Predicting Adverse Events Through Monitoring

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Disclosures

• None
Predictability of adverse events

- Situation & environment interactions
  - Pediatric Vs. adult
  - In- or Out-of-ICU events

- “Safety nets”
  - Medical emergency response teams
  - Early warning scores
  - Monitors

- Prediction does not imply appropriate response or improved outcomes
“Lucky for you there was a safety net.”
Rapid Response Teams
A Systematic Review and Meta-analysis

Paul S. Chan, MD, MSc; Renuka Jain, MD; Brahmajee K. Nallmothu, MD, MPH; Robert A. Berg, MD; Comilla Sasson, MD, MS

Arch Intern Med. 2010;170(1):18-26

Decrease in preventable non-ICU cardiac arrest

No significant change in the hospital mortality & LOS
Implementation of a Multicenter Rapid Response System in Pediatric Academic Hospitals Is Effective
Afrothite Kotsakis, Anna-Theresa Lobos, Christopher Parshuram, Jonathan Gilleland, Rose Gaiteiro, Hadi Mohseni-Bod, Ram Singh, Desmond Bohn and on behalf of the Ontario Pediatric Critical Care Response Team Collaborative
*Pediatrics* 2011;128;72; originally published online June 20, 2011; DOI: 10.1542/peds.2010-0756

### TABLE 4 PRRS Outcome Measures

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Before PRRS, n (No. per 1000 Hospital Admissions)</th>
<th>After PRRS, n (No. per 1000 Hospital Admissions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause hospital mortality</td>
<td>553 (10)</td>
<td>540 (9.6)</td>
</tr>
<tr>
<td>PICU mortality rate after urgent PICU admission</td>
<td>70 (1.3)</td>
<td>61 (1.1)</td>
</tr>
<tr>
<td>PICU mortality rate after PICU readmission</td>
<td>16 (0.3)</td>
<td>7 (0.1)</td>
</tr>
<tr>
<td>Total code blue events</td>
<td>210 (4)</td>
<td>150 (3)</td>
</tr>
<tr>
<td>Actual cardiopulmonary arrests</td>
<td>69 (1.9)</td>
<td>66 (1.8)</td>
</tr>
<tr>
<td>Near cardiopulmonary arrests</td>
<td>123 (3.4)</td>
<td>67 (1.9)</td>
</tr>
</tbody>
</table>

*a P < .05.*
Multicentre validation of the bedside paediatric early warning system score: a severity of illness score to detect evolving critical illness in hospitalised children

Christopher S Parshuram, et al  Critical Care 2011,15:R184

Figure 1 The receiver operating characteristic curve for the performance of the Bedside Paediatric Early Warning System score. Data are presented for 2,074 patients who were admitted to inpatient wards of four university-affiliated paediatric hospitals in a frequency-matched case-control study with two control patients per case. Case patients had either an immediate call to a resuscitation team or were urgently admitted to a paediatric intensive care unit (PICU) without a call to the resuscitation team. Control patients had neither. The maximum Bedside Paediatric Early Warning System score was calculated for the 12 hours ending 1 hour before the resuscitation team call or urgent PICU admission in case patients and for 12 hours in control patients.
### Bedside Pediatric Early Warning System score

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Age group</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>0 to &lt; 3 months</td>
<td>&gt; 110 and &lt; 150</td>
<td>≥ 150 or ≤ 110</td>
<td>≥ 180 or ≤ 90</td>
<td>≥ 190 or ≤ 80</td>
</tr>
<tr>
<td></td>
<td>3 to &lt; 12 months</td>
<td>&gt; 100 and &lt; 150</td>
<td>≥ 150 or ≤ 100</td>
<td>≥ 170 or ≤ 80</td>
<td>≥ 180 or ≤ 70</td>
</tr>
<tr>
<td></td>
<td>1-4 years</td>
<td>&gt; 90 and &lt; 120</td>
<td>≥ 120 or ≤ 90</td>
<td>≥ 150 or ≤ 70</td>
<td>≥ 170 or ≤ 60</td>
</tr>
<tr>
<td></td>
<td>&gt; 4-12 years</td>
<td>&gt; 70 and &lt; 110</td>
<td>≥ 110 or ≤ 70</td>
<td>≥ 130 or ≤ 60</td>
<td>≥ 150 or ≤ 50</td>
</tr>
<tr>
<td></td>
<td>&gt; 12 years</td>
<td>&gt; 60 and &lt; 100</td>
<td>≥ 100 or ≤ 60</td>
<td>≥ 120 or ≤ 50</td>
<td>≥ 140 or ≤ 40</td>
</tr>
<tr>
<td>Systolic pressure</td>
<td>0 to &lt; 3 months</td>
<td>&gt; 60 and &lt; 80</td>
<td>≥ 80 or ≤ 60</td>
<td>≥ 100 or ≤ 50</td>
<td>≥ 130 or ≤ 45</td>
</tr>
<tr>
<td></td>
<td>3 to &lt; 12 months</td>
<td>&gt; 80 and &lt; 100</td>
<td>≥ 100 or ≤ 80</td>
<td>≥ 120 or ≤ 70</td>
<td>≥ 150 or ≤ 60</td>
</tr>
<tr>
<td></td>
<td>1 to 4 years</td>
<td>&gt; 90 and &lt; 110</td>
<td>≥ 110 or ≤ 90</td>
<td>≥ 125 or ≤ 75</td>
<td>≥ 160 or ≤ 65</td>
</tr>
<tr>
<td></td>
<td>&gt; 4 to 12 years</td>
<td>&gt; 90 and &lt; 120</td>
<td>≥ 120 or ≤ 90</td>
<td>≥ 140 or ≤ 80</td>
<td>≥ 170 or ≤ 70</td>
</tr>
<tr>
<td></td>
<td>&gt; 18 and &lt; 100</td>
<td>&gt; 100 and &lt; 130</td>
<td>≥ 130 or ≤ 100</td>
<td>≥ 150 or ≤ 85</td>
<td>≥ 190 or ≤ 75</td>
</tr>
<tr>
<td>Capillary refill</td>
<td>&lt; 3 seconds</td>
<td></td>
<td>≥ 3 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>0 to &lt; 3 months</td>
<td>&gt; 29 and &lt; 61</td>
<td>≥ 61 or ≤ 29</td>
<td>≥ 81 or ≤ 19</td>
<td>≥ 91 or ≤ 15</td>
</tr>
<tr>
<td></td>
<td>3 to &lt; 12 months</td>
<td>&gt; 24 or &lt; 51</td>
<td>≥ 51 or ≤ 24</td>
<td>≥ 71 or ≤ 19</td>
<td>≥ 81 or ≤ 15</td>
</tr>
<tr>
<td></td>
<td>1 to 4 years</td>
<td>&gt; 19 or &lt; 41</td>
<td>≥ 41 or ≤ 19</td>
<td>≥ 61 or ≤ 15</td>
<td>≥ 71 or ≤ 12</td>
</tr>
<tr>
<td></td>
<td>&gt; 4 to 12 years</td>
<td>&gt; 19 or &lt; 31</td>
<td>≥ 31 or ≤ 19</td>
<td>≥ 41 or ≤ 14</td>
<td>≥ 51 or ≤ 10</td>
</tr>
<tr>
<td></td>
<td>&gt; 12 years</td>
<td>&gt; 11 or &lt; 17</td>
<td>≥ 17 or ≤ 11</td>
<td>≥ 23 or ≤ 10</td>
<td>≥ 30 or ≤ 9</td>
</tr>
<tr>
<td>Respiratory effort</td>
<td>Normal</td>
<td>Mild increase</td>
<td>Moderate increase</td>
<td>Severe increase/any apnea</td>
<td></td>
</tr>
<tr>
<td>SpO2</td>
<td>&gt; 94</td>
<td>91 to 94</td>
<td>≤ 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O2 therapy</td>
<td>Room air</td>
<td>Any to &lt; 4 L/minute or &lt; 50%</td>
<td>≥ 4 L/minute or ≥ 50%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Components to MET are important:

• Rapid response to defined clinical signs
  – age-related physiologic variables and clinical judgment: inconsistent & institutional specific

• Education, analysis of critical events, and feedback to ward staff

• Sensitivity & specificity of MET:
  – Inadequately defined and controlled outcomes
  – Lack of complete elimination of events
  – Incidence of calls requiring no intervention
  – Inconsistent activation: “local culture”
Patient surveillance

• Adverse events preceded by variable period of instability
• Instability may be patient or practitioner related
• Corollary: Continuously monitor all patients when not directly observed
• Lessons learned from forecasting: Big Data
Limitations for continuous patient surveillance

- Patient comfort & *minimize false positives*
- *Static targets*: population based Vs. patient specific; particular concern for pediatric demographic
- *Poor integration* with the EMR, bed side monitors and calculations
- *Limited learning*, prediction and pattern recognition
- *Threshold monitoring*:
  - one or more signals: Variable
  - “Scores” based on number of breached thresholds
  - LATE WARNING SYSTEM rather than EARLY.
Monitoring Systems: Limitations

- **Discrete data**
  - Multiple device platforms that may not stream to EMR
  - Biomedical device integration

- **Real-time display: clinician interpretation**

- **Central monitoring stations**
  - Remote to bed side
  - Not visible of the patient care area

- **Limited capture, analysis & integration of data**
A controlled trial of electronic automated advisory vital signs monitoring in general hospital wards.

Bellomo et al; for the Vital Signs to Identify, Target and Assess Levels of Care Study (VITAL care study)


10 hospitals, 18,000 patients

Improved response to respiratory criteria (21-31%)
Improved survival following MET activation
Early recording of data
Patterns of unexpected in-hospital deaths: a root cause analysis

Lawrence A Lynn¹, J Paul Curry²,³*

*Patient Safety in Surgery 2011, 5:3

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**Figure 1.** Type I Pattern of Unexpected Hospital Death (e.g., Sepsis, CHF).

- **SpO₂**: oxygen saturation
- **PaCO₂**: Arterial carbon dioxide tension
- **Ve**: minute ventilation
- **RR**: respiratory rate
- **P-50**: Oxygen tension where hemoglobin is 50% saturated

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Terminal rise of RR due to severe metabolic (lactic) acidosis

Onset Potentially Mortal Event (e.g., Sepsis, CHF, PE)

Divergence Pattern of SpO₂ and RR

First SpO₂ Threshold Warning (breach ~ 85)

Potentially Fatal False Sense of Security (may exceed 12 hours)
Figure 2. Type II Pattern of Unexpected Hospital Death (CO$_2$ Narcosis).
THE MASIMO PATIENT SAFETYNET SYSTEM

A cost-effective solution that seamlessly integrates into your hospital's IT infrastructure or operates as a stand-alone system

Masimo Patient SafetyNet remote monitoring and clinician notification system is designed from the ground up to be an integrated IT solution, using IEEE industry standards for connectivity to allow for more efficient sharing of data across your hospital's IT platforms. By leveraging existing IT infrastructure when possible, Masimo Patient SafetyNet may provide your hospital with a lower overall cost of ownership and improved financial benefits.

> Automatically Transmit Patient Data to a Caregiver Who Can Intervene with Confidence

Multiple patient data views provide maximum clinical flexibility

The Patient SafetyNet Central Station can be custom configured to provide you with patient data views that meet your specific clinical needs.
Quantifying the volume of documented clinical information in critical illness

Orit Manor-Shulman MD\textsuperscript{a,c,e}, Joseph Beyene PhD\textsuperscript{c,d}, Helena Frndova MSc\textsuperscript{a}, Christopher S. Parshuram MBChB. DPhil\textsuperscript{a,b,c,d,e,f,g,*}


**Fig. 1** Volume of documented clinical data per patient-day. This histogram represents the number of items of documented clinical information per patient-day. Data are from 5623 critically ill children admitted for 41202 complete 24-hour periods (midnight-midnight). The dashed red line represents the mean of 1341 items per patient-day.

**Fig. 2** Documented clinical items by ICU technology. The number of items of documented clinical information per complete (24-hour) patient-day is represented for patients receiving different ICU therapies. The data are from 5623 critically ill children admitted for 41202 days. Children receiving mechanical ventilation, inotropes, HFOV, dialysis, and ECMO are described separately.
Critical care

Interface between human talents & technology

Needs

Meaningful visualization and analysis of real time monitoring
Aim: Safe and efficient patient journey

Admission

- Risk Adjustment
- Disease
- Procedure
- Acuity Index

Guidelines / Protocols
Early Warning Systems
Quality Metrics

Discharge

- Outcomes
- Benchmarks
- Mortality
- Morbidity
- Quality of Life

Monitoring devices

EHR
Problem

• Large volume of data available, but:
  – Limited capture & storage of continuous data
  – Not integrated: clinician expectation
  – No real-time intelligence or analytics

• Requires interpretation & communication:
  – Different mental models:
    • individual & institutional
    • Signal (objective data) : Noise (subjective reality)
  – Human and system characteristics:
    • Decision making: intuitive Vs. analytic
Critical Care environment

- Diagnoses, procedures & demographics
  - Heterogeneous
- Environment & surface area
  - Expanding, patient & family centric, regulated
- Resources & monitoring
  - Expanding, expensive, vendor specific & non-integrated
- Staff models
  - Expanding, diversified & regulated
Adverse impacts

• Dispersed knowledge & experience
  – Impaired *Analytic* & *Intuitive* decision making

• Fragmented team dynamics
  – More staff and space: unsustainable model

• Fragmented solutions:
  – More resources / monitoring & EHR
  – Not user-centric
  – Impaired meaningful visibility & communication
  – Change the way we think, not how we think
## CICU Cardiac Arrest: target for improvement

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>New ICU (7/05)</th>
<th>24/7 in-house attending (7/07)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (median)</strong></td>
<td>84 1do-72yr</td>
<td>88</td>
<td>84</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>4.0 1.2 kg – 140 kg</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>% admissions / year</strong></td>
<td>3.5</td>
<td>3.6</td>
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</tr>
<tr>
<td><strong>Failure to rescue %</strong></td>
<td>11.9</td>
<td>11.2</td>
<td>9.4</td>
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<td><strong>LOS (median days)</strong></td>
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<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td><strong>“Possibly preventable” Failure to perceive %</strong></td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>
What we need:....

Meaningful Use of physiologic data

• Meaningful visualization which is accessible, scalable and interactive
• Physiologic data capture with bio-medical device integration
• Clinician & patient defined boundaries according to predicted trajectory
• Modeling of integration data points to derive relevant patient, diagnosis and procedure specific indices
• Annotate events and capture decision making
• Feedback loops for dynamic learning
<table>
<thead>
<tr>
<th>Data capture &amp; Visualization</th>
<th><strong>Current ICU</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Limited time frame (96hrs)</td>
</tr>
<tr>
<td></td>
<td>• Vendor specific</td>
</tr>
<tr>
<td></td>
<td>• Fragmented &amp; isolated data streams</td>
</tr>
<tr>
<td>Data storage</td>
<td>Not accessible or usable</td>
</tr>
<tr>
<td>Data sharing</td>
<td>Not available</td>
</tr>
</tbody>
</table>
Meaningful visualization and analysis of real time monitoring

Tracking, Trajectory & Trigger
Aim: Safe and efficient patient journey

Admission
- Risk Adjustment
- Disease
- Procedure
- Acuity Index

Guidelines / Protocols
- Early Warning Systems
- Quality Metrics

Discharge
- Outcomes
- Benchmarks
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- Morbidity
- Quality of Life

Monitoring devices
EHR

Patient & Unit VIEWs
Capture and store data

Data capture

Integration hospital systems

Data analysis & integration

Data Storage
Patient VIEWs
Scalable, portable, responsive

Web based

Adjust time-frame and zoom in and out to view trends

Analyze trends through drag and drop interface

Customizable dashboard of physiologic variables with 5 min, 30 min and 12 hour views, targets, priority
New information: Continuous physiologic calculations

Zoom in feature (up to 5 second increments) for event analysis, and to set patient specific targets and ranges based on data
Annotations: point-in-time notes to capture events and decisions
Patient specific targets

Set targets:
- Manual
- Standard
- Patient control
Meaningful analysis

- Predictive analysis:
  - Acuity indices
  - Dynamic learning algorithms

- Select physiologic variables
- Set targets
- Utility mapping of dominant trends
Capture, store & share data

1. **IMPROVED VISIBILITY LEADING TO IMPROVED CARE: MEANINGFUL VISUALIZATION AND EARLY WARNING**

   - Knowledge and Perspective
   - Advocacy and Communication
   - The Unit VIEW

2. **PLATFORM TO HOST ALGORITHM DEVELOPMENT AND MODELING FROM STORED AND SHARED DATA**

   - Reduction in practice variability
   - Efficient resource utilization
Moving from descriptive to predictive analytics

- Physiological Monitors
  - “What is happening?”
  - “Where exactly is the problem?”
- Signal Enhancement
  - “What actions are needed?”
- Alarm Boundaries
  - “Why is this happening?”
- Multivariate Weighting
  - “What will happen next?”
- Composite and Prediction

Degree of Intelligence and Learning