Effect of a Rapid Response Team on Hospital-wide Mortality and Code Rates Outside the ICU in a Children's Hospital

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Context Introduction of a rapid response team (RRT) has been shown to decrease mortality and cardiopulmonary arrests outside of the intensive care unit (ICU) in adult inpatients. No published studies to date show significant reductions in mortality or cardiopulmonary arrests in pediatric inpatients.

Objective To determine the effect on hospital-wide mortality rates and code rates outside of the ICU setting after RRT implementation at an academic children's hospital.

Design, Setting, and Participants A cohort study design with historical controls at a 264-bed, free-standing, quaternary care academic children's hospital. Pediatric inpatients who spent at least 1 day on a medical or surgical ward between January 1, 2001, and March 31, 2007, were included. A total of 22 037 patient admissions and 102 537 patient-days were evaluated preintervention (before September 1, 2005), and 7257 patient admissions and 34 420 patient-days were evaluated postintervention (on or after September 1, 2005).

Intervention The RRT included a pediatric ICU–trained fellow or attending physician, ICU nurse, ICU respiratory therapist, and nursing supervisor. This team was activated using standard criteria and was available at all times to assess, treat, and triage decompensating pediatric inpatients.

Main Outcome Measures Hospital-wide mortality rates and code (respiratory and cardiopulmonary arrests) rates outside of the ICU setting. All outcomes were adjusted for case mix index values.

Results After RRT implementation, the mean monthly mortality rate decreased by 18% (1.01 to 0.83 deaths per 100 discharges; 95% confidence interval [CI], 5%-30%; $P=.007$), the mean monthly code rate per 1000 admissions decreased by 71.7% (2.45 to 0.69 codes per 1000 admissions), and the mean monthly code rate per 1000 patient-days decreased by 71.2% (0.52 to 0.15 codes per 1000 patient-days). The estimated code rate per 1000 admissions for the postintervention group was 0.29 times that for the preintervention group (95% likelihood ratio CI, 0.10-0.65; $P=.008$), and the estimated code rate per 1000 patient-days for the postintervention group was 0.28 times that for the preintervention group (95% likelihood ratio CI, 0.10-0.64; $P=.007$).

Conclusion Implementation of an RRT was associated with a statistically significant reduction in hospital-wide mortality rate and code rate outside of the pediatric ICU setting.

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In the report *To Err Is Human*,[1] the Institute of Medicine concluded that between 44 000 and 98 000 deaths per year occur in hospitals in the United States as a result of errors. Since publication, these data have captured the attention of the nation,[2,3] resulting in aggressive calls for further research,[4,5] regulatory interventions,[6-8] third-party payer involvement,[9,10] and health care organization initiatives to improve this situation. One such initiative, promoted by the Institute for Healthcare Improvement known as the 100 000 Lives Campaign, recommended 6 strategies to decrease the number of preventable inpatient deaths in the United States by 100 000 during the period between December 2004 and June 2006.[11] One of these 6 recommended strategies was the implementation of a rapid response team (RRT).

An RRT, also known as a medical response team or medical emergency team, is a multidisciplinary team most frequently consisting of intensive care

For editorial comment see p 2311.

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unit (ICU)-trained personnel who are available 24 hours per day, 7 days per week for evaluation of patients not in the ICU who develop signs or symptoms of clinical deterioration. At the time of the 100 000 Lives Campaign kickoff, evidence existed that RRTs reduced rates of cardiopulmonary arrests outside of the ICU in adults[12-14] by as much as 67%,[13] and reduced mortality rates in adults[13,15,16] by as much as 35%.[15] The RRT intervention was developed in response to research that revealed adult patients on general medical and surgical hospital units often have evidence of physiological deterioration several hours before cardiopulmonary arrest,[17-20] and that after a cardiac arrest occurred, survival rates were poor.[19,20] Given that there appears to be a window of opportunity to identify and proactively treat "prearrest" adult inpatients effectively, the Institute for Healthcare Improvement recommended RRTs be implemented nationwide in an effort to decrease inpatient mortality rates.

Limited published data exist evaluating the effectiveness of RRT implementation in pediatric inpatients. Similar to adults, evidence exists that pediatric inpatients can manifest physiological deterioration for several hours before cardiopulmonary arrest.[21,22] Furthermore, survival rates of pediatric inpatients following cardiopulmonary arrest, including patients in the ICU, is poor,[22-24] with just 34% surviving 24 hours, 27% surviving to discharge,[23] and 15% surviving 1 year.[24] Survival data focusing on codes outside of the pediatric ICU setting are similar, with just 33% surviving to discharge.[23,24] These data suggest RRTs have the potential to be an effective intervention in pediatric inpatients as well.

To date, however, there are only 2 published studies describing the effect of an RRT on pediatric outcomes. In a study at the Royal Children's Hospital in Melbourne, Australia,[25] total hospital cardiopulmonary arrest rates and total hospital mortality for 41 months before and 12 months after RRT implementation were compared, revealing a statistically nonsignificant decrease in both. In patients identified as meeting criteria for RRT intervention, statistically significant decreases in cardiopulmonary arrest and mortality rates were witnessed, although the numbers were small. In the Cincinnati Children's Hospital study,[26] total code rate (respiratory arrests plus cardiopulmonary arrests) and mortality rate were compared for 15 months before and 8 months after implementation of an RRT. A significant decrease in code rate (per non-ICU admissions and per 1000 patient-days) was found, but no difference in hospital-wide mortality rate was observed. Despite this paucity of pediatric data, and no demonstration of significant improvements in pediatric mortality or cardiopulmonary arrest rates outside of the ICU at the time of the 100 000 Lives Campaign kickoff, the Institute for Healthcare Improvement endorsed the RRT recommendation for pediatric inpatients as well.[11] The result was that multiple children's hospitals embarked on this intervention with the hope that the adult experiences would translate to better outcomes for children.

In this study, our goal was to evaluate the effect of RRT implementation on hospital-wide mortality rates and code (respiratory and cardiopulmonary arrests) rates outside of the ICU in pediatric inpatients at an academic children's hospital.

METHODS

To determine the effect of an RRT intervention on hospital-wide mortality rates and code rates outside of the ICU setting, we conducted a cohort study using historical controls at the main campus of Lucile Packard Children's Hospital (LPCH). Lucile Packard Children's Hospital is a 264-bed quaternary care children's hospital of which 218 beds are located on the main campus. The distribution of hospital beds at the main campus includes 76 medical-surgical beds, 64 critical-care beds (12 pediatric ICU, 12 cardiovascular ICU, and 40 neonatal ICU), 52 obstetric beds, and 26 non–neonatal ICU nursery beds. Between September 1, 2005, and August 31, 2006, LPCH had 78 177 inpatient days, 13 265 patient discharges (excludes well newborns), 4490 surgeries, and 5100 births. Lucile Packard Children's Hospital maintains active heart, solid organ and bone marrow transplant services, neurosurgery and cardiovascular surgery programs, and a full complement of pediatric medical and surgical specialties. This project was reviewed and approved by the Stanford University School of Medicine Institutional Review Board. Informed consent was waived.

Participants were included if they were admitted to LPCH between January 1, 2001, and March 31, 2007, and spent at least 1 day on the nonobstetric, non–nursery-based, non-ICU medical or surgical wards. The preintervention period was between January 1, 2001, and August 30, 2005, and the postintervention period was between September 1, 2005, and March 31, 2007. We did not exclude patients admitted during the 3-month rollout period in our study, although rollout periods varying from 2 months to 2 years[12,13,15,25,26] have been excluded from the analysis in prior RRT studies. Patients admitted in the first 3 months after implementation were included in the postintervention group. All obstetric patients, as well as patients managed exclusively in the pediatric ICU, neonatal ICU, cardiovascular ICU, well baby nursery, or the intermediate ICUs were excluded from the analyses. Cardiopulmonary arrests occurring in patients in the operating department or postanesthesia care unit were excluded from the analysis as well.

Intervention

Beginning in December 2004, LPCH constructed an RRT composed of a physician (pediatric ICU attending physician or fellow), an experienced pediatric ICU or cardiovascular ICU nurse, an ICU-trained respiratory therapist, and a nursing supervisor. Education regarding the program and literature were provided to staff on all nonobstetric,

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non–nursery-based, non-ICU medical or surgical patient care units at LPCH during the 2 months (July 2005 to August 2005) before implementation. A wallet-sized index card with RRT information, including circumstances appropriate to activate the RRT, was provided to all appropriate LPCH staff.

When activated, the RRT was expected to initiate an evaluation of a patient within 5 minutes of the call, write orders necessary for any diagnostic studies and therapeutic interventions, discuss management with the primary physician, and determine the optimal location for the patient's care. All RRT calls were activated via the hospital operator using an emergency paging system. The LPCH RRT program was officially launched on September 1, 2005. The criteria recommended to activate the RRT at LPCH, similar to those used in the experiences reported by the studies of Tibballs et al[25] and Brilli et al,[26] were (1) any staff member worried about a patient, (2) acute change in respiratory rate, (3) acute change in oxygen saturation, (4) acute change in heart rate, (5) acute change in blood pressure, and (6) acute change in level of consciousness. We considered allowing parent activation of the RRT; however, at the time of RRT program implementation, the LPCH Family Advisory Council recommended against doing so.

Main Outcome Measures

The primary outcome measures were hospital-wide mortality rates (all deaths, irrespective of where they occurred in the hospital) and code rates outside of the ICU (per 1000 eligible patient-days and per 1000 eligible admissions). A code outside of the ICU was defined as any patient requiring tracheal intubation, chest compressions, or both (respiratory arrest or cardiopulmonary arrest) who was an inpatient on any of the nonobstetric, non–nursery-based, non-ICU medical or surgical units at LPCH. An eligible patient-day was defined as a day during which a patient was an inpatient on 1 of the nonobstetric, non–nursery-based, non-ICU medical or surgical units at LPCH. An eligible patient admission was defined as any admission during which a patient spent at least 1 day on 1 of the nonobstetric, non–nursery-based, non-ICU medical or surgical units at LPCH. Case mix index, based on the US Centers for Medicare and Medicaid Services cost weights, was assessed monthly for the hospital (well baby nursery and obstetric patients were excluded as defined in the Centers for Medicare and Medicaid Services pediatric methodology) and compared preintervention and postintervention to determine if significant differences in severity of illness existed.[27]

Demographic data, including age, sex, and race preintervention and postintervention were assessed as surrogate markers that could reflect important population differences. Race/ethnicity classification was self-reported by the patient or a family member, with standard options provided by LPCH at the time of admission. Data describing the reasons for RRT activation, the actions taken by the RRT once activated, and the patient disposition after RRT were collected. The primary diagnosis assigned to each deceased patient was categorized into a major diagnostic code,[28] and these codes were compared preintervention and postintervention to determine if significant differences in patient diagnoses existed.

Statistical Analysis

A quasi-experimental approach was used to assess the impact of the implementation of the RRT on mortality rate.[29,30] Because the mortality rate outcomes are reported monthly, time series modeling was performed to model the potential autocorrelations in time (high mortality rate in January could possibly affect the mortality rate in February or March). Autoregressive integrated moving average (ARIMA) models with a 12-month seasonality effect were implemented, with the Akaike Information Criterion used for covariance model selection to avoid overparameterization of the time series model while maintaining adequate fit. Normalized prediction errors from the full model were evaluated to ensure model accuracy. Possible linear trends preintervention and postintervention were examined. The estimated coefficient of the preintervention vs postintervention periods is interpreted as the impact of the intervention, expressed as the number of additional or decreased deaths per 100 discharges that have occurred per month since the date of implementation. Similar time series methodology has been recently used to evaluate the efficacy of various public health interventions.[31-33]

Code rates showed no evidence of autocorrelation or seasonality, and many of the months had zero codes. Therefore, codes were modeled using Poisson regression, a method appropriate for data consisting of counts of rare events. With the multiplicative Poisson model, the exponents of the coefficients are equal to the incidence rate ratio (relative risk).[34] Differences in major diagnostic categories preintervention and postintervention were analyzed by using χ^2 tests. All models were adjusted for monthly case mix index.[27] SAS statistical software version 9.1.3 (SAS Institute, Cary, North Carolina) was used for statistical analysis.[35]

RESULTS

There were no significant differences between pre-RRT and post-RRT populations based on age (mean [SD], 6.8 [6.3] vs 7.0 [6.3] years; $P=.13$) or severity of illness as represented by case mix index (mean [SD], 1.74 [0.13] vs 1.74 [0.08]; $P=.99$) (TABLE 1). Statistically significant differences were noted for patient sex (45.2% females vs 46.5% males, $P=.049$) and race/ethnicity, with fewer white and Hispanic individuals, and more black and Asian individuals, in the postintervention group. There was a significant increase in mean (SD) length of stay during the postimplementation period (6.15 [11.1] vs 7.04 [13.6] days, $P<.001$).

A significant decrease in hospital-wide mortality rate of 18% occurred after implementation of the RRT. Mean

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monthly mortality rates preintervention and postintervention were 1.01 and 0.83 deaths per 100 discharges, respectively (95% confidence interval [CI], 5%-30%; $P=.007$) (TABLE 2 and FIGURE 1). The top 3 major diagnostic code categories[28] for the primary diagnosis at death preintervention and postintervention were newborns and other neonates with conditions originating in the perinatal period (40.73% vs 40.49%, $P=.96$), diseases and disorders of the circulatory system (18.0% vs 19.02%, $P=.77$), and diseases and disorders of the respiratory system (7.45% vs 10.43%, $P=.22$). There were no significant differences preintervention and postintervention in the primary diagnosis at death for any of the 25 major diagnostic code categories.

The rate of codes outside of the ICU per 1000 eligible patient-days decreased by 71.2% after RRT implementation, with preintervention and postintervention rates of 0.52 and 0.15, respectively ($P=.008$) (Table 2). The rate of codes outside of the ICU setting per 1000 eligible admissions decreased as well by 71.7%, with preintervention and postintervention rates of 2.45 vs 0.69, respectively ($P=.007$) (Table 2 and FIGURE 2). For comparison, the code rates during the 3-month rollout period (September 1, 2005, to November 30, 2005) were 0.54 per 1000 eligible patient-days and 2.64 per 1000 eligible admissions. The estimated code rate per 1000 admissions for the postintervention group was 0.29 times that for the preintervention group (95% likelihood ratio CI, 0.10-0.65; $P=.008$), and the estimated code rate per 1000 patient-days for the postintervention group was 0.28 times that for the preintervention group (95% likelihood ratio CI, 0.10-0.64; $P=.007$).

The ARIMA (2,0,0)(1,0,0) model contained an intercept term, 2 autocorrelation terms, a yearly seasonal effect, and a significant step intervention starting September 2005. Examination of model fit showed small, normalized prediction errors; all were less than 2.5 in magnitude. Predictor error autocorrelation, partial autocorrelation, and inverse autocorrelation were insignificant at all time lags, indicating that the model prediction errors had no significant patterns that had not been modeled. The white noise test indicated that no significant patterns in the model prediction errors existed, and stationarity of the prediction errors was observed by the unit root and seasonal root tests. There was no evidence of a linear trend preintervention or postintervention. Parameter estimates of the autoregressive integrated moving average intervention model are shown in TABLE 3.

The impact of the RRT intervention, using statistical modeling, was a decrease of 0.178 (95% CI, 0.052-0.304) deaths per 100 discharges or 1.78 deaths per 1000 discharges. The average number of discharges per month in our hospital during the entire study period was 974. Therefore, during the 19-month postintervention period, the RRT intervention is estimated to have resulted in 32.9 lives saved.

During the 19-month postimplementation phase, there were a total of 143 RRT activations. The most common indication for RRT activation was respiratory distress, the most common action taken by the RRT once activated was basic airway support, and the most common patient disposition post-RRT was transfer to the pediatric ICU (TABLE 4). A total of 12 patients died

Table 1. Demographic Characteristics of Pre-RRT and Post-RRT Intervention Populations[a]

Characteristics	Preintervention (n = 22 036)	Postintervention (n = 7287)	*P* Value
Age, mean (SD), y[b]	6.8 (6.3)	7.0 (6.3)	.13
Female, No. (%)	9952 (45.2)	3388 (46.5)	.049
Race/ethnicity, No. (%)[c]			
White, non-Hispanic	11 408 (51.8)	3159 (43.4)	<.001
White, Hispanic	4595 (20.9)	1408 (19.3)	
Black	740 (3.3)	302 (4.1)	
Asian	2397 (10.9)	1021 (14.0)	
Native American	104 (0.5)	105 (1.4)	
Other	1820 (8.6)	899 (12.4)	
Unknown	972 (4.4)	393 (5.4)	
Length of stay, mean (SD), d	6.15 (11.1)	7.04 (13.6)	<.001
Case mix index, mean (SD)[b]	1.74 (0.13)	1.74 (0.08)	.99

Abbreviation: RRT, rapid response team.
[a] Preintervention is between January 1, 2001, and August 31, 2005, and postintervention is between September 1, 2005, and March 31, 2007.
[b] Two-sample *t* test assuming equal variances was used for age and case mix index.
[c] χ^2 Test was used for race/ethnicity.

Table 2. Outcomes Before and After Implementation of an RRT[a]

Outcome	Preintervention	Postintervention	*P* Value
No. of deaths	547	158	NA
No. of hospital-wide admissions	53 911	19 112	NA
Hospital-wide mortality rate per 100 discharges[b]	1.01	0.83	.007[c]
No. of codes	53	5	NA
No. of admissions eligible for RRT	22 037	7257	NA
No. of patient-days eligible for RRT	102 537	34 420	NA
Codes per 1000 patient-days	0.52	0.15	.008[d]
Codes per 1000 admissions	2.45	0.69	.007[d]

Abbreviations: NA, not applicable; RRT, rapid response team.
[a] Preintervention is between January 1, 2001, and August 31, 2005, and postintervention is between September 1, 2005, and March 31, 2007.
[b] Defined as the number of deaths per calendar month divided by the number of admissions per calendar month, excluding obstetric patients.
[c] Autoregressive integrated moving average model intervention analysis.
[d] Poisson regression.

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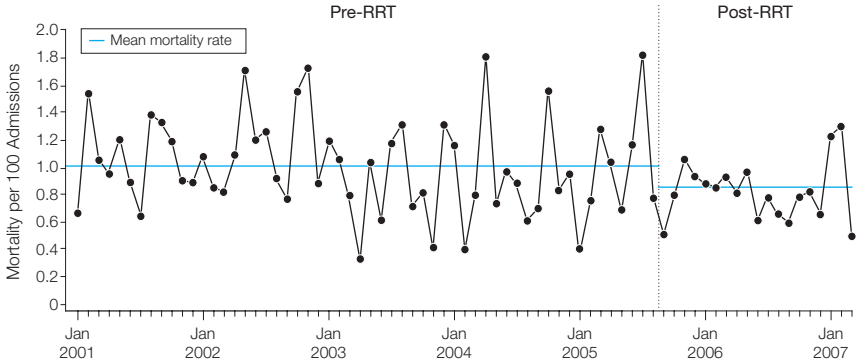
in the pediatric ICU and 2 patients (1 with do not resuscitate/do not intubate status and 1 who had life support withdrawn) died outside of the pediatric ICU; therefore, 129 patients who had treatment by an RRT survived to discharge.

COMMENT

To our knowledge, this is the first published study of pediatric inpatients to show significant reductions in both hospital-wide mortality rate and code rate outside of the ICU setting after implementation of an RRT. These data support the recommendation made by the Institute for Healthcare Improvement in its 100 000 Lives Campaign to implement RRTs as a strategy to decrease nationwide in-hospital mortality. That recommendation was not without controversy. For example, the commentary by Winters et al[37] claimed that there are insufficient data to support the Institute's recommendation to implement RRT programs nationwide. These authors based their conclusions on their own systematic review,[38] which included the influential yet inconclusive MERIT study.[39] Our results add important information to this debate, providing evidence that RRTs can have a significant impact on hospital-wide mortality within a quarternary care children's hospital setting.

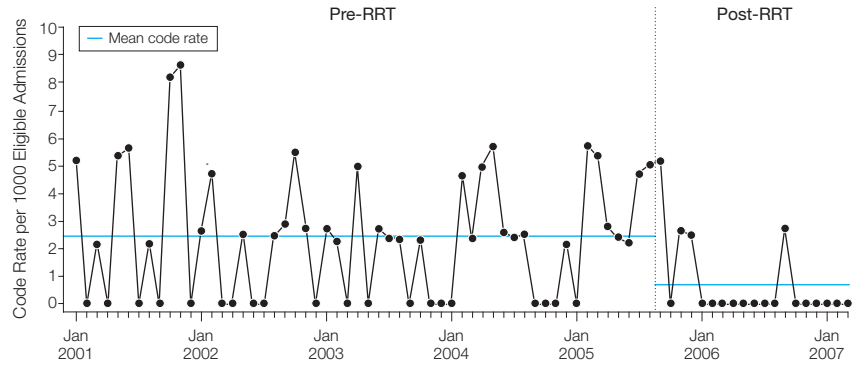
There are at least 2 plausible explanations for the significant reductions in hospital-wide mortality and code rate outside of the pediatric ICU setting witnessed at our hospital vs other pediatric hospitals. First, LPCH serves a particularly high-risk population of hospitalized children. Lucile Packard Children's Hospital had the third highest case mix index among the 76 children's hospitals in the United States included in the National Association of Children's Hospitals and Related Institutions Case Mix Comparative Program between October 1, 2005, and September 30, 2006 (A. Castro, MHA, National Association of Children's Hospitals and Related Institutions, written communication, April 11, 2007). As a result, we speculate that LPCH has a higher proportion of children at risk for codes on its

Figure 1. Hospital-wide Mortality Rates per 100 Admissions by Month, Excluding Obstetrical Population



RRT indicates rapid response team. The pre-RRT period is between January 1, 2001, and August 30, 2005, and the post-RRT period is between September 1, 2005, and March 31, 2007.

Figure 2. Code Rates (Respiratory and Cardiopulmonary Arrests) Outside the Intensive Care Unit Setting per 1000 Eligible Patient Admissions by Month



RRT indicates rapid response team. The pre-RRT period is between January 1, 2001, and August 30, 2005, and the post-RRT period is between September 1, 2005, and March 31, 2007.

Table 3. Parameter Estimates of the Impact of the RRT Intervention on Mortality Rate and Code Rates

Parameter	Estimate (SE)	*P* Value
Mortality rate[a]		
Intercept	0.88 (0.47)	.06
Intervention	−0.18 (0.06)	.007
Case mix index	0.07 (0.27)	.79
Codes per 1000 eligible patient-days[b]		
Intercept	−5.94 (1.75)	<.001
Intervention	−1.27 (0.47)	.007
Case mix index	−0.94 (−0.93)	.35
Codes per 1000 eligible admissions[b]		
Intercept	−4.83 (1.75)	.006
Intervention	−1.25 (0.47)	.008
Case mix index	−0.69 (1.01)	.49

Abbreviation: RRT, rapid response team.
[a] Autoregressive integrated moving average model parameter estimates.
[b] Poisson regression parameter estimates.

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medical and surgical wards than do children's hospitals with lower case mix indexes. A comparison of the preintervention code rate at LPCH to those reported by Royal Children's Hospital in Melbourne and Cincinnati Children's Hospital is consistent with this explanation; LPCH's preintervention code rate outside of the ICU was 12.8 times higher than that reported at Melbourne (2.45 vs 0.1908 per 1000 admissions)[25] and 1.6 times higher than that reported at Cincinnati (2.45 vs 1.54 per 1000 admissions).[26] Indeed, in the study by Tibballs et al,[25] one explanation offered for the lack of a significant decrease in code rate outside of the ICU setting was the "relatively small incidence of paediatric cardiac arrest." This difference in case mix index likely explains why this study found significant improvements in code rate and mortality rate only when including patients who met RRT criteria,[25] and why the study by Brilli et al[26] found a significant decrease in code rate per 1000 patient-days only when using a single-tailed statistical test. We chose not to stratify outcomes based on whether patients met RRT criteria because meeting criteria was not required for RRT consultation. The decision to include all patients eligible for RRT in our analysis rather than just those who met RRT criteria adds further strength to our conclusion that our RRT intervention was associated with significantly improved mortality and code rates, as does the inclusion of the 3-month roll-out phase into the postintervention period for analysis.

A second possible explanation for our improved outcomes is that our postintervention period is substantially longer than both Melbourne's (12 months) and Cincinnati's (8 months). It is possible that the diffusion of the intervention takes several months to occur and the full impact of the RRT intervention was not observed at either Melbourne or Cincinnati during the shorter postintervention time frames they reported. There does not appear to be a significant difference in the composition of RRTs at the 3 sites.

It has been suggested that the improved outcomes associated with RRT implementation might be the result of the education associated with the RRT rollout rather than the team's activity itself.[37,40] We believe that this is an unlikely explanation for these significant improvements. Educational interventions, in particular those covering a large number of staff (nurses, physicians, and respiratory therapists) who work throughout a hospital, are often ineffective and rarely attain such dramatic effects on outcomes.[41-45] Also, there were no concerted educational in-

Table 4. Reasons, Interventions, and Disposition Following RRT Activation (n = 143)[a]

	No. (%) of Activations
Reasons for RRT calls	
Respiratory distress	52 (36.3)
Hypotension	21 (14.7)
Hypoxemia	18 (12.6)
Altered neurological status	18 (12.6)
Tachycardia	8 (5.6)
Bleeding	7 (4.9)
Tachypnea	4 (2.8)
Feeling "worried"	3 (2.1)
Airway threat	3 (2.1)
Bradycardia	2 (1.4)
Anaphylaxis	2 (1.4)
Abdominal pain	2 (1.4)
Cardiac arrest	0
Other[b]	3 (2.1)
Primary action by RRT[c]	
Respiratory support[d]	55 (38.5)
Resuscitation fluids	23 (16.1)
Bilevel positive airway pressure or continuous positive airway pressure[e]	12 (8.4)
Transfer to pediatric ICU[f]	11 (7.7)
Radiology	8 (5.6)
Medications, excluding dopamine	7 (4.9)
Advice only	6 (4.2)
Low-dose dopamine	6 (4.2)
None	6 (4.2)
Cooling measures	4 (2.8)
Parental reassurance	2 (1.4)
Compressions	0
Defibrillation	0
Other[g]	3 (2.1)
Immediate disposition[h]	
Transferred to pediatric ICU	81 (56.7)
Remained on ward	42 (29.4)
Transferred to intermediate ICU	14 (9.8)
Transferred to hematology-oncology ward	4 (2.8)
Expired	0
Other[i]	2 (1.4)

Abbreviations: ICU, intensive care unit; RRT, rapid response team.
[a] Because of rounding, percentages may not total 100.
[b] Hypertension, pericardial effusion, or intravenous access (0.7% each).
[c] Action deemed by RRT members to be the most critical to stabilization or improvement of the patient's status.
[d] Consisted of basic airway support (airway positioning, airway suctioning, administration of supplemental oxygen, pulse oximetry, or all four[36]) in 47 patients (32.9%) and a few positive-pressure breaths administered with a bag valve mask before implementation of basic airway support in 8 patients (5.6%). No patient required rescue breaths with a bag valve mask or tracheal intubation, and no patients had a respiratory arrest.
[e] Minor adjustments in bilevel positive airway pressure or continuous positive airway pressure settings in patients already using these modalities. Tracheal intubation was not necessary in any of these patients.
[f] Listed as an "action" when the only action taken by RRT was to move the patient to the pediatric ICU.
[g] Intubation, intravenous/intraosseous access, or unplugged nasogastric tube (0.7% each).
[h] Refers to location of the patient at the conclusion of the RRT visit.
[i] Surgical ward or operating department (0.7% each).

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terventions related to the RRT after the RRT intervention was initiated at LPCH; however, the improved outcomes continued. Furthermore, these improved outcomes have continued despite turnover among the resident physicians, nurses, and other staff, suggesting that the team rather than the education associated with the rollout is more likely the source of the improvements. Real-time education related to the recognition and care of decompensating patients for medical-surgical staff by ICU-trained RRT members certainly could impact patient care and outcomes in the near term. However, we believe improvements as dramatic as those observed in our study require systematic changes beyond a simple educational intervention to continue over time. For example, it is conceivable that the initial hospital-wide educational intervention, combined with the immediate availability of an ICU-trained RRT that provides reinforcement and enhancement of this education with each activation, resulted in an increased ability of clinical staff to recognize and proactively address patient deteriorations. This explanation is supported by the decrease in RRT calls during the 19-month intervention period to levels below the effective threshold suggested by the Institute for Healthcare Improvement (20-25 calls per 1000 discharges).[46]

Strategies other than an RRT that identify and respond to patients earlier in the course of a decompensation could have the same effect as an RRT. For example, 1 potential strategy to decrease codes outside of the ICU setting suggested by Winters et al[37] is the integration of hospitalists. We are in a good position to evaluate a hospitalist intervention at a local level, because we introduced a medical-surgical ward hospitalist service 26 months (July 2003) before RRT implementation. Assuming that there was no delayed effect, the introduction of the hospitalist service, although valuable for multiple reasons, did not affect either mortality rate or code rate outside of the ICU setting. Both outcomes were unchanged until the RRT intervention commenced. The lack of impact by the hospitalist program on these outcomes was in part responsible for the addition of the RRT intervention at LPCH 26 months later.

The commentary by Winters et al[37] also presented concerns about the implications of the Institute for Healthcare Improvement recommendation for RRT implementation on resource allocation. Specifically, they stated "national efforts to improve patient safety should be supported by sufficiently strong evidence to warrant such a commitment of resources." At LPCH, the RRT program was designed and implemented with no additional increase in funding for staffing, a decision supported by the time allocation required for calls during the first 19 months of the intervention. Specifically, the RRT program resulted in a mean of 7.5 RRT calls per month (143 calls during 19 months), with a mean time spent by the 4 RRT members of 22.5 minutes each per patient (median, 18 minutes). The cost-effectiveness of the RRT intervention should be studied in more depth, however, to address this concern adequately.

Our study limitations are similar to those of other cohort studies using historical controls. In particular, there are 2 relevant biases that could have affected the results. First, it is possible that the reduced rates of mortality and codes outside of the ICU were simply the result of differences in the preintervention and postintervention populations and are independent of the RRT intervention. We found no differences between control and intervention populations related to age and, more significantly, case mix index, suggesting that the intervention population was no less ill than the control population. All-patient refined diagnosis related groups, which provide a more discriminating measure of severity of illness than case mix index, are not calculated at LPCH; therefore, we could not use this method.[47] We did observe small differences in sex and race between preintervention and postintervention populations. We do not think that these small differences are clinically significant, although statistically significant due to large sample sizes, or likely to bias our main outcome measures. No data suggest female children are less susceptible to codes or death after codes than male children are,[24] and emerging literature suggests that minority patients are at higher risk for poor outcomes and patient safety breaches during an inpatient stay than are non-Hispanic white patients.[48,49] Thus, the slightly higher percentages of female and minority patients in the postintervention population are not likely to be the cause of the improved outcomes.

Second, it is possible that there were 1 or more other interventions implemented contemporaneously that might have decreased mortality rates and code rates outside of the ICU setting. We are not aware of any such interventions. Although this remains a possibility, it would be an unlikely coincidence that unidentified interventions would have such a profound effect on mortality and code rates outside of the ICU, and that these would impact the rates at the exact time that the RRT intervention was introduced. Finally, we recognize that these data represent a single center's experience; therefore, the results cannot necessarily be generalized to other pediatric hospitals.

CONCLUSION

Implementation of an RRT in our free-standing, quaternary care academic children's hospital was associated with statistically significant reductions in hospital-wide mortality rates and code rates outside of the ICU setting. These reductions cannot be explained by differences in patient characteristics or severity of illness between the control and postintervention populations. Based on our findings, we estimate that 33 children's lives were saved in 19 months at LPCH as a direct result of the RRT implementation. The potential implications of these findings on national mortality rates for children are dramatic. Future research should focus on replicating these findings in other pe-

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diatric inpatient settings, including settings where children are treated in predominantly adult-focused hospitals, developing efficient methods for implementing RRTs, and evaluating the cost-effectiveness of this intervention.

Author Contributions: Dr Sharek had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Sharek, Parast, Leong, Coombs, Earnest, Sullivan, Frankel, Roth.
Acquisition of data: Sharek, Leong, Coombs, Earnest, Frankel.
Analysis and interpretation of data: Sharek, Parast, Roth.
Drafting of the manuscript: Sharek, Leong, Roth.
Critical revision of the manuscript for important intellectual content: Parast, Coombs, Earnest, Sullivan, Frankel.
Statistical analysis: Sharek, Parast, Roth.
Administrative, technical, or material support: Sharek, Parast, Leong, Coombs, Earnest, Sullivan, Frankel, Roth.
Study supervision: Sharek, Leong, Frankel, Roth.
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