ORIGINAL ARTICLE

Outcomes of In-Hospital Ventricular Fibrillation in Children

Ricardo A. Samson, M.D., Vinay M. Nadkarni, M.D., Peter A. Meaney, M.D., M.P.H., Scott M. Carey, Marc D. Berg, M.D., and Robert A. Berg, M.D., for the American Heart Association National Registry of CPR Investigators*

ABSTRACT

BACKGROUND

Ventricular fibrillation and ventricular tachycardia are less common causes of cardiac arrest in children than in adults. These tachyarrhythmias can also begin during cardiopulmonary resuscitation (CPR), presumably as reperfusion arrhythmias. We determined whether the outcome is better for initial than for subsequent ventricular fibrillation or tachycardia.

METHODS

All cardiac arrests in persons under 18 years of age were identified from a large, multicenter, in-hospital cardiac-arrest registry. The results from children with initial ventricular fibrillation or tachycardia, children in whom ventricular fibrillation or tachycardia developed during CPR, and children with no ventricular fibrillation or tachycardia were compared by chi-square and multivariable logistic-regression analysis.

RESULTS

Of 1005 index patients with in-hospital cardiac arrest, 272 (27 percent) had documented ventricular fibrillation or tachycardia during the arrest. In 104 patients (10 percent), ventricular fibrillation or tachycardia was the initial pulseless rhythm; in 149 patients (15 percent), it developed during the arrest. The time of initiation of ventricular fibrillation or tachycardia was not documented in 19 patients. Thirty-five percent of patients with initial ventricular fibrillation or tachycardia survived to hospital discharge, as compared with 11 percent of patients with subsequent ventricular fibrillation or tachycardia (odds ratio, 2.6; 95 percent confidence interval, 1.2 to 5.8). Twenty-seven percent of patients with no ventricular fibrillation or tachycardia survived to hospital discharge, as compared with 11 percent of patients with subsequent ventricular fibrillation or tachycardia (odds ratio, 3.8; 95 percent confidence interval, 1.8 to 7.6).

CONCLUSIONS

In pediatric patients with in-hospital cardiac arrests, survival outcomes were highest among patients in whom ventricular fibrillation or tachycardia was present initially than among those in whom it developed subsequently. The outcomes for patients with subsequent ventricular fibrillation or tachycardia were substantially worse than those for patients with asystole or pulseless electrical activity.

From the Steele Children's Research Center, University of Arizona, Tucson (R.A.S., M.D.B., R.A.B.); Children's Hospital of Philadelphia and University of Pennsylvania — both in Philadelphia (V.M.N., P.A.M.); and Digital Innovation, Forest Hill, Md. (S.M.C.). Address reprint requests to Dr. R. Berg at the Steele Children's Research Center, College of Medicine, University of Arizona, 1501 N. Campbell Ave., P.O. Box 245073, Tucson, AZ 85724-5073, or at rberg@peds.arizona.edu.

*The members of the American Heart Association National Registry of CPR Investigators are listed in the Appendix.

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Ventricular fibrillation and ventricular tachycardia are among the most common causes of cardiac arrest in adults but are much less common causes of cardiac arrest in children. In children, cardiac arrests are more typically the consequence of progressive respiratory failure or shock, with electrocardiographic asystole or pulseless electrical activity, rather than primary arrhythmogenic events. Nevertheless, ventricular fibrillation or tachycardia can also occur during cardiopulmonary resuscitation (CPR) for asystole or pulseless electrical activity after progressive respiratory failure or shock, presumably as a reperfusion arrhythmia.[1-3] We refer to ventricular fibrillation or tachycardia as initial if it is present at the beginning of cardiac arrest and as subsequent if it commences during CPR.

Most studies of in-hospital cardiac arrests in children have been small, single-institution investigations. Shockable rhythms (ventricular fibrillation or tachycardia) were described in 1 to 17 percent of these children.[4-10] The National Registry of CPR (NRCPR) is a large, multicenter database of in-hospital cardiac arrests.[11] We conducted this study to determine the incidence of ventricular fibrillation or tachycardia among the first 1005 consecutive index patients with cardiac arrests in this registry. We hypothesized that the proportion of children with ventricular fibrillation or tachycardia would be substantially higher in this registry than in previous studies, because both initial and subsequent ventricular fibrillation or tachycardia were prospectively and rigorously documented.

In studies in animals, the outcome is better for initial than for subsequent ventricular fibrillation, presumably because the latter is preceded by severe myocardial and cerebral ischemia.[2,12] We therefore hypothesized that the survival outcomes in children would also be better after initial than after subsequent ventricular fibrillation or tachycardia.

METHODS

NRCPR

The NRCPR is a prospective, multisite, in-hospital resuscitation registry sponsored by the American Heart Association. Data were analyzed from all 159 NRCPR hospitals recording cardiac arrests in patients under 18 years of age that provided more than six months of data from January 1, 2000, through June 30, 2004. Because the primary purpose of the NRCPR is quality improvement, participating hospitals are not required to obtain approval from their institutional review boards. Nevertheless, this study was approved by the institutional review boards at the University of Arizona and the Children's Hospital of Philadelphia.

At each institution, research coordinators abstract information about each cardiac arrest from hospital medical records. The resulting database contains precisely defined variables derived from the Utstein-style data-reporting guidelines for cardiac arrest.[13,14] Data abstractors must complete a certification examination consisting of multiple-choice questions and a mock scenario covering operational definitions and criteria for inclusion and exclusion.

Case-study methods were used to evaluate data abstraction, the accuracy of entries, and compliance with operational definitions before data were accepted. The six major categories of variables are facility data, patient demographic data, pre-event data, event data, outcome data, and quality-improvement data. Explicit operational definitions were generated for every data element. An index event is defined as the patient's first cardiac arrest during hospitalization. Each patient is assigned a unique code, and specific patient identifiers are not transmitted to the central database repository, in compliance with Healthcare Information Portability and Accountability Act regulations. The data are securely submitted to a central data repository (Digital Innovation). The American Heart Association oversees the entire process of data collection, analysis, and reporting through its national center staff, scientific advisory board, and executive database steering committee.

Ventricular fibrillation and ventricular tachycardia occurring during pulseless cardiac arrest were combined, because their epidemiologic characteristics and treatment are similar and because pulseless ventricular tachycardia often converts to ventricular fibrillation.[14,15]

PARTICIPANTS

All patients under 18 years of age with cardiac arrest at participating institutions were eligible for this study. Comprehensive and redundant methods to include all cardiac arrests included review of hospital and unit-based cardiac-arrest medical-record logs, hospital telephone and page-operator logs of all cardiac-arrest calls, “code blue” committee minutes, pharmacy and material-management “code-cart” records, pharmacy tracer drug records for resuscitation medications, and routine “walk-through” rounds in high-risk areas (e.g., intensive care units). Cardiac arrest was defined as the documented cessation of cardiac mechanical activity as determined by the absence of a palpable central pulse, unresponsiveness, and apnea. Out-of-hospital arrests, arrests occurring in the delivery room or neonatal intensive care unit, and arrests resolved by implantable cardioverter–defibrillator shocks were excluded.

OUTCOMES

The prospectively selected primary outcome measure was survival to hospital discharge.[13-16] The secondary outcome measures included return of spontaneous circulation for more than 20 minutes, 24-hour survival, and the neurologic outcome. The neurologic outcome was determined according to the pediatric cerebral performance category (PCPC) scale, in which category 1 represents a normal neurologic state, 2 mild disability, 3 moderate disability, 4 severe disability, 5 coma or vegetative state, and 6 death.[17,18] Neurologic status before the arrest and at discharge was determined by chart review. A good neurologic outcome was defined by a PCPC score of 1, 2, or 3 or no change from baseline PCPC score.[4] Outcomes and other data were described and analyzed only for the initial cardiac arrest if a child had more than one arrest.[14]

STATISTICAL ANALYSIS

All statistical analyses were performed with a commercially available statistical package (SAS, version 8.2). Summary results are presented as means ±SD for variables that are distributed normally. Differences between groups in discrete variables were analyzed by the chi-square test or Fisher’s exact test. Variables that were not distributed normally are presented as medians and interquartile ranges. Differences between groups were analyzed by the Wilcoxon rank-sum test for continuous variables and the chi-square test for dichotomous variables. Comparisons between subgroups of patients with ventricular fibrillation or tachycardia were further assessed by multiple logistic-regression analysis. Patient and event variables associated with survival by univariate analysis ($P<0.05$) were included in multivariable logistic-regression analysis. On the basis of the a priori assumption that the duration of CPR is in the causal pathway between rhythm group and outcome (i.e., patients with subsequent ventricular fibrillation or tachycardia underwent CPR for some time before the rhythm changed, and factors associated with prolonged CPR were potentially mediators of worse outcome), the duration of CPR was not included in the initial multivariable analyses. Nevertheless, post hoc multivariable logistic-regression analyses adjusted for the duration of CPR were performed. Odds ratios for survival and 95 percent confidence intervals were determined for factors that demonstrated significant confounding. The sample size was not planned. All P values are two-sided and have not been adjusted for multiple testing.

The integrity of the data was checked by means of a detailed periodic reabstraction process. NRCPR participants were asked to submit records of events they had entered into the database for the preceding quarter. Code numbers were assigned to each record and facility and patient identifiers were stripped from the record to ensure confidentiality. A random sample of stripped event records and corresponding NRCPR worksheets were sent to clinicians on the NRCPR scientific advisory board, who identified errors on the worksheet or indicated whether a data element could not be confirmed by the event record. The mean error rate for all data was 2.5±2.7 percent. A Web-based remediation program was developed to remediate and support data integrity continuously for participating sites. Ongoing enrollment of new hospitals involves certification of data accuracy before data are accepted in the central database.

RESULTS

Of 1005 index children with cardiac arrests at 159 participating centers, 272 (27 percent) had documented ventricular fibrillation or tachycardia at some point during the arrest and 733 (73 percent) had no documented ventricular fibrillation or tachycardia (Fig. 1). Ventricular tachycardia was diagnosed in 78 of 272 patients with ventricular fibrillation or tachycardia (29 percent). The incidence of ventricular fibrillation or tachycardia according to age was 27 of 130 neonates (21 percent), 64 of 302 infants from 1 month to

1 year of age (21 percent), 64 of 260 young children from 1 through 7 years of age (25 percent), and 117 of 313 older children from 8 through 17 years of age (37 percent). A total of 104 patients (10 percent) had initial ventricular fibrillation or tachycardia, and 149 (15 percent) had subsequent ventricular fibrillation or tachycardia. In 19 patients (2 percent), ventricular fibrillation or tachycardia occurred during the arrest but the initial arrest rhythm was not documented. Consequently, these 19 patients were excluded from both the initial and the subsequent ventricular fibrillation or tachycardia groups. In 131 patients without documented ventricular fibrillation or tachycardia, the initial pulseless rhythm was not described, and these patients were also excluded from further analysis.

The characteristics of the patients in the initial and the subsequent ventricular fibrillation or tachycardia groups before the cardiac arrest and the characteristics of the arrest are listed in Tables 1 and 2, respectively. The characteristics of the patients before the arrest were similar in the two groups, although congestive heart failure and medical cardiac illnesses were more common among patients with initial ventricular fibrillation or tachycardia, and hypotension and metabolic abnormalities were more common among patients with subsequent ventricular fibrillation or tachycardia. Age was not independently associated with the timing of ventricular fibrillation or tachycardia or with the outcome. In both groups, the factors immediately related to the cardiac arrest were most commonly shock or an acute respiratory deterioration. Hypotension was more commonly the immediate factor related to arrest in patients with subsequent ventricular fibrillation or tachycardia than in those with initial ventricular fibrillation or tachycardia (58 percent vs. 43 percent, P<0.05). The only prearrest proarrhythmic treatments documented in the database were vasoactive infusions. The types of CPR interven-

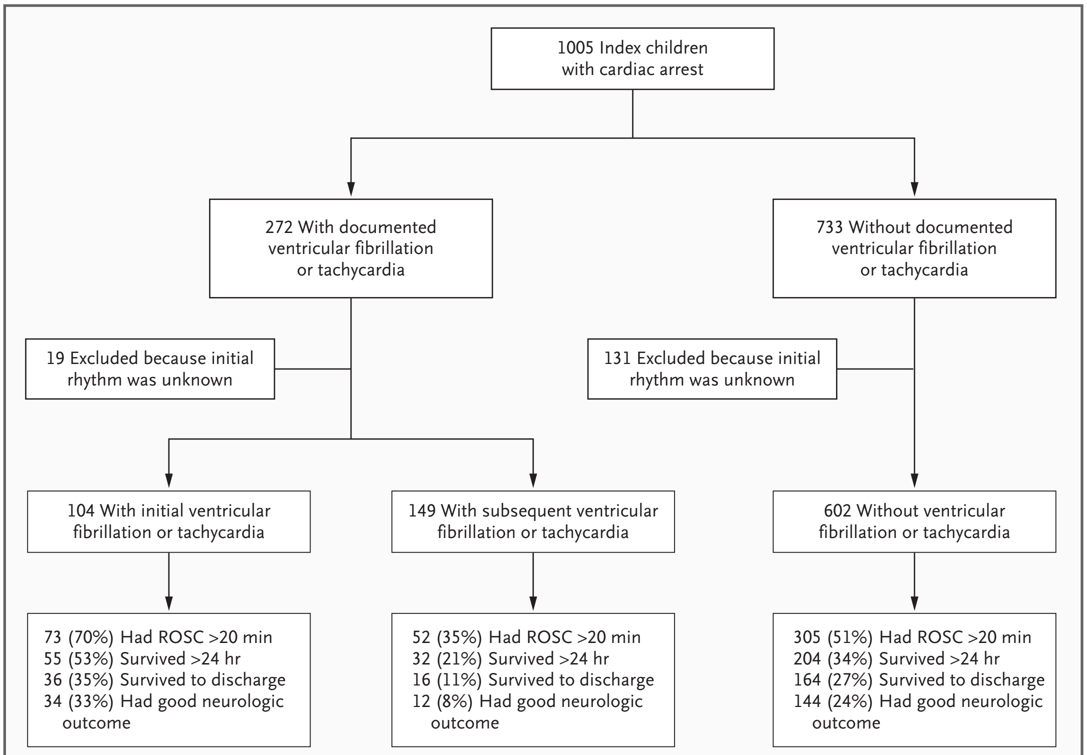

Figure 1. Enrollment and Outcomes.

Among patients with subsequent ventricular fibrillation or tachycardia, asystole or pulseless electrical activity was documented as the initial rhythm during the cardiac arrest. A good neurologic outcome is defined by a pediatric cerebral performance category of 1, 2, or 3 at discharge or no change in pediatric cerebral performance category from prearrest status. ROSC denotes return of spontaneous circulation.

Table 1. Characteristics of the Patients before Cardiac Arrest.*

Characteristic	Initial Ventricular Fibrillation or Tachycardia (N=104)	Subsequent Ventricular Fibrillation or Tachycardia (N=149)	No Ventricular Fibrillation or Tachycardia (N=602)
Age — yr			
Median	4.0	4.0	1.4
Interquartile range	0–14	0 –15	0–9
Male sex — no. (%)	59 (57)	84 (56)	327 (54)
Race or ethnic group — no. (%)†			
White	58 (56)	72 (48)	303 (50)
Black	14 (14)‡§	45 (30)	163 (27)
Hispanic	17 (16)	13 (9)	69 (11)
Other or unknown	15 (14)	19 (13)	67 (11)
Event location — no. (%)			
Intensive care unit (including operating room and PACU)	85 (82)§	108 (72)§	395 (66)
Inpatient monitored	3 (3)	4 (3)	10 (2)
Inpatient ward	8 (8)	17 (11)	83 (14)
Emergency department	8 (8)¶	17 (11)¶	101 (17)
Other or unknown	0	3 (2)	13 (2)
Illness category — no. (%)			
Medical, cardiac	32 (31)‖ **	28 (19)	93 (15)
Medical, noncardiac	32 (31)†† **	65 (44)	302 (50)
Surgical, cardiac	19 (18)	25 (17)	101 (17)
Surgical, noncardiac	4 (4)	8 (5)	42 (7)
Trauma	16 (15)¶	23 (15)¶	53 (9)
Other	1 (1)	0	11 (2)

tions were similar, although sodium bicarbonate, epinephrine, atropine, calcium, and extracorporeal membrane oxygenation were more commonly administered to patients with subsequent ventricular fibrillation or tachycardia. The duration of CPR was less than 15 minutes in 44 percent of patients with initial ventricular fibrillation or tachycardia, as compared with only 14 percent of those with subsequent ventricular fibrillation or tachycardia (P<0.001). Moreover, the median duration of CPR was longer in patients with subsequent ventricular fibrillation or tachycardia (30 vs. 20 minutes, P<0.01).

Some potentially confounding factors significantly related to each primary and secondary survival outcome are listed in Table 3. Comparisons of the primary and secondary outcomes are shown in Table 4, after adjustment for these potentially confounding factors. As hypothesized, the primary and secondary survival outcomes were better in the group with initial ventricular fibrillation or tachycardia than in the group with subsequent ventricular fibrillation or tachycardia. Thirty-five percent of patients with initial ventricular fibrillation or tachycardia survived to hospital discharge, as compared with 11 percent of those with subsequent ventricular fibrillation or tachycardia (adjusted odds ratio, 2.6; 95 percent confidence interval, 1.2 to 5.8). In contrast, there were no significant differences in outcomes between patients with initial ventricular fibrillation or tachycardia and those without ventricular fibrillation or tachycardia.

Unexpectedly, the outcomes were substantially

Table 1. (Continued.)

Characteristic	Initial Ventricular Fibrillation or Tachycardia (N=104)	Subsequent Ventricular Fibrillation or Tachycardia (N=149)	No Ventricular Fibrillation or Tachycardia (N=602)
Preexisting conditions — no. (%)			
Respiratory insufficiency	56 (54)	88 (59)	360 (60)
Hypotension	27 (26)‖ ¶	55 (37)	248 (41)
Congestive heart failure	43 (41)‖ ¶	48 (32)	175 (29)
Pneumonia or septicemia	22 (21)	33 (22)	141 (23)
Renal insufficiency	9 (9)‡	30 (20)§	67 (11)
Metabolic or electrolyte abnormality	7 (7)†† **	34 (23)	137 (23)
Toxicologic problem	3 (3)	4 (3)	5 (1)
None	5 (5)	7 (5)	51 (8)
Mode of discovery of event — no. (%)‡‡			
Witnessed	101 (97)	142 (95)	558 (93)
Monitored by ECG	94 (90)¶	135 (91)¶	480 (80)
Monitored by pulse oximetry	92 (88)¶	131 (88)¶	482 (80)
Interventions in place at time of event — no. (%)			
Vascular access	96 (92)**	142 (95)**	508 (84)
Arterial catheter	42 (40)§	52 (35)§	160 (27)
Vasoactive infusion	48 (46)¶	70 (47)¶	218 (36)
Mechanical ventilation	63 (61)	91 (61)	348 (58)

* ICU denotes intensive care unit, PACU post-anesthesia care unit, and ECG electrocardiogram.
† Race or ethnic group was self-reported or reported by parents or guardians.
‡ P<0.01 for the comparison with the group with subsequent ventricular fibrillation or tachycardia.
§ P<0.01 for the comparison with the group without ventricular fibrillation or tachycardia.
¶ P<0.05 for the comparison with the group without ventricular fibrillation or tachycardia.
‖ P<0.05 for the comparison with the group with subsequent ventricular fibrillation or tachycardia.
** P<0.001 for the comparison with the group without ventricular fibrillation or tachycardia.
†† P<0.001 for the comparison with the group with subsequent ventricular fibrillation or tachycardia.
‡‡ The NRCPR definition of "monitored" includes monitoring by ECG, by apnea–bradycardia monitor, or by pulse oximeter.

worse in the group with subsequent ventricular fibrillation or tachycardia than in the group without ventricular fibrillation or tachycardia (Table 4). The rate of survival to hospital discharge was 27 percent in the group without ventricular fibrillation or tachycardia, as compared with 11 percent in the group with subsequent ventricular fibrillation or tachycardia (adjusted odds ratio, 3.8; 95 percent confidence interval, 1.8 to 7.6). The characteristics of these two groups before the arrest were similar, except that patients with subsequent ventricular fibrillation or tachycardia were more likely to have had medical cardiac disease, trauma, renal insufficiency, vasoactive-drug infusions, vascular access, and monitoring before the arrest (Table 1). Although the CPR interventions were similar, patients with subsequent ventricular fibrillation or tachycardia were more likely to receive sodium bicarbonate, epinephrine, atropine, vasopressin, calcium, antiarrhythmic agents, and extracorporeal membrane oxygenation. The duration of CPR was less than 15 minutes in only 14 percent of patients with subsequent ventricular fibrillation or tachycardia, as compared with 33 percent of those with no ventricular fibrillation or tachycardia (P<0.001). Moreover, the median duration of CPR was longer in patients with subsequent ventricular fibrillation or tachycardia than in those with initial ventricular fibrillation or tachycardia (30 vs. 20 minutes, P=0.004).

Table 2. Characteristics of the Cardiac Arrest.*

Characteristic	Initial Ventricular Fibrillation or Tachycardia (N=104)	Subsequent Ventricular Fibrillation or Tachycardia (N=149)	No Ventricular Fibrillation or Tachycardia (N=602)
Immediate factors related to event — no. (%)			
Acute respiratory insufficiency	44 (42)	81 (54)	316 (52)
Hypotension	45 (43)†‡	87 (58)	348 (58)
Acute myocardial infarction or ischemia	1 (1)	2 (1)	8 (1)
Metabolic or electrolyte disturbance	8 (8)	25 (17)	77 (13)
Acute pulmonary edema	5 (5)†	13 (9)‡	18 (3)
Airway obstruction	3 (3)	3 (2)	32 (5)
Toxicologic problem	1 (1)	3 (2)	4 (1)
Interval to initiation of CPR — min§			
Median	0¶	0‖	0**
Interquartile range	0–0	0–0	0–0
Interval to first attempted defibrillation — min			
Median	1††	0‡‡	NA
Interquartile range	0–4	0–2	NA
Duration of CPR — min			
Median	20†§§	30‡¶¶	20‖‖
Interquartile range	7–37	15–53	9–38
Interval to first epinephrine dose — min			
Median	2***	0†††	0‡‡‡
Interquartile range	0–5	0–3	0–0
Pharmacologic interventions — no. (%)			
Fluid bolus	30 (29)§§§¶¶¶	62 (42)	256 (43)
Atropine	26 (25)§§§ ¶¶¶	84 (56)	262 (44)
Sodium bicarbonate	63 (61)§§§	123 (83)¶¶¶	370 (61)
Vasopressin	7 (7)	12 (8)	24 (4)
Magnesium sulfate	16 (15)¶¶¶	26 (17)¶¶¶	19 (3)
Calcium chloride or calcium gluconate	50 (48)§§§	96 (64)¶¶¶	258 (43)
Amiodarone	24 (23)¶¶¶	23 (15)¶¶¶	13 (2)
Procainamide	1 (1)	5 (3)¶¶¶	2 (<1)
Lidocaine	49 (47)¶¶¶	56 (38)¶¶¶	31 (5)

Among those with subsequent ventricular fibrillation or tachycardia, survivors were more likely than nonsurvivors to have been born prematurely (24 percent vs. 3 percent, P=0.004) and less likely to have hypotension (31 percent vs. 61 percent, P=0.04).

Overall, more survivors than nonsurvivors underwent CPR for less than 15 minutes (58 percent vs. 32 percent, P<0.001). The rates of survival to discharge among the three groups (initial, subsequent, or no ventricular fibrillation or tachycardia) were similar, with or without post hoc adjustment for the duration of CPR (Table 5).

DISCUSSION

This report of 1005 consecutive in-hospital pediatric cardiac arrests documents the shockable rhythms of ventricular fibrillation or tachycardia in 272 arrests (27 percent). These tachyarrhythmias

Table 2. (Continued.)

Characteristic	Initial Ventricular Fibrillation or Tachycardia (N=104)	Subsequent Ventricular Fibrillation or Tachycardia (N=149)	No Ventricular Fibrillation or Tachycardia (N=602)
No. of epinephrine doses given — no. (%)‖‖‖			
0	31 (30)§§§ ¶¶¶	4 (3)	64 (11)
1–2	19 (18)†	12 (8)‡	109 (18)
> 2	25 (24)§§§	81 (54)¶¶¶	215 (36)
Unknown	29 (28)	52 (35)	214 (36)
No. of shocks given — no. (%)			NA
0	0	0	
1–2	34 (33)	55 (37)	
> 2	37 (36)	64 (43)	
Unknown	33 (32)	30 (20)	
Induced hypothermia — no. (%)	1 (1)	3 (2)‡	0
ECMO — no. (%)	9 (9)	20 (13)¶¶¶	30 (5)

* NA denotes not applicable, and ECMO extracorporeal-membrane oxygenation.
† P<0.05 for the comparison with the group with subsequent ventricular fibrillation or tachycardia.
‡ P<0.05 for the comparison with the group without ventricular fibrillation or tachycardia.
§ All intervals commence with recognition of the cardiac arrest.
¶ The data were obtained from 95 patients.
‖ The data were obtained from 139 patients.
** The data were obtained from 576 patients.
†† The data were obtained from 74 patients.
‡‡ The data were obtained from 108 patients.
§§ The data were obtained from 99 patients.
¶¶ The data were obtained from 126 patients.
‖‖ The data were obtained from 535 patients.
*** The data were obtained from 65 patients.
††† The data were obtained from 73 patients.
‡‡‡ The data were obtained from 369 patients.
§§§ P<0.01 for the comparison with the group with subsequent ventricular fibrillation or tachycardia.
¶¶¶ P<0.01 for the comparison with the group without ventricular fibrillation or tachycardia.
‖‖‖ The number of epinephrine doses was not recorded before September 2003.

occurred as the initial cardiac-arrest rhythm in about 10 percent of patients and as a subsequent rhythm in about 15 percent. The data also establish that the outcomes of initial ventricular fibrillation or tachycardia are superior to those of subsequent ventricular fibrillation or tachycardia. Moreover, the outcomes of subsequent ventricular fibrillation or tachycardia are substantially worse than those of the nonshockable rhythms of asystole and pulseless electrical activity.

In prior investigations of in-hospital pediatric cardiac arrests, ventricular fibrillation or tachycardia was described in 1 to 17 percent of the patients.[4-10] However, those studies were limited by the small numbers of patients, and they reported only initial cardiac-arrest rhythms. In the previous studies, the actual number of children with initial ventricular fibrillation or tachycardia ranged from 1 to 24.[4-10] Furthermore, the study that reported the lowest incidence of ventricular fibrillation or tachycardia excluded children with medical and surgical cardiac disease — children who are especially likely to have ventricular fibrillation or tachycardia.[4] The larger number of patients and the multicenter nature of our study allow for meaningful comparisons of subgroups (e.g., initial vs. subsequent ventricular fibrillation or tachycardia) and suggest greater generalizability to in-hospital pediatric cardiac arrests throughout the United States.

Sudden arrhythmic events (ventricular fibrillation or tachycardia) are among the most common

Table 3. Factors Significantly Associated with Survival in Multivariable Analysis.*

Factor	No. of Patients	Primary Outcome (Survival to Discharge)	Secondary Outcomes		
			Survival for 20 min	Survival for 24 hr	Survival with Good Neurologic Outcome
Preexisting conditions					
Cardiac surgery — no. (%)	145	53 (37)	83 (57)	71 (49)	49 (34)
No cardiac surgery — no. (%)	710	162 (23)	347 (49)	220 (31)	143 (20)
Odds ratio (95% CI)		2.3 (1.3–3.9)	1.6 (0.9–2.7)	2.5 (1.5–4.3)	2.4 (1.4-4.2)
Major trauma — no. (%)	95	10 (11)	36 (38)	16 (17)	10 (11)
No major trauma — no. (%)	760	205 (27)	394 (52)	275 (36)	182 (24)
Odds ratio (95% CI)		0.3 (0.2– 0.7)	0.5 (0.3–0.9)	0.4 (0.2–0.7)	0.4 (0.2–0.8)
Septicemia — no. (%)	118	10 (8)	51 (43)	27 (23)	9 (8)
No septicemia — no. (%)	737	205 (28)	379 (51)	264 (36)	183 (25)
Odds ratio (95% CI)		0.3 (0.1– 0.6)	0.8 (0.5–1.2)	0.6 (0.4–1.1)	0.3 (0.1–0.7)
Renal insufficiency — no. (%)	106	14 (13)	57 (54)	33 (31)	12 (11)
No renal insufficiency — no. (%)	749	201 (27)	373 (50)	258 (34)	180 (24)
Odds ratio (95% CI)		0.5 (0.2–0.9)	1.3 (0.8–2.2)	1.0 (0.6–1.8)	0.5 (0.2–1.0)†
Cancer — no. (%)	40	2 (5)	18 (45)	9 (23)	1 (3)
No cancer — no. (%)	815	213 (26)	412 (51)	282 (35)	191 (23)
Odds ratio (95% CI)		0.2 (0.0–0.7)	0.6 (0.3–1.3)	0.5 (0.2–1.1)	0.1 (0.0–0.6)
Prearrest interventions					
Arterial catheter — no. (%)	253	64 (25)	143 (57)	106 (42)	57 (23)
No arterial catheter — no. (%)	602	151 (25)	287 (48)	185 (31)	135 (22)
Odds ratio (95% CI)		1.6 (1.0–2.5)	1.9 (1.3–2.8)	2.3 (1.5–3.5)	1.4 (0.8–2.2)
Vasoactive infusions — no. (%)	336	65 (19)	156 (46)	109 (32)	60 (18)
No vasoactive infusions — no. (%)	519	150 (29)	274 (53)	182 (35)	132 (25)
Odds ratio (95% CI)		0.4 (0.3–0.7)	0.5 (0.3–0.7)	0.5 (0.4– 0.8)	0.4 (0.3–0.7)
Factor immediately associated with event					
Airway obstruction — no. (%)	38	21 (55)	28 (74)	20 (53)	15 (39)
No airway obstruction — no. (%)	817	194 (24)	402 (49)	271 (33)	177 (22)
Odds ratio (95% CI)		2.9 (1.4–6.3)	2.3 (1.0–5.3)	1.7 (0.8–3.6)	1.6 (0.7–3.5)
Interventions					
ECMO — no. (%)	59	22 (37)	44 (75)	40 (68)	20 (34)
No ECMO — no. (%)	796	193 (24)	386 (48)	251 (32)	172 (22)
Odds ratio (95% CI)		3.6 (1.8–7.2)	5.1 (2.5–10.7)	8.0 (3.9–16.6)	3.4 (1.7–7.1)
Sodium bicarbonate — no. (%)	556	105 (19)	258 (46)	162 (29)	89 (16)
No sodium bicarbonate — no. (%)	299	110 (37)	172 (58)	129 (43)	103 (35)
Odds ratio (95% CI)		0.8 (0.5–1.2)	1.2 (0.8–1.8)	1.0 (0.7–1.6)	0.7 (0.4–1.1)
Calcium — no. (%)	404	71 (18)	183 (45)	118 (29)	61 (15)
No calcium — no. (%)	451	144 (32)	247 (55)	173 (38)	131 (29)
Odds ratio (95% CI)		0.6 (0.4–1.0)†	0.8 (0.6–1.2)	0.8 (0.5–1.1)	0.6 (0.4–0.9)
>2 Doses of epinephrine — no. (%)	616	102 (17)	239 (39)	143 (23)	84 (14)
1–2 Doses of epinephrine — no. (%)	140	52 (37)	105 (75)	74 (53)	48 (34)
No epinephrine — no. (%)	99	61 (62)	86 (87)	74 (75)	60 (61)
Odds ratio (95% CI)		0.4 (0.3–0.6)	0.3 (0.2–0.4)	0.3 (0.2–0.4)	0.4 (0.3–0.5)

* CI denotes confidence interval, and ECMO extracorporeal membrane oxygenation.
† The 95 percent confidence interval was rounded to 1.0 even though the actual interval does not contain 1.0.

causes of cardiac arrest in adults and are often associated with coronary artery disease. Children rarely have coronary artery disease, and their cardiac arrests are typically due to progressive hypoxia, ischemia, or both. Moreover, studies in animals indicate that a critical mass of myocardium is necessary to maintain ventricular fibrillation, a result raising the possibility that neonates and infants are less likely to have ventricular fibrillation because of their small myocardial mass.[19] Nevertheless, our results show that the incidence of ventricular fibrillation or tachycardia is substantial among children with in-hospital cardiac arrest, even among infants and newborns.

We hypothesized that patients with initial ventricular fibrillation or tachycardia would have better outcomes than those with subsequent ventricular fibrillation or tachycardia, because the latter often had severe myocardial and cerebral hypoxia or ischemia before the development of ventricular fibrillation or ventricular tachycardia. Those with subsequent ventricular fibrillation or tachycardia were more likely to have hypotension before the arrest and more likely to have hypotension as the immediate factor related to the event. Only 14 percent of the patients with subsequent ventricular fibrillation or tachycardia underwent CPR for less than 15 minutes, as compared with 44 percent of those with initial ventricular fibrillation or tachycardia.

To our surprise, patients with subsequent ventricular fibrillation or tachycardia had worse outcomes than those without ventricular fibrillation or tachycardia, even though the former were more likely to have been monitored before the arrest and the preexisting conditions and precipitating causes of the arrests were similar in the two groups. This finding is in direct contrast to experimental evidence demonstrating that the induction of ventricular fibrillation during CPR for asystole (followed by defibrillation) improves the outcome of asystolic cardiac arrest.[20] The duration of CPR was less than 15 minutes in only 14 percent of patients with subsequent ventricular fibrillation or tachycardia, as compared with 33 percent of those without ventricular fibrillation or tachycardia (P<0.001).

Why was the outcome so poor among patients with subsequent ventricular fibrillation or tachycardia? Plausible explanations include a delay in the diagnosis of subsequent ventricular fibrillation or tachycardia during the resuscitative efforts,

Table 4. Comparison of Major Outcomes.*

Outcome	Initial (N=104) vs. Subsequent (N=149) Ventricular Fibrillation or Tachycardia	No (N=602) vs. Subsequent (N=149) Ventricular Fibrillation or Tachycardia
Primary outcome		
Survival to hospital discharge — %	35 vs. 11	27 vs. 11
Odds ratio (95% CI)	2.6 (1.2–5.8)	3.8 (1.8–7.6)
Secondary outcomes		
Return of spontaneous circulation for >20 min — %	70 vs. 35	51 vs. 35
Odds ratio (95% CI)	2.8 (1.5–5.4)	2.1 (1.3–3.4)
24-Hr survival — %	53 vs. 21	34 vs. 21
Odds ratio (95% CI)	2.9 (1.5–5.8)	2.3 (1.3–4.1)
Good neurologic outcome — %	33 vs. 8	24 vs. 8
Odds ratio (95% CI)	2.8 (1.2–6.6)	3.8 (1.8–8.1)

* There were 104 children with initial ventricular fibrillation or tachycardia, 149 with subsequent ventricular fibrillation or tachycardia, and 602 without ventricular fibrillation or tachycardia. CI denotes confidence interval. The odds ratios were adjusted for factors associated with each outcome measure after multivariable logistic regression. All comparisons revealed significant differences at P<0.05.

adverse effects of resuscitative interventions (e.g., too much epinephrine), and the severity of the underlying myocardial condition. Unfortunately, our registry data cannot provide answers to this important question.

Traditionally, ventricular fibrillation and ventricular tachycardia have been considered “good” cardiac-arrest rhythms that result in better outcomes than asystole and pulseless electrical activity.[21-23] Our findings suggest that the outcomes after initial ventricular fibrillation or tachycardia are “good,” but that the outcomes after subsequent ventricular fibrillation or tachycardia are substantially worse than those after asystole or pulseless electrical activity without subsequent ventricular fibrillation or tachycardia (Table 4).

Like all multicenter registries, the database used in this study has potential limitations related to the integrity and validity of the data and sampling bias. The rigorous abstractor-training process, uniform data collection, use of consistent definitions, detailed periodic reabstraction process, and large sample were prospectively instituted to address the issues of data integrity and validity. The data are from consecutive cases of cardiac arrest in children reported voluntarily by

Table 5. Survival to Hospital Discharge with Post Hoc Adjustment for Duration of CPR.*

Outcome	Initial (N=99) vs. Subsequent (N=126) Ventricular Fibrillation or Tachycardia	No (N=535) vs. Subsequent (N=126) Ventricular Fibrillation or Tachycardia
Survival to hospital discharge — %	35 vs. 9	26 vs. 9
Unadjusted odds ratio (95% CI)	3.3 (1.4–8.0)	4.3 (1.9–9.7)
Adjusted odds ratio (95% CI)	3.3 (1.3–8.0)	4.5 (2.0–10.0)

* There were 99 children with initial ventricular fibrillation or tachycardia, 126 with subsequent ventricular fibrillation or tachycardia, and 535 without ventricular fibrillation or tachycardia. CI denotes confidence interval. The odds ratios were adjusted for factors associated with each outcome measure after multivariable logistic regression. All comparisons revealed significant differences at $P<0.05$. Data from 95 patients were excluded from these post hoc analyses because the duration of CPR was not documented.

institutions. Efforts to minimize sampling biases included comprehensive and redundant methods to ascertain all cardiac-arrest cases, strict inclusion and exclusion criteria, a large sample, and the multi-institutional study design.

How should these results affect our approach to children with in-hospital cardiac arrest? First, the results emphasize the importance of early electrocardiographic monitoring during resuscitation, because the shockable rhythms of ventricular fibrillation or tachycardia occurred in more than 25 percent of these children. Even in the setting of progressive respiratory failure and shock, with an initial electrocardiogram showing asystole or pulseless electrical activity, subsequent shockable ventricular fibrillation or tachycardia developed in a substantial number of these children during CPR. Prompt, successful resuscitation from ventricular fibrillation requires electrocardiographic diagnosis and defibrillation. Second, many children can have good outcomes after cardiac arrest, including children with initial ventricular fibrillation or tachycardia, subsequent ventricular fibrillation or tachycardia, and nonshockable rhythms (asystole or pulseless electrical activity). Although most children with cardiac arrest do not survive to hospital discharge, CPR and advanced life support are certainly not futile. Even though the outcomes were worse among patients with subsequent ventricular fibrillation or tachycardia than in the other groups, more than 10 percent of these children survived to hospital discharge. Finally, prompt diagnosis and defibrillation in children with initial ventricular fibrillation or tachycardia are often lifesaving: one third of these children survived to hospital discharge, and most of them had good neurologic outcomes.

The shockable rhythms of ventricular fibrillation or tachycardia occurred in 27 percent of children with in-hospital cardiac arrest. The outcome of initial ventricular fibrillation or tachycardia, presumably the arrhythmogenic precipitant of the cardiac arrest, was quite different from that of subsequent ventricular fibrillation or tachycardia, presumably a reperfusion arrhythmia. Survival outcomes were substantially better after initial than after subsequent ventricular fibrillation or tachycardia. Moreover, the outcomes of subsequent ventricular fibrillation or tachycardia were substantially worse than the outcomes of the nonshockable rhythms of asystole and pulseless electrical activity.

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APPENDIX

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