27 Paediatric perioperative cardiac arrest


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Key findings

- Perioperative cardiac arrest in children is rare.
- Perioperative cardiac arrest is relatively more common in neonates, infants and children with congenital heart disease (CHD).
- Frequent precipitants of cardiac arrest in non-cardiac surgery included severe hypoxaemia, bradycardia and major haemorrhage.
- Cardiac tamponade and isolated severe hypotension feature prominently as causes of cardiac arrest in children undergoing cardiac surgery or catheter laboratory interventions.
- Initial outcomes for cardiac arrest events in children were good when compared with the rest of the NAP7 dataset. This was particularly true for patients undergoing cardiac surgery or catheterisation procedures.
- Inappropriate choices and doses of drug for intravenous induction of anaesthesia and high concentrations of volatile anaesthetic for induction or maintenance in unwell children precipitated severe hypotension and cardiac arrest.
- High concentrations of volatile anaesthetic agents and airway manipulation precipitated bradycardias.
- Atropine was used in cases of cardiac arrest when adrenaline is recommended.
- Inadequate monitoring led to delayed recognition of deterioration, in particular the lack of invasive arterial blood pressure monitoring in cardiac catheterisation cases.
- Supervision of trainees by senior anaesthetists was almost universal. There were cases in which risk was so high that the presence of two consultants would likely represent best practice.
- Access to senior support was occasionally inadequate when anaesthesia was delivered in isolated locations.
- There were several instances of cardiac arrest associated with tracheal tube displacement postoperatively in the intensive care setting.
- Fatal cardiac arrest events were more likely to be followed up by a debrief (78%) compared with cases in which the child survived (35%).

What we already know

Cardiac arrest in the paediatric perioperative population is rare with rates reported as 1 : 1900 anaesthetics and an associated mortality of 18% (Christensen 2018). It is recognised that children with CHD have an increased incidence of cardiac arrest compared with the general paediatric population and that the complexity and variability of cardiac arrests in this group require a more specialised approach than that provided by paediatric advanced life support (ALS) guidelines (Skellet 2021). A statement document has been issued to provide specific guidance for cardiac arrest management in children with CHD (Marino 2018).

Paediatric anaesthesia is a subspecialty but is delivered in both district general hospital (DGH) and tertiary settings. In the UK, all anaesthetists receiving a certificate of completion of training (CCT) will have undertaken paediatric anaesthesia training and

therefore as a minimum should be competent to provide safe perioperative care for common non-complex elective and emergency procedures in children aged one year and older. The Royal College of Anaesthetists (RCoA) recommends that anaesthetists providing care to a wider and more complex paediatric population must have acquired more advanced competencies and specifically that they should have satisfied the advanced level competency-based training requirements in paediatric anaesthesia on the 2010 RCOA Curriculum or have completed the final stage of training (stage 3) and specialist interest area or equivalent (RCoA 2010, 2021). This also often applies to anaesthetists who wish to have paediatric lists as a significant part of their job plan in non-tertiary centres. The RCoA has published comprehensive Guidelines for the Provision of Anaesthetic Services (GPAS) with specific recommendations for paediatric services (RCoA 2023). These guidelines state that consultant anaesthetists who care for children in DGHs should have the opportunity to undertake regular supernumerary attachments to operating lists or secondments to specialist tertiary paediatric lists for continuous professional development purposes (to maintain confidence and skills). In many DGHs, this is not presently available, supported or funded. The RCoA suggests that this should, in part, be the responsibility of the regional children's surgery operational delivery networks. Many other consultants without regular paediatric anaesthetic sessions are required to provide an on-call service that includes the stabilisation and treatment of sick children. Adequate continuing professional development (CPD) opportunities are equally important for this group of anaesthetists but they are not covered by the RCoA recommendations.

This chapter focuses on the NAP7 findings on perioperative cardiac arrest in children and is closely related to Chapter 33 Critically ill children, which examines the special cases of cardiac arrests during care of critically ill children in non-specialist centres.

What we found

Baseline Survey

The Baseline Survey provides an overview of paediatric anaesthesia activity in the UK. Of 197 anaesthetic departments responding, 154 (78%) anaesthetise paediatric patients, 78 (51%) have a paediatric high-dependency unit (HDU) and 21 (14%) have a paediatric intensive care unit (PICU) on site. Of all anaesthetists, 17% included paediatric anaesthesia as their subspecialty.

Twenty three (15%) departments did not have access to paediatric advanced airway equipment in locations where children were anaesthetised. In the 152 hospitals that cared for children and had an emergency department, a paediatric resuscitation equipment trolley was not available in 1 (1%) emergency department. In the 120 hospitals caring for children that had a critical care unit (adult or paediatric), a paediatric resuscitation equipment trolley was not available in 39 (33%) critical care units.

The Baseline Survey (see Chapter 10 Anaesthetists survey) collected data relating to individual anaesthetists' formal resuscitation training. Overall, up to date training in adult ALS was more common than paediatric ALS. Rates varied very little between grades but the finding was consistent. Respondents were notably more likely to be out of date with, or never trained in, paediatric ALS than adult ALS.

Activity Survey

The Activity Survey (Chapter 11 Activity Survey) collected data on 3,455 anaesthetics in infants and children (0 to < 18 years) during the four-day observation period, accounting for 14.3% of all cases and equating to approximately 390,000 procedures annually. Neonates (0–28 days) accounted for 47 cases (0.19% of overall activity, 1.4% of paediatric activity), and patients aged 28 days to less than 1 year accounted for 197 cases (0.81% of overall activity, 5.7% of paediatric activity). Of all children anaesthetised, 1,034 (30%) were aged 1–5 years, 1,696 (49%) were 6–15 years, and 481 (14%) were 16 to <18 years. Most (2934, 85%) were ASA 1–2, but neonates and infants had a higher proportion of ASA 3–5 scores than older children and young adults (see Chapter 11 Activity Survey). Most children were of White ethnicity (78%), although this was a lower proportion than in adults (89%). Asian and Asian British ethnicity was more frequent in children (20%) compared with adults (5.2%; see Chapter 30 Ethnicity). Most (68%) surgery was elective (which was the same as observed in the adult population) but a significantly greater proportion of paediatric activity involved minor surgical procedures (48%) compared with the adult cases (25%) and a significantly smaller proportion of children underwent major/complex surgical procedures compared with adults (8.9% versus 31%). Dental, ear, nose and throat, general surgery, trauma and urology were the five most represented specialties, making up more than 50% of the paediatric workload (Table 27.1).

Table 27.1 Number of paediatric surgical cases by specialty

Specialty	Cases, *n* (%)
Dental	539 (15.6)
ENT	448 (13.0)
General surgery	336 (9.7)
Orthopaedics: trauma	262 (7.6)
Urology	244 (7.1)
Orthopaedics: cold/elective	203 (5.9)
Radiology: diagnostic	178 (5.2)
Plastics	174 (5.0)
Maxillofacial	155 (4.5)
Other	150 (4.3)
Ophthalmology	124 (3.6)
Abdominal: lower gastrointestinal	108 (3.1)
Gastroenterology	101 (2.9)
Neurosurgery	56 (1.6)
Other minor operation	53 (1.5)
Abdominal: upper gastrointestinal	45 (1.3)
Radiology: interventional	43 (1.2)
Cardiac surgery	38 (1.1)
Gynaecology	32 (0.9)
Spinal	30 (0.9)
Cardiology: interventional	26 (0.8)
Abdominal: other	15 (0.4)
Cardiology: electrophysiology	13 (0.4)
Obstetrics: labour analgesia	13 (0.4)
Cardiology: diagnostic	12 (0.3)
Burns	11 (0.3)
Obstetrics: caesarean section	11 (0.3)
Thoracic surgery	7 (0.2)
Transplant	7 (0.2)
None	6 (0.2)
Other major operation	5 (0.1)
Abdominal: hepatobiliary	4 (0.1)
Vascular	4 (0.1)
Obstetrics: other	2 (0.1)
Total	3455 (100.0)

The rates of anaesthetic techniques used in children differed compared with adults, with general anaesthesia being the most common technique used (0–18 years, 3,233/3,455, 93.5%, vs > 18 years, 13,673/20,717, 66.0%). Neuraxial techniques were much less frequent (0–18 years, 76/3,455, 2.2% vs > 18 years, 5,077/20,717, 24.5%), as were regional blocks (0–18 years, 209/3,455, 6.0% vs > 18 years, 2671/20717, 12.8%).

Of the 1922 complications reported in the Activity Survey, 255 (13.2%) were reported in children, similar to the overall proportion of paediatric cases (see Chapter 12 Activity Survey – complications). One or more complications occurred in 5.5% of all anaesthetic cases; however, in the neonatal age group, 17% of cases reported at least one complication, in infants 10% and in children aged 1–5 years the rate was 5.8%. Complication rates were lowest in the whole dataset in older children (6–15 years, 3.7%; 16–18 years, 3.7%). Airway complications were prominent in children. The most common complication was laryngospasm (52 cases, 20% of all paediatric complications), which differed from the complications rates in the whole dataset, where laryngospasm was third most common following major haemorrhage and severe hypotension (Table 27.2). Of these 52 cases of laryngospasm, three reported a period of severe

Table 27.2 Frequency of paediatric complications reported to NAP7 in 3,455 cases

Complication	Reports (*n*)
Laryngospasm	52
Failed mask ventilation, supraglottic airway placement or intubation	15
Severe hypotension (central vasopressors considered/started)	14
Severe hypoxaemia	13
Severe ventilation difficulties (eg bronchospasm/high airway pressure)	13
Hypercapnia or hypocapnia	12
Major haemorrhage	12
New significant acidosis/acidaemia	10
Hyperthermia or hypothermia	10
Emergency call for anaesthesia assistance	10
Other airway complication	9
Severe brady- or tachyarrhythmia causing compromise	8
Significant electrolyte disturbance (Ca^{2+}, Na^+, K^+ or Mg^{2+})	8
Aspiration or regurgitation	6
Ventilator disconnection	5
Equipment failure	5
Intraoperative conversion of anaesthesia (eg local/regional or sedation to general anaesthesia)	4
Airway haemorrhage	3
Septic shock	3
Endobronchial intubation	2
Cardiac ischaemia	2
Cardiac arrest	2
Seizure	2
Drug error	2
Emergency DC cardioversion	1
Intracranial hypertension (eg new fixed/dilated pupil or coning)	1
Death	1
Total	225

hypoxaemia, of which one reported severe ventilation difficulties. No cases of paediatric laryngospasm were associated with severe brady- or tachyarrhythmia causing compromise or cardiac arrest.

Table 27.3 shows the nature of complications by age. Breathing, circulation, metabolic and airway complications are all prominent in neonates and infants before decreasing in children aged over one year. For several complication categories, the risk in infants and neonates is 10-fold higher than in young adults and is higher than in any other age group.

Table 27.3 Raw complication rate by type and age per 10,000 cases

Complications	Age (years)												
	< 28 d	28 d to < 1	1–5	6–15	16–18	19–25	26–35	36–45	46–55	56–65	66–75	76–85	> 85
Airway	444.4	456.9	338.5	182.8	175.1	218.2	220.2	269.5	214.6	187.7	150.7	129.1	118.9
Breathing	1555.6	355.3	183.8	70.8	0.0	104.4	166.3	144.1	158.1	131.4	106.4	60.3	52.8
Circulation	1333.3	253.8	106.4	82.5	109.4	208.7	215.3	218.4	308.7	334.7	354.6	533.8	383.1
Neurological	222.2	0.0	0.0	5.9	43.8	47.4	0.0	18.6	41.4	18.8	20.7	8.6	26.4
Metabolic	666.7	253.8	67.7	59.0	65.6	104.4	117.4	102.2	97.9	137.6	165.5	167.9	184.9
Other	444.4	203.0	67.7	35.4	43.8	85.4	53.8	27.9	37.7	59.4	38.4	51.7	79.3

Reports to NAP7

There were 104 paediatric cardiac arrests reported to NAP7, representing 12% of the entire dataset. Of these 104 cases, 44 (42%) were related to cardiac surgery although this group accounts for only 1.1% of all paediatric anaesthesia activity. A total of 88 (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 'standalone' hospital and four DGHs. Two did not respond to this question when reporting.

Most (61%) cases occurred in infants (28 days to less than 1 year) and neonates (35% in infants and 26% in neonates) and more than half (54%) of these were patients with CHD; 26% of cases occurred in neonates. Thus, patients less than one year and/or those undergoing general anaesthesia for cardiac surgery or cardiac catheterisation procedures for CHD were particularly high risk groups for perioperative cardiac arrest.

Incidence

The incidence rate of perioperative cardiac arrest in all children was 0.03% (1 : 3333) with 83% (86/104) surviving the initial event (sustained return of spontaneous circulation [ROSC] > 20 minutes), 41% surviving to hospital discharge and 33% still admitted at the time of reporting (ie 26% had died at the point of reporting to NAP7). In infants, the incidence of cardiac arrest was 0.2% (1 : 500) with 83% (52 of 63) surviving the initial event, 37% surviving to hospital discharge and 37% still admitted at the time of reporting. In neonates, the incidence was 0.5% (1 : 200) with 67% (18 of 27) surviving the initial event, 33% surviving to hospital discharge and 26% still admitted at the time of reporting.

The most frequent precipitants of cardiac arrest in non-cardiac surgery included severe hypoxaemia (22%), bradycardia (11%) and major haemorrhage (8.6%). These causes also featured prominently for cardiac surgery cases, but the most frequently cited causes were isolated severe hypotension (16%) and cardiac tamponade (11%; Figure 27.1). The specialties most associated with cardiac arrest events were cardiac surgery, ear nose and throat surgery (ENT) and interventional cardiology procedures (Figure 27.2).

Of 25 children who died, 11 deaths were judged the result of an inexorable process, 4 partially and 10 not. The panel determined that of those who survived, 13 patients experienced severe harm and 66 moderate harm as a result of cardiac arrest.

Care before the cardiac arrest was judged to be good in 64% and poor in 6.9% but, overall, care was judged to be good in 62% and poor in only 1%. Comparative figures in adults are, before cardiac arrest, good in 46%, poor in 11% and overall good in 52% and poor in 2.4%, suggesting that children were somewhat more likely to be judged to have received good and less likely to be judged to have received poor care. Care during and after cardiac arrest was similar in children and adults (> 80% good, < 1% poor).

Figure 27.1 Unanticipated events in cases of paediatric cardiac arrest reported to NAP7. Died ■, Survived ■.

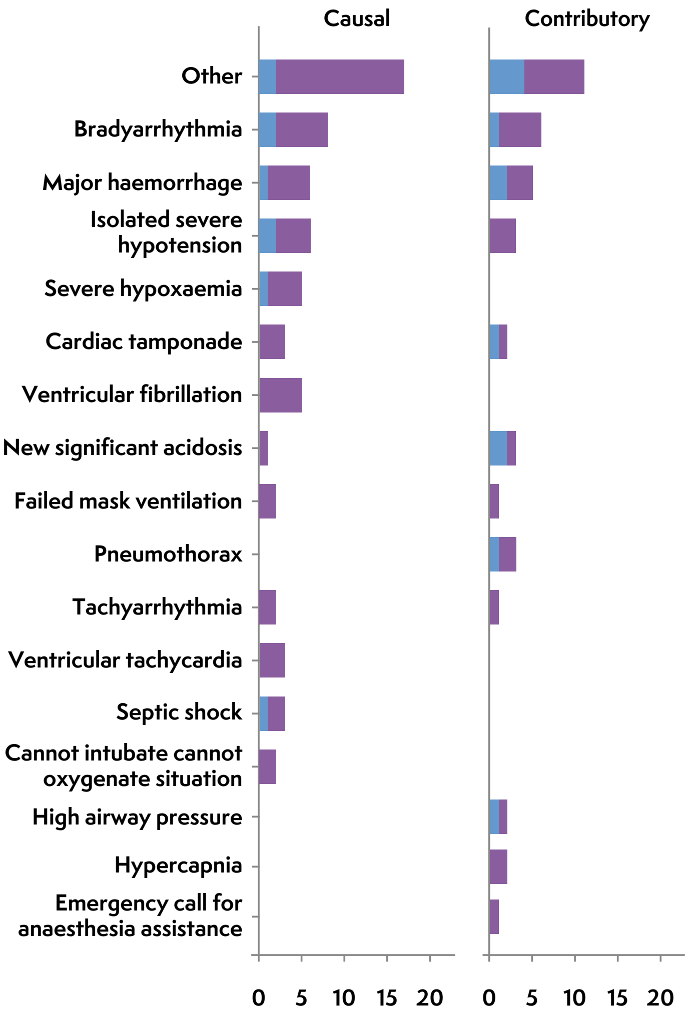
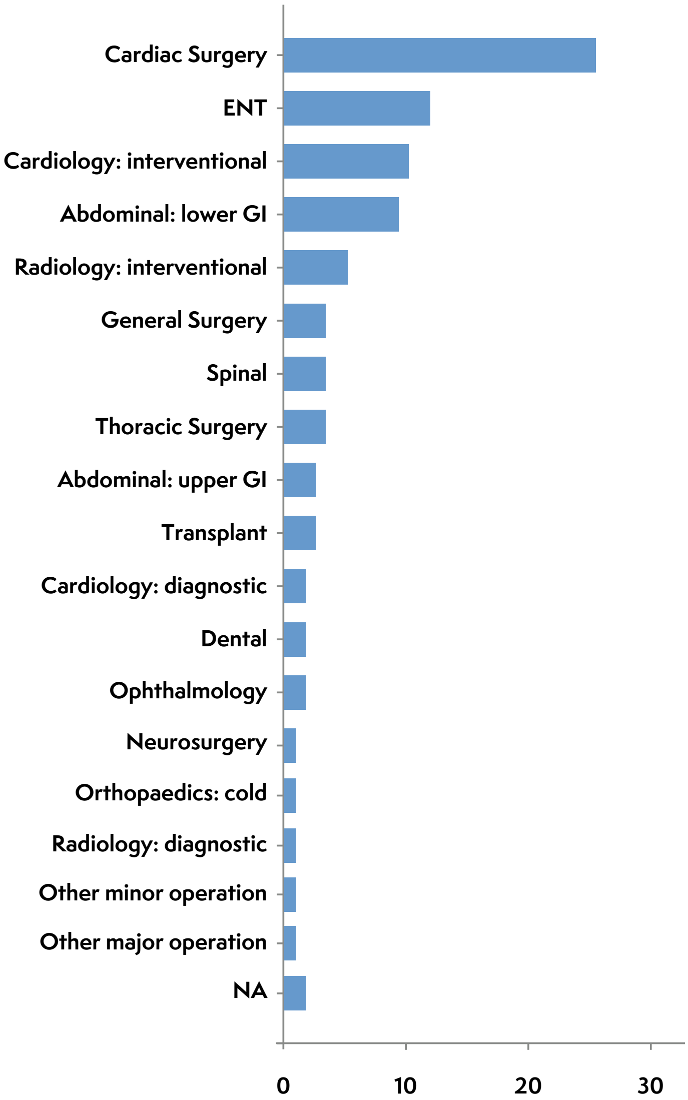


Figure 27.2 104 paediatric cardiac arrest cases by specialty. ENT, ear, nose and throat; GI, gastrointestinal; NA, not available.



The 104 paediatric patients who had a cardiac arrest reported to the NAP7 registry, when compared with the 3429 paediatric cases in the NAP7 Activity Survey, were more often: male (65% vs 59%); younger (Figure 27.3), sicker and had more comorbidities (Figure 27.4) and were of non-White ethnicity (Figure 27.5). They also more often underwent urgent or immediate surgery (50% vs 17%), more non-elective surgery (63% vs 31%), more major or complex surgery (65% vs 8.9%) and more often received general anaesthesia for the procedure (97% vs 90%).

The following subpopulations were analysed separately to explore potential patterns and high-risk groups for perioperative cardiac arrest: (1) children aged over 1 year; (2) infants 28 days to less than 1 year; (3) neonates less than 28 days; (4) children with CHD; and (5) children undergoing non-cardiac surgery/intervention.

1) Children aged over one year

Of the 41 reports including children aged over one year, nine (22%) died. Of the nine deaths, four were judged the result of an inexorable process, three partially, one was not and one uncertain. The panel determined that 4 of the surviving patients experienced severe harm and 28 moderate harm. Care before cardiac arrest was judged good in 60% and poor in 5% (ie two cases) and overall care good in 62% and poor in 0%. The most common causes of cardiac arrest were severe hypoxaemia (44%), bradycardia and isolated severe hypotension. Key contributory factors were the patient in 85%, surgery in 37% and anaesthesia in 37%. Five cases were related to cardiac surgery, and four each related to ENT, spinal surgery and interventional cardiology. Patients were slightly more often male (61%), mostly comorbid or unwell (37% ASA 3, 27% ASA 4, 9.8% ASA 5), surgery was commonly elective (39%), mostly major or complex (53%) but minor in 22% and almost exclusively conducted with general anaesthesia (95%.) Cardiac arrests were often during the day (51%). The location of cardiac arrest was in a theatre suite in 60%, in a remote location in 15% and in PICU in 20%. The most common time was during anaesthesia (68%). Most cardiac arrests involved pulseless electrical activity (PEA; 39%), bradycardia (20%) or asystole (15%) with three cases of pulseless ventricular tachycardia (pVT; 7%) and two of ventricular fibrillation (VF; 5%).

Figure 27.3 Age distribution among patients in NAP7 in the Activity Survey and who had a cardiac arrest reported to the registry. Activity Survey ■, Case registry ■.

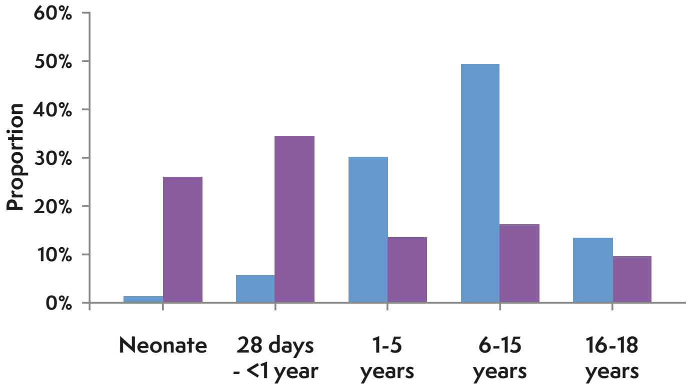


Figure 27.4 ASA distribution among patients in NAP7 in the Activity Survey and who had a cardiac arrest reported to the registry. Activity Survey ■, Case registry ■.

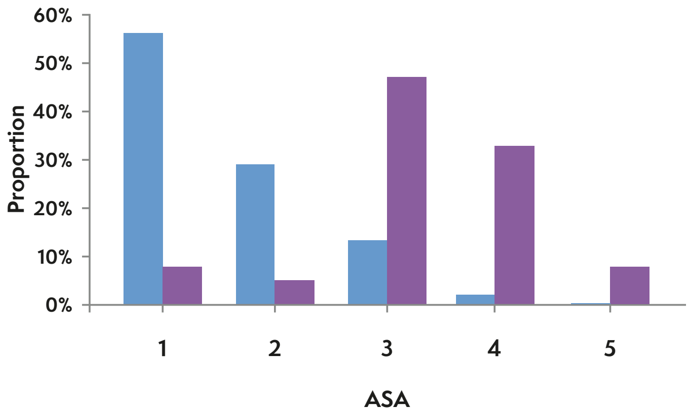
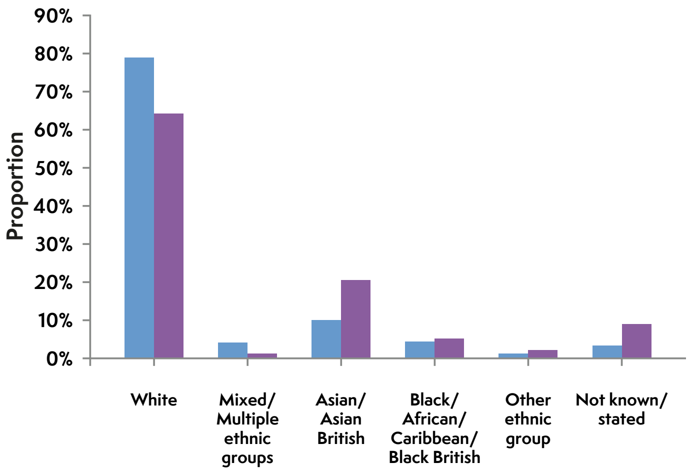


Figure 27.5 Distribution of ethnicity among patients in NAP7 in the Activity Survey and who had a cardiac arrest reported to the registry. Activity Survey ■, Case registry ■.



Cardiac arrest duration was less than 10 minutes in 63%, less than 20 minutes in 76% and over 2 hours in 0%; 34 children (83%) survived initial resuscitation. Debriefs occurred or were planned after 100% of deaths and after 59% of successful resuscitations.

2) Infants (28 days to less than 1 year)

Of the 36 reports in infants (28 days to < 1 year), five (14%) died. Of the five deaths, three were judged the result of an inexorable process, one partially and one was not. The panel determined that 7 of the surviving patients experienced severe harm and 24 moderate harm. Care before cardiac arrest was judged good in 62% and poor in 8.8%, and overall care good in 62% and poor in 2.9% (ie one case). The most common causes of cardiac arrest were severe hypoxaemia (44% of cases), bradycardia and isolated severe hypotension. Key contributory factors were the patient in 89%, surgery in 47% and anaesthesia in 31%; 14 cases were related to cardiac surgery, 7 to ENT and 5 to cardiac surgery or interventional cardiology procedures. Patients were slightly more often male (58%), almost all comorbid or unwell (69% ASA 3, 25% ASA 4, 2.7% ASA 5), surgery was uncommonly elective (28%), mostly major or complex (70%) and almost exclusively conducted with general anaesthesia (97%). Cardiac arrests were mostly during the day (72%). Location of cardiac arrest was in theatre suite in 33%, in a remote location in 14% and in ICU in 44%. Most cardiac arrests involved severe bradycardia (55%), PEA (25%) with one case each of asystole and VF. Cardiac arrest 34 infants (94%) survived initial resuscitation. Debriefs occurred or were planned after 73% of deaths and after 40% of successful resuscitation.

3) Neonates (less than 28 days)

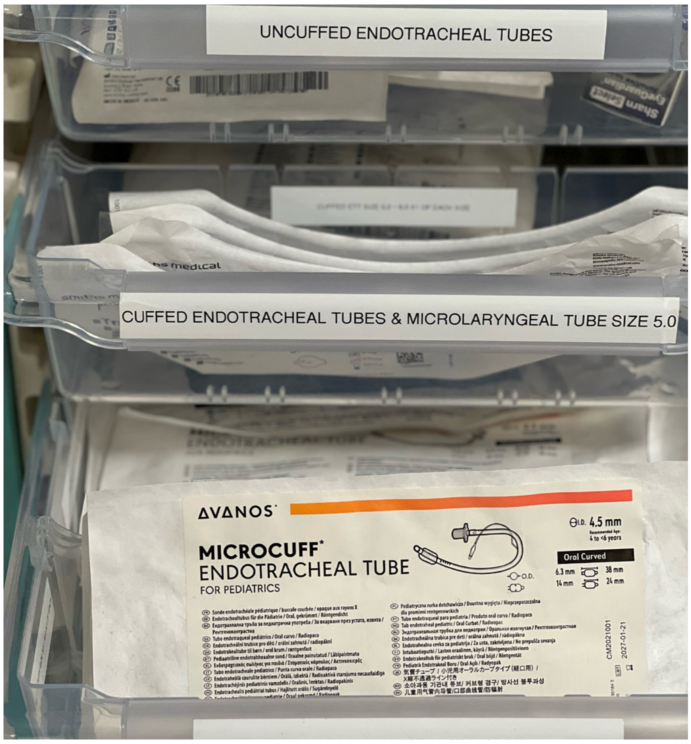
Of the 27 reports in neonates, 11 (41%) died. Of the 11 deaths, 4 were judged the result of an inexorable process, 1 partially and 6 were not. The panel determined that 2 of the surviving patients experienced severe harm and 14 moderate harm. Care before cardiac arrest was judged good in 74% and poor in 7.4% (ie two cases) and overall care good in 63% and poor in 0%. The most common causes of cardiac arrest were isolated severe hypotension, severe hypoxaemia, bradycardia and major haemorrhage. Key contributory factors were the patient in 93%, surgery in 44% and anaesthesia in 26%. Eleven cases related to cardiac surgery, six to general surgery and three to cardiac surgery or interventional cardiology procedures. Patients were mostly male (82%), mostly comorbid or unwell (33% ASA 3, 52% ASA 4, 11% ASA 5), surgery was rarely elective (7.4%), mostly major or complex (70%) and almost exclusively conducted with general anaesthesia (96%). Cardiac arrests were mostly during the day (72%). Location of cardiac arrest was in theatre suite in 48%, in a remote location in 18% and in ICU in 30%. Most cardiac arrests were bradycardia (61%), PEA (29%) with one case each of asystole and VF. Cardiac arrest duration was less than 10 minutes in 48%, less than 20 minutes in 70% and over 2 hours in 7.4%; 18 (67%) survived initial resuscitation. Debriefs occurred or were planned after 78% of deaths and after 44% of successful resuscitations.

4) Children with congenital heart disease

Of the 44 cardiac arrests in children with CHD undergoing cardiac surgery or catheter laboratory interventions, 11 (25%) died. Of the eleven deaths, three were judged the result of an inexorable process, two partially, three were not and three were unknown. The panel determined that 8 of the surviving patients experienced severe harm and 25 moderate harm. Care before cardiac arrest was judged good in 63% and poor in 9.8% and overall care good in 66% and poor in 2.4% (ie one case). The most common causes of cardiac arrest were isolated severe hypotension bradycardia, cardiac tamponade and major haemorrhage (each 10–16%). Key contributory factors were the patient in 91%, surgery in 55% and anaesthesia in 23%. Thirty cases were related to cardiac surgery, 12 to interventional cardiology and two to diagnostic cardiology. Patients were mostly male (70%), 32% neonates and 45% infants (28 days to < 1 year), all ASA 3 or above (57% ASA 3, 41% ASA 4, 2.3% ASA 5), surgery was most commonly expedited or urgent (68%), mostly major or complex (86%) and all conducted with general anaesthesia. Cardiac arrests were mostly during the day (66%). Location of cardiac arrest was most commonly in critical care 44%, in theatre suite in 27% and in a remote location in 25%. Cardiac arrests in theatre suites were more commonly in the anaesthetic room than in theatre (seven vs five). Among 35 cases with a rhythm recorded most were bradycardia (46%), PEA (43%) with three cases of VF and one of pVT. Cardiac arrest duration was less than 10 minutes in 57%, less than 20 minutes in 73% and over 2 hours in 4.5%; 38 (84%) survived initial resuscitation. Debriefs occurred or were planned after 83% of deaths and after 45% of successful resuscitations.

5) Children undergoing non-cardiac surgery/intervention

Of the 60 cardiac arrests in children not undergoing either cardiac surgery or interventional/diagnostic cardiology procedures, 17 (18%) died. Of the 17 deaths, 8 were judged the result of an inexorable process, 3 partially, 5 were not and in 1 there was uncertainty. The panel determined that 5 of the surviving patients experienced severe harm and 38 moderate harm. Care before cardiac arrest was judged good in 65% and poor in 5% and overall care good in 60% and poor in 0%. The most common causes of cardiac arrest were severe hypoxaemia (22%), bradycardia (11%), major haemorrhage (9%), and isolated severe hypotension (5%). Key contributory factors were the patient in 87%, surgery in 33% and anaesthesia in 38%, this being the only paediatric group where anaesthesia exceeded surgery as a key contributory factor. In 14 (23%) cases anaesthesia was judged to be the sole key factor. A total of 14 (23%) cases were related to ENT surgery, 14 to abdominal surgery and six to anaesthesia for radiological procedures. Patients were mostly often male (62%), 22% were neonates and 27% infants (28 days to < 1 year) and 17% aged 1–5 years, many were comorbid or severely unwell (40% ASA 3, 27% ASA 4, 12% ASA 5). Surgery was most commonly expedited or urgent (52%) and 18% immediate priority, 47% was major or complex and 50% intermediate or minor and 95% was conducted with general anaesthesia. Cardiac arrests were mostly during the day (66%). Location of cardiac arrest was most commonly in the theatre suite in 63%, in a remote location in 8% and in critical care in 22%. A total of 30% of events occurred at or soon after induction and 37% during surgery. Cardiac arrests in theatre were more commonly in the theatre than anaesthetic room (33 vs 3). Among 52 cases with a rhythm recorded most were bradycardia (48%), PEA (31%) or asystole (15%). Cardiac arrest duration was less than 10 minutes in 65%, less than 20 minutes in 78% and over 2 hours in none; 48 (80%) survived initial resuscitation. Debrief occurred or was planned after 82% of deaths and after 50% of successful resuscitations.



Quality of care

Overall care was judged by the panel to be good in 62% (63/104) of cases (compared with 53% of all NAP7 cases). Severe harm or death resulted from one third of cardiac arrests, with some aspect of care rated as poor in 26% of these events. Care before cardiac arrest was the phase most frequently rated as poor with choice and dose of induction agent being a recurring theme.

Identification and care of high-risk cases

The panel judged that ASA was underscored in 5.8% (6 cases), this compares with 4% in reported adult cases. Three cases were cardiac and three were non-cardiac. Of the non-cardiac cases, all were unstable patients requiring emergency surgery. The cardiac cases were in infants (n = 2) and neonates (n = 1) undergoing urgent interventions for complex congenital heart disease.

Concerns were raised in several cases about drug dosing or choice. The choice and excessive dosage of propofol in unwell children lead to hypotensive cardiac arrests. Similarly, inhalational inductions with high concentrations of volatile anaesthetic agent resulted in bradycardic events. There were also instances where the use of a combination of intravenous (bolus and total intravenous anaesthesia) and volatile agents resulted in cardiovascular instability and cardiac arrest (see also Chapter 26 Drug choice and dosing).

A child with complex comorbidity presented for an elective procedure. A gas induction was performed with no monitoring in place. Anaesthesia was achieved and monitors were applied, during which time the volatile anaesthetic agent was increased to the maximum deliverable concentration. A profound bradycardia was noted on the ECG and chest compressions commenced. The delivered volatile concentration was reduced and atropine was administered resulting in heart rate recovery after four cycles of CPR.

A child with sepsis with poor perfusion required minor surgery. Dilute adrenaline was prepared. An IV induction was performed using 5 mg/kg of propofol followed by a volatile agent for maintenance of anaesthesia. CPR was started in response to severe hypotension. ROSC was achieved following administration of IV adrenaline.

Drugs used in cardiac arrest

There were 10 cases of bradycardic cardiac arrests in non-cardiac surgery. In four of these cases, atropine or glycopyrrolate was used as the first line drug instead of adrenaline.

A child with a predicted difficult airway required emergency surgery. Intubation was challenging and oxygen desaturation occurred resulting in bradycardia. CPR was commenced and IV atropine was given. Cardiac output improved only following correction of hypoxaemia. Adrenaline was not used.

It was also noted that calcium and bicarbonate were used in 31% and 19% of paediatric cardiac arrests, respectively. This was particularly noted in resuscitation of patients in cardiac settings and in paediatric critical care. This falls outside resuscitation guidelines and often there appeared to be no specific indication (see also Chapter 15 Controversies).

Monitoring

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

Personnel

There were 16 instances where two or more consultants were present for induction of anaesthesia. For patients aged less than one year, 15% (10/66) had two consultants present at induction and in one case three were present.

Supervision of trainees and the involvement of senior clinicians in resuscitation attempts was almost universal, with a consultant present at induction of anaesthesia in 94% of cases. 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. However, the panel considered that the presence or rapid availability of senior personnel could have prevented deterioration and cardiac arrest in several instances. These included high-risk cases, where the presence of two anaesthetists for induction would likely represent best practice, and remote site anaesthesia where access to experienced paediatric specific support was inadequate or delayed.

During day surgery in a remote location, a non-consultant anaesthetist performed an inhalational induction and insertion of a supraglottic airway resulted in bradycardia and cardiac arrest. Glycopyrrolate was given intravenously. Help was summoned which arrived after five minutes. The responding consultant did not have regular paediatric sessions as part of their job plan.

Airway events

There were 15 airway-related cardiac arrests; 14% of all paediatric cardiac arrests. Of these, six resulted from misplaced or obstructed tracheal tubes on paediatric or neonatal ICUs (PICU/NICU) in the postoperative period. Accidental extubation also occurred in PICU and NICU during patient repositioning or tracheal tube manipulation. Capnography was in place for all of these cases; however, in all instances, intubation was known to be difficult. A common theme was failure to plan for tracheal tube displacement and rapid and challenging reintubation. For the remaining nine cases, the precipitant or causative events varied but included failed intubation, endobronchial intubation, postoperative airway swelling and cannot intubate cannot oxygenate situations. Among these cases, 1 patient died (as a result of an inexorable process), 1 experienced severe harm and 13 children survived with moderate harm.

An infant with a known difficult airway underwent surgery and was transferred to PICU postoperatively. The tracheal tube required repositioning to optimise ventilation. The patient was sedated and paralysed but during manipulation of the tracheal tube accidental extubation occurred. Face mask ventilation failed and multiple reintubation attempts were unsuccessful, leading to a hypoxaemic cardiac arrest. The use of videolaryngoscopy was reportedly delayed until an anaesthetist attended. ROSC was achieved following successful intubation via videolaryngoscopy and correction of hypoxaemia.

Debriefing

Debriefs were infrequent (35%) in cases where the patient survived the cardiac arrest but more common (78%) in cases where the initial outcome was death. In adult case reports debriefs were undertaken in 41% when the patient survived and 59% when the patient died.

Discussion

Incidences

Based on NAP7 data, the incidence of perioperative cardiac arrest in children in the UK is 3 per 10,000 anaesthetics (1 : 3333) with a mortality rate of 17%. The incidence is similar to adults. However, the incidence is significantly higher in the neonatal and infant populations at 50 and 20 per 10,000 cases, respectively. The rate of initial successful resuscitation was also lower in neonates (67%) than in other paediatric age groups and only 59% had survived when reported to NAP7. The overall incidence was lower than a previous report (Hache 2020), which identified 5.3 per 10,000 paediatric anaesthetics, including cardiac arrests within 24 hours of surgery, although the mortality rate of 18% was similar. The neonatal population (which includes a large proportion of patients undergoing surgery for congenital heart disease) had a higher risk of perioperative cardiac arrest, lower rate of ROSC 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 (Sperotto 2023). Rates of cardiac arrest in the congenital heart disease population can be reduced via quality improvement programmes, such as the cardiac arrest prevention (CAP) bundle, which was introduced by the Pediatric Cardiac Critical Care Consortium collaborative (Alten 2022).

Quality of care

Identification of high-risk cases

ASA underscoring was noted in 5.8% of paediatric cardiac arrests, slightly more than for reported adult cardiac arrests (4%). All these cases were in children presenting for emergency non-cardiac surgery or urgent cardiac interventions and the ASA score was based on the child's pre-morbid status rather than their current physiological condition. The ASA scoring system has been published with paediatric-specific examples for each grade to address the longstanding issues presented by the adult-based definitions of the original ASA score (Ferrari 2021). Anaesthetists should refer to these examples when quantifying preoperative risk in children.

Teamwide acknowledgement of the high-risk nature of the case or intervention and the use of preventative measures is used in some paediatric cardiac ICUs (PCICU) to reduce the incidence of in hospital cardiac arrest. The formal introduction of a CAP bundle has recently been reported to reduce cardiac arrest rates in PCICU by 30% (Alten 2022). Although theatres and anaesthesia are very different, the use of a similar but modified process could have potential to impact anaesthesia care safety in all high-risk cases.

District general hospital care

The majority of paediatric cases reported to NAP7 were from tertiary paediatric centres (85%) with only 4% of cases occurring in the DGH setting. This suggests the incidence of cardiac arrest in lower-risk children anaesthetised in DGHs is much lower than that seen in tertiary referral centres. This likely reflects an effective triage system within paediatric anaesthesia care with escalation of complex cases to specialist centres. The incidence of perioperative cardiac arrest is higher for critically ill children anaesthetised for specialist retrieval in the DGH setting. This echoes the concerns of stakeholders and NAP7 panel members, which led to the special inclusion of this particular group of patients in the project and it may be that the most valuable learning for the DGH anaesthetist caring for children is in this context (see Chapter 33 Critically ill children).

Drug choice and dosing

There were several cases where the choice and dose of intravenous induction drug was judged to have contributed to hypotensive cardiac arrest in haemodynamically unstable patients. This was not exclusive to the paediatric subset but represents a common theme seen throughout the NAP7 dataset (see also Chapter 26 Drug choice and dosing). If propofol is used in such settings, a 'standard' dose of 4–5 mg/kg is excessive in clinically compromised patients. Other intravenous induction

agents such as ketamine should be considered in instances where vasodilation or myocardial depression is likely to lead to cardiovascular collapse. Similarly, there were examples of severe bradycardias requiring CPR resulting from excessive concentrations of inhalational induction agents. It is accepted that the application of monitoring to distressed children is not always practical and where surgery is deemed essential a balance must be sought between achieving anaesthesia and monitoring physiological parameters. However, in these instances very high concentrations of volatile anaesthetic agents may not represent safe practice. The practice of adding nitrous oxide to the inhaled gas mixture should be considered in selected cases, as this may allow a reduction in the inhaled volatile concentration (Gupta 2022).

Drug choice in bradycardic cardiac arrest

There were 10 cases of bradycardia leading to cardiac arrest in non-cardiac surgery. The propensity of children to bradycardia is well documented and many anaesthetic interventions (eg airway manipulation, anaesthetic drugs) may precipitate such a response. There were instances where the choice of drugs used in response to bradycardia associated with cardiac arrest was not consistent with international guidelines. In these cases where bradycardia is significant enough to prompt chest compressions (heart rate < 60 per minute), adrenaline is the drug of choice not atropine or glycopyrrolate (Skellett 2021). It is possible these agents were administered due to their rapid availability as both are commonly drawn up as emergency drugs at the start of paediatric lists. However, in instances of bradycardia requiring CPR, children should be treated using cardiac arrest algorithms (Skellett 2021). In situations in which bradycardia is associated with hypotension as opposed to cardiac arrest requiring cardiac compressions, atropine or glycopyrrolate may be appropriate choices. GPAS strongly 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 are ideally multidisciplinary and scenario based' (RCoA 2023).

Cardiac arrests in children with congenital heart disease

The National Institute for Cardiovascular Outcomes Research (NICOR) audits all activity in children with CHD having surgical or cardiac catheter laboratory-based procedures in the UK (NICOR 2021). The overall outcomes after paediatric cardiac surgery continue to improve, with a 30-day survival rate of 98%. A total of 8286 procedures (surgery and catheter laboratory procedures) were performed in 2019/20 (NICOR 2021). Post-procedure-related complication rates included the requirement for extracorporeal membrane oxygenation (2.4%), unplanned pacemaker (1.2%), prolonged pleural drainage (3.5%) and renal replacement therapy (3.5%). Measurement of complication rate variables is an area of continuing development but NICOR does not report the cardiac arrest rate in these children. In reports to NAP7, cardiac arrests occurred in 44 children undergoing cardiac surgery or catheter laboratory interventions, 42% of the paediatric dataset, with an 18% mortality. Of note the most common location in which cardiac arrest occurred was on PICU, highlighting the vulnerability of this patient population in the postoperative period and probably related to the significant incidence of low cardiac output syndrome (LCOS) in the 8–12 hours following surgery and the use of cardiopulmonary bypass. Low cardiac output syndrome is particularly prevalent in neonates (40% of cases) and infants (10–20% of cases) in this setting. Seventy-seven per cent of the cardiac arrests reported to NAP7 in children with CHD were in neonates and infants. Importantly, 31% of the cases occurred during diagnostic or interventional procedures in the cardiac catheter laboratory (see comments in monitoring section). NAP7 therefore adds important additional data relating to cardiac arrests in this population.

Monitoring in cardiac catheter laboratory

More than 50% of the paediatric cardiac arrests reported to NAP7 occurred in children with CHD having a procedure or surgery. This complex group is recognised to be at risk of cardiac arrest and specific guidelines have been formulated to reflect this (Marino 2018). Several cases reported to NAP7 did not have IABP in place at the time of the cardiac arrest especially during interventional or diagnostic procedures in the cardiac catheter

laboratory. One of the problems in this environment is that children with critical cardiac lesions (who would normally have invasive monitoring lines inserted as part of routine care before surgical procedures) have these lines inserted by the cardiology team during the procedure. The difficulty is that deterioration may occur and lead to cardiac arrest either at the time of anaesthetic induction before the cardiologists establish arterial/central venous access or during the procedure itself when the monitoring or access available 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 they would be for high-risk invasive surgery with the insertion of invasive blood pressure monitoring as early as possible. Preprocedural team briefings could 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 must be conducted by the team and during the consent process with the parents or legal guardians.

Personnel

Senior involvement in cases was very good with a consultant present at induction of anaesthesia in 94%. This is higher than in the rest of the NAP7 dataset (86%). There were, however, a few instances where the patient and/or surgery was judged by the panel to be so high risk that the presence of two consultant anaesthetists was likely to represent best practice. GPAS recognises that infants are particularly at risk and strongly recommends allocating two anaesthetic assistants to a list where an infant is involved (RCoA 2023.)

A few cases occurred in remote locations or involved trainees working independently. There were cases where supervisors did not have appropriate paediatric training or there was a delay in assistance arriving when called. The Cappuccini test advocated by the RCoA means all trainees should know who to call and how to call them for supervision and the supervisor should know who they are supporting and what they are doing (RCoA 2019).

Airway events

The causes of cardiac arrest varied between non-cardiac and cardiac surgical groups. Severe hypoxaemia and resulting bradycardia secondary to airway and respiratory events were the most common precipitants in non-cardiac surgery and also occurred after transfer to the intensive care unit.

There were a number of cardiac arrest events associated with the need to re-position or manipulate a tracheal tube in the postoperative period in PICU/NICU. Initial correct placement may avoid subsequent need for readjustment in the infants and children requiring continuing PICU/NICU management. However, this can be difficult, especially in the neonatal population and further guidance on the role of x-ray or sonographic confirmation of placement for the anaesthetist is needed. Meticulous preparation for airway repositioning, exchange or physiotherapy interventions are necessary to avoid these adverse events relating to airway displacement. Interestingly, airway manipulation and suctioning has been identified as a high-risk procedure requiring a CAP intervention in the PICU environment (Alten 2022).

The RCoA recommends that a standardised paediatric airway trolley and emergency equipment such as a defibrillator should be available in all the hospital locations in which paediatric airway management and anaesthesia takes place (RCoA 2023). Equipment should be standardised across all remote areas to match the main paediatric departmental facilities including emergency departments and critical care units (RCoA 2023). Of some concern, the Baseline Survey showed a significant proportion of UK hospitals are poorly equipped for emergencies in paediatric anaesthesia. One in six responding departments that anaesthetise children did not have access to advanced airway equipment and difficult airway trolleys in every operating room where paediatric anaesthesia takes place.

Debriefing

Debriefing after a major event serves two equally important purposes; first to learn from the event and second to provide initial support to involved staff and to ensure those who may need more specific support are identified and appropriately signposted. It is important to learn from perioperative cardiac arrests. Only 35% of reports of children who survived cardiac arrest were followed up with a debrief. Failure to review cases is likely to mean individuals and organisations will miss key lessons and opportunities to improve patient safety. In the NAP4 report it was stated that 'Teams who are required to perform to a very high level often report that the single most useful team activity they undertake is a thorough debriefing following every event, whether things went smoothly or not' (Shaw 2011). Intraoperative cardiac arrest in children is rare and when events do occur, they are likely to be particularly traumatic experiences for the individuals involved. There is evidence of this from NAP7 and all involved in a paediatric cardiac arrest are likely to benefit from routine provision of support after the event (see Chapter 17 Managing the aftermath).

Recommendations

National

- Training in the UK should reflect the high-risk nature of paediatric anaesthesia with additional time allocated to paediatric anaesthesia, especially the care of infants and neonates.
- National guidelines should be produced that ensure adequate time is included in the contracts of all consultants and other permanent clinicians who undertake paediatric anaesthesia to ensure maintaining skills is practical. These should include increased access to local paediatric CPD opportunities in both the clinical and simulation environments.
- Honorary contracts to enable hands-on paediatric CPD training at external specialist centres enable CPD should be facilitated in all tertiary centres.
- The care of children with CHD (who are at high risk of perioperative cardiac arrest) should be provided in specialist centres by specialist teams for the most invasive surgery.

Institutional

- Institutions should ensure adequate staffing, training and resources to provide 24/7 consultant anaesthetic availability for emergency anaesthesia of infants and children at high risk of cardiac arrest.
- Institutions should consider allocating two consultants to manage the highest-risk paediatric cases.
- Non-consultant anaesthetists working alone, especially in remote locations, should be provided with a clear plan of who to contact for appropriate senior support, including in the event of a clinical emergency.
- Institutions with cardiac catheter laboratory should ensure multidisciplinary team training is provided on the recognition and management of perioperative cardiac arrest.
- Institutions should create a culture where an open and honest debrief is expected after every intraoperative cardiac arrest regardless of outcome.

Individual

- Individuals who may have to manage sick children and infants should ensure they are up to date with national paediatric resuscitation guidelines.
- Individuals should be aware that sick children may become unstable on induction of anaesthesia and an appropriate anaesthetic agent and dose chosen.
- Individual consultants should ensure a debrief and case review occurs in the event of a perioperative cardiac arrest, whatever the outcome.

Research

- Research is needed to assess if there is a more sensitive risk-prediction tool for children in addition to ASA scoring.
- There is need for research to establish the best way to reduce tracheal tube displacement during manipulations in children in the postoperative ICU environment.

References

Alten 2022: Alten J, Cooper DS, Klugman D *et al* preventing cardiac arrest in the pediatric cardiac intensive care unit through multicentre collaboration. *JAMA Pediatr* 2022; 176: 1027–1036.

Christensen 2018: Christensen RE, Lee AC, Gowen MS *et al* Pediatric perioperative cardiac arrest, death in the off hours: a report from Wake Up Safe, The Pediatric Quality Improvement Initiative: *Anaesth Analg* 2018; 127: 472–7.

Ferrari 2021: Ferrari L, Leahy I, Staffa S *et al* The pediatric-specific American Society of Anaesthesiologists physical status score: a multicenter study. *Anaesth Analg* 2021; 132: 807–17.

Gupta 2022: Gupta N, Gupta A, Narayanan V. Current status of nitrous oxide use in pediatric patients. *World J Clin Pediatr* 2022; 11: 93–104.

Hache 2020: Hache M, Sun L, Gadi, G *et al* Outcomes from wake up safe, the pediatric anesthesia quality improvement initiative: *Pediatr Anesth* 2020; 30: 1348–54.

Marino 2018: Marino BS, Tabbutt S, MacLaren G *et al* Cardiopulmonary resuscitation in infants and children with cardiac disease. a scientific statement from the AHA: *Circulation* 2018; 137: 691–782.

NICOR 2021: National Cardiac Audit Programme. *National Congenital Heart Disease Audit 2021 Summary Report*. Leicester: National Institute for Cardiovascular Outcomes Research; 2021. https://www.nicor.org.uk/wp-content/uploads/2021/10/NCHDA-Domain-Report_2021_FINAL.pdf (accessed 23 May 2023).

RCoA 2010: Royal College of Anaesthetists. *CCT in Anaesthetics: Annex E Advanced Level Training*, 2nd edn. London: Royal College of Anaesthetists; 2010. https://www.rcoa.ac.uk/sites/default/files/documents/2019-08/TRG-CCT-ANNEXE.pdf (accessed 25 May 2023).

RCoA 2019: Royal College of Anaesthetists. Cappuccini test. https://rcoa.ac.uk/safety-standards-quality/patient-safety/cappuccini-test (accessed 10th May 2023).

RCoA 2021: Royal College of Anaesthetists. 2021 Curriculum learning syllabus: stage 3 special interest areas. London: Royal College of Anaesthetists; 2021. https://rcoa.ac.uk/documents/2021-curriculum-learning-syllabus-stage-3-special-interest-areas/paediatric-anaesthesia (accessed 25 May 2023).

RCoA 2023: Chapter 10: *Guidelines for the Provision of Paediatric Anaesthesia Services 2023*. London: Royal College of Anaesthetists; 2023. https://www.rcoa.ac.uk/gpas/chapter-10#chapter-1 (accessed 12 April 2023).

Shaw 2011: Shaw J, Frerk C, Russell J. A commentary on human factors aspects of cases reported to NAP 4. In: Cook, T, Woodall N, Frerk C, eds. *Major Complications of Airway management in the United Kingdom. 4th National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society: Report and findings*. London: Royal College of Anaesthetists; 2011. pp. 193–201.

Skellett 2021: Skellett S, Maconochie I, Bingham R *et al Paediatric Advanced Life Support Guidelines*. London: Resuscitation Council UK; 2021. https://www.resus.org.uk/library/2021-resuscitation-guidelines/paediatric-advanced-life-support-guidelines (accessed 10th May 2023).

Sperotto 2023: Sperotto F, Daverio M, Amigoni A *et al* Trends in in-hospital cardiac arrest and mortality among children with cardiac disease in the intensive care unit: a systematic review and meta-analysis. *JAMA* 2023; 6: e2256178.