

# Effect of Hospital Characteristics on Outcomes From Pediatric Cardiopulmonary Resuscitation: A Report From the National Registry of Cardiopulmonary Resuscitation

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## ABSTRACT

**OBJECTIVE.** Cardiac arrest is uncommon among pediatric patients. Prehospital data demonstrate differences in care processes between children and adults receiving cardiopulmonary resuscitation and advanced life support. We sought to evaluate whether children receiving in-hospital cardiopulmonary resuscitation would attain superior 24-hour survival in hospitals with a higher level of pediatric physician staffing, greater intensity of pediatric care services, and higher pediatric patient volume.

**METHODS.** A retrospective cohort of 778 hospital inpatients aged <18 years receiving cardiopulmonary resuscitation was identified from the National Registry of Cardiopulmonary Resuscitation from January 2000 to December 2002. Data on hospital pediatric facilities were obtained via telephone survey. Univariate analyses comparing 24-hour survivors and nonsurvivors were conducted using Wilcoxon rank-sum testing for continuous variables and  $\chi^2$  analysis for dichotomous variables. Multivariate regression analysis was done to examine hospital characteristics as independent predictors of 24-hour survival.

**RESULTS.** Complete data were available for 677 patients. Univariate analyses showed an association between several pediatric-specific facility characteristics and 24-hour survival. After accounting for indicators of pre-event clinical condition and monitoring, multivariate analysis showed improved 24-hour survival in hospitals staffed by pediatric residents and surgeons and pediatric residents, surgeons, and fellows than for hospitals with no pediatric physician staffing or pediatric surgeons alone. Measures of available facilities and patient volume were not associated with improved outcome.

**CONCLUSIONS.** Improved 24-hour survival for children receiving in-hospital cardiopulmonary resuscitation is associated with the presence of pediatric residents and fellows.

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### Key Words

cardiopulmonary resuscitation, hospital performance, cardiac arrest

### Abbreviations

CPR—cardiopulmonary resuscitation  
NRCPR—National Registry of Cardiopulmonary Resuscitation  
NoPeds—no pediatric housestaff or surgeons  
PedSurg—pediatric surgeons only  
PedRes—pediatric surgeons and residents  
PedFellow—pediatric surgeons—residents—and pediatric emergency medicine and/or pediatric critical care medicine fellows  
OR—odds ratio  
CI—confidence interval  
ED—emergency department

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CARDIAC ARREST IS an uncommon phenomenon in children. Differences in physiology and etiology between adults and children have led to the creation of separate treatment algorithms for cardiac arrest in children and adults. Research in pediatric cardiac arrest and cardiopulmonary resuscitation (CPR) has not yielded consistent evidence that the most commonly used processes of care in pediatric CPR improve clinical outcomes. A recent collective review by Young and Seidel<sup>1</sup> reported an overall survival rate of 13% among out-of-hospital and in-hospital arrests combined and a high prevalence of neurocognitive morbidity among survivors. Outcomes from inpatient pediatric CPR are better, with 24-hour survival rates ranging from 33% to 37% and less neurologic morbidity than in patients receiving out-of-hospital CPR.<sup>2-4</sup>

Although numerous studies have demonstrated significant differences in processes of care for children receiving CPR and advanced life support when compared with adults in the prehospital setting,<sup>5-7</sup> little is known about how processes of care or hospital resources impact survival. Differences in processes of care and clinical outcomes for children by hospital characteristics have been investigated in other clinical contexts, such as abdominal trauma, intussusception, and procedural sedation and analgesia.<sup>8-10</sup> A number of these studies have looked specifically at differences between processes of care in children's hospitals and hospitals that care for adults, as well as children.

This study was designed to examine the effect of hospital and physician staffing characteristics on 24-hour survival after in-hospital CPR in children. Specifically, we examined whether a higher level of pediatric physician staffing, increased volume of pediatric patients, or increased pediatric specialization were associated with improved 24-hour survival after CPR while controlling for likely clinical confounders such as age, location of arrest, underlying diagnosis, and intensity of pre-event clinical support.

## METHODS

A retrospective cohort of all patients aged <18 years who required in-hospital CPR were selected from the National Registry of Cardiopulmonary Resuscitation (NRCPR) during the 36-month period between January 1, 2000, and December 31, 2002. The NRCPR is a multisite database sponsored by the American Heart Association in which hospitals voluntarily participate. Participating hospitals pay an annual fee for data support and report generation. Data abstractors at participating hospitals are trained and certified before beginning data collection. Data quality assurance measures include data completeness reports, random reabstraction of data with error rate reports, and intrinsic data quality checks in database software. During our study period, 258 hospitals in 49 states were participating in the NRCPR. No

standard indices of rural or urban hospital status are used.

Patients enrolled in the database are those who experience a resuscitation event, defined as "cardiopulmonary arrest requiring chest compressions and/or defibrillation of ventricular fibrillation or pulseless ventricular tachycardia," and for whom "a hospital-wide (eg, for general inpatient area) or unit-based emergency response by facility personnel" is prompted. Patients for whom resuscitation efforts were altered because of palliative care or preexisting do-not-attempt-resuscitation orders were excluded. Neonates who received CPR at the time of delivery or in the NICU were also excluded. An additional subset of patients were identified that seemed consistent with cases of sudden infant death syndrome with out-of-hospital cardiopulmonary arrest; these children were <1 year of age, underwent CPR in the emergency department, had a presenting rhythm of asystole, had no preexisting medical conditions, and did not survive. Thirteen patients in all met these criteria. Despite the fact that the attempted resuscitation of these patients began in the hospital and not in the prehospital phase, these children were deemed by investigator consensus to have likely suffered out-of-hospital arrests and, as such, were excluded.

Data included in the analysis for each patient were age, location of the event within the hospital, illness category, whether or not the patient was pulseless at onset of CPR, and details of preexisting clinical interventions when the event occurred. For pre-event clinical interventions, a separate categorical variable was generated as shown in Table 1. A list of hospital characteristics pertinent to pediatric care were generated by the investigators and is shown in Table 2. Values for these variables were obtained by telephone interviews and were self-reported by hospital personnel designated as contacts for the NRCPR database. Data elements not collected by this method were obtained by alternate hospital contacts, from NRCPR facility data, or from the National Resident Matching Program Web site ([www.nrmp.org](http://www.nrmp.org)).

Dichotomous variables in the hospital data sets were tested for collinearity; no pairwise comparison was suf-

**TABLE 1 Ordinal Variable for Prearrest Level of Clinical Intervention**

| NRCPR Data:<br>Pre-event Clinical Intervention(s)  | Intervention Level<br>(Variable Coding) |
|--|---|
| Unmonitored inpatient (non-ICU, no monitors)   | 1                                       |
| Monitored inpatient (non-ICU; any combination of ECG, pulse oximeter, and apnea monitor) | 2                                       |
| ICU inpatient (without assisted ventilation or hemodynamic support)                      | 3                                       |
| Assisted ventilation or vasopressor/antidysrhythmic support                              | 4                                       |
| Assisted ventilation and vasopressor/antidysrhythmic support                             | 5                                       |

**TABLE 2 Hospital Characteristics**

| Characteristic  | Data Source                              |
|---|--|
| Pediatric residency program, No. of residents               | Telephone interview                      |
| Pediatric inpatient ward, No. of beds                       | Telephone interview                      |
| Pediatric ICU, No. of beds                                  | Telephone interview; NRCPR facility data |
| Pediatric ED  | Telephone interview                      |
| Annual ED visits by patients <18 y of age                   | Telephone interview                      |
| Annual admissions of patients <18 y of age                  | Telephone interview                      |
| Pediatric emergency medicine fellowship, No. of fellows     | Telephone interview; NRMP Web site       |
| Pediatric critical care medicine fellowship, No. of fellows | Telephone interview; NRMP Web site       |
| Pediatric surgeon on staff                                  | Telephone interview                      |
| Pediatric radiologist on staff                              | Telephone interview                      |
| Pediatric trauma center designation                         | Telephone interview                      |

ficiently collinear to collapse any variables. A variable was generated to reflect differences in pediatric physician staffing, resulting in 4 mutually exclusive categories: no pediatric housestaff or surgeons (NoPeds); pediatric surgeons only (PedSurg); pediatric surgeons and residents (PedRes); and pediatric surgeons, residents, and pediatric emergency medicine and/or pediatric critical care medicine fellows (PedFellow).

The outcome of interest was survival at 24-hours after CPR event. This was determined by the presence of return of spontaneous circulation in the absence of external chest compressions and a postevent length of stay of  $\geq 1$  day. This outcome likely reflects the effects of both resuscitation and postresuscitation interventions on short-term clinical outcome. Patients for whom postevent length of stay was missing from the database ( $n = 7$ ) were excluded. Patients for whom postevent length of stay was <1 day and whose discharge disposition was coded as "discharged alive" ( $n = 27$ ) were also excluded. On subsequent examination, these 27 patients were children for whom CPR was initiated at their enrolling hospital, achieved return of spontaneous circulation, and were transferred to other facilities. These patients, whereas not included in the main analysis, were examined separately to determine the potential for bias resulting from their exclusion (see below).

Descriptive statistics were performed on all of the variables; measures of spread in continuous variables were expressed as medians and ranges. Univariate analyses were performed between survivors and nonsurvivors by  $\chi^2$  analysis for all of the hospital characteristic variables and for several clinical variables that were potential sources of confounding (age category, shockable versus nonshockable rhythm, level of pre-event clinical intervention, event location, and illness category). Multivariate regression analysis was performed to examine the effect of hospital characteristics on 24-hour survival while controlling for clinical confounders, with relation-

ships between predictor and 24-hour survival expressed as odds ratios (ORs) with 95% confidence intervals (CIs). Generalized estimating equations were used to account for clustering by hospital.

Pairwise comparisons for event locations and diagnostic categories demonstrated significant differences in 24-hour survival for events that occurred in the emergency department ([ED] worse survival compared with all other locations), patients whose diagnostic category was trauma (worse survival compared with all other categories), and patients whose diagnostic category was surgical (better survival compared with all other categories). The distribution of event locations and diagnostic categories also differed by hospital category. Therefore, these variables were coded as ED versus other for event location and trauma versus surgical versus other for diagnostic category and were included in the multivariate model as potential clinical confounders. In addition, the categorical variable for pre-event intervention level was included in the model as a surrogate measure of illness severity and clinical status. The final model was the result of a stepwise multivariate regression where the initial model included a complete set of all hospital characteristics. Characteristics of which the  $\beta$  coefficients yielded  $P$  values <0.2 were also considered for inclusion in the final model as possible independent predictors of survival. All of the potential clinical confounders remained in our final model irrespective of the level of significance in the preliminary analysis with the exception of shockable rhythm, which had no association with our exposure or outcome of interest on univariate analysis.

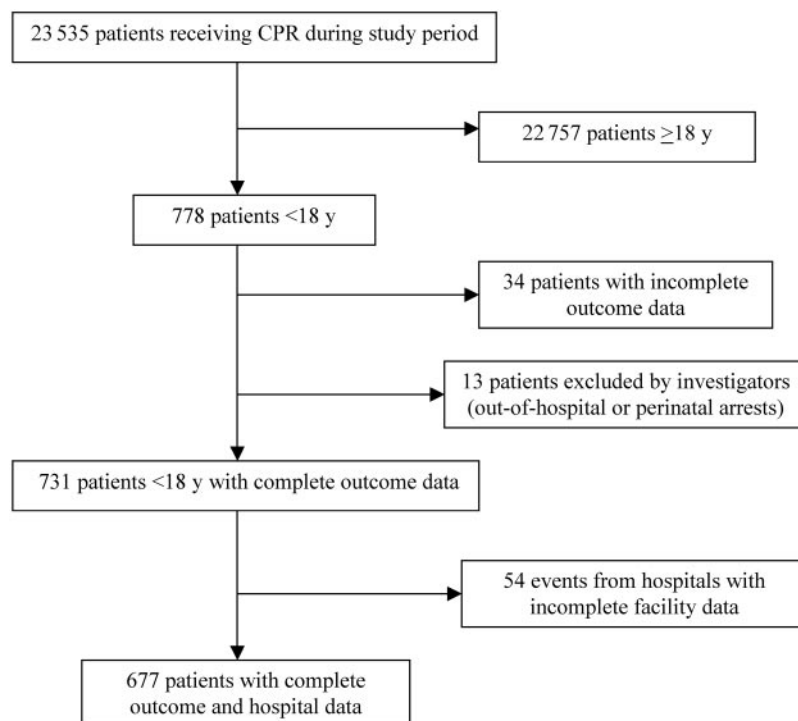
All of the statistical analyses were performed by using Stata 8.0 software (Stata Corp, College Station, TX). All aspects of this study were reviewed and approved by the Children's Hospital of Philadelphia Institutional Review Board and the Science Advisory Board of the American Heart Association NRCPR.

## RESULTS

A total of 23 535 events were recorded during the study period. Of these, 778 (3.3%) occurred in children <18 years. Among the 778 pediatric events, 34 had either incomplete or no data on survival at 24 hours after event; 13 were apparent sudden infant death syndrome or delivery room events; and 54 occurred in hospitals with incomplete facility data. Thus, 677 events were included in the final analysis (see Figure 1).

Overall 24 hour survival was 347 (51%) of 677. The mean age of the patients in the data set was 4 years; mean age was 3.3 years for survivors and 4.8 years for nonsurvivors ( $P = .0002$ ). The majority of events occurred in an ICU (479 of 677 [70.8%]); ED events accounted for only 60 (8.9%) of 677 patients but these patients had significantly worse 24-hour survival than patients at other locations ( $P < .001$  for all pairwise

FIGURE 1  
Flow diagram for patient inclusion.



comparisons). The majority of patients were in medical illness categories (368 of 677 [54.3%]). Trauma patients accounted for 41 (6.1%) of 677 of the patients in the data set and had worse 24-hour survival than patients in all of the other diagnostic categories ( $P < .001$  for all pairwise comparisons). Descriptive and univariate statistics for clinical variables are shown in Table 3.

CPR events in children were reported in a total of 91 hospitals. A complete set of hospital characteristics were collected on 62 of the 91 hospitals via telephone interviews. Hospitals without available facility data accounted for 54 (7%) of 731 patients meeting all of the other inclusion criteria. Hospital characteristics are summarized in Table 4; univariate comparison between 24-hour survivors and nonsurvivors by hospital characteristic and hospital category is shown in Table 5. Hospitals with no pediatric specialists (NoPeds) had significantly worse 24-hour survival than all of the other categories ( $P = .014$  for PedSurg and  $P < .001$  for PedRes and PedFellow). Pairwise comparisons and PedSurg, PedRes, and PedFellow hospitals did not demonstrate significant differences in 24-hour survival.

Multivariate logistic regression results are shown in Table 6. Improved 24-hour survival was noted in PedRes hospitals (OR: 3.46; 95% CI: 1.25–9.62) and PedFellow hospitals (OR: 4.22; 95% CI: 1.59–11.2). The difference in survival between PedRes and PedFellow was not significant. Patients whose CPR was initiated in an ED had worse 24-hour survival; patients aged <1 year had im-

TABLE 3 Univariate Analysis of Clinical Data

| Variable   | 24-h Survival, n/N (%) | $\chi^2$          |
|--|------------------------|-------------------|
| Event location <sup>a</sup>                                  |                        |                   |
| ICU  | 257/479 (54)           | 0.05              |
| Inpatient ward   | 40/77 (52)             | 0.90              |
| ED   | 14/60 (23)             | 0.0001            |
| OR/PACU  | 7/27 (26)              | 0.01              |
| Diagnostic/intervention                                      | 7/20 (35)              | 0.15              |
| Other (ambulatory, visitors, unknown)                        | 6/14 (43)              | 0.52              |
| Diagnostic category <sup>a</sup>                             |                        |                   |
| Medical: cardiac   | 56/120 (47)            | 0.27              |
| Medical: noncardiac  | 159/314 (51)           | 0.77              |
| Surgical: cardiac  | 83/141 (59)            | 0.04              |
| Surgical: noncardiac   | 37/54 (69)             | 0.01              |
| Trauma   | 10/41 (24)             | <0.001            |
| Obstetric  | 2/7 (29)               | 0.21 <sup>b</sup> |
| Intervention level <sup>c</sup>                              |                        |                   |
| Unmonitored inpatient (level 1)                              | 12/42 (28)             | NA                |
| Monitored inpatient (level 2)                                | 44/88 (50)             | $P = .025$        |
| ICU patient (no respiratory or hemodynamic support; level 3) | 69/102 (67)            | $P < .001$        |
| ICU, ventilated or pressor support (level 4)                 | 128/222 (57)           | $P = .001$        |
| ICU, ventilated and pressor support (level 5)                | 94/223 (42)            | $P = .119$        |
| Rhythm and perfusion status                                  |                        |                   |
| Shockable rhythm (initial)                                   | 34/73 (47)             | $P = .397$        |
| Nonshockable rhythm (initial)                                | 313/604 (52)           |                   |
| Pulse present at initiation of CPR                           | 169/289 (58)           | $P = .001$        |
| Pulseless at initiation of CPR                               | 178/388 (46)           |                   |

NA indicates not applicable; OR, operating room; PACU, post-anesthesia care unit.

<sup>a</sup> Versus other locations.

<sup>b</sup> Fisher's exact test.

<sup>c</sup> Versus level 1.

**TABLE 4 Hospital Characteristics: Descriptive Statistics**

| Characteristic           | Hospitals<br>(n = 62),<br>n (%) | Patients<br>(n = 677),<br>n (%) | Median<br>(Range)    |
|--------------------------|---------------------------------|---------------------------------|----------------------|
| Physician staffing       |                                 |                                 |                      |
| Pediatric residency      | 26 (42)                         | 602 (89)                        | 30 (8–112)           |
| Pediatric EM fellows     | 8 (13)                          | 390 (58)                        | 3 (2–15)             |
| Pediatric CCM fellows    | 12 (19)                         | 457 (68)                        | 4 (1–18)             |
| Pediatric surgeon        | 38 (61)                         | 639 (94)                        |                      |
| Pediatric radiologist    | 30 (48)                         | 552 (82)                        |                      |
| Facilities               |                                 |                                 |                      |
| Pediatric inpatient ward | 53 (85)                         | 621 (92)                        | 22 (2–273)           |
| PICU                     | 36 (58)                         | 632 (93)                        | 6 (4–73)             |
| Pediatric ED             | 26 (42)                         | 527 (78)                        |                      |
| Pediatric trauma center  | 21 (33)                         | 460 (68)                        |                      |
| Patient caseload         |                                 |                                 |                      |
| Pediatric admissions     |                                 |                                 | 2000 (144–21 000)    |
| Pediatric ED visits      |                                 |                                 | 12 674 (1186–87 000) |

EM indicates emergency medicine; CCM, critical care medicine.

**TABLE 5 Univariate Analysis of Hospital Data**

| Variable                             | 24-h Survival<br>(n = 677), n/N (%) | P                  |
|--------------------------------------|-------------------------------------|--------------------|
| Characteristic (dichotomous)         |                                     |                    |
| Pediatric residency                  |                                     | <.001 <sup>a</sup> |
| PICU                                 |                                     | <.001 <sup>a</sup> |
| PEM fellowship                       |                                     | .005 <sup>a</sup>  |
| PCCM fellowship                      |                                     | .001 <sup>a</sup>  |
| Pediatric inpatient ward             |                                     | .230 <sup>a</sup>  |
| Pediatric surgeon                    |                                     | <.001 <sup>a</sup> |
| Pediatric radiologist                |                                     | .013 <sup>a</sup>  |
| Pediatric trauma center              |                                     | .234 <sup>a</sup>  |
| Pediatric ED                         |                                     | .144 <sup>a</sup>  |
| Characteristic (continuous)          |                                     |                    |
| No. of pediatric residents           |                                     | .006 <sup>b</sup>  |
| No. of PICU beds                     |                                     | .001 <sup>b</sup>  |
| No. of PEM fellows                   |                                     | .008 <sup>b</sup>  |
| No. of PCCM fellows                  |                                     | .003 <sup>b</sup>  |
| No. of pediatric inpatient beds      |                                     | <.001 <sup>b</sup> |
| No. of annual pediatric admissions   |                                     | .001 <sup>b</sup>  |
| No. of annual pediatric ED visits    |                                     | .074 <sup>b</sup>  |
| Staffing category (No. of hospitals) |                                     |                    |
| NoPeds (n = 24)                      | 6/38 (16)                           | NA                 |
| PedSurg (n = 12)                     | 15/37 (41)                          | .014 <sup>c</sup>  |
| PedRes (n = 13)                      | 59/118 (50)                         | <.001 <sup>c</sup> |
| PedFellow (n = 13)                   | 267/484 (55)                        | <.001 <sup>c</sup> |

NA indicates not applicable; PEM, pediatric emergency medicine; PCCM, pediatric critical care medicine.

<sup>a</sup>  $\chi^2$  test.

<sup>b</sup> Wilcoxon rank sum.

<sup>c</sup>  $\chi^2$  (versus category 1).

proved 24-hour survival; no illness category or pre-event intervention level was significantly associated with 24-hour survival. Additional multivariate models were constructed to determine whether effect modification was present between the presence of a pulse at the onset of CPR and hospital category; no significant interaction was present.

Twenty-seven patients transferred after their events

**TABLE 6 Multivariate Analysis**

| Factor   | OR for 24-h Survival<br>(95% CI) |
|--|----------------------------------|
| ED patient   | 0.39 (0.19–0.80)                 |
| Trauma patient   | 0.47 (0.21–1.06)                 |
| Surgical patient   | 1.42 (0.97–2.06)                 |
| Age <1 y (vs 1 to 8 y old)   | 1.88 (1.26–2.80)                 |
| Age >8 y (vs 1 to 8 y old)   | 1.19 (0.74–1.92)                 |
| Monitored inpatient (vs unmonitored inpatient)                                 | 1.40 (0.58–3.37)                 |
| ICU inpatient (no response or cardiovascular support vs unmonitored inpatient) | 2.26 (0.92–5.58)                 |
| ICU, ventilated or hemodynamic support (vs unmonitored inpatient)              | 1.54 (0.67–3.55)                 |
| ICU, ventilated and hemodynamic support (vs unmonitored inpatient)             | 0.66 (0.28–1.55)                 |
| Pulse present at initiation of CPR   | 1.36 (0.97–1.91)                 |
| PedSurg category   | 2.75 (0.84–8.93)                 |
| PedRes category  | 3.46 (1.25–9.62)                 |
| PedFellow category   | 4.22 (1.59–11.2)                 |

were examined in more detail. Most of these patients had CPR initiated in an ED, but other clinical settings, such as the operating room and ICU, were represented as well. One of the events occurred at a pediatric hospital; the remainder occurred in centers for which the primary patient focus was reported by facility personnel as “mixed” or “adult.” When we included these patients and assigned them the same overall survival as the larger data set, the effects of our exposures of interest were unchanged. We then performed a sensitivity analysis in which we varied the 24-hour survival rate and whether the survivors included the 1 patient cared for in a pediatric center. If the pediatric center patient survived, the effects of interest remained significant so long as  $\geq 1$  of the remaining patients died (ie,  $\leq 27$  of 28 patients survived 24 hours). If the pediatric center patient died, the effects of interest remained significant so long as  $\geq 6$  of the remaining patients died (ie,  $\leq 22$  of 28 patients survived 24 hours). Given the fact that the hypothetical situations that would render our findings insignificant are inconsistent with the observed survival for similar patients, we believe that the exclusion of this group of patients does not significantly bias our results.

## DISCUSSION

Our study suggests that 24-hour survival for children requiring inpatient CPR is associated with the presence of pediatric physicians when compared with hospitals without pediatric personnel. The presence of pediatric residents was associated with the greatest improvement in 24-hour survival. We did not find any significant association on multivariate analysis between the presence or size of specialized care areas, such as ICUs, and improved 24-hour survival. We also found no association on multivariate analysis between measures of patient volume and 24-hour survival.

Our findings with respect to survival after CPR extend

those of previously published studies on pediatric inpatients. Emerging epidemiological data on pediatric inpatient CPR has suggested that clinical outcomes are superior to those from prehospital CPR and that greater understanding of the epidemiology of inpatient CPR in children is necessary for improving treatment and outcomes further. Studies from Brazil,<sup>2</sup> Finland,<sup>3</sup> and the United States<sup>4</sup> have examined outcomes from inpatient pediatric CPR while using consensus Utstein definitions; 24-hour survival rates from these studies ranged from 33% to 37%. These studies, however, have been predominantly conducted in single centers and have not attempted to examine relationships between characteristics of different hospitals and patient outcomes. Our overall 24-hour survival rate of 51% is, in fact, higher than these studies. Given the demonstrated association between a higher level of pediatric staffing and improved outcome, the fact that a large majority of our patients received CPR in hospitals staffed by pediatric residents and/or fellows may account for this elevated survival rate.

The association between improved care processes and outcomes for children in hospitals with greater levels of pediatric specialization has been demonstrated in previous studies of children with blunt splenic injury, intussusception, and ED procedural sedation and analgesia.<sup>8–10</sup> These studies have suggested that variation in pediatric volumes may have an effect on both practice patterns and outcomes. Studies of PICUs have demonstrated relationships between the presence of pediatric critical care fellows and improved survival,<sup>11</sup> as well as patient volume and improved survival.<sup>12</sup> In our study, we identified pediatric-trained physician staffing as a predictor of improved outcome, whereas other measures of patient volume were not associated with improved survival after CPR.

The majority of the children in our data set were inpatients at hospitals with pediatric housestaff and tertiary pediatric services. Children cared for in pediatric hospitals have greater complexity and severity of underlying illness and are likely at greater risk for clinical events requiring CPR. Children at such hospitals had improved odds of survival after CPR in our study, despite these differences. Resuscitation training in pediatric hospitals likely confers a greater familiarity with developmental physiology, equipment, medication indications and dosing, and other processes of care essential for critically ill children. Our data demonstrate that the presence of physicians with such pediatric-specific training is associated with improved short-term outcomes after CPR.

Survival at 24 hours after cardiac arrest is a discreet, measurable outcome of clinical significance that reflects resuscitation and postresuscitation interventions more completely than even shorter-term outcomes, such as return of spontaneous circulation. Longer-term out-

comes, such as survival to hospital discharge and neurologically intact survival, although of great clinical importance, were not examined in this study for a number of reasons. First, underlying medical conditions are likely to have a greater effect on long-term outcomes after CPR, and the distribution of patients with such conditions was irregular across hospital types. Second, with a longer time horizon to our outcome of interest, factors related to regionalization of pediatric tertiary care and interfacility transport are likely to be of significance and were beyond the scope of the source of data used. Third, practices related to end-of-life and palliative care in children are more likely to emerge for children who survive such an event. These practices are common in pediatric intensive care settings<sup>13</sup> but vary significantly by hospital and patient characteristics.<sup>14,15</sup>

Several limitations to our study should be acknowledged. The NRCPR database collects data on all patients requiring CPR, but the vast majority of patients enrolled are adults. The data collection form reflects this fact in that the list of diagnoses and clinical interventions are replete with conditions common to adults, such as myocardial infarction, stroke, and so forth. In our analysis, the diagnostic category had no significant confounding effect on our exposures of interest. It is probable that severity of illness for children is incompletely captured by the data elements available from the NRCPR. In our present model, the categorical variable reflecting the pre-event level of clinical intervention suggests that patients have optimal survival likelihood when patients are in an ICU but do not require assisted ventilation or hemodynamic support. We believe that this variable characterizes the prearrest severity of illness in an accurate way, and our results remain significant while controlling for this factor.

Children's hospitals with tertiary services inevitably have higher caseloads of ill children than general centers. A greater knowledge and experience with children with specific complex diseases may allow patient care teams to anticipate and prevent complications to a greater extent than facilities without the same level of experience. Patients benefiting from this phenomenon would not be enrolled in the database, despite being part of the population at risk, and, as such, this may result in an underestimate of the effect of tertiary pediatric facilities. In addition, subjects enrolled from such facilities may, therefore, represent a group of patients with higher illness severity. This may result in a biased distribution of illness severity among hospitals, with the children in tertiary centers being more severely ill and possibly less likely to survive. Therefore, our results may underestimate the true association between variables common in pediatric hospitals with 24-hour survival.

The centers contributing data to the NRCPR during our study period comprise ~10% of all hospitals in the United States, and although they represent a wide vari-

ety of hospital sizes and settings, the database does constitute a convenience sample. Enrollment in the NRCPR is voluntary, and the possibility exists of bias based on differences in the catchment areas, regionalization patterns, or other unknown hospital-level factors. In our study, the use of a population-based generalized estimating equation attempted to control for clustering effects by hospital, but additional covariates that may be associated with the hospital to which a child was admitted are difficult to measure. Although the use of propensity scores may allow an estimate of this, the absence of significant collinearity between our measured variables for hospital characteristics makes it difficult to construct these scores in our data set.

The efficacy and indications for CPR in a patient with a pulsatile rhythm but gross hypoperfusion is not clear. Current pediatric advanced life support guidelines state that bradycardia in the presence of poor perfusion is an indication for chest compressions but also acknowledge that an absolute heart rate at which CPR should be initiated has not been identified by current data.<sup>16</sup> In our data set, 289 patients (42%) had CPR initiated while a pulse was present. Although the case definition for the NRCPR is cardiopulmonary arrest requiring chest compressions or defibrillation, it is possible that some of these patients who were not pulseless at the onset of the systematic response received chest compressions when they were not indicated. Because presence of a pulse was univariately associated with both hospital type and 24-hour survival, it was necessary to exclude it as both a confounder and a source of effect modification in our multivariate analyses. Although our data did not, on multivariate analysis, demonstrate an association between 24-hour survival and the presence of a pulse at the initiation of CPR, this group of children bears further study to delineate patient characteristics and clinical interventions that affect their outcomes.

Differences in 24-hour survival from cardiac arrest based on availability of pediatric personnel have potential implications with respect to hospital physician and nursing staffing, mandatory training and certification of caretakers of hospitalized children, and baseline preparedness for critical situations of hospitals that admit children. Future research is required to identify specific processes of care or clinical interventions that are associated with improved short- and longer-term outcomes for infants, children, and adolescents who suffer cardiac arrest, toward which improvements in readiness and knowledge can be directed.

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