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Impact of a Rapid Response System in a Children's Hospital

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IMPACT OF A RAPID RESPONSE SYSTEM IN A CHILDREN'S HOSPITAL

CAPSTONE PROJECT PAPER

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by
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Abstract

Objectives: To determine the effect of a rapid response system on rates of cardiopulmonary arrests, proportion of children transferred to intensive care and the financial impact of a rapid response team.

Methods: Prospective cohort analysis from June 2009 through June 2014 of all children admitted to a children’s hospital within a hospital aged birth to 21 years who required rapid response team services. Rates of cardiopulmonary arrests and transfers to intensive care were observed over time; risk of these events was obtained. Mean differences in costs between rapid response calls sent to the ICU and those who remained on the Acute Care Unit were compared.

Results: A rapid response system reduced the rate of cardiopulmonary arrest outside of the intensive care unit from 1.91/10,000 bed-days to 0.23/10,000 bed-days (RR = 0.120; 95% CI: 0.005, 0.868). As the rapid response system matured, the proportion of calls transferred to intensive care decreased from 48% to 24% (RR = 0.508; 95% CI: 0.327, 0.809). The number needed to treat to prevent one transfer to intensive care was 4. Analysis of direct costs showed preventing transfers to intensive care saved an average of $2,757-$6,210 per case for children <2 years old and $928-$2,255 for children 2 years and older.

Conclusions: A rapid response system functioning in a children’s hospital within a hospital reduced cardiopulmonary arrests, reduced the proportion of children transferred to intensive care and saved the healthcare enterprise money.
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Chapter 1 - Introduction

To Err is Human?

Being admitted to the hospital, whether as an adult or a child, carries risk of significant harm. Complications related to hospitalization are known problems the healthcare industry has attempted to address for years.\(^1,2\) In 2004, the Institute for Healthcare Improvement (IHI) launched the *100,000 Lives Campaign* with the goal of saving 100,000 lives of hospitalized patients through quality improvement and safety initiatives.\(^3\) Don Berwick, the director of IHI in 2006, offered six interventions to accomplish the goal of saving 100,000 hospital patients from serious safety events. They included evidence based care for acute myocardial infarction, medication reconciliation to prevent adverse drug events, prevention of central line bloodstream infections, ventilator associated pneumonia and surgical site infections and implementation of rapid response teams to respond to patient deteriorations.\(^3\) These rapid response teams (RRT) would function essentially like an in-hospital 911 system to address a patient’s declining physiologic status *before* a cardiopulmonary arrest occurred; this was in direct contrast to the prevailing safety net of “code teams” who would respond to a “code blue” or cardiopulmonary arrest.

Data from 2003 showed some benefit from implementation of a rapid response system (RRS) and the US healthcare system began adopting them.\(^4\) As more places began adopting an RRS, the body of literature regarding their effectiveness, or lack thereof, began to emerge. The adult literature contains numerous articles which support the RRT concept and many which refute it. As
is typical, the pediatric literature lagged behind; Chapter 2 will address a more comprehensive literature review. The next section will address the concept and anatomy of an RRS.

**Anatomy of a Rapid Response System**

A rapid response system requires four functional arms to achieve its goal: an afferent arm, efferent arm, administrative arm and a quality assurance arm. The afferent arm is the detection of a crisis. This consists of various methods for detecting a crisis: automated team launch via electronic medical record surveillance of charting and vital signs, family activation of the team, and care team concern for a deteriorating situation. Hospitals have determined evidence based clinical criteria for team activation, however, no national standard or guideline dictates minimum criteria for team activation. The efferent arm is the response team. The composition of teams varies from institution to institution and no single model has proven superior to the other. A true rapid response team consists of nurses and technicians with intensive care experience while a medical emergency team adds a physician to the team. An RRT needs to possess the skills to stabilize and resuscitate a deteriorating patient to prevent cardiopulmonary arrest while contacting and involving the patient’s primary care team. The administrative arm is responsible for the daily management of team operations and generally oversees the quality assurance functions of the team as well. Frequently, the administration team involves a physician medical director and a nurse manager. Quality assurance and improvement are critical to any team that functions in a system. The Quality Improvement arm is responsible for
debriefing any code blues which occur and creating small cycles of change to foster continued service growth and customer service. Data from RRT calls are entered into the medical record by responders, entered into a local database and monitored by the quality assurance and administrative arm. Dashboards for performance are created, based on database information, and serve as visual indicators of team performance and customer service; these are critical for driving process improvement.

The Rapid Response System at Kentucky Children’s Hospital

Plans for implementing an RRS at Kentucky Children’s Hospital (KCH) was begun in 2008 under the direction of Dr. J. Tim Bricker, Chairman of the Department of Pediatrics. He saw the potential utility of this system and asked for an RRT at KCH. A multidisciplinary team was formed and plans were created to launch an RRT; physicians were not to be assigned as team members but the physicians labeled by the medical record as primary care physicians in the hospital were to be utilized after a call had been made to the RRT. A major education campaign was undertaken two months prior to the launch of the RRT.

When the launch was set for June 2009, the administration team of the RRT knew that significant culture change was necessary to make the RRT successful. For decades, when a nurse on the floor had a patient begin to deteriorate, they would call the Pediatric Intensive Care Unit (PICU) and ask for a PICU nurse consult. This PICU nurse would come out to assess the patient and make recommendations such as call the primary team to transfer to the PICU or
suggest potential therapies to the primary physician team. Hospital policies were
developed to eliminate the informal nurse consult and utilize RRT services.

The team was launched to prevent cardiopulmonary arrests (CPA) from
occurring outside of the PICU. An additional goal was to reduce the number of
admitted children who were transferred to the PICU after receiving rapid
response services. Many hospital’s teams were launched with the explicit task of
reducing mortality.6-11 Since standardized mortality, the ratio of observed to
expected deaths based on severity of illness, was not deemed to be a
problematic issue at KCH, it was not included in the team goals. Initially the RRT
only covered the Acute Care units of KCH, not the procedural areas of UK
Healthcare. In a later modification to the RRS at KCH, the RRT now covers all
areas in KCH and Chandler Medical Center.

Since its inception in 2009, the rapid response system at Kentucky
Children's Hospital has undergone two revisions. The first revision, a nurse
driven, peer-to-peer quality improvement project to improve team utilization and
acceptance of services, occurred in September of 2010 and was implemented in
October 2010. This resulted in an increased use of the RRT services and made
nurses more willing to call for assistance with a deteriorating child.12,13 The
second revision occurred in January 2013 with implementation of an early
warning score into the electronic medical record in February 2013.14 This early
warning score utilized an externally validated scoring system and data from the
medical record to generate physiologically based risk stratification for
deterioration for individual patients.14 This system was intelligent enough to
automatically request RRT assistance via the electronic paging system at UK HealthCare. When vital signs and nursing assessments are entered in the electronic medical record, a program created within the software generates an early warning score. This program then activates the paging system, requesting the rapid response team to the patient’s location. A quality improvement project investigating the effectiveness of this automated launch system is currently underway. No data related to the effectiveness of the automated launch are available.

The evaluation of the success of the aforementioned goals of reduced cardiopulmonary arrests and PICU transfers related to RRT calls are the main motivations of this project. Additionally, financial studies of rapid response system impact are lacking from the body of literature. The questions to be answered by this capstone include:

1) did the implementation of a pediatric rapid response team prevent cardiopulmonary arrests outside the ICU?

2) did the implementation of a rapid response system reduce the proportion of deteriorating children being transferred to the pediatric ICU?

3) what are the financial impacts of rapid response team implementation in a children's hospital?

The current environment of healthcare, as we all know, is changing rapidly. With the passage of the Affordable Care Act (ACA) and the ACA’s focus of quality of care coupled with performance based reimbursement and accountable care, healthcare systems can no longer minimize the economic
effects of prolonged length of stay and preventable adverse safety events. The
10th Essential Public Health Service is to "research for new insights and
innovative solutions to health problems."\textsuperscript{15} In a time of active healthcare reform,
the healthcare community owes a debt to their patients to critically evaluate the
evidence and apply interventions that are safe, efficient, effective and financially
smart. This project will attempt to add to the body of literature surrounding rapid
response systems. It will attempt to add to a specific niche within the rapid
response system literature. The study takes place in what is known as a
children's hospital with in a hospital; the children's hospital is a floor or a wing
within a larger adult centric hospital. As we will see in the literature review, adult
hospitals have volumes of data regarding rapid response system effectiveness
while the amount of data for children's hospitals is considerably lacking. The data
are even sparser for a setting like Kentucky Children's Hospital: a hospital with
in a hospital. Though this could be looked at as a limitation of the generalizability
of this study, it is actually quite helpful for healthcare systems that do not have a
standalone children's hospital.

In the pages that follow, the literature surrounding rapid response team
evolution and effectiveness will be explored. Following that, the study
methodology will be explained followed by the results of the analysis of the rapid
response team at Kentucky Children's Hospital.
Chapter 2 - Literature Review

This literature review will summarize the historical background surrounding the implementation of rapid response systems. This is followed by separate evaluations of the adult and pediatric evidence surrounding rapid response system effectiveness. The works cited include studies from the peer reviewed literature as well as systematic reviews. PubMed was the database utilized to find scholarly works. Additionally, the reference lists and bibliographies of sources identified in the PubMed search were examined to find primary sources. The following search strategy for PubMed was utilized:

- Hospital Rapid Response Team/economics OR (Rapid Response Team$ AND economics)
- (Hospital Rapid Response Team[MAJR] OR Rapid Response Teams) and children
- (Hospital Rapid Response Team/trends OR Hospital Rapid Response Team/utilization OR Hospital Rapid Response Team/statistics and numerical data OR Hospital Rapid Response Team/standards) AND children
- Hospital Rapid Response Team and (Patient Transfers)
- Hospital Rapid Response Team AND Mortality AND Children.

Results of this search strategy, as well as the examination of reference lists yielded 183 articles for initial review; this was reduced to 103 articles after removing non-research-based articles (i.e. news articles, non-peer-reviewed medical literature).
Initial Studies

The first well-recognized study to truly evaluate a rapid response system was published in the *Medical Journal of Australia* in 2000 by Peter Bristow and colleagues. This prospective cohort study compared the implementation of a medical emergency team at one adult hospital to two other hospitals which retained conventional cardiac arrest team structures. While the study did not find a significant difference in the rate of cardiac arrests or total deaths between the three hospitals, the odds of unanticipated ICU admissions were more than 1.5 times higher in the hospitals that did not contain the medical emergency team (95% CI: 1.24 – 2.16).

In children, the first study evaluating rapid response systems was published in the *Archives of Diseases in Childhood* in 2005 by James Tibballs and colleagues from the Royal Children's Hospital at the University of Melbourne, Australia. They performed a pre-and post-intervention study under the direction of the quality assurance division of the hospital and published their preliminary data. They retrospectively examined cardiac arrest rates and deaths in the 41 month period before introduction of the service and a 12 month period after introduction of the service. Their intervention reduced cardiopulmonary arrest rates from 0.19/1000 admissions to 0.11/1000 admissions. This risk ratio comparing risk before and after intervention of 1.77 was not statistically significant (95% CI: 0.59, 5.01). Mortality showed similar, non-significant decreases when the two periods were compared: 0.12/1000 admissions to 0.06/1000 admissions, risk ratio 2.22, 95% CI: 0.59, 9.87. What was interesting
about this study was the apparent increase in unplanned ICU transfers in the post-intervention period (20/month vs. 24/month, p = 0.07). While not statistically significant, it accounted for over 20% of new admissions to the PICU after team implementation. These two, methodologically weak studies were the catalyst for launching myriad recommendations by agencies such as the IHI and Joint Commission to establish an RRS within hospital settings to prevent serious safety events in patient care.

The Adult Literature

While the focus of this evaluation is to evaluate a pediatric rapid response system, it is imperative to evaluate the adult literature that sparked the pediatric adoption of rapid response systems. Although hundreds of adult studies have been published, many are methodologically weak. Although no Cochrane Review exists, several meta-analyses and systematic reviews of the adult literature exist; this review will cover the systematic review published by Chan in 2010 in *Archives of Internal Medicine*. While there is a more recent systematic review published by Winters and colleagues in the *Annals of Internal Medicine* in 2013, its methodology of evaluation is not as robust as the systematic review published by Chan. While more contemporary literature is included in the 2013 systematic review, there is no statistical evaluation of the impact of the new data; due to this limitation, it will not be discussed in this review.

Chan's meta-analysis contained both adult and pediatric data and attempted to answer the specific questions surrounding out of ICU cardiopulmonary arrest rates as well as relative risk of mortality related to RRT.
implementation. Ten total studies were included in the analysis of out of ICU cardiopulmonary arrest, with one study being counted twice due to the study containing a single intervention hospital compared to two separate hospitals which did not contain a rapid response system. The forest plot for the adult data did show a pooled relative risk that favored a reduction in out of ICU cardiopulmonary arrest after implementation of rapid response team (RR = 0.66, 95% CI: 0.54, 0.80). There was significant heterogeneity among all of these studies thus limiting the generalizability of the findings (I² = 80.5%, p < 0.001). When hospital mortality was pooled, a non-significant reduction in relative risk was noted (RR = 0.96, 95% CI: 0.84, 1.09), however significant heterogeneity was noted once again (I² = 91.4%, p < 0.001).

When the methodology of adult studies is evaluated, nearly all of the studies are of low methodological quality; they consist of before and after studies, usually related to quality improvement interventions. At the time of this manuscript, there are still only two randomized controlled trials to evaluate the effectiveness of rapid response teams. The first trial was a randomized cluster design with phased introduction published by Priestley in 2004. Hospital wards were randomly selected to go through a training period, followed by introduction of a rapid response system; the wards in which a rapid response team was not implemented served as controls. Priestley’s group documented a statistically significant reduction in hospital-wide mortality for the wards which received rapid response system services (OR = 0.70 95% CI: 0.50, 0.97). While these results are encouraging, performing his intervention at a single facility does limit its
generalizability and can create bias via a Hawthorne effect, an inconsistent or unpredictable change in individual or group behaviors based on their knowledge they are under observation\textsuperscript{20}.

The only other randomized trial related to rapid response systems was published by Hillman and colleagues in 2005.\textsuperscript{21} In this study, 11 hospitals in Australia were randomized into a control group which consisted of not implementing a rapid response system while 12 hospitals were randomized into a group in which a rapid response system was created. During the six-month study, there were no significant differences between the groups when the rates of cardiac arrests, unplanned ICU admissions and unexpected deaths were compared.\textsuperscript{21}

In summary, it appears from the adult literature there is a slight reduction in out of ICU cardiopulmonary arrests related to the implementation of a rapid response team. While this is a promising finding, it does not pay off in a reduction in overall mortality. However, it should be noted that the methodological quality of many of the adult studies is weak which results in significant heterogeneity of the results and limited generalizability.

The Pediatric Literature

The pediatric body of literature contains numerous accounts of quality improvement initiatives, development of call criteria and satisfaction studies. At the time of this manuscript preparation, seven studies have been published related to non-intensive care unit cardiopulmonary arrest and six studies related
to hospital mortality in the pediatric population. Finally, a single article related to
cost benefit analysis of pediatric rapid response systems will be discussed.

The first article in the pediatric series was published by Brilli, et al. in 2007
in the journal *Pediatric Critical Care Medicine*. This study was a retrospective
chart analysis before and after implementation of a rapid response system in a
stand-alone tertiary care children’s hospital. Their goal was to reduce cardiac and
respiratory arrests outside the ICU by 50%. Baseline data from the 15 months
prior to RRT implementation was compared to 12 months of post-RRT
implementation. Comparing these reference frames, the combined rates of
cardiac and respiratory arrests declined from 0.27/1000 bed-days to 0.11/1000
bed-days (RR = 0.42, 95% CI: 0, 0.89). When mortality rates were compared
between the two periods, there was a non-significant reduction in mortality.
(RR = 0.50, 95% CI: 0, 1.9). This finding is not surprising since the study was
not powered sufficiently to detect such a small difference in mortality. Brilli and
colleagues had to define their own call criteria which may limit the application of
their findings to other institutions with differing RRT calling criteria.

The next in the series of articles was published by Zenker, et al. in 2007 in
the *Joint Commission Journal on Quality and Patient Safety*. This before and
after study from the University of Minnesota was the first study to investigate the
usage and effectiveness of a true RRT; one that contained only a PICU nurse
and a respiratory therapist. The RRT at the University of Minnesota was
launched with qualitative goals: “to assess and stabilize the patient, educate and
support the staff, assist with communication and assist with patient transfers if
needed." A 23 month pre-implementation period was compared to a 12 month post-implementation period with data abstracted from patient charts after discharge, as well as a RRT log housed in the PICU. When an RRT call was requested, it resulted in PICU transfer 36% of the time and additional medical interventions 85% of the time. While mortality was not impacted, the relative risk of cardiac or respiratory arrest was 0.64 (95% CI: 0.47, 0.87), a 36% reduction in occurrence.

Dr. Paul Sharek and associates from Stanford’s Lucile Packard Children’s Hospital, a large free-standing children’s hospital, performed a cohort study with historical controls to evaluate the impact of an RRS at their institution. Their objective was to determine the impact of a medical emergency team (MET) on hospital-wide mortality and code rates outside the ICU. They showed a monthly mortality rate decrease of 18% (95% CI: 5-30%), as well a decrease in code event rates from 2.45 codes/1000 admissions to 0.69 codes/1000 admissions (p< 0.01). This study was unique for several reasons. They were the first group to document both reductions in code events outside the PICU as well document a decrease in hospital-wide mortality. These findings were adjusted for temporal variations in mortality that accompanied the seasonality of illness severity in pediatrics, as well as the case-mix index which adjusts for severity of disease. These results were the first to show a potential difference in RRT impact when comparing adult and pediatric data.

Hunt, et al. in Baltimore looked at the impact on code rates after removing the traditional structure of separate “code team” and RRT’s. Traditionally,
hospitals would staff an RRT and a code blue team; Hunt’s group decided to investigate the outcome of removing the traditional code team, replacing it solely with a rapid response team.\textsuperscript{11} Again, before and after study methods were utilized with the goal of examining the changes in rates of codes after changing team structure; evaluation of mortality was never a goal of the study.\textsuperscript{11} Their study found no change in cardiac arrest rates between the two groups (rate ratio 0.49; 95% CI: 0.18, 1.20).\textsuperscript{11} However, they did find a significant reduction in respiratory arrests after changing team structure (0.23 respiratory arrests/1000 bed-days vs. 0.06 respiratory arrests/1000 bed-days; $p = 0.03$).\textsuperscript{11} The authors noted that many of their respiratory arrests outside of the ICU setting resulted in endotracheal intubation of the patient, an invasive procedure with significant risk in an uncontrolled setting.\textsuperscript{11} The study did not contain any information examining the financial impact of averting an out of ICU endotracheal intubation and subsequent mechanical ventilation. While the overall rate of cardiopulmonary arrest was unchanged, the power of the study to detect such a change was weakened by a small sample size.\textsuperscript{11}

James Tibballs and Sharon Kinney were next to publish their results in a free-standing tertiary care pediatric hospital in Melbourne Australia in 2009.\textsuperscript{7} In similar fashion to prior studies, they performed a before-and-after intervention study which included over 100,000 admissions in a 41 month pre-intervention period and nearly 140,000 admissions during a 48 month post-intervention period.\textsuperscript{7} Their primary goal was to determine the effect of medical emergency teams on the incidence of unexpected cardiac arrests and deaths in the
hospital. During the post-intervention study period, hospital deaths decreased from 4.38 to 2.87 per 1000 admissions (p < 0.0001) and unexpected deaths outside the ICU decreased from 0.12 to 0.04 per 1000 admissions (p = 0.03). However there was no change in the rate of cardiac arrests between the pre-intervention and post intervention groups (0.19 versus 0.17 per 1000 admissions; p = 0.75). Although no reduction in the cardiac arrest rate was noted, there was a noticeable increase in survival related to out of ICU cardiac arrest, from 35% to 74% after introduction of the medical emergency team (RR for survival = 2.11, 95% CI: 1.11, 4.02). This result is in stark contrast to the typical published survival rates from in-hospital pediatric cardiac arrest of less than 50%. In a somewhat unique way, mortality was impacted, not by preventing the events, but by performing better when the adverse events occurred. By examining their data closely, it is possible that factors other than the introduction of the medical emergency team biased their results. Since there was an increased effort to educate staff on deteriorating patients and on medical emergencies outside the ICU, staff may have been better prepared to recognize critically ill children prior to deteriorating to the point of cardiac arrest. While Tibballs and Kinney demonstrated favorable data supporting the use of rapid response systems in hospitals, mortality reduction cannot be solely attributable to the rapid response system introduction.

In 2009, a study was published out of the University of North Carolina which examined the effect of a rapid response system on the duration of clinical instability of patients as well as subsequent rates of cardiac arrests. The
primary measures of outcome were documented patient days between out of ICU cardiac arrest and the duration of clinical instability before evaluation by critical care personnel.\textsuperscript{23} After implementation of a rapid response system, the mean number of patient days between out of ICU cardiopulmonary arrests increased from 2512 days to 9418 days; this change was noted to be outside of the upper control limits of their statistical process control.\textsuperscript{23} The relative risk of out of ICU cardiopulmonary arrest was 0.35 (95\% CI: 0, 1.24).\textsuperscript{23} Although not statistically significant, the rate of death outside of the ICU decreased from 1.5 to 0.45 deaths per 1000 ward admissions after implementation of a rapid response system (RR = 0.30; 95\% CI: 0, 1.04).\textsuperscript{23} The median time that a patient spent clinically unstable out of the ICU was decreased significantly by implementing a rapid response system in this hospital. Prior to implementing the pediatric rapid response system, the median time to PICU assessment for a deteriorating child was 9 h 55 min (95\% CI: 4 h 50 min., 18 h 15 min.).\textsuperscript{23} After the implementation of the rapid response system the median time had decreased to 4 h and 15 min. (95\% CI: 2 h 7 min., 13 h 10 min), a decrease of 5 h and 40 min.\textsuperscript{23} This earlier recognition of a critically ill patient may have allowed for earlier intervention, thus averting potential cardiac arrest or ICU transfer. For those patients who were transferred to the ICU, they did not show an increased rate in ICU cardiopulmonary arrests, thus dispelling the myth that sicker patients were transferred from the wards to the ICU and simply arrested in a different location.\textsuperscript{23}
Anwar-ul-Haque, et al. in 2010 was the first study to report on the implementation of a pediatric rapid response team on a pediatric ward within a tertiary care hospital which was not a free-standing children's hospital in Pakistan.\textsuperscript{24} In their pre-and post-intervention study, they documented a trend of decreasing code rates from 5.2 to 2.7 codes per 1000 admissions ($p = 0.08$).\textsuperscript{24} In 61% of their calls, transfer to the intensive care unit was not required, thus hypothesizing increased cost-effectiveness in a resource poor hospital.\textsuperscript{24} However, no formal cost analysis was performed. This study was the first to show that a rapid response system for a children's hospital within a hospital is functionally viable.

Finally, Kotsakis et al. published a study in 2011 describing the implementation of a pediatric rapid response system across four children's hospitals in Ontario, Canada.\textsuperscript{25} The primary goal was to determine the effect of a physician led rapid response system on the rate of cardiopulmonary arrests, as well as its effect on rate of PICU mortality after readmission and urgent PICU admission.\textsuperscript{25} Study authors found no difference in the rate of cardiopulmonary arrest during either phase of the study (1.9 versus 1.8 events per 1000 hospital admissions ($RR = 0.95$; 95% CI: 0.76, 1.96)).\textsuperscript{25} There was no significant difference noted in PICU mortality when the pre-intervention and post-intervention phases were compared. The PICU mortality rate was 1.3 deaths per 1000 admission prior to the implementation of the rapid response system and 1.1 deaths per 1000 admission after implementation of the rapid response system ($RR = 0.97$; 95% CI: 0.83, 1.12).\textsuperscript{25} The authors did find a significant 46%
reduction in the rate of “near-cardiopulmonary arrests. These events are children who deteriorate, but do not require artificial ventilation or chest compressions. These data support a similar finding from Hanson’s study in 2009. Rapid response systems may be detecting more clinically unstable children, some of whom may need to be transferred to the intensive care unit. However, those children who are sent to the intensive care unit are not simply displacing a cardiac arrest from the ward environment to the ICU environment, nor are they displacing their mortality events into the ICU.

Several of these aforementioned studies were included in a systematic review of rapid response systems published in 2010. When several the studies were combined to examine pooled relative risks of cardiopulmonary arrest outside of the pediatric intensive care unit, the pooled estimates showed a relative risk of 0.62 within 95% confidence interval of 0.46 to 0.84. No significant heterogeneity was detected among the studies (I² = 10.2%, p = 0.35). A pooled estimate of the relative risk of hospital mortality after pediatric rapid response team implementation was also performed by Chan in his systematic review and showed a relative risk of 0.79 with a 95% confidence interval 0.63 - 0.98. Significant heterogeneity was noted in this pooled evaluation (I² = 66.0%, p = 0.03).

While there is an adequate body of literature surrounding cardiopulmonary arrests and mortality changes due to RRT introduction, the medical literature is relatively devoid of financial analyses surrounding rapid response team implementation. A single study by Dr. Christopher Bonafide from the Children's
Hospital of Philadelphia is the only cost-benefit analysis of a medical emergency
team in a children’s hospital published to date.\textsuperscript{26} This work stems from the
development of a pragmatic measure to document rapid response team events
known as Critical Deteriorations.\textsuperscript{27} A Critical Deterioration is defined as an
unplanned transfer to the intensive care unit with initiation of mechanical
ventilation or medications for blood pressure support within 12 hours after the
patient is transferred to the ICU.\textsuperscript{27} Additional works by the same study group
documented a decreased rate of Critical Deteriorations with implementation of a
medical emergency team.\textsuperscript{28} Using a retrospective cohort from an urban tertiary
care children’s hospital in Philadelphia, Pennsylvania, the total cost (direct and
indirect) associated with critical deteriorations was determined, as well as the
cost associated with several different staffing models for rapid response
systems.\textsuperscript{26} Patients who met criteria for Critical Deterioration, on average,
accrued additional hospital costs of over $99,000 per patient (95\% CI: $69,000-$130,000) directly attributable to the Critical Deterioration.\textsuperscript{26} To estimate staffing
costs, several models were investigated. These included freestanding teams
versus teams with concurrent responsibilities in the intensive care unit.\textsuperscript{26}
Estimates of the cost range for a concurrent responsibility team consisting of a
nurse and a respiratory therapist on up to a nurse, respiratory therapist and
attending physician ranged from $287,000-$629,000 annually.\textsuperscript{26} A reduction in
the number of Critical Deterioration events needed to offset the cost of the team
in this setting would range from 2.9 to 6.3 events annually.\textsuperscript{26} If a freestanding
team was desired, a team consisting of a nurse and a respiratory therapist would
cost approximately $990,000 annually, while the addition of an attending physician to that same team increases the annual cost to approximately $2.4 million per year. In order to offset this cost, Critical Deteriorations must be decreased by 9.9 to 23.6 events per year to cover this range of costs.

In summary, the data surrounding cardiac arrest rates, mortality and implementation of pediatric rapid response systems is relatively clear. Implementation of rapid response systems within children's hospitals appears to reduce cardiopulmonary arrest outside of the intensive care unit. This appears to be true in large, standalone children's hospitals. It is also suggested that this effect occurs in smaller children's hospitals within larger hospitals. It remains to be seen if this effect occurs within smaller community hospitals that still care for pediatric patients. While the abundance of evidence is in favor of rapid response systems, it should be noted that the study methods of many of the papers in the published literature are of week methodological quality and are observational in nature. While a randomized controlled trial of rapid response systems would be ideal, from an ethical standpoint, the current body of evidence, which suggests reduced risk in hospital settings from having RRT's, would not support the implementation of such a trial. Several studies have been published since Chan's systematic review; a repeated systematic review, which includes this new literature, could be of benefit to the healthcare community.

The data do not appear to be as clear for evaluating rapid response systems effects on hospital mortality. There is significant heterogeneity in the body of literature examining mortality. Since mortality figures in children's
hospitals are significantly lower than adults, to power a study to detect small
differences in overall mortality would require enormous sample sizes, which
could only be provided through large multicenter, collaborative trials.

When costs are considered, it is quite clear to see how preventing one out
of ICU deterioration can equal substantial savings for the institution. A team
whose function is to intervene and stabilize a deteriorating child, whether a
freestanding rapid response team or team with concurrent responsibilities in the
intensive care unit, will work more efficiently and effectively as compared to an
ad hoc team. As processes are streamlined and clinical skills are honed
surrounding the care of a deteriorating child, it becomes simpler to reduce the
number of Critical Deterioration events outside of the ICU thus not only saving
lives, but saving the healthcare system significant amounts of money. While Dr.
Bonafide’s study is the seminal evaluation of cost benefit analysis related to rapid
response systems, the work at Kentucky Children's Hospital can also add to the
body of knowledge surrounding the financial impacts of rapid response systems,
particularly those systems that operate in a children's hospital within a hospital.
Chapter 3 – Methodology

This chapter will describe the architecture of the study to determine if the rapid response system at Kentucky Children’s Hospital reduced cardiopulmonary arrests outside the PICU, reduced RRT calls transferred to the PICU and saved UK HealthCare money. It will consist of a discussion of the methodology, the definition and acquisition of the study population, the procedures utilized in obtaining the data as well as the analytic methods used to examine the data.

When the rapid response system was created at Kentucky Children's Hospital, quality assurance metrics were created to monitor team utilization and performance. A database of team performance was created and housed within the pediatric ICU. Monthly analyses were conducted by the nursing manager and the medical director and compiled in a secured spreadsheet and presented at the monthly Quality and Safety meeting at Kentucky Children's Hospital. Details of these metrics and methods for calculating them are contained in Appendix C. Additional data, such as age, gender and underlying medical condition were abstracted from the electronic medical records. Charts which did not contain complete information, lacked financial information and duplicate records were removed from the analysis. Data were securely stored in an electronic database within UK HealthCare Information Technology Services.

Study Design

This study uses a prospective cohort model, with data being collected since its inception; data collection continues to present date using these same methodologies. The cohort consists of all children, from birth to 21 years of age.
admitted to any area of Kentucky Children’s Hospital from June 2009 through June 2014. All services, medical and surgical, are included in the cohort. While the RRT covers procedural areas for outpatient visits, these data are not captured in the person-time estimates unless a call to the RRT occurs in a procedural area and the child is admitted to the hospital. When a child is admitted in inpatient status to KCH, the child is at risk for deterioration; the time the child is at risk is measured in bed-days. This calculation of bed-days is obtained monthly from the Kentucky Medical Services Foundation (KMSF) who is responsible for billing and coding for UK HealthCare. Descriptive statistics were generated to analyze the cohort using SPSS v22. Chi-square analysis was performed on categorical data. Two tailed, independent sample t-tests were performed to compare means. All statistics were considered significant if a p value was less than 0.05. Frequency distributions were created to describe age distributions and length of stay data.

As mentioned previously in Chapter 1, several modifications to the RRT at KCH have occurred since its launch in 2009. This requires evaluating the RRS over time in its three different versions as a time series. Team version 1 is considered the base case and included subjects from June 2009 through September 2010 (16 months); this was the original team prior to any quality improvements. Version 2 consists of subjects from October 2010 through January 2013 (28 months); this team included data after the nurse driven, peer-to-peer education project. Version 3 runs February 2013 through June 2014 (17 months); this team includes data after the implementation of the automated early
warning system in the electronic medical record.\textsuperscript{12-14,30-32} Data were lacking on deteriorations and cardiopulmonary arrests prior to implementation of the RRT at KCH.

\textbf{Evaluation of Study Objectives}

\textbf{Cardiopulmonary Arrests}

To evaluate the effect of the RRT on cardiopulmonary arrests outside of the ICU, rates of cardiopulmonary arrests per 10,000 bed-days were calculated and reported monthly. Data on out of ICU cardiopulmonary arrests were abstracted from standard clinical documentation describing the events. Person-time estimates in the form of bed-days were obtained from KMSF; this allowed for direct calculation of risk. These data were entered into the RRT database and stored for evaluation. Rates were calculated on a monthly basis for presentation at Quality and Safety Committee meetings as well as for time series analysis. Statistical analysis of the cardiopulmonary arrest rates and risk of cardiopulmonary arrest across the time series was performed using OpenEpi version 3.03.\textsuperscript{33} The risk ratio for cardiopulmonary arrest, as well as 95\% confidence intervals, were obtained using the Mid-P exact method.\textsuperscript{33} The risk ratio was adjusted across the time series using the Mantel-Haenszel procedure.\textsuperscript{33}

\textbf{Intensive Care Unit Transfers}

The RRT at KCH was implemented with the express goal of reducing children transferred to the PICU in the setting of clinical deterioration. The objective was to recognize deterioration early, intervene and maintain the patient on the acute care floor. To evaluate the proportion of children transferred to the
PICU related to RRT calls, the number of RRT-related PICU transfers was compared to the total number of RRT calls per month. These data were tabulated monthly and presented to the Quality and Safety committee in the monthly format and followed as a time series. Risk ratios and 95% confidence intervals across the time series were computed, as well as absolute risk reduction which allowed for calculation of a number needed to treat (NNT) to prevent one PICU transfer related to an RRT call.

\[
NNT = \frac{1}{Risk \ Reduction \ (absolute)}
\]

Linear regression was performed to examine a potential dose response relationship between the incidence of RRT calls and proportion of RRT calls transferred to the PICU.

**Financial Implications**

Cases for financial analysis were identified from the log of RRT calls; it involves analysis of the entire time series as a single group and does not attempt to stratify by team version. Encounter codes (medical record number plus a four digit unique visit identifier) were submitted to a financial analyst at KMSF. Direct costs refer to hospital bed charges, i.e., how much money does it cost Kentucky Children’s Hospital to house a pediatric patient in a certain bed in a certain level of care. These direct costs, for patients who had an RRT called, were obtained for Acute Care Services as well as PICU services and totaled. A full micro-costing analysis was not under taken. Due to the short time course of evaluation, adjustments for inflation were omitted.
Subjects were then stratified by those who had an RRT resulting in PICU transfer versus those who remained in Acute Care. Furthermore, these groups were then stratified by age into children <2 years old and those ≥2 years old. Each stratum was analyzed for outliers based on length of stay using the “Explore” function in SPSS. While using outlier removal slightly dilutes the data set, it allows for the creation of a best case/worst case scenario. With outliers removed, an idealized “best case” scenario is created. When the outliers are included, it represents a “worst case” scenario. Descriptive statistics for the for the different strata, inclusive and exclusive of outliers were calculated using SPSS v22. Differences in mean costs between RRT calls that required only Acute Care services and those transferred to the PICU were compared using a 2-tailed independent sample t-tests. Even though all children in the cohort received RRT services, it was hypothesized that if children can be stabilized in Acute Care and not transferred to the PICU this would come with a cost saving to UK HealthCare. A sensitivity analysis was performed to determine the impact of potential cost savings to UK HealthCare.
Chapter 4 – Results and Discussion

This chapter will present the results and discuss the interpretation of the findings of this study. The study group will first be described, followed by an analysis of the impact of the rapid response team on cardiopulmonary arrests outside of the intensive care unit. This will be followed by evaluation of the impact of the rapid response team at stabilizing deteriorating children and preventing transfer to the pediatric intensive care unit. Finally, an analysis of cost associated with the rapid response team will be presented.

Study Group Characteristics

The pediatric RRT database contained 628 calls for the study period of June 2009 through June 2014. This group was then analyzed for completeness of medical records, RRT logs and financial data. No financial data could be found in 56 encounters, 86 charts had no direct costs for Acute Care and 110 entries in the RRT log were incomplete. This resulted in 376 records meeting criteria for inclusion in the study. This 376 was analyzed with the “Explore” function in SPSS to detect outliers based on length of stay (LOS). SPSS detected 25 addition cases that were deemed outliers based on LOS. Similar procedures were applied to the individual subpopulations of patients aged less than two years and those aged two years and older. SPSS detected 26 outliers in the population of 203 children aged less than two years old and eight outliers in the population of 173 children aged two years and older.

Table 1 describes some of the demographic data of the study population, including outliers, and Figures 1-3 contains histograms depicting the age
distributions. The measures of central tendency for the total study population show a skewed distribution. When subpopulations of children less than 2 years old and 2 years and older were created, the subpopulation data was still markedly right skewed in children less than two years old. Of the 203 RRT calls in children <2 years old, 70% occur in children <6 months old ($\chi^2 = 32.32, p < 0.0001$). This finding suggests children less than six months old are at higher risk for deterioration and rapid response team calls when hospitalized.

When the frequency distribution of children older than two years was examined, there appeared to be two subpopulations within that age distribution. Children who are less than 10 years old appear to have a very right skewed distribution of their use of rapid response team services. Adolescents who are 10 years of age and older appear to have different utilization of rapid response team resources as well. Further evaluation of service utilization, as well as etiologies of rapid response team calls is warranted based on the apparent distribution of populations at risk.

**Impact on Cardiopulmonary Arrests**

There were five cardiopulmonary arrests outside the ICU in team version 1, seven in team version 2 and one in team version 3. The results of cardiopulmonary arrest rates are shown in Table 2. The overall rates of cardiopulmonary arrests showed a significant decrease over time. Based on the estimates demonstrated by the risk ratios, children who are admitted to Kentucky Children's Hospital with the current version of the rapid response team have an
88% reduced risk of cardiopulmonary arrest occurring outside of the intensive care unit relative to five years ago when the rapid response team was launched. This relative risk reduction is statistically significant; however the confidence interval is very large. When adjusted across the time series using the Mantel Haenszel procedure, the risk reduction is maintained, with children having 65% less risk of cardiopulmonary arrest outside of the intensive care unit. Due to the rare nature of cardiopulmonary arrests outside of the ICU, no formal evaluation of mortality was undertaken. An individual case series could be utilized to examine outcomes related to out of ICU cardiopulmonary arrest, however this analysis is beyond the scope of this project.

During the second version of the rapid response team, initial reductions in out of ICU cardiopulmonary arrest could be seen. However, this result was not statistically significant. While the statistics may not be significant, the impact to the children and their families of avoiding an out of ICU cardiopulmonary arrest is significant. The 30% reduced risk of out of ICU cardiopulmonary arrest was encouraging to the team and was a finite recognition of team impact. It is difficult to determine whether the impacts that were seen in the reduction of cardiopulmonary arrest were directly related to the rapid response team or were related to confounding factors. Since the rapid response team was launched, there have been numerous initiatives at Kentucky Children’s Hospital surrounding recognition of patient deterioration, simulation of deteriorating patients, as well as increased training efforts in pediatric advanced life support. These additional training efforts and activities could potentially bias the study results away from
the null. While bias may be introduced, the bottom line is children and their families have less risk of out of ICU cardiopulmonary arrest in the current version of the rapid response system at Kentucky Children’s Hospital.

**Impact on Transfers to the Pediatric Intensive Care Unit**

The primary goal at the launch of the pediatric rapid response team at Kentucky Children’s Hospital was to prevent deteriorating children from being transferred to the intensive care unit. Table 3 presents the data related to rapid response team utilization, patients transferred to the intensive care unit and the relative risk of transfer over time. During the first version of the rapid response team, over 48% of patients who had a rapid response called on them were transferred to the intensive care unit. As the rapid response system matured and innovations occurred to the team, the proportion of patients who were transferred to the intensive care unit steadily declined. The percentage of patients transferred to the PICU during the second version of the rapid response team was 39.9% and was 24.5% with the current version of the rapid response team. The current version of the rapid response system, when a child is deteriorating and has a rapid response called on them, the child has 50% less risk of being transferred to the PICU related to their call relative to the original team version. Additionally, since the absolute risk reduction is able to be calculated, a number needed to treat to prevent one transfer to the ICU is calculable. In the current rapid response system, the number needed to treat is four. While the duties of the rapid response team are an additional duty added to the current responsibilities of nurses and technicians already hard at work in the hospital, it
does not take a large number of calls to make a significant impact at the patient level.

Another striking feature of the utilization data is the duration for each version and the numbers of calls to the rapid response team during each version. In the initial 16 months of the rapid response team, only 54 calls were made to the rapid response team. During the nearly equivocal length of time in version 3, more than one and a half times more bed days of risk were accumulated as well as more than five times the number of call to the rapid response team, while at the same time reducing the risk of transferring an RRT call to the PICU. This implies an inverse dose response relationship. Linear regression was performed and is shown in Figure 4. In this analysis, each point represents a monthly rate of RRT utilization on the abscissa and the monthly corresponding proportion of RRT calls transferred to the PICU on the ordinate. The linear regression model is statistically significant and shows an inverse relationship between rapid response team call rate and the proportion of patients transferred to the PICU. This model only explains 8% of the variability in the response variable, i.e. the data are widely scattered around this estimated line of best fit which limits the precision of the estimate made. The observed effects are potentially due to random error or are part of a more complex, multivariate interaction. Investigation of these factors is beyond the scope of this project.

It is clearly evident that institution of a rapid response team at Kentucky Children's Hospital reduced the proportion of patients transferred to the pediatric ICU over time. Significant improvements were across the time series. The data
suggest a dose response relationship between team utilization and reduction in PICU transfer. While the linear regression model is not precise, it can emphasize the fact that increasing call rates and team utilization will potentially reduce the proportion of RRT calls transferred to the PICU.

The setting of this study cannot be overlooked as a significant factor in its potential generalizability. As was mentioned in the literature review, only a single study has examined the function of a rapid response team outside of a freestanding children's hospital. This study was performed on a single ward in a larger hospital in Pakistan, potentially limiting its generalizability to the American healthcare system. These data, coupled with the findings from the previous section related to reduced incidence of cardiopulmonary arrests outside the intensive care unit, show that rapid response systems in children's hospitals within larger hospitals do impact patient safety and quality of care. What has yet to be determined is the financial impact of housing a rapid response team in a children's hospital within a larger hospital. This will be examined in the following section.

Financial Impact of a Rapid Response System in a Children's Hospital

Evaluating costs within a healthcare system can be a daunting and difficult task. In order to simplify this, an analysis of direct costs of hospital unit bed charges was performed; unless specifically defined, "costs" will henceforth refer these previously mentioned direct costs. Direct costs are those costs tied exclusively to a subunit of the hospital and disappears from financial analyses when that unit closes. In this analysis, direct costs refer to the cost Kentucky
Children’s Hospital associated with hospital unit bed charges, i.e., the hospital cost associated with a child occupying a specific bed in a specific hospital unit. Total direct costs were tabulated and stratified between children less than two years old and two years and older who had rapid response calls while admitted to Kentucky Children’s Hospital. In addition, costs were analyzed with and without outliers. Total direct costs, mean direct costs with standard deviation and median direct costs were calculated. Differences between the mean costs of children receiving RRT services were analyzed and are summarized in Table 4. In this analysis, all children received RRT services. Children listed in Table 4 as “Acute Care” are children who received an RRT call, but were stabilized on the Acute Care unit, i.e. avoided transfer to the PICU. “PICU,” in Table 4, represents those children who received and RRT call which resulted in transfer to the PICU. The difference in cost between these two groups was calculated and is shown in the bottom portion of Table 4.

What is evident from Table 4 is that for all patients, except those two years of age and older when outliers are removed, when the rapid response team intervened on a deteriorating patient and prevented them from going to the intensive care unit, significant cost savings were associated with those efforts. Accounting for outliers, the rapid response team can save UK HealthCare, on average, a minimum of $1,938 up to a maximum of $4,539 in bed occupancy direct costs for each PICU admission prevented. The majority of the costs saved were hospital unit bed charges and physician professional fees. This amount is significantly higher in children less than two years of age: $2,757-$6,210. For
children two years of age and older, when outliers are removed the mean difference was not statistically significant. However, if the same exercise applied previously is applied to this age group, preventing one ICU transfer will save the institution $928-$2,255.

While ranges of savings based on a single case prevented from going to the ICU is an interesting finding, administrators will be more interested in the larger impact of the rapid response system at the organizational level. To determine this, sensitivity analysis was performed to evaluate potential impact to the healthcare system of the rapid response team. This sensitivity analysis will determine the potential impact on direct costs as the number needed to treat is varied. Recall that the number needed to treat is determined by the reduction in the proportion of rapid response calls transferred to the PICU. Utilizing the total number of calls to the rapid response team during version 3, which accumulated 286 calls over 19 months, an annual number of calls of 181 is estimated \[286 \times \left(\frac{12}{19}\right).\] The data in Table 4 allow us to assume that 54% of the rapid response calls will be in children less than two years old and 46% will be in children older than two years old. With these assumptions, the number needed to treat can be varied and an estimate of calls prevented in both subgroups, as well as an estimate of the range of potential cost savings calculated. These findings are shown in Table 5. With the team in its current state, with a number needed to treat to avoid one PICU transfer of 4, the 45 calls which were prevented from going to the PICU saved UK HealthCare an estimated $86,000-$200,000. Even team version 2, which had a number needed to treat of 12, saved the enterprise
approximately $29,000-$66,000. Data such as these are critical for evaluating the risk that will be associated with launching a standalone rapid response team.

As previously mentioned, the current rapid response team is additional duty added on to the daily work of two nurses and one respiratory therapist. Based on statistics from the Bureau of Labor Statistics, the median annual salary for registered nurse is $60,000 while the median salary for a respiratory therapist is approximately $56,000.35,36 Based on these estimates, it would cost approximately $176,000 in annual wages, not including fringe benefits. The sensitivity analysis does not support creating a standalone rapid response team at this time; there is too much financial risk associated with a standalone team compared to adding on the responsibilities as an additional daily duty to current staff.

Analyzing only direct costs, while easy for KMSF to provide the data, only reflects such costs as bed charges, physician billing, nursing care costs and technical services such as respiratory therapy. It does not account for the infrastructure or indirect costs. A more granular micro-costing analysis has the potential to yield different results. It is uncertain just how a micro-costing analysis would influence the results; this however is beyond the scope of this project.
Chapter 5 – Conclusions

This project was undertaken to investigate three specific areas related to the rapid response team at Kentucky Children's Hospital:

1. Did the implementation of a pediatric rapid response team prevent cardiopulmonary arrests outside of the PICU?
2. Did the implementation of a rapid response system reduce the proportion of deteriorating children being transferred to the PICU?
3. What are the financial impacts of the rapid response team implementation at Kentucky Children's Hospital?

Based on analysis of the data, the pediatric rapid response team at KCH reduced cardiopulmonary arrests outside of the intensive care unit. With the rapid response team in place at Kentucky Children's Hospital, children face 88% less risk of cardiopulmonary arrest outside the PICU as they did at the inception of the rapid response team in 2009.

The rapid response system at Kentucky Children's Hospital has reduced the proportion of rapid response calls transferred to the pediatric intensive care unit. When a rapid response is called today at Kentucky Children's Hospital, that child has 50% less risk of being transferred to the intensive care unit as compared to the original version of the rapid response team. While team version 2, the first revision of the rapid response team, also reduced the proportion of calls transferred to the PICU, it was not as robust as the current version of the team. With the current level of risk reduction provided by the rapid response team, it only takes for calls to the rapid response team to prevent one child from...
being transferred to the ICU. A quick glance of the data suggests there is a dose response relationship between increased call rate and decreased transfer proportion to the ICU, however the large amount of variability in the model makes predictions exceedingly imprecise.

Financial impacts of the rapid response team are real and can be extrapolated on a systems level. Statistically significant differences in mean costs were noted in all groups except for children two years of age and older who had outliers removed from their evaluation. Sensitivity analysis shows that even team version 2, which yielded only a meager improvement, saved the healthcare system an estimated $30,000-$70,000. At its current level of performance, the rapid response team saves UK HealthCare approximately $86,000-$200,000 annually.

This study contributes to the larger body of healthcare literature in several ways. It is the first US study to demonstrate the impact of a rapid response system in a children's hospital within a hospital. These data show that rapid response systems are effective outside of freestanding children's hospitals. It also shows that rapid response teams, manned by staff that performs this function as an additional daily duty, can be just as effective as standalone teams.

While this study did answer many questions, it generated new questions. Further investigations should be undertaken to determine the factors that confound the relationship between the incidence of rapid response team calls and proportion of calls transferred to the PICU. Additionally, children less than six months old appear to be a particularly high risk group for rapid response calls.
Further investigation into specific risk factors, illness patterns and cost outcomes in children less than six months old are warranted. Furthermore, investigation into two potential subpopulations within the cohort of children older than two years old with regard to differences in rapid response calls would be beneficial. Analysis of the outliers which were removed from the investigation could shed light on interesting disease patterns or risk factors that could be used to predict increased length of stay as well as hospital costs. Additionally, analysis of the changes in costs over various versions of the RRT would be valuable to investigate.

Several limitations are noted with the study. First and foremost, is the reliance on administrative data. The initial cohort contained 628 calls logged in the rapid response team database. Through various acts of attrition, such as missing financial data, incomplete records in the database and incomplete medical records, only 376 records were available for analysis. This was a loss of 40% of the potential data that could have been included in the study. While the study yielded significant results, selection bias is present, which is a threat to the validity of the study. Logarithmic transformation is a method used to normalize skewed data and would remove selection bias associated with removal of outliers. Re-examination using natural logarithmic transformation of the frequency data does not yield significant changes to the data set.

Additionally, there is a potential for a significant Hawthorne effect that would account for improvement in the metrics. Nursing staff understand there is another set of eyes watching their patients, which has potential to make them
more diligent about monitoring and evaluating their patients. Using only the direct costs potentially introduces selection bias by ignoring the effects of indirect costs. Finally, the economic impacts in the sensitivity analysis are based on a certain set of assumptions. The analysis is only as good as the assumptions it is based on. A simple sensitivity analysis such as the one performed in this study cannot consider any interaction among additional variables. There is potential for multivariate analysis which could account for multiple confounding factors at once thus making the economic analysis more robust.

Overall, rapid response teams appear to be a smart investment in patient safety in a children's hospital within a hospital. The data support reductions and cardiopulmonary arrests outside of the intensive care unit, reduced proportions of deteriorating children who were transferred to the intensive care unit as well as savings in direct costs related to rapid response team deployment.
Chapter 6 - References Cited


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## Appendix A - Tables and Figures

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**Length of Stay in Days**

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Table 1: Demographics of the study group who had Pediatric Rapid Response calls while hospitalized; N=number of subjects, OE=outlier excluded, OI=outlier included, SD=standard deviation, yrs=years)
Figure 1: Frequency distribution of the entire study population included in the analysis. Based on these data, age distributions were stratified into children <2 years old and those 2 years and older.
Figure 2: Frequency distribution of RRT calls by age group in children less than 2 years old. Note that 70% of the RRT calls occur in children 6 months and younger.
Figure 3: Frequency distribution of RRT calls in children 2 years of age and older
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Table 2: Temporal trends in cardiopulmonary arrest rates at Kentucky Children's Hospital. The total rate is adjusted for the time series using the Mantel Haenszel procedure. CPA = cardiopulmonary arrest. RR = risk ratio; 95% CI = 95% confidence interval
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</table>

Table 3: Proportion of rapid response calls transferred to the pediatric ICU over time; NNT = number needed to treat, PTP = proportion transferred to PICU, RD = risk reduction (absolute), RR = risk ratio; Total RR is Mantel Haenszel adjusted, 95% CI = 95% Confidence Interval
Figure 4: Linear regression of rate of rapid response team utilization versus proportion of patients transferred to the pediatric intensive care unit. Dark blue line represents the line of best fit while the light blue lines represent the 95% confidence interval for the line of best fit.
<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>&lt;2 years</th>
<th>&gt;2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acute Care</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DC(_{\text{total}})</td>
<td>$1,343,183</td>
<td>$641,822</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>$3,572</td>
<td>$3,162</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>$3941</td>
<td>$4046</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>$2,250</td>
<td>$1,861</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>376</td>
<td>203</td>
</tr>
<tr>
<td><strong>Acute Care</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without outliers</td>
<td>DC(_{\text{total}})</td>
<td>$1,093,662</td>
<td>$404,386</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>$3,116</td>
<td>$2,285</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>$2,784</td>
<td>$1,910</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>$2,174</td>
<td>$1,652</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>351</td>
<td>177</td>
</tr>
<tr>
<td><strong>PICU</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with outliers</td>
<td>DC(_{\text{total}})</td>
<td>$2,068,309</td>
<td>$1,405,865</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>$8,111</td>
<td>$9,372</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>$16,317</td>
<td>$19,868</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>$3,802</td>
<td>$4,162</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>255</td>
<td>150</td>
</tr>
<tr>
<td><strong>PICU</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without outliers</td>
<td>DC(_{\text{total}})</td>
<td>$1,167,426</td>
<td>$625,237</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>$5,054</td>
<td>$5,042</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>$4,739</td>
<td>$4,293</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>$3,464</td>
<td>$3,774</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>231</td>
<td>124</td>
</tr>
</tbody>
</table>

**Mean Differences of Costs**

<table>
<thead>
<tr>
<th></th>
<th>Mean(_{\text{AC}})</th>
<th>Mean(_{\text{PICU}})</th>
<th>ΔMean</th>
<th>p value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outliers included</td>
<td>$3,572</td>
<td>$3,162</td>
<td>$4,054</td>
<td>&lt;0.001</td>
<td>$2,527, $6,551</td>
</tr>
<tr>
<td></td>
<td>$8,111</td>
<td>$9,372</td>
<td>$6,309</td>
<td>&lt;0.001</td>
<td>$3,005, $9,416</td>
</tr>
<tr>
<td></td>
<td>$4,539</td>
<td>$6,210</td>
<td>$2,255</td>
<td>0.01</td>
<td>$533, $3,977</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>$2,527</td>
<td>$6,551</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$3,005</td>
<td>$9,416</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$533</td>
<td>$3,977</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outliers removed</td>
<td>$3,116</td>
<td>$2,285</td>
<td>$3,669</td>
<td>&lt;0.001</td>
<td>$1,323, $2,552</td>
</tr>
<tr>
<td></td>
<td>$5,054</td>
<td>$5,042</td>
<td>$4,597</td>
<td>&lt;0.001</td>
<td>$1,994, $3,521</td>
</tr>
<tr>
<td></td>
<td>$1,938</td>
<td>$2,757</td>
<td>$928</td>
<td>0.06</td>
<td>-$23, $1,879</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Cost analysis for the Pediatric Rapid Response Team at Kentucky Children’s Hospital. Only direct costs were examined and were not adjusted for inflation. \( \text{DC}_{\text{total}} = \text{total direct costs}, \text{Mean}_{\text{AC}} = \text{mean direct cost of Acute Care services}, \text{Mean}_{\text{PICU}} = \text{mean direct cost of PICU services}, \Delta \text{Mean} = \text{difference in mean between Acute Care and PICU services}, N = \text{number of subjects in the category}, \text{SD} = \text{standard deviation}, 95\% \text{ CI} = 95\% \text{ Confidence Interval} \)
<table>
<thead>
<tr>
<th>NNT</th>
<th>%pop &lt;2</th>
<th>%pop ≥2</th>
<th>Annual Calls</th>
<th>Calls Prevented</th>
<th>Cost LL</th>
<th>Cost UL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>&lt;2</td>
<td>&gt;2</td>
</tr>
<tr>
<td>3</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>60</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>45</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>36</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>30</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>20</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>54</td>
<td>46</td>
<td>181</td>
<td>15</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 5: Sensitivity analysis of RRT cost savings based on variations of the Number Needed to Treat. See the preceding text for assumption integrated into this model. NNT = number needed to treat, % pop <2 = percentage of population aged <2 years, % pop ≥2 = percentage of population aged 2 years and older, Cost LL = lower estimate of cost savings, Cost UL = upper estimate of cost savings.
EXEMPTION CERTIFICATION

MEMO: Erich Maul, DO
Pediatrics
H-404, Chandler Medical Center
0298
PI phone #: (859)258-2581

FROM: Institutional Review Board
e/o Office of Research Integrity

SUBJECT: Exemption Certification for Protocol No. 14-0610-X2B

DATE: September 3, 2014

On September 3, 2014, it was determined that your project entitled, Economic Impact of a Rapid Response System in a Children’s Hospital, meets federal criteria to qualify as an exempt study.

Because the study has been certified as exempt, you will not be required to complete continuation or final review reports. However, it is your responsibility to notify the IRB prior to making any changes to the study. Please note that changes made to an exempt protocol may disqualify it from exempt status and may require an expedited or full review.

The Office of Research Integrity will hold your exemption application for six years. Before the end of the sixth year, you will be notified that your file will be closed and the application destroyed. If your project is still ongoing, you will need to contact the Office of Research Integrity upon receipt of that letter and follow the instructions for completing a new exemption application. It is, therefore, important that you keep your address current with the Office of Research Integrity.

For information describing investigator responsibilities after obtaining IRB approval, download and read the document “PI Guidance to Responsibilities, Qualifications, Records and Documentation of Human Subjects Research” from the Office of Research Integrity’s IRB Survival Handbook web page [http://www.research.uky.edu/ori/IRB-Survival-Handbook.html#PIResponsibilities]. Additional information regarding IRB review, federal regulations, and institutional policies may be found through ORI’s website [http://www.research.uky.edu/ori]. If you have questions, need additional information, or would like a paper copy of the above mentioned document, contact the Office of Research Integrity at (859) 257-9428.
Appendix C - Rapid Response Team Metrics

1. Baseline data obtained on a monthly basis
   a. Raw number of PRRT calls-PRRT logs
   b. Total admits and bed-days-obtained from Clint Lush in KMSF
   c. Number of “code events” outside PICU-PRRT logs and Code Sheets
      i. All code events outside PICU are to be classified as
         1. Cardiopulmonary arrest (CPA)-a patient who is
            a. pulseless or bradycardic AND
            b. receives chest compressions or electrical therapy
         2. Acute Respiratory Compromise (ARC)-a patient who transferred to PICU who
            a. Received PPV on the floor OR
            b. Mechanical ventilation immediately upon arrival to the PICU
         3. Critical Deterioration (CD)-a patient who is transferred to PICU and receives any of the following in the first 12 hours after transfer
            a. NIPPV
            b. Mechanical ventilation
            c. Pressors
   d. Number of PRRT calls transferred to PICU
   e. Need to determine type of code event outside of ICU
2. Calculated metrics (all results are calculated to 4 decimal places)

a. Rate of team utilization
   i. Calculate calls/1000 bed-days
   ii. \( \left( \frac{PRRT \text{ Calls}}{\text{bed days}} \right) \times 1000 \)

b. Rate of code events outside PICU
   i. Calculate floor codes/1000 bed-days
   ii. \( \left( \frac{Acute \text{ Care Codes}}{\text{bed days}} \right) \times 1000 \)

c. Proportion of calls transferred to PICU
   i. Calculate PICU transfer proportion
   ii. \( \left( \frac{PRRT \text{ Calls Transferred to PICU}}{PRRT \text{ Calls}} \right) \)
      iii. Result is a number between 0 and 1

d. Rate of CPA
   i. Calculate CPA/1000 bed-days
   ii. \( \left( \frac{CPA}{\text{bed days}} \right) \times 1000 \)

e. Rate of ARC
   i. Calculate ARC/1000 bed-days
   ii. \( \left( \frac{ARC}{\text{bed days}} \right) \times 1000 \)

f. Rate of CD
   i. Calculate CD/1000 bed-days
   ii. \( \left( \frac{CD}{\text{bed days}} \right) \times 100 \)
Appendix D - Acknowledgments

- Nikki, my Saint of Sunny Slope Trace-I can never thank you enough for your sacrifices to help me accomplish this
- Elise, Charlie, Liv and Avery-for always being there to offer hugs of encouragement; don’t give up when things get tough
- Clint Lush, MBA-for financial data and your assistance above and beyond your normal duties
- Tag Heister-medical librarian par excellence
- Drs. Carman, Mays, Hankins and Pfeifle-for helping get my academic career launched
- Jan, Lee Ann, Suellen and the KCH RRT Crew-the nurses and technicians who exemplify “Best Care Anywhere!”
- Jeff, Jaime, Berry, TJ, Curtis, Lindsay, Alan, Phyllis-filling in for me at the hospital when school sucked me away.
Appendix E - Biographical Sketch

Dr. Erich Maul is an Associate Professor of Pediatrics and Pediatric Hospitalist at the University of Kentucky College of Medicine in Lexington, Kentucky. He earned his Bachelors of Science in Biology Magna Cum Laude from Bloomsburg University of Pennsylvania and his Doctor of Osteopathic Medicine, with honors, from the Ohio University College of Osteopathic Medicine. Dr. Maul served with distinction as a General Pediatrician in the United States Air Force Medical Service for 11 years, separating at the rank of Major, prior to arriving in Lexington. He is a Fellow of the American Academy of Pediatrics and serves on two AAP planning committees.

Contact Information

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