their expected range of clinical practice and responsibilities. These competencies should be maintained by annual training that is ideally multidisciplinary and scenario-based [5].

Senior anaesthetist involvement in cases was good with a consultant present at induction of anaesthesia in 94% of reports to NAP7; this is higher than in the rest of the NAP7 data set (86%). There were, however, a few instances where the patient and/or surgery was judged by the panel to be high enough risk that the presence of two consultant anaesthetists was likely to represent best practice. Guidance recognises that infants are particularly at risk and strongly recommends allocating two anaesthetic assistants to a list where an infant is involved [5]. A few cases occurred in remote locations or involved trainees working independently and when help was summoned, supervisors did not have appropriate paediatric training or there was a delay in assistance arriving when called. The Cappuccini test advises that all trainees should know who to call and how to contact assistance [21]. Supervisors should know who they are supporting and the cases they are undertaking.

In fewer than half of all paediatric reports to NAP7 was a debrief undertaken and this was less common when the child was successfully resuscitated. Failure to review cases is likely to mean individuals and organisations will miss key lessons and opportunities to improve patient safety. This project has also shown anaesthetists more commonly report adverse impact on future care delivery when involved in the cardiac arrest of a child [8] and this is likely to be true for other team members. Debrief should be routine following any paediatric peri-operative cardiac arrest.

There are some limitations to our report. It is likely that we did not achieve 100% case capture over the 12-month registry period. These data were deliberately limited in order to reduce the risk of identification of staff, locations or patients. Similarly, our methodology is limited in the extent to which it can extract the detail required to analyse human factors elements in depth.

The results of NAP7 reported here provide a detailed insight into paediatric anaesthetic practice in the UK. We report rates of complications in routine practice and described the incidence and nature of peri-operative cardiac arrests in this patient cohort for the first time.

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Supporting Information

Additional supporting information may be found online via the journal website.

Appendix S1. Panel agreed cause(s) of cardiac arrest.

Appendix S2. Results data in tabular form.

