Reduction in Mortality Following Pediatric Rapid Response Team Implementation*

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Objective: To evaluate the effectiveness of a physician-led rapid response team program on morbidity and mortality following unplanned admission to the PICU.

Design: Before-after study.

Setting: Single-center quaternary-referral PICU.

Patients: All unplanned PICU admissions from the ward from 2005 to 2011.

Interventions: The dataset was divided into pre- and post-rapid response team groups for comparison.

Measurements and Main Results: A Cox proportional hazards model was used to identify the patient characteristics associated with mortality following unplanned PICU admission. Following rapid response team implementation, Pediatric Risk of Mortality, version 3, illness severity was reduced (28.7%), PICU length of stay was less (19.0%), and mortality declined (22%). Relative risk of death following unplanned admission to the PICU after rapid response team implementation was 0.685.

Conclusions: For children requiring unplanned admission to the PICU, rapid response team implementation is associated with reduced mortality, admission severity of illness, and length of stay. Rapid response team implementation led to more proximal capture and aggressive intervention in the trajectory of a decompensating pediatric ward patient. (*Pediatr Crit Care Med* 2018; 19:477–482)

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Although the potential benefits of rapid response team (RRT) implementation have been routinely advocated since their inclusion as part of the Institute for Healthcare Improvement's "100,000 Lives Campaign" (1), the evidence supporting this benefit has not been demonstrated (2, 3). Whereas some reports indicate pediatric RRT system implementation results in lower in-hospital mortality and reduced code rates outside the ICU (4, 5), a more recent multicenter collaborative failed to show a significant decrease in code rate following a comprehensive practice change that included RRT implementation and/or enhancement (6). Recent publications demonstrate the improvement in a proximate measure, the critical deterioration rate, after RRT implementation (7). However, the impact of RRTs on other key outcomes, such as rate of unplanned ICU admission, severity of illness at the time of ICU admission, hospital and ICU length of stay, cardiopulmonary resuscitation (CPR) events, or ICU resource use, remains unknown.

Therefore, we designed a study to evaluate the effect of a hospital-wide RRT program on illness severity, resource utilization, and outcome for children brought to the PICU from our own hospital's inpatient units by comparing the periods before and after RRT program implementation. We hypothesized that successful RRT implementation would result in lower severity of illness upon PICU admission, less immediate PICU resource use, and lower PICU mortality. This study was conducted in compliance with the requirements of the Washington University institutional review board.

MATERIALS AND METHODS

Setting

In 2007, St. Louis Children's Hospital (SLCH), a 258-bed hospital that serves as the primary pediatric teaching facility for the Washington University School of Medicine, partnered with the Division of Pediatric Critical Care Medicine (PCCM) to establish and implement a RRT program. A pediatric intensivist (N.S.K.) was appointed to lead the RRT development and was paired with a hospital-based advanced practice nurse to attend the Society of Critical Care Medicine's Rapid Response System Training. Following intensive, hospital-wide training, the SLCH RRT was launched on June 1, 2008. The RRT was composed of a PCCM fellow, PICU charge nurse, respiratory therapist, and the hospital-wide nursing administrative supervisor. Criteria for RRT activation included an acute change in a patient's physiologic condition or caregiver concern for instability. Upon RRT activation, team members were paged and expected to be at the patient's bedside within 15 minutes. Critical assessment and consultation occurred with treatment modifications and recommendations based on this timely evaluation. Since implementation, the RRT system is now fully incorporated into the SLCH workplace safety culture. Unplanned admissions to the PICU are initiated via RRT activation; the residents and nursing staff are taught this during their orientation. RRT activations create documentation that can be reviewed by both the ward and PICU attending physicians, and these are then entered into the patient's electronic health record.

Patient Selection and Definitions

To identify RRT-related PICU admissions, we used the SLCH Virtual Pediatric Systems, LLC (VPS) database. VPS is a web-based PICU data repository that receives patient-level data from over 100 PICUs in the United States and abroad (VPS LLC, Los Angeles, CA) (8). From our VPS database, we queried all unplanned transfers from our own hospital's inpatient units to the PICU between January 1, 2005, and December 31, 2011, by combining admission codes for "unplanned admission" and admission source "ward." This study period commenced with the VPS database inception at SLCH and included two comparable time periods before and after RRT program introduction. To avoid potential bias arising from a change in PICU population that occurred when our dedicated cardiac ICU opened in 2007, we excluded all the PICU transfers from 2005 to 2007 who were admitted to the cardiac intensive care service. Unplanned admissions for escalation of therapy (i.e., antibiotic desensitization) were excluded after review of the admission note. Following RRT activation, unplanned admissions were admitted to the PICU via RRT activation. This was intentional so that appropriate resources could be mobilized to expedite PICU admissions. Discrepancies were reconciled via review of the attending note and faculty schedule.

From this query, we composed a final dataset that included patient demographics (admitting diagnosis, severity of illness, Pediatric Risk of Mortality version 3 [PRISM III]-12 [9] and Pediatric Index of Mortality, version 2 [PIM-2] [10] scales), surgical procedures, PICU resource utilization (duration of mechanical ventilation, use of invasive monitoring and imaging), and outcome (PICU length of stay and mortality). We divided our dataset into two groups for comparison: the 42-month period before RRT program implementation (January 1, 2005, to May 31, 2008) and the 36-month period following RRT program implementation (January 1, 2009, to December 31, 2011). We excluded a 7-month transition period between June 1, 2008, and December 31, 2008, to ensure that the post-RRT period included only those cases brought to the PICU by a mature, fully implemented RRT program.

Outcomes of Interest

For the population of unplanned PICU admissions under study, our primary outcome was PICU mortality in the post-RRT period compared with the pre-RRT period. Secondary outcomes included number of CPR events and time to CPR, number of intubation events and time to intubation, duration of mechanical ventilation, and PICU length of stay. Acute respiratory compromise (ARC) events were included as part of the inpatient code dataset. ARC is defined by the American Heart Association's Resuscitation Registry as "absent, agonal, or inadequate respiration that requires emergency assisted ventilation and elicits a hospital-wide or unit-based emergency response" (11).

To assess our primary outcome, we specified a Cox proportional hazards model for time from entry into the PICU to either death or censoring (defined as leaving the PICU alive). The dichotomous tracheotomy variable was stratified in the model to improve fit. We checked the proportional hazards assumption (the model hazard $h[t,X]$ vs the baseline hazard $h_0[t]$ with a log-log plot of time vs hazard), which supported the proportionality assumption of the model. The primary variable of interest was pre- or post-RRT status. We included the PRISM III, patient age in months, the presence of continuous nebulization, the presence of a venous catheter, the presence of an arterial catheter, whether the patient was intubated, the presence of a chest tube, the presence of a dialysis/apheresis catheter, and an interaction between continuous nebulized treatments and central venous catheters. Our specified model included a set of clinical covariates that were anticipated to have strong explanatory power for time to event.

Secondary outcomes included number of CPR events and time to CPR, number of intubation events and time to intubation, duration of mechanical ventilation, and PICU length of stay. Summary statistics were generated using the *t* test comparison of means, the Mann-Whitney *U* test, or chi-square test of significance, as appropriate. We used *p* value less than 0.05 to indicate statistical reliability.

RESULTS

Our final dataset included 2,152 patients, of which 1,097 were in the pre-RRT group and 1,055 were in the post-RRT group (**Table 1**). There were no significant differences in the groups' demographics or severity of illness at the time of PICU admission based on PIM-2 scores. Mortality was decreased following the implementation of the RRT (4.9% vs 3.8%; $p < 0.001$). There was no significant difference between the standardized mortality ratio and PIM-2 between groups. The mean PRISM III score was lower in the post-RRT period than in the pre-RRT period (2.26 vs 3.17; $p < 0.001$).

TABLE 1. Characteristics of Patients With Unplanned PICU Admissions Before and After Rapid Response Team Implementation

Variable Years	Pre-RRT (*n* = 1,097) 2005–2008	Post-RRT (*n* =1,055) 2009–2011	*p*
Age (yr), mean (SD)	7.1	7.4	NS
Female, %	45.7	43.6	NS
Ethnicity, %			
African American	33.3	30.3	NS
Caucasian	63.6	65.1	NS
Hispanic	0.9	1.6	NS
Other	2.2	2.9	NS
Admission day of the week, %			
Weekend	27.8	28.2	NS
Weekday	72.2	71.8	NS
Pediatric Risk of Mortality, version 3, score, mean (SD)	3.17 (4.9)	2.26 (4.1)	0.001
Pediatric Index of Mortality, version 2, score, mean (SD)	−4.59 (1.1)	−4.65 (1.1)	NS
PICU length of stay (d), median (interquartile range)	2 (1–5)	2 (1–4)	0.02
PICU mortality, %	4.9	3.8	0.001
Standardized mortality ratio	1.1	0.8	NS

NS = not significant, RRT = rapid response team.

In the PICU, the absolute number and rate of CPR events per 1,000 patient-days were significantly lower in the post-RRT period compared with the pre-RRT period (9.1 events per 1,000 patient-days pre-RRT vs 6.4 post-RRT; $p < 0.001$) (**Table 2**). There were no CPR events in the first hour after unplanned PICU admission in the post-RRT period (compared with four events in the first hour in the pre-RRT period), although this did not reach statistical significance. The time to CPR was shorter in the post-RRT period (8.6 vs 269 hr in the pre-RRT period). CPR is an extremely infrequent event, even in high-acuity patients. Drawing significance from such infrequent events is unwarranted. Although twice as many patients were intubated in the first hour after PICU admission in the post-RRT period than the pre-RRT period (88 vs 49 patients; $p < 0.001$), there was no difference between time periods in the overall proportion of RRT patients who ultimately required mechanical ventilation nor was there a difference in the duration of mechanical ventilatory support. However, PICU length of stay was significantly shorter in the post-RRT period compared with the pre-RRT period (19.8% reduction, from 5.8 to 4.7 d; $p = 0.02$).

The time to death in ICU patients was significantly longer following RRT implementation (1.6 vs 16.9 d; $p < 0.001$) (Table 2). This difference in mortality was evident by PICU admission day 2 and was statistically reliable by day 20 (**Fig. 1**). This difference occurred despite no change in either the overall or the standardized mortality ratio of the PICU population as a whole during this time.

The RRT program has improved care over time. **Figure 2** is a time series graph of codes, CPR, ARC, and mortality rates for the inpatient units from 2007 to 2016. Codes were defined as any activation of the code system; CPR involved chest compressions and medications, and ARC was the application of bag-mask or bag-tracheostomy ventilation. Inpatient day information was only available after 2010. The averaged patient days from 2010 to 2013 were used to estimate hospital mortality, ARC, code, and CPR rates for 2007–2009. Figure 2 shows little change over time for all codes or ARC.

DISCUSSION

In this study, we found that deployment of a hospital-wide RRT was associated with a significant decrease in mortality for unplanned PICU admissions. Even when controlling for factors such as severity of illness transfer, this finding persisted. Furthermore, RRT implementation resulted in a decrease in resuscitation events in the PICU and an overall shortening of the PICU length of stay by 1 day. These findings are consistent with other studies demonstrating benefits to both mortality and readmission rates after RRT program implementation (3).

We also found that the mean time to death in the post-RRT cohort was significantly longer than in the pre-RRT cohort, reflecting the goal of the program: earlier capture of patients prior to decompensation. The fact that our standardized mortality ratio, which was similar both before and after RRT implementation, was the evidence that our goal was achieved. If children were admitted to the PICU earlier in their trajectory of illness, then they would be expected to have a lower observed and expected mortality rate. Prior to the development of the RRT, many patients would arrive to the PICU in decompensated shock leading to irreversible multiple organ failure and rapid demise. Since deployment of the program, patients are admitted to the PICU earlier in their course of illness, resulting in reduced mortality. We believe that this is a consequence of improved situational awareness and anticipatory team behavior when presented with a new admission from the inpatient units.

Using interventions recorded in the VPS database, the authors collected data on procedures commonly employed for critically ill patients during the first 24 hours of PICU care. These elements were selected based on relevance to the clinical condition and availability in the dataset. We found that the relative increase in critical interventions correlated well with the PIM-2 and PRISM III scores and was highly correlative to the risk of mortality in the PICU. We have begun to analyze these data and validate what we are describing as a Therapeutic Intensity Score (TIS), as we believe that this information may be informative about patient acuity as it quantifies the intensity of intervention (e.g., physician response to perceived acuity) at

TABLE 2. Patient Outcome Before and After Rapid Response Team Implementation

	Pre-RRT (*n* = 1,097)	Post-RRT (*n* =1,055)	*p*
Mortality, %			
Inpatient ward	0.04	0.07	NS
ICU	4.9	3.8	0.001
PICU standardized mortality ratio[a]	1.4	1.2	NS
RRT cohort standardized mortality ratio	2.0	2.0	NS
Time to death (d), mean (SD)	1.6 (4.3)	16.9 (21.5)	< 0.001
Code rate/1,000 patient-days			
Inpatient units	0.52	0.51	NS
ICU	9.1	6.4	0.001
CPR events for patients admitted to the PICU			
Patients receiving CPR during PICU admission, *n*	29	8	0.001
CPR within first hour of ICU admission, *n*	4	0	NS
Time to CPR (hr), mean (SD)	269 (468)	8.6 (6.9)	< 0.001
Mechanical ventilation for patients admitted to the PICU			
Mechanical ventilation, *n* (%)	285 (26.0)	233 (22.1)	NS
Intubation within first hour of ICU admission, *n* (%)	49 (4.5)	88 (8.3)	< 0.001
Time to intubation (hr), mean (SD)	36.3 (98.9)	39.4 (103.4)	NS
Length of ventilation (d), mean (SD)	10.6 (18.2)	9.6 (15.9)	NS
PICU length of stay (d), mean (SD)	5.8 (12.2)	4.7 (9.4)	0.02

CPR = cardiopulmonary resuscitation, NS = not significant, RRT = rapid response team.
[a]Standardized mortality ratio = actual mortality rate/expected mortality rate based on Pediatric Risk of Mortality, version 3, severity of illness score.

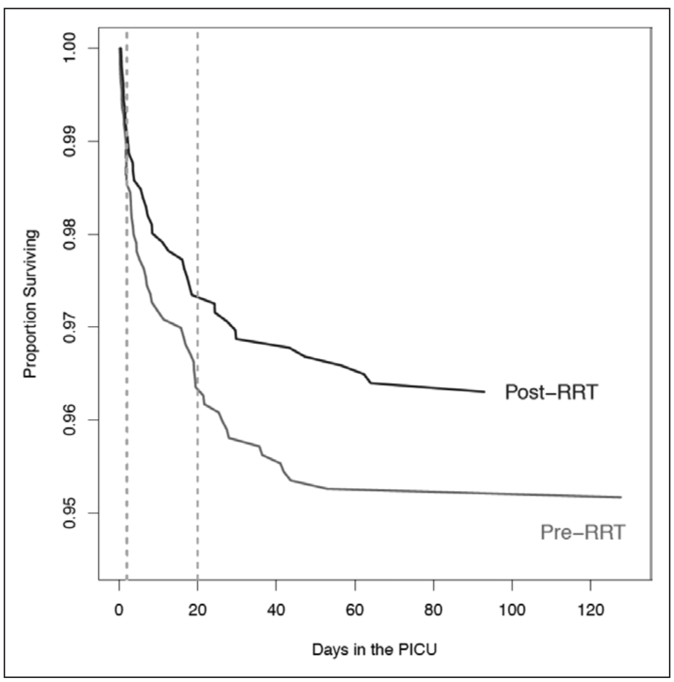

Figure 1. Survival for unplanned PICU admissions. PICU days versus survival proportion Kaplan-Meier curves for pre-rapid response team (RRT) period and post-RRT period. Separation of the two curves starts at 2 d and is statistically reliable after 20 d, illustrated with two *vertical lines* in the figure.

the time of PICU transfer. The TIS score is being developed, and is not yet validated, to identify elements of care that were clinically relevant and easily obtained via data captured for both billing and quality improvement. This score represents an area of future work on this complex topic and is included as **supplementary material** (Supplemental Digital Content 1, http://links.lww.com/PCC/A629).

With PICU transfer earlier in the course of illness, one might expect a reduction in resource utilization. This was not seen. This may indicate a more aggressive response by the PICU team at the time of admission. This possible change in approach may represent cultural momentum arising from the RRT deployment/education, which focused upon "early capture" of children with evolving decompensation on the ward. It is possible that earlier administration of these interventions prevented further decompensation and certainly warrants further exploration.

Although the relationship between lower mortality and RRT program implementation is clear, there are several limitations to our study. First, SLCH piloted a Pediatric Early Warning System (PEWS) in one of the inpatient units in the last 6 months of our data collection period with a second unit added in December 2011. PEWS has been developed and validated to create objective criteria that herald imminent deterioration (12). This system has

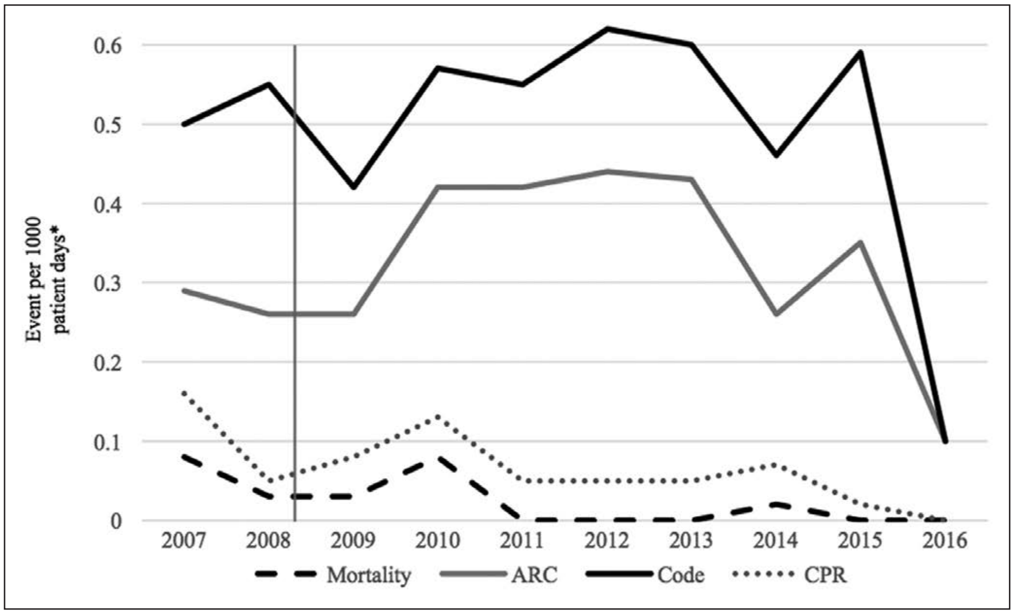

Figure 2. Time series outcomes graph: 2017–2016. *Unit level patient data available dating back to 2010. Total patient day calculations for years 2007–2009 are the average of years 2010–2013. *Vertical line* represents rapid response team deployment, June 2008. ARC = acute respiratory compromise, CPR = cardiopulmonary resuscitation.

been enhanced (Bedside PEWS) and has now undergone multicenter validation (13). SLCH incorporated PEWS scoring into triggering automatic RRT activation with a low RRT activation threshold (PEWS score = 3 out of a possible 9 points). Although PEWS-driven RRTs might have impacted the number of admissions, our in-hospital data indicate that there was no change in the number of RRTs from these two units during the 6-month overlap period.

Second, critical care division expansion in both the fellowship and advanced practice nurse practitioner programs occurred in the post-RRT period. This may have affected the acuity and size of the ward-to-PICU transfer population. Although the expansion was not intended to impact RRT staffing, all fellows and nurse practitioners are primary RRT responders. With an increase in inexperienced providers, it is conceivable that these providers had a lower threshold to transfer patients to the PICU. However, if this had resulted in a lower acuity population, then we would have expected an unambiguous drop in the acuity of the post-RRT population. Because PIM-2 scores remained stable, it is not entirely clear to what extent this may have occurred. Given that PIM-2 scores are measured only once within an hour after PICU admission, this may explain the lack of difference in the pre- and post-RRT groups. The changes identified in the PRISM III scores may be more reflective of earlier intervention that occurred as a result of the RRT program.

Finally, the division's faculty coverage model changed during the final 5 months of the study. Beginning July 2011, the nightly coverage model was modified resulting in a 50% increase in attending availability overnight. An increased presence of critical care faculty may have resulted in more, earlier interventions at the time of PICU admission and potentially this, not the RRT system, was what resulted in lower mortality. In-house attending coverage reduced the number of adverse tracheal intubation events in data analyzed in the National Airway Registry for Children (14). In our data, the reduction in mortality was visible before the schedule change, and would not explain some of the additional time-specific findings.

The authors recognize the limitation of the inpatient code data presented in Figure 2. The extrapolated patient days for the years 2006–2009 represent the average of the patient days for the years 2010–2013, as equivalent data prior to 2010 were unavailable. No clear change was seen prior to 2010; although it is possible that the code rate was lower in the years leading up to the RRT, that seems less likely given the sustained change over time. However, beginning in 2010, a sustained decline is seen in both CPR and mortality rates in our hospital. We believe that this is a result of improved recognition of the deteriorating patient and a culture shift in which patients are admitted to the ICU before critical decompensation.

The authors recognize the inherent limitation to the before-after study design, but our finding of sustained decreases in both CPR and mortality on the inpatient units supports the argument that the RRT has improved survival for children in our hospital.

CONCLUSIONS

A decade after the 100,000 Lives Campaign, many children's hospitals have embraced quality improvement efforts and have implemented RRT programs. In our institution, the deployment of these teams lowered morbidity and improved survival in the children who require PICU transfer after RRT activation. In our model, children presenting to our PICU via rapid response had measurable lower acuity of illness via PRISM III scoring yet received more immediate and aggressive intervention by the PICU team. This combination of conditions resulted in a reduction in PICU length of stay and PICU mortality. This suggests that RRT implementation facilitates capture of decompensating children earlier in the trajectory of illness and results in timelier access to life-saving interventions.

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