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Clinical paper

# Practice patterns for acquiring neuroimaging after pediatric in-hospital cardiac arrest

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**Abstract**

**Aims**: To determine which patient and cardiac arrest factors were associated with obtaining neuroimaging after in-hospital cardiac arrest, and among those patients who had neuroimaging, factors associated with which neuroimaging modality was obtained.

**Methods**: Retrospective cohort study of patients who survived in-hospital cardiac arrest (IHCA) and were enrolled in the ICU-RESUS trial (NCT02837497).

**Results**: We tabulated ultrasound (US), CT, and MRI frequency within 7 days following IHCA and identified patient and cardiac arrest factors associated with neuroimaging modalities utilized. Multivariable models determined which factors were associated with obtaining neuroimaging. Of 1000 patients, 44% had $\geq$ 1 neuroimaging study (US in 31%, CT in 18%, and MRI in 6% of patients). Initial USs were performed a median of 0.3 [0.1,0.5], CTs 1.4 [0.4,2.8], and MRIs 4.1 [2.2,5.1] days post-arrest. Neuroimaging timing and frequency varied by site. Factors associated with greater odds of neuroimaging were cardiac arrest in CICU (versus PICU), longer duration CPR, receiving ECMO post-arrest, and post-arrest care with targeted temperature management or EEG monitoring. US performance was associated with congenital heart disease. CT was associated with age $\geq$ 1-month, greater pre-arrest disability, and receiving CPR for $\geq$ 16 min. MRI utilization increased with pre-existing respiratory insufficiency and respiratory decompensation as arrest cause, and medical cardiac and surgical non-cardiac or trauma illness category. Overall, if neuroimaging was obtained, US was more common in CICU while CT/MRI were utilized more in PICU.

**Conclusions**: Practice patterns for acquiring neuroimaging after IHCA are variable and influenced by patient, cardiac arrest, and site factors.

**Keywords**: Cardiac arrest, Pediatric ICU, Neuroimaging, CT, Ultrasound, MRI

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## Introduction

More than 15,000 children experience an in-hospital cardiac arrest (IHCA) in the United States annually, most occurring in intensive care units (ICUs), operating rooms, or emergency departments.[1–3] Although most patients achieve return of circulation (ROC), resultant brain injury is a major contributor to patient morbidity and mortality.[4–6] Post-arrest neuroimaging (i.e., head or brain ultrasound [US], computerized tomography [CT], or magnetic resonance imaging [MRI]) is primarily utilized to determine if the cardiac arrest was due to brain pathology, if neurosurgical intervention is indicated, to guide post-cardiac arrest care, and to inform neuroprognostication.[7] American Heart Association guidelines recommend considering early brain imaging to diagnose treatable causes of cardiac arrest.[8]

Decisions to obtain neuroimaging may be influenced by patient demographics, preexisting conditions, and pre-, intra-, and post-cardiac arrest factors, as well as institutional pathways. In infants with open fontanelles, US can be performed at bedside post-cardiac arrest to screen for hemorrhage. CT scans are relatively quick to obtain and often performed early after return of circulation to diagnose neurologic causes of cardiac arrest, but typically require patient transport. MRIs are usually performed later in the hospital course and are largely used to inform prognostic discussions. Single center data indicate approximately 50% of patients have a CT scan performed within 24 h of out-of-hospital cardiac arrest (OHCA).[9,10] Pediatric IHCA is most commonly due to progressive respiratory failure or shock, and thus early neuroimaging may be less common.[11–13] Practice patterns related to post-cardiac arrest neuroimaging have not been described following IHCA.

Using the ICU-Resuscitation Project (ICU-RESUS) study of IHCA, we aimed to 1) determine which patient and cardiac arrest factors were associated with the decision to obtain a neuroimaging study (US, CT, or MRI) within seven days after IHCA; and 2) determine which patient and cardiac arrest factors were associated with specific neuroimaging modalities (US, CT, or MRI). We secondarily sought to characterize neuroimaging practice variability between pediatric and cardiac ICUs.

## Materials and methods

***ICU-RESUS Trial.*** We performed a secondary analysis of ICU-RESUS, a parallel-stepped-wedge hybrid cluster-randomized interventional trial of a training bundle targeting improvement in delivery of cardiopulmonary resuscitation (CPR) for IHCA (ClinicalTrials.gov Identifier: NCT02837497). The trial was conducted in 18 ICUs at 10 U.S. sites; 9 pediatric (PICU) and 9 pediatric cardiac ICUs (CICUs) between October 1, 2016, and March 31, 2021. The methods and primary results were previously published.[14] Inclusion criteria were age 37 weeks corrected gestation to $\leq$ 18 years and CPR of any duration. The intervention included a quality improvement bundle of point-of-care manikin-based CPR training and structured debriefs. The primary outcome was survival to hospital discharge with favorable neurologic outcome, defined as Pediatric Cerebral Performance Category (PCPC) score of 1–3 or no change from pre-arrest.[15–17] The size and ICU diversity of the ICU-RESUS study provide a broad-based opportunity to examine the epidemiology of neuroimaging after IHCA.

Data elements collected in the ICU-RESUS trial included subject demographics, arrest characteristics and post-cardiac arrest care data. Performance of US, CT, or MRI scan within seven days post-arrest was recorded, as was the day the imaging study was obtained. The study protocol did not provide recommendations on neuroimaging. Each site performed neuroimaging per their routine standard of care. Pediatric RISk of Mortality (PRISM) was determined 2–6 h prior to cardiac arrest. Vasoactive inotropic score was assigned 2 h prior to cardiac arrest.

***Patients.*** Patients enrolled in the ICU-RESUS trial were eligible for this study. We included only the index cardiac arrest. We excluded patients who did not achieve return of circulation (ROC). The institutional review board (IRB) at the University of Utah served as the single IRB and approved the ICU-RESUS study (ID: 00093320) with waiver of parental permission.

***Analyses.*** Patient and cardiac arrest event characteristics were summarized using frequencies and percentages or median and quartiles. We tabulated percent of patients who had an US, CT, and MRI within the first seven days following cardiac arrest such that patients who underwent imaging with multiple modalities could be counted within each category. We examined patient and cardiac arrest characteristics between patients who did and did not undergo neuroimaging using Fisher's exact test for categorical variables and Wilcoxon rank-sum test for continuous variables. P-values were reported based on a 2-sided alternative and considered statistically significant when less than 0.05. Univariable and multivariable models of US, CT, and MRI utilization within seven days post-arrest were conducted using a bi-direction stepwise selection model with a threshold p-value < 0.1. To examine the proportion of patients from each site with a given imaging modality, we collapsed sites with similar proportions. We forced collapsed site variables as a predictor in multivariable models. We performed analyses using SAS software v9.4 (Cary, NC).

## Results

***Patients***. Of 1000 patients with ROC, 443 (44%) had at least one neuroimaging study performed within seven days post-arrest. Thirty-one percent (309/1,000) had at least one US, 18% (180/1,000) had at least one CT, and 6% (60/1,000) had at least one MRI scan. Of those with neuroimaging, the median age was 0.34 [IQR 0.08, 1.13] years old and 53% (233/443) were male (Table 1). Sixty-seven percent (296/443) were neurologically normal (PCPC = 1) prior to their cardiac arrest. The majority of patients with neuroimaging had pre-cardiac arrest central venous catheters (73% [324/443]), were receiving vasoactive infusions (58% [255/443]), and were invasively mechanically ventilated (73% [324/443]) (Table 2).

A total of 549 neuroimaging studies were performed; some patients had multiple scans with the same or different imaging modalities. Initial USs were performed 0.3 [0.1,0.5] days, CTs 1.4 [0.4,2.8] days, and MRIs 4.1 [2.2,5.1] days post-arrest. Repeat imaging was common (Fig. 1).

***Factors associated with decision to obtain neuroimaging.*** Patients who received neuroimaging were younger (highest proportion among patients < 1 year old), had lower baseline PCPC scores, had preexisting congenital heart disease or hypotension, surgical cardiac illness category, and higher pre-arrest PRISM score

**Table 1 – Patient characteristics by neuroimaging modality.**

| | Any Neuroimaging | | | Ultrasound | | | CT | | | MRI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes (N = 443) | No (N = 557) | P-value | Yes (N = 309) | No (N = 134) | P-value | Yes (N = 180) | No (N = 263) | P-value | Yes (N = 60) | No (N = 383) | P-value |
| **Age** | | | <.001[1] | | | <.001[1] | | | <.001[1] | | | 0.014[1] |
| < 1 month | 112 (25.3%) | 58 (10.4%) | | 103 (33.3%) | 9 (6.7%) | | 20 (11.1%) | 92 (35.0%) | | 11 (18.3%) | 101 (26.4%) | |
| 1 month – < 1 year | 217 (49.0%) | 217 (39.0%) | | 197 (63.8%) | 20 (14.9%) | | 66 (36.7%) | 151 (57.4%) | | 24 (40.0%) | 193 (50.4%) | |
| 1 year – < 12 years | 91 (20.5%) | 211 (37.9%) | | 8 (2.6%) | 83 (61.9%) | | 74 (41.1%) | 17 (6.5%) | | 18 (30.0%) | 73 (19.1%) | |
| > 12 years | 23 (5.2%) | 71 (12.7%) | | 1 (0.3%) | 22 (16.4%) | | 20 (11.1%) | 3 (1.1%) | | 7 (11.7%) | 16 (4.2%) | |
| **Male** | 233 (52.6%) | 305 (54.8%) | 0.523[1] | 162 (52.4%) | 71 (53.0%) | 0.918[1] | 93 (51.7%) | 140 (53.2%) | 0.772[1] | 33 (55.0%) | 200 (52.2%) | 0.781[1] |
| **Race** | | | 0.257[1] | | | 0.065[1] | | | 0.068[1] | | | 0.262[1] |
| White | 217 (49.0%) | 257 (46.1%) | | 160 (51.8%) | 57 (42.5%) | | 79 (43.9%) | 138 (52.5%) | | 28 (46.7%) | 189 (49.3%) | |
| Black or African American | 109 (24.6%) | 142 (25.5%) | | 67 (21.7%) | 42 (31.3%) | | 54 (30.0%) | 55 (20.9%) | | 14 (23.3%) | 95 (24.8%) | |
| Other | 20 (4.5%) | 38 (6.8%) | | 13 (4.2%) | 7 (5.2%) | | 9 (5.0%) | 11 (4.2%) | | 0 (0.0%) | 20 (5.2%) | |
| Unknown or Not Reported | 97 (21.9%) | 120 (21.5%) | | 69 (22.3%) | 28 (20.9%) | | 38 (21.1%) | 59 (22.4%) | | 18 (30.0%) | 79 (20.6%) | |
| **Preexisting conditions** | | | | | | | | | | | | |
| Respiratory insufficiency | 375 (84.7%) | 486 (87.3%) | 0.270[1] | 260 (84.1%) | 115 (85.8%) | 0.774[1] | 154 (85.6%) | 221 (84.0%) | 0.689[1] | 58 (96.7%) | 317 (82.8%) | 0.003[1] |
| Hypotension | 310 (70.0%) | 306 (54.9%) | <.001[1] | 215 (69.6%) | 95 (70.9%) | 0.822[1] | 131 (72.8%) | 179 (68.1%) | 0.294[1] | 37 (61.7%) | 273 (71.3%) | 0.133[1] |
| Congestive heart failure | 66 (14.9%) | 56 (10.1%) | 0.025[1] | 48 (15.5%) | 18 (13.4%) | 0.664[1] | 28 (15.6%) | 38 (14.4%) | 0.787[1] | 4 (6.7%) | 62 (16.2%) | 0.053[1] |
| Pneumonia | 37 (8.4%) | 88 (15.8%) | <.001[1] | 19 (6.1%) | 18 (13.4%) | 0.015[1] | 19 (10.6%) | 18 (6.8%) | 0.220[1] | 6 (10.0%) | 31 (8.1%) | 0.616[1] |
| Sepsis | 57 (12.9%) | 80 (14.4%) | 0.518[1] | 26 (8.4%) | 31 (23.1%) | <.001[1] | 32 (17.8%) | 25 (9.5%) | 0.014[1] | 5 (8.3%) | 52 (13.6%) | 0.306[1] |
| Trauma | 9 (2.0%) | 20 (3.6%) | 0.184[1] | 1 (0.3%) | 8 (6.0%) | <.001[1] | 7 (3.9%) | 2 (0.8%) | 0.035[1] | 3 (5.0%) | 6 (1.6%) | 0.109[1] |
| Renal insufficiency | 42 (9.5%) | 77 (13.8%) | 0.039[1] | 20 (6.5%) | 22 (16.4%) | 0.002[1] | 22 (12.2%) | 20 (7.6%) | 0.136[1] | 5 (8.3%) | 37 (9.7%) | 1.000[1] |
| Malignancy | 18 (4.1%) | 20 (3.6%) | 0.741[1] | 3 (1.0%) | 15 (11.2%) | <.001[1] | 15 (8.3%) | 3 (1.1%) | <.001[1] | 4 (6.7%) | 14 (3.7%) | 0.285[1] |
| Congenital heart disease | 312 (70.4%) | 282 (50.6%) | <.001[1] | 263 (85.1%) | 49 (36.6%) | <.001[1] | 105 (58.3%) | 207 (78.7%) | <.001[1] | 25 (41.7%) | 287 (74.9%) | <.001[1] |
| Pulmonary hypertension | 66 (14.9%) | 94 (16.9%) | 0.435[1] | 52 (16.8%) | 14 (10.4%) | 0.109[1] | 29 (16.1%) | 37 (14.1%) | 0.588[1] | 4 (6.7%) | 62 (16.2%) | 0.053[1] |
| **Illness category** | | | <.001[1] | | | <.001[1] | | | <.001[1] | | | <.001[1] |
| Medical cardiac | 119 (26.9%) | 127 (22.8%) | | 87 (28.2%) | 32 (23.9%) | | 56 (31.1%) | 63 (24.0%) | | 10 (16.7%) | 109 (28.5%) | |
| Medical non-cardiac | 105 (23.7%) | 229 (41.1%) | | 41 (13.3%) | 64 (47.8%) | | 52 (28.9%) | 53 (20.2%) | | 31 (51.7%) | 74 (19.3%) | |
| Surgical cardiac | 206 (46.5%) | 150 (26.9%) | | 177 (57.3%) | 29 (21.6%) | | 63 (35.0%) | 143 (54.4%) | | 14 (23.3%) | 192 (50.1%) | |
| Surgical non-cardiac or trauma | 13 (2.9%) | 51 (9.2%) | | 4 (1.3%) | 9 (6.7%) | | 9 (5.0%) | 4 (1.5%) | | 5 (8.3%) | 8 (2.1%) | |
| **Baseline PCPC score** | | | 0.001[2] | | | 0.071[2] | | | 0.007[2] | | | 0.436[2] |
| 1 – Normal | 296 (66.8%) | 328 (58.9%) | | 212 (68.6%) | 84 (62.7%) | | 110 (61.1%) | 186 (70.7%) | | 43 (71.7%) | 253 (66.1%) | |
| 2 – Mild disability | 83 (18.7%) | 92 (16.5%) | | 64 (20.7%) | 19 (14.2%) | | 31 (17.2%) | 52 (19.8%) | | 9 (15.0%) | 74 (19.3%) | |
| 3 – Moderate disability | 34 (7.7%) | 68 (12.2%) | | 16 (5.2%) | 18 (13.4%) | | 19 (10.6%) | 15 (5.7%) | | 4 (6.7%) | 30 (7.8%) | |
| 4 – Severe disability | 27 (6.1%) | 63 (11.3%) | | 16 (5.2%) | 11 (8.2%) | | 18 (10.0%) | 9 (3.4%) | | 4 (6.7%) | 23 (6.0%) | |
| 5 – Coma/vegetative state | 3 (0.7%) | 6 (1.1%) | | 1 (0.3%) | 2 (1.5%) | | 2 (1.1%) | 1 (0.4%) | | 0 (0.0%) | 3 (0.8%) | |
| **PRISM**[4] | 5.0 [0.0,11.0] | 3.0 [0.0,8.0] | 0.004[2] | 5.0 [0.0,10.0] | 5.0 [0.0,12.0] | 0.676[2] | 5.0 [0.0,11.0] | 5.0 [0.0,10.0] | 0.785[2] | 3.0 [0.0,8.0] | 5.0 [0.0,11.0] | 0.072[2] |
| **Vasoactive inotropic score**[5] | | | <.001[2] | | | 0.026[2] | | | 0.915[2] | | | <.001[2] |
| None | 229 (51.7%) | 360 (64.6%) | | 145 (46.9%) | 84 (62.7%) | | 94 (52.2%) | 135 (51.3%) | | 47 (78.3%) | 182 (47.5%) | |
| > 0–20 | 187 (42.2%) | 161 (28.9%) | | 151 (48.9%) | 36 (26.9%) | | 72 (40.0%) | 115 (43.7%) | | 11 (18.3%) | 176 (46.0%) | |
| > 20 | 27 (6.1%) | 36 (6.5%) | | 13 (4.2%) | 14 (10.4%) | | 14 (7.8%) | 13 (4.9%) | | 2 (3.3%) | 25 (6.5%) | |

PRISM = Pediatric RISk of Mortality; PCPC = Pediatric Cerebral Performance Category; CT= Computed Tomography; MRI = Magnetic Resonance Imaging.

[3] Baseline PCPC represents subject status prior to the event leading to hospitalization.

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.

[4] PRISM was evaluated 2–6 h prior to the event.

[5] Vasoactive inotropic score was evaluated 2 h prior to the event.

**Table 2 – Cardiac arrest event characteristics by neuroimaging modality.**

| | Any Neuroimaging | | | Ultrasound | | | CT | | | MRI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes (N = 443) | No (N = 557) | P-value | Yes (N = 309) | No (N = 134) | P-value | Yes (N = 180) | No (N = 263) | P-value | Yes (N = 60) | No (N = 383) | P-value |
| **Interventions in place prior to event** | | | | | | | | | | | | |
| Central venous catheter | 324 (73.1%) | 354 (63.6%) | 0.001[3] | 239 (77.3%) | 85 (63.4%) | 0.003[3] | 129 (71.7%) | 195 (74.1%) | 0.586[3] | 33 (55.0%) | 291 (76.0%) | 0.001[3] |
| Vasoactive infusion | 255 (57.6%) | 248 (44.5%) | <.001[3] | 184 (59.5%) | 71 (53.0%) | 0.210[3] | 112 (62.2%) | 143 (54.4%) | 0.117[3] | 14 (23.3%) | 241 (62.9%) | <.001[3] |
| Invasive mechanical ventilation | 324 (73.1%) | 381 (68.4%) | 0.109[3] | 229 (74.1%) | 95 (70.9%) | 0.486[3] | 133 (73.9%) | 191 (72.6%) | 0.827[3] | 34 (56.7%) | 290 (75.7%) | 0.003[3] |
| Non-invasive ventilation | 69 (15.6%) | 111 (19.9%) | 0.082[3] | 49 (15.9%) | 20 (14.9%) | 0.887[3] | 24 (13.3%) | 45 (17.1%) | 0.350[3] | 16 (26.7%) | 53 (13.8%) | 0.020[3] |
| **Immediate cause(s) of event** | | | | | | | | | | | | |
| Arrhythmia | 75 (16.9%) | 92 (16.5%) | 0.865[3] | 45 (14.6%) | 30 (22.4%) | 0.053[3] | 34 (18.9%) | 41 (15.6%) | 0.370[3] | 8 (13.3%) | 67 (17.5%) | 0.578[3] |
| Cyanosis without respiratory decompensation | 28 (6.3%) | 19 (3.4%) | 0.035[3] | 24 (7.8%) | 4 (3.0%) | 0.059[3] | 11 (6.1%) | 17 (6.5%) | 1.000[3] | 4 (6.7%) | 24 (6.3%) | 0.782[3] |
| Hypotension | 277 (62.5%) | 245 (44.0%) | <.001[3] | 192 (62.1%) | 85 (63.4%) | 0.831[3] | 123 (68.3%) | 154 (58.6%) | 0.045[3] | 31 (51.7%) | 246 (64.2%) | 0.064[3] |
| Respiratory decompensation | 203 (45.8%) | 351 (63.0%) | <.001[3] | 137 (44.3%) | 66 (49.3%) | 0.352[3] | 77 (42.8%) | 126 (47.9%) | 0.332[3] | 37 (61.7%) | 166 (43.3%) | 0.012[3] |
| **CPR time**[1] | | | 0.492[3] | | | 0.263[3] | | | 0.408[3] | | | 0.251[3] |
| Weekday | 234 (52.8%) | 299 (53.7%) | | 171 (55.3%) | 63 (47.0%) | | 91 (50.6%) | 143 (54.4%) | | 27 (45.0%) | 207 (54.0%) | |
| Weeknight | 92 (20.8%) | 100 (18.0%) | | 61 (19.7%) | 31 (23.1%) | | 43 (23.9%) | 49 (18.6%) | | 12 (20.0%) | 80 (20.9%) | |
| Weekend | 117 (26.4%) | 158 (28.4%) | | 77 (24.9%) | 40 (29.9%) | | 46 (25.6%) | 71 (27.0%) | | 21 (35.0%) | 96 (25.1%) | |
| **First documented rhythm** | | | 0.580[3] | | | <.001[3] | | | 0.180[3] | | | 0.440[3] |
| Pulseless electrical activity / asystole | 174 (39.3%) | 222 (39.9%) | | 105 (34.0%) | 69 (51.5%) | | 79 (43.9%) | 95 (36.1%) | | 28 (46.7%) | 146 (38.1%) | |
| Ventricular fibrillation / tachycardia | 39 (8.8%) | 39 (7.0%) | | 26 (8.4%) | 13 (9.7%) | | 17 (9.4%) | 22 (8.4%) | | 5 (8.3%) | 34 (8.9%) | |
| Bradycardia with poor perfusion | 230 (51.9%) | 296 (53.1%) | | 178 (57.6%) | 52 (38.8%) | | 84 (46.7%) | 146 (55.5%) | | 27 (45.0%) | 203 (53.0%) | |
| **Duration of CPR (minutes)** | | | <.001[3] | | | 0.791[3] | | | <.001[3] | | | <.001[3] |
| <6 | 154 (34.8%) | 357 (64.1%) | | 106 (34.3%) | 48 (35.8%) | | 44 (24.4%) | 110 (41.8%) | | 20 (33.3%) | 134 (35.0%) | |
| 6–15 | 102 (23.0%) | 106 (19.0%) | | 68 (22.0%) | 34 (25.4%) | | 38 (21.1%) | 64 (24.3%) | | 23 (38.3%) | 79 (20.6%) | |
| 16–35 | 85 (19.2%) | 52 (9.3%) | | 61 (19.7%) | 24 (17.9%) | | 44 (24.4%) | 41 (15.6%) | | 13 (21.7%) | 72 (18.8%) | |
| >35 | 102 (23.0%) | 42 (7.5%) | | 74 (23.9%) | 28 (20.9%) | | 54 (30.0%) | 48 (18.3%) | | 4 (6.7%) | 98 (25.6%) | |
| **Number of epinephrine boluses** | 3.0 [1.0,7.0] | 2.0 [1.0,3.5] | <.001[4] | 3.0 [1.0,7.0] | 3.0 [1.5,7.0] | 0.857[4] | 4.0 [2.0,10.0] | 2.0 [1.0,5.0] | <.001[4] | 3.0 [1.0,5.0] | 3.0 [1.0,8.0] | 0.149[4] |
| **Mortality** | | | | | | | | | | | | |
| Death within 7 days | 71 (16.0%) | 105 (18.9%) | 0.004[3] | 41 (13.3%) | 30 (22.4%) | 0.020[3] | 44 (24.4%) | 27 (10.3%) | 0.060[3] | 5 (8.3%) | 66 (17.2%) | 0.496[3] |
| **Post-resuscitation** | | | | | | | | | | | | |
| Targeted temperature management within 6 hrs | 182 (41.1%) | 82 (14.7%) | <.001[3] | 137 (44.3%) | 45 (33.6%) | 0.036[3] | 81 (45.0%) | 101 (38.4%) | 0.170[3] | 21 (35.0%) | 161 (42.0%) | 0.326[3] |
| Vasoactive inotropic score at 6 hrs | 5.0 [0.0,10.0] | 0.0 [0.0,7.5] | <.001[4] | 5.0 [0.0,9.5] | 2.8 [0.0,10.0] | 0.893[4] | 4.0 [0.0,10.0] | 5.0 [0.0,10.0] | 0.770[4] | 0.0 [0.0,6.7] | 5.0 [0.0,10.0] | 0.012[4] |
| ECMO within 6 hrs | 45 (10.2%) | 27 (4.8%) | 0.002[3] | 28 (9.1%) | 17 (12.7%) | 0.304[3] | 24 (13.3%) | 21 (8.0%) | 0.078[3] | 3 (5.0%) | 42 (11.0%) | 0.247[3] |
| Highest lactate within 6 hrs | 9.2 [4.3,14.7] | 5.0 [2.2,9.1] | <.001[4] | 8.8 [4.2,14.7] | 9.9 [5.4,14.6] | 0.604[4] | 11.3 [6.8,16.0] | 7.5 [3.2,13.1] | <.001[4] | 6.7 [2.1,9.7] | 9.7 [4.7,15.0] | <.001[4] |
| EEG within 24 hrs | 158 (35.7%) | 103 (18.5%) | <.001[3] | 125 (40.5%) | 33 (24.6%) | 0.002[3] | 60 (33.3%) | 98 (37.3%) | 0.420[3] | 22 (36.7%) | 136 (35.5%) | 0.885[3] |

CPR = cardiopulmonary resuscitation; PICU = pediatric intensive care unit; CICU = cardiac intensive care unit; CT= Computed Tomography; MRI = Magnetic Resonance Imaging.

[2]Average interval between epinephrine doses is only calculated on subjects with at least 2 doses of epinephrine.

[1] Weekday is between 7 AM and 11 PM Monday – Friday; weeknight is after 11 PM Monday – Thursday; Weekend is from 11 PM on Friday through 7 AM on the following Monday.

[3] Fisher's exact test.

[4] Wilcoxon rank-sum test.

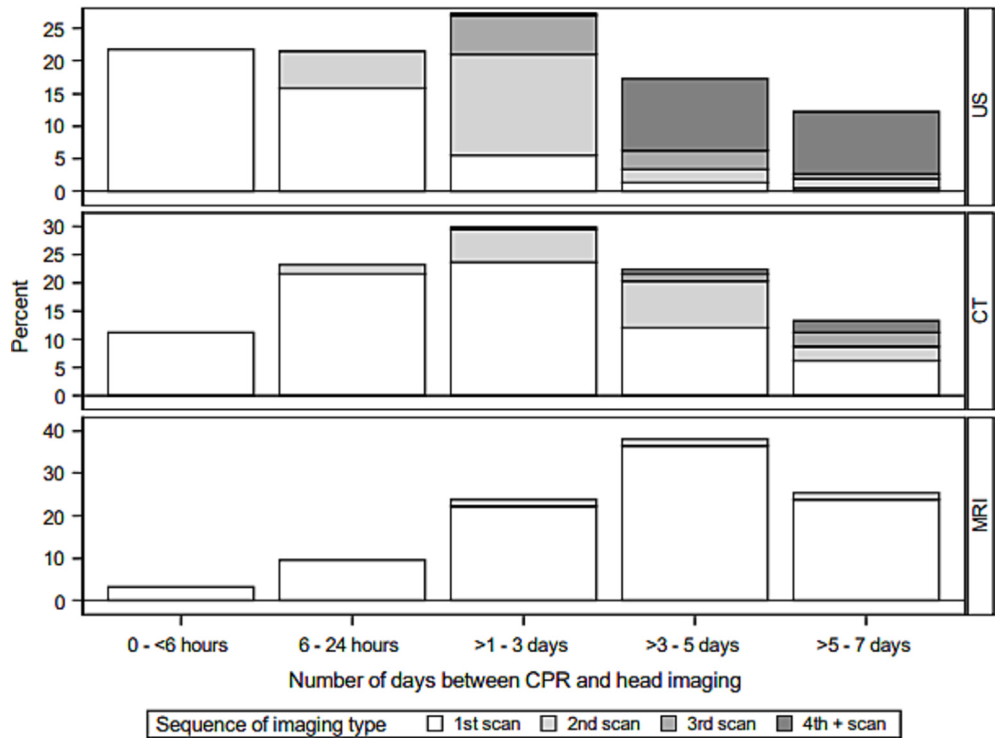


**Fig. 1 – Percentage of patients with post-arrest neuroimaging stratified by time period. Stacked Bar charts illustrate the percent of patients with ultrasound (US, top panel), computed tomography (CT, middle panel), and magnetic resonance imaging (MRI, bottom panel) performed at different time points following cardiac arrest. Patients scanned multiple times with a given modality were counted for multiple time points. Only the first incidence of a given imaging modality was used within each time point. For example, if a patient had their 2nd, 3rd and 4th US within the 5–7 day time period, only the 2nd scan was represented in the figure. The grayscale represents the sequence of imaging performed within each modality.**

(Table 1). Pre-arrest VIS score was associated with neuroimaging acquisition with fewer patients having neuroimaging if they did not require vasopressors (52% vs 65%) and more patients having neuroimaging in the VIS 0–20 group (42% versus 29%). There was no difference in imaging acquisition practices in those with VIS > 20, though there were fewer patients in this category (Table 1).

Patients with neuroimaging more commonly received CPR $\geq$ 6 min, received more doses of epinephrine, had higher post-arrest lactate and VIS, and were more likely to receive targeted temperature management (TTM), EEG monitoring, and extracorporeal membrane oxygenation (ECMO) support within 6 h of arrest (Table 2). Neuroimaging was more commonly obtained in patients who had hypotension as the cause of cardiac arrest. Neuroimaging was not more frequent based on race, sex, first documented rhythm, or time of day the arrest occurred. Patients with neuroimaging were less likely to survive 7 days.

In multivariable regression analysis, factors associated with higher odds of having neuroimaging were cardiac arrest in the CICU (vs. PICU), longer duration CPR, post-arrest TTM, post-arrest EEG monitoring, and ECMO support within 6 h of arrest. Age > 1 year and respiratory decompensation as immediate cause of arrest were associated with lower odds of post-arrest neuroimaging. The odds of receiving neuroimaging were dependent on study site (Table 3).

***Factors associated with US.*** Post-arrest US was more common for: <1 year old, pre-existing congenital heart disease, medical or surgical cardiac illness category, first documented rhythm of bradycardia with poor perfusion, and pre-arrest VIS of > 0–20 (Tables 1 and 2). Frequency of US performance did not differ by CPR duration, number of epinephrine doses, or post-arrest lactate. Post-arrest US was more common in patients receiving TTM and EEG monitoring. Patients with post-arrest US were less likely to survive to 7 days. In multivariable regression analysis, higher odds of post-arrest US was associated with congenital heart disease (Table 3), whereas lower odds was associated with trauma and age > 1 year.

***Factors associated with post-arrest CT.*** Post-arrest CT scans were more common for: >1 year old, pre-existing sepsis, trauma, or malignancy, baseline PCPC scores $\geq$ 3, hypotension as cause of arrest, and all illness categories except surgical cardiac (Tables 1 and 2). Post-arrest CT scans were less common among children with congenital heart disease, but were more common in children with CPR > 15 mins, more doses of epinephrine, and high post-arrest lactate levels (Table 2). After a multivariable regression analysis, higher odds of post-arrest CT was associated with age $\geq$ 1 month, baseline PCPC of 4 or 5, and CPR for $\geq$ 16 min, whereas lower odds of post-arrest CT was associated with medical non-cardiac compared to medical cardiac illness category (Table 3).

***Factors associated with having post-arrest MRI.*** Post-arrest MRIs were more common for: 1 month to 12 years old, pre-existing respiratory insufficiency, no pre-arrest vasopressor requirement, and illness categories of medical or surgical non-cardiac or trauma. Baseline functional status, race and sex were not associated with MRI utilization patterns (Table 1). MRIs were obtained less fre-

**Table 3 – Multivariable models of whether a neuroimaging study was performed and what modality was utilized.**

| | Any Neuroimaging | | Ultrasound | | CT | | MRI | |
|---|---|---|---|---|---|---|---|---|
| | Odds ratio (95% CI) | P-value | Odds ratio (95% CI) | P-value | Odds ratio (95% CI) | P-value | Odds ratio (95% CI) | P-value |
| **Age** | | <.001 | | <.001 | | <.001 | | |
| < 1 months | Reference | | Reference | | Reference | | | |
| 1 months – < 1 year | 0.70 (0.45, 1.08) | | 1.11 (0.44, 2.65) | | 2.80 (1.47, 5.48) | | | |
| 1 year – < 12 years | 0.27 (0.17, 0.45) | | 0.01 (0.00, 0.03) | | 42.52 (16.81, 116.60) | | | |
| > 12 years | 0.20 (0.10, 0.39) | | 0.01 (0.00, 0.05) | | 133.08 (29.94, 788.59) | | | |
| **Study site** | | <.001 | | 0.260 | | 0.003 | | 0.054* |
| A | Reference | | Reference | | Reference | | Reference | |
| B | 0.50 (0.29, 0.88) | | 0.70 (0.21, 2.45) | | 0.55 (0.22, 1.32) | | 1.87 (0.65, 5.24) | |
| C | 0.86 (0.47, 1.57) | | 2.89 (0.71, 12.76) | | 0.36 (0.13, 0.92) | | 0.33 (0.05, 1.39) | |
| D | 0.43 (0.24, 0.76) | | 1.09 (0.29, 4.42) | | 1.28 (0.52, 3.18) | | 0.58 (0.19, 1.69) | |
| E | 0.24 (0.13, 0.43) | | 0.97 (0.27, 3.83) | | 0.34 (0.13, 0.84) | | 3.51 (1.12, 10.92) | |
| F | 0.26 (0.14, 0.47) | | 0.64 (0.17, 2.73) | | 0.45 (0.15, 1.26) | | 3.09 (0.93, 9.96) | |
| G | 0.21 (0.10, 0.39) | | 0.22 (0.05, 1.06) | | 0.44 (0.12, 1.64) | | 1.93 (0.42, 7.77) | |
| H | 1.02 (0.53, 1.95) | | 1.41 (0.36, 6.00) | | 1.89 (0.81, 4.49) | | 1.23 (0.37, 3.73) | |
| I | 0.34 (0.15, 0.74) | | 0.37 (0.06, 2.86) | | 0.86 (0.16, 4.20) | | – | |
| J | 0.51 (0.25, 1.03) | | 2.59 (0.40, 21.09) | | 0.17 (0.03, 0.73) | | 0.85 (0.16, 3.45) | |
| **Preexisting conditions** | | | | | | | | |
| Respiratory insufficiency | | | | | | | 7.42 (1.96, 49.70) | 0.002 |
| Trauma | | | 0.05 (0.00, 0.67) | 0.024 | | | | |
| Congenital heart disease | | | 3.93 (1.79, 8.60) | <.001 | | | | |
| **Illness category** | | | | | | 0.021 | | <.001 |
| Medical cardiac | | | | | Reference | | Reference | |
| Medical non-cardiac | | | | | 0.30 (0.13, 0.69) | | 7.26 (2.87, 20.20) | |
| Surgical cardiac | | | | | 0.61 (0.32, 1.16) | | 1.19 (0.47, 3.14) | |
| Surgical non-cardiac or trauma | | | | | 1.24 (0.24, 7.48) | | 17.20 (3.54, 87.42) | |
| **Baseline PCPC score** | | | | | | 0.032 | | |
| 1 – Normal | | | | | Reference | | | |
| 2 – Mild disability | | | | | 0.65 (0.33, 1.28) | | | |
| 3 – Moderate disability | | | | | 1.42 (0.52, 3.84) | | | |
| 4/5 – Severe disability, coma | | | | | 3.13 (1.18, 8.64) | | | |
| **Arrest location** | | <.001 | | | | | | |
| PICU | Reference | | | | | | | |
| CICU | 1.91 (1.31, 2.78) | | | | | | | |
| **Immediate cause(s) of event** | | | | | | | | |
| Respiratory decompensation | 0.61 (0.45, 0.83) | 0.002 | | | | | | |
| **Duration of CPR (minutes)** | | <.001 | | | | <.001 | | 0.021 |
| <6 | Reference | | | | Reference | | Reference | |
| 6–15 | 2.05 (1.40, 3.01) | | | | 1.98 (0.97, 4.07) | | 1.96 (0.94, 4.14) | |
| 16–35 | 2.90 (1.82, 4.63) | | | | 4.67 (2.26, 9.90) | | 1.42 (0.60, 3.33) | |
| >35 | 4.44 (2.78, 7.20) | | | | 6.57 (3.25, 13.76) | | 0.39 (0.11, 1.16) | |
| **ECMO within 6 h** | 2.16 (1.21, 3.91) | 0.009 | | | | | | |
| **TTM within 6 h** | 2.44 (1.69, 3.54) | <.001 | | | | | | |
| **EEG within 24 h** | 1.54 (1.06, 2.24) | 0.024 | | | | | | |

CPR = cardiopulmonary resuscitation; PICU = pediatric intensive care unit; CICU = cardiac intensive care unit; TTM – targeted temperature management.

* A site did not have MRIs performed so was excluded from this analysis.

**Table 4 – Patient and cardiac arrest characteristics for patients who received neuroimaging in the CICU compared to the PICU.**

| | Any Neuroimaging | | | Ultrasound | | | CT | | | MRI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CICU (N = 294) | PICU (N = 149) | P-value | CICU (N = 240) | PICU (N = 69) | P-value | CICU (N = 105) | PICU (N = 75) | P-value | CICU (N = 28) | PICU (N = 32) | P-value |
| Age | | | <.001[1] | | | <.001[1] | | | <.001[1] | | | 0.002[1] |
| < 1 month | 101 (34.4%) | 11 (7.4%) | | 94 (39.2%) | 9 (13.0%) | | 19 (18.1%) | 1 (1.3%) | | 9 (32.1%) | 2 (6.3%) | |
| 1 month – < 1 year | 152 (51.7%) | 65 (43.6%) | | 141 (58.8%) | 56 (81.2%) | | 49 (46.7%) | 17 (22.7%) | | 14 (50.0%) | 10 (31.3%) | |
| 1 year – < 12 years | 34 (11.6%) | 57 (38.3%) | | 4 (1.7%) | 4 (5.8%) | | 30 (28.6%) | 44 (58.7%) | | 4 (14.3%) | 14 (43.8%) | |
| > 12 years | 7 (2.4%) | 16 (10.7%) | | 1 (0.4%) | 0 (0.0%) | | 7 (6.7%) | 13 (17.3%) | | 1 (3.6%) | 6 (18.8%) | |
| Preexisting conditions | | | | | | | | | | | | |
| Respiratory insufficiency | 241 (82.0%) | 134 (89.9%) | 0.036[1] | 197 (82.1%) | 63 (91.3%) | 0.091[1] | 88 (83.8%) | 66 (88.0%) | 0.521[1] | 28 (100.0%) | 30 (93.8%) | 0.494[1] |
| Hypotension | 224 (76.2%) | 86 (57.7%) | <.001[1] | 181 (75.4%) | 34 (49.3%) | <.001[1] | 81 (77.1%) | 50 (66.7%) | 0.130[1] | 21 (75.0%) | 16 (50.0%) | 0.064[1] |
| Congestive heart failure | 41 (13.9%) | 25 (16.8%) | 0.480[1] | 30 (12.5%) | 18 (26.1%) | 0.008[1] | 19 (18.1%) | 9 (12.0%) | 0.303[1] | 3 (10.7%) | 1 (3.1%) | 0.331[1] |
| Pneumonia | 8 (2.7%) | 29 (19.5%) | <.001[1] | 4 (1.7%) | 15 (21.7%) | <.001[1] | 5 (4.8%) | 14 (18.7%) | 0.005[1] | 1 (3.6%) | 5 (15.6%) | 0.201[1] |
| Sepsis | 20 (6.8%) | 37 (24.8%) | <.001[1] | 13 (5.4%) | 13 (18.8%) | 0.001[1] | 9 (8.6%) | 23 (30.7%) | <.001[1] | 1 (3.6%) | 4 (12.5%) | 0.359[1] |
| Trauma | 0 (0.0%) | 9 (6.0%) | <.001[1] | 0 (0.0%) | 1 (1.4%) | 0.223[1] | 0 (0.0%) | 7 (9.3%) | 0.002[1] | 0 (0.0%) | 3 (9.4%) | 0.241[1] |
| Renal insufficiency | 21 (7.1%) | 21 (14.1%) | 0.025[1] | 14 (5.8%) | 6 (8.7%) | 0.408[1] | 8 (7.6%) | 14 (18.7%) | 0.037[1] | 2 (7.1%) | 3 (9.4%) | 1.000[1] |
| Malignancy | 5 (1.7%) | 13 (8.7%) | 0.001[1] | 2 (0.8%) | 1 (1.4%) | 0.533[1] | 4 (3.8%) | 11 (14.7%) | 0.013[1] | 0 (0.0%) | 4 (12.5%) | 0.116[1] |
| Congenital heart disease | 266 (90.5%) | 46 (30.9%) | <.001[1] | 228 (95.0%) | 35 (50.7%) | <.001[1] | 88 (83.8%) | 17 (22.7%) | <.001[1] | 24 (85.7%) | 1 (3.1%) | <.001[1] |
| Pulmonary hypertension | 47 (16.0%) | 19 (12.8%) | 0.400[1] | 39 (16.3%) | 13 (18.8%) | 0.589[1] | 21 (20.0%) | 8 (10.7%) | 0.104[1] | 3 (10.7%) | 1 (3.1%) | 0.331[1] |
| Baseline PCPC score | | | 0.219[1] | | | 0.683[1] | | | 0.243[1] | | | 0.375[1] |
| 1 – Normal | 200 (68.0%) | 96 (64.4%) | | 163 (67.9%) | 49 (71.0%) | | 66 (62.9%) | 44 (58.7%) | | 22 (78.6%) | 21 (65.6%) | |
| 2 – Mild disability | 60 (20.4%) | 23 (15.4%) | | 52 (21.7%) | 12 (17.4%) | | 22 (21.0%) | 9 (12.0%) | | 2 (7.1%) | 7 (21.9%) | |
| 3 – Moderate disability | 18 (6.1%) | 16 (10.7%) | | 11 (4.6%) | 5 (7.2%) | | 9 (8.6%) | 10 (13.3%) | | 2 (7.1%) | 2 (6.3%) | |
| 4 – Severe disability | 15 (5.1%) | 12 (8.1%) | | 13 (5.4%) | 3 (4.3%) | | 8 (7.6%) | 10 (13.3%) | | 2 (7.1%) | 2 (6.3%) | |
| 5 – Coma/vegetative state | 1 (0.3%) | 2 (1.3%) | | 1 (0.4%) | 0 (0.0%) | | 0 (0.0%) | 2 (2.7%) | | | | |
| Pre-arrest PRISM | 5.0 [0.0,11.0] | 3.0 [0.0,9.0] | 0.047[1] | 6.0 [0.5,11.0] | 1.0 [0.0,7.0] | <.001[1] | 3.0 [0.0,11.0] | 5.0 [0.0,12.0] | 0.258[1] | 3.0 [0.0,7.0] | 2.0 [0.0,10.0] | 0.885[1] |
| Pre-arrest vasoactive inotropic score[5] | | | <.001[2] | | | <.001[2] | | | 0.002[2] | | | 0.026[2] |
| None | 125 (42.5%) | 104 (69.8%) | | 100 (41.7%) | 45 (65.2%) | | 42 (40.0%) | 52 (69.3%) | | 18 (64.3%) | 29 (90.6%) | |
| > 0–20 | 153 (52.0%) | 34 (22.8%) | | 128 (53.3%) | 23 (33.3%) | | 57 (54.3%) | 15 (20.0%) | | 10 (35.7%) | 1 (3.1%) | |
| > 20 | 16 (5.4%) | 11 (7.4%) | | 12 (5.0%) | 1 (1.4%) | | 6 (5.7%) | 8 (10.7%) | | 0 (0.0%) | 2 (6.3%) | |
| Immediate cause(s) of event | | | | | | | | | | | | |
| Arrhythmia | 50 (17.0%) | 25 (16.8%) | 1.000[1] | 35 (14.6%) | 10 (14.5%) | 1.000[1] | 20 (19.0%) | 14 (18.7%) | 1.000[1] | 5 (17.9%) | 3 (9.4%) | 0.454[1] |
| Cyanosis without respiratory decompensation | 20 (6.8%) | 8 (5.4%) | 0.681[1] | 19 (7.9%) | 5 (7.2%) | 1.000[1] | 6 (5.7%) | 5 (6.7%) | 1.000[1] | 2 (7.1%) | 2 (6.3%) | 1.000[1] |
| Hypotension | 197 (67.0%) | 80 (53.7%) | 0.007[1] | 159 (66.3%) | 33 (47.8%) | 0.007[1] | 79 (75.2%) | 44 (58.7%) | 0.023[1] | 16 (57.1%) | 15 (46.9%) | 0.451[1] |
| Respiratory decompensation | 118 (40.1%) | 85 (57.0%) | <.001[1] | 92 (38.3%) | 45 (65.2%) | <.001[1] | 40 (38.1%) | 37 (49.3%) | 0.169[1] | 16 (57.1%) | 21 (65.6%) | 0.598[1] |
| First documented rhythm | | | 0.020[1] | | | 0.632[1] | | | 0.189[1] | | | 0.004[1] |
| Pulseless electrical activity / asystole | 102 (34.7%) | 72 (48.3%) | | 79 (32.9%) | 26 (37.7%) | | 40 (38.1%) | 39 (52.0%) | | 7 (25.0%) | 21 (65.6%) | |
| Ventricular fibrillation / tachycardia | 29 (9.9%) | 10 (6.7%) | | 22 (9.2%) | 4 (5.8%) | | 11 (10.5%) | 6 (8.0%) | | 3 (10.7%) | 2 (6.3%) | |
| Bradycardia with poor perfusion | 163 (55.4%) | 67 (45.0%) | | 139 (57.9%) | 39 (56.5%) | | 54 (51.4%) | 30 (40.0%) | | 18 (64.3%) | 9 (28.1%) | |

(*continued on next page*)

**Table 4 (continued)**

| | Any Neuroimaging | | | Ultrasound | | | CT | | | MRI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CICU (N = 294) | PICU (N = 149) | P-value | CICU (N = 240) | PICU (N = 69) | P-value | CICU (N = 105) | PICU (N = 75) | P-value | CICU (N = 28) | PICU (N = 32) | P-value |
| Duration of CPR (minutes) | | | 0.069[1] | | | 0.457[1] | | | <.001[1] | | | 0.003[1] |
| <6 | 93 (31.6%) | 61 (40.9%) | | 80 (33.3%) | 26 (37.7%) | | 14 (13.3%) | 30 (40.0%) | | 8 (28.6%) | 12 (37.5%) | |
| 6–15 | 64 (21.8%) | 38 (25.5%) | | 52 (21.7%) | 16 (23.2%) | | 21 (20.0%) | 17 (22.7%) | | 6 (21.4%) | 17 (53.1%) | |
| 16–35 | 63 (21.4%) | 22 (14.8%) | | 52 (21.7%) | 9 (13.0%) | | 30 (28.6%) | 14 (18.7%) | | 10 (35.7%) | 3 (9.4%) | |
| >35 | 74 (25.2%) | 28 (18.8%) | | 56 (23.3%) | 18 (26.1%) | | 40 (38.1%) | 14 (18.7%) | | 4 (14.3%) | 0 (0.0%) | |
| Number of epinephrine boluses | 3.0 [1.0,7.0] | 3.0 [1.0,7.0] | 0.792[2] | 3.0 [1.0,7.0] | 4.0 [1.0,11.0] | 0.171[2] | 5.0 [2.0,11.0] | 3.0 [2.0,8.0] | 0.188[2] | 4.0 [2.0,6.5] | 3.0 [1.0,4.0] | 0.042[2] |
| Mortality | | | | | | | | | | | | |
| Death within 24 h post-arrest | 4 (1.4%) | 5 (3.4%) | 0.121[1] | 3 (1.3%) | 5 (7.2%) | 0.007[1] | 3 (2.9%) | 0 (0.0%) | 0.548[1] | | | |
| Post-resuscitation | | | | | | | | | | | | |
| Targeted temperature management within 6 hrs | 124 (42.2%) | 58 (38.9%) | 0.541[1] | 107 (44.6%) | 30 (43.5%) | 0.892[1] | 49 (46.7%) | 32 (42.7%) | 0.650[1] | 10 (35.7%) | 11 (34.4%) | 1.000[1] |
| Vasoactive inotropic score at 6 hrs | 5.0 [0.0,10.0] | 3.8 [0.0,10.0] | 0.489[2] | 5.0 [0.0,10.0] | 3.0 [0.0,8.0] | 0.077[2] | 4.0 [0.0,9.0] | 5.0 [0.0,14.0] | 0.231[2] | 4.0 [0.0,6.7] | 0.0 [0.0,7.0] | 0.243[2] |
| ECMO within 6 hrs | 27 (9.2%) | 18 (12.1%) | 0.405[1] | 23 (9.6%) | 5 (7.2%) | 0.642[1] | 10 (9.5%) | 14 (18.7%) | 0.118[1] | 0 (0.0%) | 3 (9.4%) | 0.241[1] |
| Highest lactate within 6 hrs | 9.7 [5.5,14.8] | 7.7 [3.1,14.2] | 0.023[2] | 9.4 [4.7,14.8] | 6.4 [3.1,14.7] | 0.069[2] | 11.7 [8.6,16.1] | 10.4 [5.6,14.9] | 0.096[2] | 7.1 [2.9,9.5] | 5.7 [1.0,9.7] | 0.095[2] |
| EEG within 24 hrs | 122 (41.5%) | 36 (24.2%) | <.001[1] | 107 (44.6%) | 18 (26.1%) | 0.008[1] | 41 (39.0%) | 19 (25.3%) | 0.057[1] | 10 (35.7%) | 12 (37.5%) | 1.000[1] |

PRISM = Pediatric RISk of Mortality; PCPC = Pediatric Cerebral Performance Category; FSS = Functional Status Scale; CT= Computed Tomography; MRI = Magnetic Resonance Imaging; CPR = cardiopulmonary resuscitation; PICU = pediatric intensive care unit; CICU = cardiac intensive care unit.

Row percentages are used.

[3]Baseline PCPC represents subject status prior to the event leading to hospitalization.

[4]PRISM was evaluated 2–6 h prior to the event.

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.

[5] Vasoactive inotropic score was evaluated 2 h prior to the event.

quently in patients who received < 6 min and > 35 min of CPR. (Table 2). MRIs were obtained less frequently if the patient had a higher VIS at 6 h post-arrest or higher highest lactate level within 6 h of ROC. After multivariable regression analysis, post-arrest MRI was associated with pre-existing respiratory insufficiency, and illness category of medical non-cardiac, surgical non-cardiac or trauma compared to medical cardiac (Table 3).

***Neuroimaging patterns in PICUs* versus *CICUs***. Forty-seven percent (468/1000) of patients were treated in PICUs and 53% (532/1000) in CICUs. Neuroimaging was performed in 32% (149/468) of PICU and 55% (294/532) of CICU patients. Timing of post-arrest neuroimaging was similar between the ICUs, and repeat US and CT imaging were common in both ICUs (Supplementary Fig. 1). Patients with neuroimaging in PICUs were older and had lower pre-arrest PRISM and VIS scores than patients in CICUs (Table 4). Distribution of baseline PCPC scores was similar between ICUs. Immediate cause of arrest was more commonly respiratory decompensation in PICUs and hypotension in CICUs, and initial rhythm was more commonly pulseless electrical activity (PEA)/asystole in PICUs versus bradycardia with poor perfusion in CICUs. In PICUs compared to CICUs, US was performed in 46% (69/149) versus 82% (240/294) patients, CT in 50% (75/149) versus 36% (105/294), and MRI in 21% (32/149) versus 10% (28/294). Patient and cardiac arrest factors associated with US, CT, or MRI in PICUs and CICUs are presented in Table 4.

## Discussion

We describe the landscape of current practice patterns of post-arrest neuroimaging in children who achieved return of circulation after IHCA in the large, multicenter, and diverse ICU-RESUS trial. Neuroimaging was performed in less than half of patients after IHCA. Neuroimaging was more prevalent in CICUs than PICUs, driven in part by the greater number of children less than a year of age who received US. US utilization was associated with younger age and presence of congenital cardiac disease rather than specific cardiac arrest factors. CT and MRI were utilized more in PICUs. CT utilization was associated with study site, older age, pre-existing severe neurologic disability, longer duration CPR, and non-cardiac surgical conditions (including trauma). MRI utilization was associated with pre-arrest respiratory insufficiency, and non-cardiac illness (surgical or medical). US and CT were more commonly performed early (within 24 h), and MRI was obtained later post-cardiac arrest. Serial imaging was common for US and CT.

The interval between cardiac arrest and neuroimaging acquisition can provide insight into how neuroimaging was utilized in clinical practice. Patients commonly had multiple head USs, with the index scan occurring within the first 24 h, often within the first 6 h post-arrest. As expected, USs were acquired primarily in patients less than one year old, and most were in infants with congenital heart disease. Although US provides a limited view of the brain, it is non-invasive, does not use ionizing radiation, and can be acquired quickly at the bedside in patients with an open fontanelle. In this context, US was likely used either for differential diagnosis of cardiac arrest etiology (e.g., intracranial hemorrhage or hydrocephalus) or to assess complications of the resuscitation. These infants were often at increased risk for intracranial pathology due to anticoagulation or receiving antiplatelet agents or evolution of a brain injury sustained during recent cardiopulmonary bypass for congenital heart disease surgery.

Many patients underwent serial USs, although it is unclear what proportion was performed as intermittent screening evaluations or as follow-up for abnormal findings. As 40% of patients who had at least one US also had post-arrest EEG monitoring, these patients may have experienced more severe injury or their institutions may include both modalities in post-arrest pathways. Given that the use of US was not associated with measured *peri*-arrest factors supports the likely role of protocolized post-arrest pathways. The AHA recommends that US be considered for post-arrest patients with heart disease to assess for cerebral edema, impending herniation syndromes, or intracranial hemorrhage, but does not recommend US for universal screening after cardiac arrest.[18] While < 1% of patients in this cohort were cannulated onto ECMO, the 2020 Extracorporeal Life Support Organization (ELSO) guidelines also recommend screening USs in neonates at ECMO initiation, and then every 1–2 days thereafter.[19,20].

CT scans were often obtained in the first 24 h post-arrest; however, they were also acquired between days 1–5. During this interval, clinicians may have suspected new or evolving brain injury because of changes in neurologic status (e.g., seizures, unreactive pupils, unresponsiveness after cessation of sedation, or concerning EEG features or near infrared spectroscopy [NIRS] signals). Clinicians were more likely to acquire CT scans in patients with longer duration CPR, presumably given the increased risk of severe brain injury. CT utilization was more common in children with pre-existing severe neurodevelopmental disabilities, likely due to challenges in clinically assessing brain injury via neurologic examination. In some situations, CTs can be used to inform prognostic discussions when performed later after cardiac arrest, since abnormal imaging patterns including loss of gray-white matter differentiation, basilar cistern or sulcal effacement, and basal ganglia injury have been associated with unfavorable outcomes and death.[9,21–25] The use of CT in patients with post-arrest vasoactive requirements and higher lactate may also be impacted by patient stability and the perceived safety of obtaining a CT versus MRI. MRI requires longer times out of the ICU which increase the risk for patients on continuous vasopressors. MRI also requires prolonged flat positioning which may not be tolerated in patients with cerebral edema.

Overall, 18% of patients received at least one CT scan. This prevalence is lower than after OHCA, since the etiology of cardiac arrest is more often known for IHCA and CT scan may not be as important to diagnose unknown treatable causes of cardiac arrest.[9,10] In addition, these IHCAs all occurred in an ICU, suggesting prompt recognition and provision of high-quality CPR with resultant shorter duration of CPR (over half had CPR for < 6 min), and consequently better outcomes than OHCAs. Thus, clinical examinations may have provided greater reassurance of neurologic status compared with OHCAs. A greater percentage of patients in PICUs than CICUs had a post-arrest CT scan (50% vs 36%), likely explained by patient characteristics, such as age and etiology of cardiac arrest. Interestingly, a medical non-cardiac illness category was associated with lower odds of acquiring CTs compared to medical cardiac illness category. This may be due to the use of anticoagulation, anti-platelet therapy, ECMO, or thrombosis risk in patients with medical cardiac disease.

We demonstrated a low prevalence (6%) of MRIs after IHCA. Initial MRIs were mostly performed 3–5d ays post-arrest. A greater percentage of PICU patients had MRIs compared to CICU patients. This lower CICU usage is likely multifactorial, including patient age (40% were < 1 year old), need for sedation and transport in medically complex patients, and institutional practice patterns and availability of MRI scanning. Additionally, patient outcomes from those enrolled in the ICU-RESUS trial may have impacted the frequency of MRI performance since approximately 55% of patients survived to hospital discharge and only 17% had new gross morbidities after their cardiac arrest.[14] It was not surprising that MRIs were performed less commonly for patients with < 6 min of CPR, as many may have promptly returned to their pre-arrest neurologic baseline. In contrast, it was somewhat surprising that among patients with > 16 min of CPR, a population that is at higher risk for not returning to their neurologic baseline within 7 days post-arrest, only 9% (17/187) had an MRI performed. Perhaps that group was more likely to be too unstable for transport to MRI (e.g., high VISs) or due to differences in institutional practice. It is also possible that some may have had MRIs more than 7 days post-arrest, and thus their MRI data was not collected in this study.

MRIs after IHCA are primarily conducted to aid in neuroprognostication since patterns and burden of hypoxic-ischemic injury are associated with unfavorable outcomes.[26–30] Advanced MRI techniques like MR spectroscopy, arterial spin label, and diffusion tensor imaging can also useful for assessing neurologic injury and assisting with outcome prediction.[28,31–33] A recent study of pediatric institutions reported that half of the 44 surveyed felt they obtain an MRI on all patients after cardiac arrest, while 32% felt they only perform MRI in patients who are not back to their prior neurologic baseline.[34] The surveyed MRI performance was influenced by whether the institution had a neurocritical care team and a post-cardiac arrest pathway. These factors may account for some of the differences in neuroimaging practice among study sites in our study and thus underscore potential selection bias in retrospective cohorts used to determine utility of post-cardiac arrest diagnostic studies.

In this study we focused solely on the epidemiology of whether imaging was performed within 7 days after IHCA and did not evaluate the association between neuroimaging and patient outcomes. We did not have sufficient data to determine the reason neuroimaging was acquired or the impact of results on patient management. We dichotomized practice patterns by whether patients were treated in PICUs or CICUs but were unable to further explore patient subgroups. We did not have information on whether neuroimaging was obtained per an institutional pathway or at the discretion of the primary critical care team or based on the recommendation of neurology consultants.

## Conclusions

Less than half of patients received neuroimaging within 7 days after IHCA and practice patterns varied based on patient, cardiac arrest, and site factors. Further studies are needed to determine the optimal neuroimaging practices after IHCA that influence patient management, improve neurologic outcomes, and inform neuroprognostication.

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## Search terms

Cardiac arrest, pediatric ICU, neuroimaging, CT, ultrasound, MRI

## Conflicts of interest

Robert Berg, Vinay Nadkarni, Robert Neumar, and Alexis Topjian are members of the Resuscitation editorial board.

## CRediT authorship contribution statement

**Matthew P. Kirschen:** Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Natalie L. Ullman:** Investigation, Methodology, Writing – review & editing. **Ron W. Reeder:** Writing – review & editing, Project administration, Methodology, Formal analysis. **Tageldin Ahmed:** Writing – review & editing, Data curation. **Michael J. Bell:** Writing – review & editing, Data curation. **Robert A. Berg:** Writing – review & editing, Supervision, Methodology, Investigation. **Candice Burns:** Writing – review & editing, Data curation. **Joseph A. Carcillo:** Writing – review & editing, Data curation. **Todd C. Carpenter:** Writing – review & editing, Data curation. **J. Wesley Diddle:** Writing – review & editing, Data curation. **Myke Federman:** Writing – review & editing, Data curation. **Ericka L. Fink:** Data curation, Writing – review & editing. **Aisha H. Frazier:** Data curation, Writing – review & editing. **Stuart H. Friess:** Writing – review & editing, Data curation. **Kathryn Graham:** Data curation, Investigation, Methodology, Writing – review & editing. **Christopher M. Horvat:** Writing – review & editing, Data curation. **Leanna L. Huard:** Writing – review & editing, Data curation. **Todd J. Kilbaugh:** Writing – review & editing, Data curation. **Tensing Maa:** Writing – review & editing, Data curation. **Arushi Manga:** Writing – review & editing, Data curation. **Patrick S. McQuillen:** Writing – review & editing, Data curation. **Kathleen L. Meert:** Writing – review & editing, Data curation. **Ryan W. Morgan:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation. **Peter M. Mourani:** Writing – review & editing, Data curation. **Vinay M. Nadkarni:** Data curation, Investigation, Methodology, Writing – review & editing, Supervision. **Maryam Y. Naim:** Data curation, Writing – review & editing. **Daniel Notterman:** Writing – review & editing, Data curation. **Chella A. Palmer:** Writing – review & editing, Methodology, Formal analysis. **Murray M. Pollack:** Writing – review & editing, Data curation. **Anil Sapru:** Writing – review & editing, Data curation. **Matthew P. Sharron:** Writing – review & editing, Data curation. **Neeraj Srivastava:** Writing – review & editing, Data curation. **Bradley Tilford:** Writing – review & editing, Data curation. **Shirley Viteri:** Writing – review & editing, Data curation. **Heather A. Wolfe:** Data curation, Writing – review & editing. **Andrew R. Yates:** Writing – review & editing, Data curation. **Alexis Topjian:** Writing – review & editing, Methodology, Investigation. **Robert M. Sutton:** Data curation, Investigation, Methodology, Funding acquisition, Writing – review & editing, Supervision. **Craig A. Press:** Data curation, Investigation, Methodology, Writing – review & editing.

## Declaration of competing interest

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

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2025.110506.

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## REFERENCES

1. Holmberg MJ, Ross CE, Fitzmaurice GJ, et al. Annual incidence of adult and pediatric in-hospital cardiac arrest in the United States. Circulation 2019;12.
2. Tsao CW, Aday AW, Almarzooq ZI, et al. Heart disease and stroke statistics-2022 update: a report from the American heart association. Circulation 2022;145:e153–639.
3. Morgan RW, Kirschen MP, Kilbaugh TJ, Sutton RM, Topjian AA. Pediatric in-hospital cardiac arrest and cardiopulmonary resuscitation in the United States: A review. JAMA Pediatr 2021;175:293–302.
4. Perkins GD, Callaway CW, Haywood K, et al. Brain injury after cardiac arrest. Lancet 2021;398:1269–78.
5. Sandroni C, Cronberg T, Sekhon M. Brain injury after cardiac arrest: pathophysiology, treatment, and prognosis. Intensive Care Med 2021;47:1393–414.
6. Jacobs I, Nadkarni V, Bahr J, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update and simplification of the Utstein templates for resuscitation registries: a statement for healthcare professionals from a task force of the International Liaison Committee on Resuscitation (American Heart Association, European Resuscitation Council, Australian Resuscitation Council, New Zealand Resuscitation Council, Heart and Stroke Foundation of Canada, InterAmerican Heart Foundation, Resuscitation Councils of Southern Africa). Circulation 2004;110:3385–97.
7. Topjian AA, de Caen A, Wainwright MS, et al. Pediatric post-cardiac arrest care: a scientific statement from the American heart association. Circulation 2019CIR0000000000000697.
8. Topjian AA, Raymond TT, Atkins D, et al. Part 4: Pediatric basic and advanced life support: 2020 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2020;142:S469–523.
9. Starling RM, Shekdar K, Licht D, Nadkarni VM, Berg RA, Topjian AA. Early head CT findings are associated with outcomes after pediatric out-of-hospital cardiac arrest. Pediatr Crit Care Med 2015;16:542–8.
10. Hunfeld M, Nadkarni VM, Topjian A, et al. Timing and cause of death in children following return of circulation after out-of-hospital cardiac arrest: a single-center retrospective cohort study. Pediatr Crit Care Med 2021;22:101–13.
11. Berg RA, Nadkarni VM, Clark AE, et al. Incidence and outcomes of cardiopulmonary resuscitation in PICUs. Crit Care Med 2016;44:798–808.
12. Matos RI, Watson RS, Nadkarni VM, et al. Duration of cardiopulmonary resuscitation and illness category impact survival and neurologic outcomes for in-hospital pediatric cardiac arrests. Circulation 2013;127:442–51.
13. Morgan RW, Stinson HR, Wolfe H, et al. Pediatric in-hospital cardiac arrest secondary to acute pulmonary embolism. Crit Care Med 2018;46:e229–34.
14. Sutton RM, Wolfe HA, Reeder RW, et al. Effect of physiologic point-of-care cardiopulmonary resuscitation training on survival with favorable neurologic outcome in cardiac arrest in pediatric ICUs: A randomized clinical trial. JAMA 2022;327:934–45.
15. Fiser DH. Assessing the outcome of pediatric intensive care. J Pediatr 1992;121:68–74.
16. Fiser DH, Long N, Roberson PK, Hefley G, Zolten K, Brodie-Fowler M. Relationship of pediatric overall performance category and pediatric cerebral performance category scores at pediatric intensive care unit discharge with outcome measures collected at hospital discharge and 1- and 6-month follow-up assessments. Crit Care Med 2000;28:2616–20.
17. Topjian AA, Scholefield BR, Pinto NP, et al. P-COSCA (Pediatric core outcome set for cardiac arrest) in Children: An advisory statement from the international liaison committee on resuscitation. Circulation 2020;142:e246–61.
18. Marino BS, Tabbutt S, MacLaren G, et al. Cardiopulmonary resuscitation in infants and children with cardiac disease: a scientific statement from the American heart association. Circulation 2018;137:e691–782.
19. Maratta C, Potera RM, van Leeuwen G, Castillo Moya A, Raman L, Annich GM. Extracorporeal life support organization (ELSO): 2020 pediatric respiratory ELSO guideline. ASAIO J 2020;66:975–9.
20. Brown G, Moynihan KM, Deatrick KB, et al. Extracorporeal life support organization (ELSO): guidelines for pediatric cardiac failure. ASAIO J 2021;67:463–75.

21. Rafaat KT, Spear RM, Kuelbs C, Parsapour K, Peterson B. Cranial computed tomographic findings in a large group of children with drowning: diagnostic, prognostic, and forensic implications. Pediatr Crit Care Med 2008;9:567–72.
22. Smith AE, Friess SH. Neurological Prognostication in Children After Cardiac Arrest. Pediatr Neurol 2020;108:13–22.
23. Hunfeld M, Ketharanathan N, Catsman C, et al. A systematic review of neuromonitoring modalities in children beyond neonatal period after cardiac arrest. Pediatr Crit Care Med 2020.
24. Yang D, Ha SG, Ryoo E, Choi JY, Kim HJ. Multimodal assessment using early brain CT and blood pH improve prediction of neurologic outcomes after pediatric cardiac arrest. Resuscitation 2019;137:7–13.
25. Taylor SB, Quencer RM, Holzman BH, Naidich TP. Central nervous system anoxic-ischemic insult in children due to near-drowning. Radiology 1985;156:641–6.
26. Fink EL, Panigrahy A, Clark RS, et al. Regional brain injury on conventional and diffusion weighted MRI is associated with outcome after pediatric cardiac arrest. Neurocrit Care 2013;19:31–40.
27. Kirschen MP, Licht DJ, Faerber J, et al. Association of MRI brain injury with outcome after pediatric out-of-hospital cardiac arrest. Neurology 2020.
28. Manchester LC, Lee V, Schmithorst V, Kochanek PM, Panigrahy A, Fink EL. Global and regional derangements of cerebral blood flow and diffusion magnetic resonance imaging after pediatric cardiac arrest. J Pediatr 2016;169. 28-35 e21.
29. Yacoub M, Birchansky B, Mlynash M, et al. The prognostic value of quantitative diffusion-weighted MRI after pediatric cardiopulmonary arrest. Resuscitation 2019;135:103–9.
30. Kirschen MP, Berman JI, Liu H, et al. Association between quantitative diffusion weighted magnetic resonance neuroimaging and outcome after pediatric cardiac arrest. Neurology 2022;99: e2615–26.
31. Fink EL, Wisnowski J, Clark R, et al. Brain MR imaging and spectroscopy for outcome prognostication after pediatric cardiac arrest. Resuscitation 2020;157:185–94.
32. Velly L, Perlbarg V, Boulier T, et al. Use of brain diffusion tensor imaging for the prediction of long-term neurological outcomes in patients after cardiac arrest: a multicentre, international, prospective, observational, cohort study. Lancet Neurol 2018;17:317–26.
33. Lopez Soto C, Dragoi L, Heyn CC, et al. Imaging for neuroprognostication after cardiac arrest: systematic review and meta-analysis. Neurocrit Care 2019.
34. Piantino JA, Ruzas CM, Press CA, et al. Use of magnetic resonance imaging in neuroprognostication after pediatric cardiac arrest: survey of current practices. Pediatr Neurol 2022;134:45–51.