Survival With Favorable Neurologic Outcome and Quality of Cardiopulmonary Resuscitation Following In-Hospital Cardiac Arrest in Children With Cardiac Disease Compared With Noncardiac Disease*

OBJECTIVES: To assess associations between outcome and cardiopulmonary resuscitation (CPR) quality for in-hospital cardiac arrest (IHCA) in children with medical cardiac, surgical cardiac, or noncardiac disease.

DESIGN: Secondary analysis of a multicenter cluster randomized trial, the ICU-RESUScitation Project (NCT02837497, 2016–2021).

SETTING: Eighteen PICUs.

PATIENTS: Children less than or equal to 18 years old and greater than or equal to 37 weeks postconceptual age receiving chest compressions (CC) of any duration during the study.

INTERVENTIONS: None

MEASUREMENTS AND MAIN RESULTS: Of 1,100 children with IHCA, there were 273 medical cardiac (25%), 383 surgical cardiac (35%), and 444 noncardiac (40%) cases. Favorable neurologic outcome was defined as no more than moderate disability or no worsening from baseline Pediatric Cerebral Performance Category at discharge. The medical cardiac group had lower odds of survival with favorable neurologic outcomes compared with the noncardiac group (48% vs 55%; adjusted odds ratio [aOR] [95% CI], aOR 0.59 [95% CI, 0.39–0.87], $p = 0.008$) and surgical cardiac group (48% vs 58%; aOR 0.64 [95% CI, 0.45–0.9], $p = 0.01$). We failed to identify a difference in favorable outcomes between surgical cardiac and noncardiac groups. We also failed to identify differences in CC rate, CC fraction, ventilation rate, intra-arrest average target diastolic or systolic blood pressure between medical cardiac versus noncardiac, and surgical cardiac versus noncardiac groups. The surgical cardiac group had lower odds of achieving target CC depth compared to the noncardiac group (OR 0.15 [95% CI, 0.02–0.52], $p = 0.001$). We failed to identify a difference in the percentage of patients achieving target CC depth when comparing medical cardiac versus noncardiac groups.

CONCLUSIONS: In pediatric IHCA, medical cardiac patients had lower odds of survival with favorable neurologic outcomes compared with noncardiac and surgical cardiac patients. We failed to find differences in CPR quality between medical cardiac and noncardiac patients, but there were lower odds of achieving target CC depth in surgical cardiac compared to noncardiac patients.

KEY WORDS: cardiopulmonary resuscitation; child; congenital heart disease; infant; in-hospital cardiac arrest

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RESEARCH IN CONTEXT

- Historically, the prevalence of in-hospital cardiac arrest and odds of survival differ between children with cardiac surgical, cardiac medical, and noncardiac disease.
- It is unknown whether these historical differences are relevant in contemporary practice or whether the quality of cardiopulmonary resuscitation (CPR) differs and matters between groups.
- This report assesses information from a 2016–2021 multicenter prospective dataset.

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Pediatric cardiac arrest affects thousands of children each year (1, 2). Although many children who receive cardiopulmonary resuscitation (CPR) survive the initial arrest with return of spontaneous circulation (ROSC), only half of these children survive hospital discharge (3). Of the survivors in the 2009–2015 Therapeutic Hypothermia for Cardiac Arrest trials, many have significant morbidity, including neurologic sequelae (4). Historically, in cohorts from the period 2008–2016, high-quality CPR was associated with improved outcomes (5–8), but the quality of CPR provided was variable even in the ICU.

In pediatric cohorts from 2002 to 2016, cardiac disease—versus not—was associated with higher rates of in-hospital cardiac arrest (IHCA) (9, 10), but there are conflicting results about higher or lower survival (10–12). Other historical cohorts, 2000–2010, suggest that amongst children with cardiac disease, cardiac surgical patients have higher rates of postresuscitation ROSC and survival to hospital discharge compared to cardiac medical patients after IHCA (13–15). In contemporary practice, it is unknown whether the quality of CPR differs in medical cardiac, surgical cardiac, or noncardiac patients or based on location of arrest (i.e., in the cardiac ICU [CICU] compared with a PICU). Therefore, the aim of our analyses was to determine in a contemporary 2016–2021 cohort, differences in survival with favorable neurologic outcomes after IHCA in children with medical cardiac, surgical cardiac, and noncardiac disease, and to assess whether CPR quality differed between groups.

MATERIALS AND METHODS

We carried out a retrospective secondary analysis of the ICU-RESUScitation (ICU-RESUS) project (NCT02837497, 2016–2021), which was published in 2022 (16). The design and planning for this secondary study occurred during ICU-RESUS patient enrollment and only data collected prospectively during this trial were included in this analysis. The ICU-RESUS study was a hybrid stepped-wedge trial in which 18 PICUs and CICUs at 10 hospitals transitioned from the contemporary standard (before 2016 enrollment) to the intervention, which was a training bundle targeting improved delivery of CPR in children experiencing cardiac arrest in the ICU. All IHCA in children (age 37 wk postconceptual to age 18 yr) were included. Traumatic arrests were excluded. Children were excluded if, before arrest, there were limitations to aggressive ICU care, concern of brain death, or an out-of-hospital CPR event associated with the same hospital admission. Surgical cardiac patients were defined as those with cardiac disease with arrest during the same admission but after cardiac surgery; medical cardiac patients were defined as those with cardiac disease with no cardiac surgical intervention during this admission; and all other arrests were categorized as noncardiac. The institutional review board (IRB) at the University of Utah served as the central IRB and authorized the study, titled "Improving Outcomes from Pediatric Cardiac Arrest—ICU RESUS" (no. 0093320, original approval date of July 18, 2016) with waiver of parental permission. All human research procedures complied with the ethical standards of the central IRB and with the Helsinki Declaration of 1975.

In the originating ICU-RESUScitation project, all data were collected at each participating site by research coordinators trained for this study. Data collected included child and CPR event characteristics consistent with the Utstein Resuscitation Registry Template for IHCA (17, 18).

Our primary hypotheses were that medical cardiac cases have worse and surgical cardiac cases have better outcomes compared with noncardiac patients, and that CPR quality, as defined by chest compression (CC) rate, ventilation rate, CC fraction, CC depth, and ability to achieve diastolic and systolic pressure goals was no different between medical cardiac, surgical cardiac, and noncardiac patients. Our secondary hypotheses were that medical cardiac and surgical cardiac patients experience extracorporeal CPR (ECPR) more frequently than noncardiac patients and that end-tidal carbon dioxide ($ETCO_2$), arterial/invasive blood pressure, and central venous access are more frequently available for surgical and medical cardiac patients than for noncardiac patients at the onset of the IHCA and, therefore, for a higher percentage of time of the entire arrest. In addition, we hypothesized that there is a shorter delay between the onset of IHCA and initiation of CC in surgical cardiac and medical cardiac patients compared with noncardiac patients.

The primary outcome was survival to hospital discharge with favorable neurologic outcome, which was defined as a Pediatric Cerebral Performance Category (PCPC) score of 1–2 or no change from baseline. Secondary outcomes included measures of intra-arrest quality including CPR mechanics such as CC rate, ventilation rate, CC fraction, and CC depth, as well as physiologic targets of diastolic and systolic pressure during CPR.

Statistical Analysis

Patient and event characteristics were summarized using frequencies and percentages for the comparison between illness categories (medical cardiac, surgical cardiac, or noncardiac). Fisher exact test was used for nominal variables and Kruskal-Wallis test for ordinal variables to determine association between patient and event characteristics with illness category. Resuscitation quality by illness category was summarized using frequencies and percentages for the binary variables. Means and quartiles are used for the continuous variables.

Associations between resuscitation quality and outcomes with illness category were assessed using logistic regression models. A priori covariates used in the model include first documented rhythm, vasoactive infusion, renal insufficiency, age category, weekday versus night/weekend, sepsis, and calcium use. *p* values were reported based on a two-sided alternative and considered statistically significant when less than 0.05. Analyses were performed using SAS 9.4 (SAS Institute; Cary, NC).

RESULTS

Patient and CPR Event Characteristics

Of 1,100 children with IHCA, 273 (25%) were medical cardiac, 383 (35%) were surgical cardiac, and 444 (40%) were noncardiac (**Table 1**). The majority of patients were 1 month to less than 1 year old in the cardiac groups whereas in the noncardiac group, the majority of arrests were in the 1 year to 12 years age group. CPR in medical and surgical cardiac patients occurred most in the CICU, and noncardiac CPR occurred most in the PICU. The presence of preexisting conditions is shown, with an expected higher prevalence of congestive heart failure and congenital heart disease in the cardiac groups and a higher prevalence of pneumonia and sepsis in the noncardiac group. Baseline PCPC differed in that 303 of 444 (68.3%) of the noncardiac group were classified as either normal or with mild disability compared to 230 of 273 (84.3%) of the medical cardiac and 330 of 383 (86.1%) of the surgical cardiac group in these outcome categories. Pre-event severity of illness was analyzed using Pediatric Risk of Mortality (PRISM) score in the time period of 2–6 hours before the event. Medical cardiac and noncardiac patients had an equivalent pre-arrest average PRISM score of 3 and surgical cardiac patients had a median score of 5.

CPR event characteristics are shown in **Table 2**. On inspection of the data, at the time of cardiac arrest, 270

TABLE 1.
Patient Characteristics

Characteristics	Overall (n = 1,100)	Medical Cardiac (n = 273)	Surgical Cardiac (n = 383)	Noncardiac (n = 444)
Age				
< 1 mo	181 (16.5%)	61 (22.3%)	107 (27.9%)	13 (2.9%)
1 mo–< 1 yr	469 (42.6%)	117 (42.9%)	199 (52.0%)	153 (34.5%)
1 yr–< 12 yr	331 (30.1%)	70 (25.6%)	60 (15.7%)	201 (45.3%)
> 12 yr	119 (10.8%)	25 (9.2%)	17 (4.4%)	77 (17.3%)
Sex				
Male	589 (53.5%)	148 (54.2%)	196 (51.2%)	245 (55.2%)
Female	511 (46.5%)	125 (45.8%)	187 (48.8%)	199 (44.8%)
Race				
Black or African American	272 (24.7%)	67 (24.5%)	82 (21.4%)	123 (27.7%)
White	520 (47.3%)	122 (44.7%)	186 (48.6%)	212 (47.8%)
Other	64 (5.8%)	15 (5.5%)	21 (5.5%)	28 (6.3%)
Unknown or not reported	244 (22.2%)	69 (25.3%)	94 (24.5%)	81 (18.2%)
Preexisting conditions[a]				
Respiratory insufficiency	952 (86.5%)	229 (83.9%)	316 (82.5%)	407 (91.7%)
Hypotension	691 (62.8%)	161 (59.0%)	289 (75.5%)	241 (54.3%)
Congestive heart failure	146 (13.3%)	61 (22.3%)	65 (17.0%)	20 (4.5%)
Pneumonia	139 (12.6%)	14 (5.1%)	6 (1.6%)	119 (26.8%)
Sepsis	180 (16.4%)	28 (10.3%)	22 (5.7%)	130 (29.3%)
Renal insufficiency	156 (14.2%)	28 (10.3%)	40 (10.4%)	88 (19.8%)
Malignancy	53 (4.8%)	6 (2.2%)	3 (0.8%)	44 (9.9%)
Congenital heart disease	650 (59.1%)	210 (76.9%)	368 (96.1%)	72 (16.2%)
Pulmonary hypertension	184 (16.7%)	55 (20.1%)	79 (20.6%)	50 (11.3%)
Pulmonary hypertension being treated with inhaled nitric oxide	101 (9.2%)	33 (12.1%)	48 (12.5%)	20 (4.5%)
Location of cardiopulmonary resuscitation event				
PICU	518 (47.1%)	49 (17.9%)	44 (11.5%)	425 (95.7%)
Cardiac ICU	582 (52.9%)	224 (82.1%)	339 (88.5%)	19 (4.3%)
Baseline Pediatric Cerebral Performance Category[b]				
1–Normal	662 (60.2%)	185 (67.8%)	249 (65.0%)	228 (51.4%)
2–Mild disability	201 (18.2%)	45 (16.5%)	81 (21.1%)	75 (16.8%)
3–Moderate disability	114 (10.4%)	24 (8.7%)	28 (7.3%)	62 (14.0%)
4–Severe disability	111 (10.1%)	19 (7.0%)	22 (5.8%)	70 (15.8%)
5–Coma/vegetative state	12 (1.1%)	0 (0.0%)	3 (0.8%)	9 (2.0%)
Baseline Functional Status Scale[a]	6.0 (6.0–10.0)	6.0 (6.0–9.0)	6.0 (6.0–9.0)	7.0 (6.0–12.0)
Pediatric Risk of Mortality score (2–6 hr before event)	3.0 (0.0–10.0)	3.0 (0.0–8.0)	5.0 (0.0–11.0)	3.0 (0.0–10.0)

[a]Subjects can appear in more than one subcategory of preexisting conditions.

[b]Baseline Pediatric Cerebral Performance Category and Functional Status Scale represent subject status before the event leading to hospitalization.

TABLE 2.
Event Characteristics

	Overall (*n* = 1,100)	Medical Cardiac (*n* = 273)	Surgical Cardiac (*n* = 383)	Noncardiac (*n* = 444)
Interventions in place				
Vascular access	1,000 (90.9%)	246 (90.1%)	352 (91.9%)	402 (90.5%)
Arterial catheter	560 (50.9%)	131 (48.0%)	270 (70.5%)	159 (35.8%)
Central venous catheter	756 (68.7%)	171 (62.6%)	316 (82.5%)	269 (60.6%)
Vasoactive infusion	575 (52.3%)	165 (60.4%)	263 (68.7%)	147 (33.1%)
Invasive mechanical ventilation	775 (70.5%)	175 (64.1%)	278 (72.6%)	322 (72.5%)
Noninvasive ventilation	206 (18.7%)	56 (20.5%)	55 (14.4%)	95 (21.4%)
First documented rhythm				
Pulseless electrical activity/asystole	443 (40.3%)	108 (39.6%)	126 (32.9%)	209 (47.1%)
Ventricular fibrillation/tachycardia	89 (8.1%)	33 (12.1%)	34 (8.9%)	22 (4.9%)
Bradycardia with poor perfusion	568 (51.6%)	132 (48.3%)	223 (58.2%)	213 (48.0%)
Immediate cause				
Hypotension	589 (53.5%)	142 (52.0%)	238 (62.1%)	209 (47.1%)
Respiratory decompensation	598 (54.4%)	131 (48.0%)	169 (44.1%)	298 (67.1%)
Arrhythmia	189 (17.2%)	69 (25.3%)	57 (14.9%)	63 (14.2%)
Time[a]				
Weekday	586 (53.3%)	143 (52.4%)	217 (56.7%)	226 (50.9%)
Weeknight	219 (19.9%)	57 (20.9%)	79 (20.6%)	83 (18.7%)
Weekend	295 (26.8%)	73 (26.7%)	87 (22.7%)	135 (30.4%)
Duration of CPR (min)	6.5 (2.0, 23.0)	9.0 (2.0, 37.0)	7.0 (2.0, 27.0)	6.0 (3.0, 18.0)
Duration of CPR (min)				
< 16	726 (66.0%)	163 (59.7%)	244 (63.7%)	319 (71.8%)
16–35	187 (17.0%)	39 (14.3%)	71 (18.5%)	77 (17.4%)
> 35	187 (17.0%)	71 (26.0%)	68 (17.8%)	48 (10.8%)
Sternum opens at the start of CPR event	111 (10.1%)	28 (10.3%)	69 (18.0%)	14 (3.2%)
Sternum opened during CPR event	52 (4.7%)	14 (5.1%)	30 (7.8%)	8 (1.8%)

CPR = cardiopulmonary resuscitation.
[a]Weekday is between 7 AM and 11 PM Monday–Friday; weeknight is after 11 PM Monday–Thursday; Weekend is from 11 PM on Friday–7 AM on the following Monday.

of 383 (70.5%) of surgical cardiac patients had an arterial catheter and 316 of 383 (82.5%) had central venous catheter, which was higher than the proportion seen in medical cardiac and noncardiac patients. The cardiac groups demonstrated a greater proportion receiving vasoactive infusion compared to noncardiac cases (60.4% medical cardiac, 68.7% surgical cardiac, 33.1% noncardiac). Surgical cardiac and noncardiac patients also had a greater percentage undergoing invasive mechanical ventilation than the medical cardiac group; whereas noninvasive ventilation was used less in surgical cardiac patients compared to the other groups. The first documented rhythm among all groups was most often bradycardia with poor perfusion. A ventricular arrhythmia was more frequent in the cardiac groups (12.1% medical cardiac, 8.9% surgical cardiac, 5% noncardiac). The proximate hemodynamics at the time of arrest was most commonly hypotension in the surgical cardiac group and respiratory decompensation in the noncardiac group. Arrhythmias at onset were more common in medical cardiac group. Most arrests were on weekdays, followed by weekends then weeknights, and there was no difference in timing of events between illness categories. The median duration of CPR was longer in the medical cardiac group and shorter in noncardiac group.

Resuscitation Quality

Resuscitation quality metrics are summarized in **Supplemental Digital Content 1** (http://links.lww.com/PCC/C430) and comparisons between illness categories are shown in **Supplemental Digital Content 2** (http://links.lww.com/PCC/C430). We failed to identify differences between any illness categories in CC rate, CC fraction, ventilation rate, or intra-arrest maintenance of target systolic and diastolic blood pressure. We also failed to identify any difference in time from cardiac arrest to initiation of CC nor to delivery of defibrillation or shock.

Compared to noncardiac patients, surgical cardiac patients less than or equal to 1 year of age had lower diastolic blood pressure (35 mm Hg vs 44 mm Hg; $p = 0.001$) and systolic blood pressure (71 mm Hg vs 92 mm Hg; $p < 0.001$) during cardiac arrest, and surgical cardiac patients greater than 1 year of age also had lower systolic blood pressures during CPR (85 mm Hg vs 99 mm Hg; $p = 0.045$). Although the CC depth was the same between these groups, the percent of patients who maintained the target average CC depth was lower in the surgical cardiac group (6.5% surgical cardiac vs 32.2% noncardiac; $p = 0.001$). There was more calcium, bicarbonate, and epinephrine used in the surgical cardiac compared with noncardiac group. The median $ETCO_2$ was lower in the surgical cardiac compared with the noncardiac group (20 mm Hg vs 27 mm Hg; $p < 0.001$).

Compared with noncardiac patients, medical cardiac patients less than or equal to 1 year of age had lower diastolic blood pressures (33 mm Hg vs 44 mm Hg; $p = 0.002$) and lower CC depths during CPR (24 mm vs 26 mm; $p = 0.04$). Although there was no difference in epinephrine administration, time to epinephrine, or number of doses, longer epinephrine dosing intervals occurred in the medical cardiac compared with noncardiac groups. The median $ETCO_2$ was lower in medical cardiac compared to noncardiac groups (21 mm Hg vs 27 mm Hg; $p = 0.003$).

When comparing CPR quality between surgical cardiac and medical cardiac patients, there was a difference in the surgical cardiac group which had greater receipt of epinephrine and calcium.

Patient Outcomes

Patient outcomes are summarized in **Table 3** and comparisons between illness categories are shown in **Table 4**. We failed to identify a difference in survival

TABLE 3.
Outcomes

Outcome	Overall ($n = 1,100$)	Medical Cardiac ($n = 273$)	Surgical Cardiac ($n = 383$)	Noncardiac ($n = 444$)
Immediate outcome of cardiopulmonary resuscitation event				
Return of spontaneous circulation ≥ 20 min	759 (69.0%)	170 (62.3%)	247 (64.5%)	342 (77.0%)
Transitioned to extracorporeal membrane oxygenation	217 (19.7%)	76 (27.8%)	109 (28.5%)	32 (7.2%)
Died	124 (11.3%)	27 (9.9%)	27 (7.0%)	70 (15.8%)
Survival to hospital discharge	639 (58.1%)	148 (54.2%)	231 (60.3%)	260 (58.6%)
Survival to hospital discharge with favorable neurologic outcomes[a]	596 (54.2%)	131 (48.0%)	222 (58.0%)	243 (54.7%)
Survival to hospital discharge with PCPC of 1, 2, or no worse than baseline	547 (49.7%)	119 (43.6%)	198 (51.7%)	230 (51.8%)

PCPC = Pediatric Cerebral Performance Category.

[a]Favorable neurologic outcome was defined as no more than moderate disability or no worsening from baseline PCPC. Baseline PCPC represents subject status before the event leading to hospitalization.

TABLE 4.
Association of Illness Category With Outcomes

Outcome	Medical Cardiac vs Noncardiac		Surgical Cardiac vs Noncardiac		Medical Cardiac vs Surgical Cardiac	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Immediate outcome of cardiopulmonary resuscitation event						
Return of spontaneous circulation ≥ 20 minutes	0.52 (0.33–0.82)	0.004	0.74 (0.47–1.17)	0.201	0.74 (0.51–1.08)	0.115
Transitioned to extracorporeal membrane oxygenation	3.81 (2.21–6.66)	< 0.001	3.03 (1.74–5.37)	< 0.001	1.19 (0.81–1.75)	0.369
Died	0.59 (0.32–1.07)	0.084	0.37 (0.19–0.70)	0.002	1.45 (0.78–2.71)	0.239
Survival to hospital discharge	0.71 (0.47–1.07)	0.100	1.09 (0.72–1.64)	0.686	0.74 (0.53–1.05)	0.097
Survival to hospital discharge with favorable neurologic outcome[a]	0.59 (0.39–0.87)	0.008	1.11 (0.74–1.66)	0.608	0.64 (0.45–0.90)	0.010
Survival to hospital discharge with PCPC of 1, 2, or no worse than baseline	0.59 (0.40–0.87)	0.007	0.96 (0.65–1.41)	0.821	0.69 (0.49–0.97)	0.033

OR = odds ratio, PCPC = Pediatric Cerebral Performance Category.
[a]Favorable neurologic outcome was defined as no more than moderate disability or no worsening from baseline PCPC. Baseline PCPC represents subject status before the event leading to hospitalization.
Results are based on logistic regression model(s) adjusting for age, vasoactive infusion, renal insufficiency, sepsis, first rhythm, time of day, and calcium.

to hospital discharge when comparing between illness categories. The medical cardiac group had lower odds of surviving hospital discharge with favorable neurologic outcomes compared with both the noncardiac group (OR 0.59 [95% CI, 0.39–0.87]; $p = 0.008$) and the surgical cardiac group (OR 0.64 [95% CI, 0.45–0.9]; $p = 0.01$). Additionally, the medical cardiac group had lower odds of surviving hospital discharge with PCPC of 1, 2, or no worse than baseline, compared with both the noncardiac group (OR 0.59 [95% CI, 0.40–0.87]; $p = 0.007$) and the surgical cardiac group (OR 0.69 [95% CI, 0.49–0.97]; $p = 0.033$). Electroencephalogram (EEG) data from the first 24 hours are shown in **Supplemental Digital Content 3** (http://links.lww.com/PCC/C430). These data were available for 261 patients and showed a similar proportion of patients in each illness category had normal EEG backgrounds in the first 24 hours. However, there was a significant difference in the distribution of abnormal EEG backgrounds. Noncardiac patients had more slow/disorganized background activity, surgical cardiac patients had more discontinuous background activity, and medical cardiac patients had more attenuated background activity. Overall, 3 of 100 surgical cardiac patients (3%) had seizures in the first 24 hours compared with 10 of 79 medical cardiac patients (12.7%) and 9 of 80 noncardiac patients (11.3%) ($p = 0.024$). Surgical cardiac and medical cardiac patients had greater odds of being transitioned to ECPR when compared with noncardiac patients (OR 3.03 [95% CI, 1.74–5.37]; $p < 0.001$ and OR 3.81 [95% CI, 2.21–6.66]; $p < 0.001$).

DISCUSSION

In this large, contemporary (2016–2021) secondary analysis of the ICU-RESUS study dataset of pediatric IHCA, medical cardiac patients had lower survival with favorable neurologic outcomes compared to noncardiac patients and surgical cardiac patients. We failed to identify difference in CPR quality between medical cardiac and noncardiac patients, but in patients in the surgical cardiac group there was lower odds of achieving target CC depth compared with

AT THE BEDSIDE

- In 2016–2021, a multicenter cohort of pediatric in-hospital cardiac arrest, medical cardiac patients had lower survival with favorable neurologic outcomes compared with noncardiac and surgical cardiac patients.
- CPR quality was similar between medical cardiac and noncardiac groups, but surgical cardiac patients had lower odds of achieving target CC depth compared with noncardiac patients.
- Cardiac groups demonstrated lower blood pressure and lower end-tidal carbon dioxide during CPR compared with the noncardiac group, which may represent features to be aware of in clinical practice.

noncardiac patients. In addition, the cardiac groups had lower blood pressures and lower $ETCO_2$ during CPR compared to the noncardiac group. Finally, surgical and medical cardiac patients had greater odds of being transitioned to ECPR than noncardiac patients.

Based on historical (2000–2010) studies (13–15), as well as more recent 2014–2016 United States Pediatric Cardiac Critical Care Consortium Registry study (19), our contemporary dataset (2016–2021) tests whether surgical cardiac patients have superior outcomes to noncardiac and medical cardiac patients after IHCA. The possible explanatory factors associated with greater odds of survival in cardiac surgical patients, all of which were present in this study, include increased presence of vascular access, use of mechanical ventilation, and increased use of ECPR. These explanatory factors plus younger age, improved recognition and presence of invasive monitoring have previously been described as being associated with better outcomes in CICU versus PICU populations (11). In the current study, we did not identify differences in survival to hospital discharge for any illness category. However, stratification to surgical cardiac and noncardiac groups was associated with greater survival to discharge with favorable neurologic outcomes compared to the medical cardiac group. The patients included in this analysis did have better survival compared to the prior published pediatric resuscitation literature dating back to cohorts from before 2014 (9, 13, 14). Survival and survival with good neurologic outcomes exceeded 50% in the 2016–2021 ICU-RESUS subjects. Although all illness categories included in our secondary analysis demonstrated higher than anticipated survival, the noncardiac subgroup exhibited the largest difference when compared with prior reports and we believe this may explain why we did not observe a difference in overall survival between illness categories.

Although we anticipated survival differences between groups and differences in other event characteristics like the presence of vascular access and the use of mechanical ventilation, we hypothesized that the quality of CPR would be the same between all illness categories. However, we did identify some key differences between the groups in terms of quality of CPR. Most notably, both surgical and medical cardiac patients had lower median $ETCO_2$ and, in those less than 1 year of age, lower diastolic blood pressure during CC compared with noncardiac patients. Although $ETCO_2$ is a well-validated marker of the quality of CPR, there is evidence to suggest a larger arterial to $ETCO_2$ tension difference in children with congenital heart disease (20–22). This finding may be secondary to pulmonary hypoperfusion, elevated pulmonary artery pressure, or pulmonary over-circulation. How these perturbations in pulmonary blood flow affect $ETCO_2$ assessments during CPR is unknown. The surgical cardiac group, compared with the noncardiac group, also had lower odds of maintenance of target CC depth. That is, the depth of CC may be lower in the surgical group due to a conscious decision by providers to minimize the risk of disrupting surgical repair, or there is a consideration of delayed sternal closure, but these details were not evaluated in the ICU-RESUS dataset. Yet, despite lower quality CPR by these measures, the surgical cardiac group had similar outcomes to the noncardiac group.

ECPR was used in approximately one-quarter of the patients in both the surgical and medical cardiac groups compared to only 1-in-14 of the noncardiac patients. In a historical dataset of children with cardiac disease, 2000–2008, ECPR was associated with improved odds of survival to hospital discharge (15). In another historical dataset, 2010–2018, there was no association between ECPR survival and ICU type using independent logistic regression; however, multivariable logistic regression did reveal cardiac surgical patients had greater odds for survival compared to cardiac medical patients (23). It is beyond the scope of our current study to understand and explain decision-making and access to ECPR, which limits to some degree conclusions about the potential survival advantage of ECPR.

There are some important limitations in our secondary analysis of the ICU-RESUS dataset. Information regarding the decision to use ECPR was not available, and we assume institutional differences exist regarding candidacy and accessibility. We elected to use the illness category rather than the patient location in a PICU or CICU for our comparisons. The majority of the cardiac patients were cared for in a CICU but, in this cohort, there were some medical and surgical cardiac patients who had IHCA in the PICU. Therefore, we cannot exclude the possibility that there are practice differences in the PICU versus the CICU that are not accounted for here. The primary outcome was survival with good neurologic outcomes, but we do not have detailed information about neurologic complications of IHCA, such as hypoxic-ischemic injury, acute hemorrhagic complications, or other brain injury as a result of the event. In addition, information regarding specific cardiac diagnoses within the medical and surgical cardiac groups was not collected. Therefore, we are unable to comment on the contribution of certain anatomic or physiologic derangements on resuscitation outcomes or measurements of quality, like $ETCO_2$.

CONCLUSIONS

In this secondary analysis of IHCA using the 2016–2021 ICU-RESUS dataset, we have identified differences in measures of quality of CPR and differences in event characteristics between the categories of cardiac and noncardiac pediatric cases. Most notably, there were differences with higher $ETCO_2$ and better target CC depth in noncardiac patients, and high use of invasive lines in surgical cardiac patients and ECPR in all cardiac groups. However, these differences are not associated with differences in survival with good neurologic outcomes. Further investigation of contemporary datasets is needed to elucidate why differences exist in CPR and outcomes based on the presence or absence of cardiac disease. Understanding these differences may lead to a more individualized approach to resuscitation of children ultimately providing the best chance for optimal outcome.

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