Smart alerts and electronic surveillance in the ICU

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Learning Objectives

• To understand problem of alerts in ICU

• To demonstrate potential solutions for improvement of alerting systems in acute setting
Overloaded…
Alarms
Cases
Data volume before and in ICU

Total data points per patient-hour

<table>
<thead>
<tr>
<th></th>
<th>Average data points per day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per Patient</td>
</tr>
<tr>
<td>Labs</td>
<td>60</td>
</tr>
<tr>
<td>Drug Orders</td>
<td>10</td>
</tr>
<tr>
<td>Microbiology</td>
<td>2</td>
</tr>
<tr>
<td>X ray</td>
<td>2</td>
</tr>
<tr>
<td>Vitals</td>
<td>1950</td>
</tr>
</tbody>
</table>
“Datapoints” in acute setting

**Ventilator monitoring**
- FiO₂
- PIP
- PEEP/CPAP
- Mean Airway Pressure
- Tidal Volume

**Labatory blood**
- Hemoglobin
- Serum electrolytes
- Blood chemistry

**Natural contexts**
- Demographic data
- Chronic diseases history
- Allergies
- Stress
- Pain

**Fluid balance**
- Fluid IN
- Fluid OUT
- Urine output

**Routine noninvasive monitoring**
- EKG
- Arterial blood pressure
- Heart rate
- Respiratory rate
- Temperature

**Invasive hemodynamic monitoring**
- Central venous pressure
- Arterial blood gases and pH
- Pulmonary arterial pressure
- Oxygen transport variables
- Intra-arterial blood pressure

**Routine cardiac monitoring**
- Cardiac output
- Hemodynamic variables
- Blood volume
- Colloidal osmotic pressure

**Brain function monitoring**
- Electroencephalography
- Intracranial pressure

**Tissue perfusion / oxygenation monitoring**
- Pulse oximetry
- Transcutaneous oxygen and carbon dioxide monitoring
Value of this data?

INFORMATION OVERLOAD OR LACK OF INFORMATION
"The mission is to give the right information to the right people at right time"
Overloaded…
Alarms
Cases
Alarms

• Alarm is an automatic warning that results from a measurement to indicate a relevant deviation from a normal state.

• Alarms improve patient safety and quality of care*

• Final goal of alarms could be to detect changes early and suggest appropriate action

Alarm-related problems

1. The rate of false alarms

2. Clinical perception of (false) alarms
Alarm fatigue a top hospital safety issue

April 24, 2011

"Alarm fatigue," or the failure of medical staff to respond to incessantly beeping devices, is one of the top conditions creating safety issues in hospitals today.
Survey of alarms in an intensive therapy unit*

T. M. O’CARROLL

Summary

The origin and frequency of alarm soundings in a general purpose intensive therapy unit were recorded by the nursing staff for 3 weeks. Only eight out of a total of 1455 soundings indicated potentially life threatening problems. There were many false alarms from the monitoring system and the infusion rate pump. The overall frequency of soundings varied little by day or night. There is a need for a graded system of alarms to reflect the priority of the disturbance detected.

Only eight out a total 1455 sounding indicated potentially life treating problems
Most subjects (about 90%) do not respond to all alarms but match their response rates to the expected probability of true alarms (probability matching).
Physicians’ Decisions to Override Computerized Drug Alerts in Primary Care

Saul N. Weingart, MD, PhD; Maria Toth, MD, PhD; Daniel Z. Sands, MD, MPH; Mark D. Aronson, MD; Roger B. Davis, ScD; Russell S. Phillips, MD

Physicians overrode 91% of drug allergy and 89% of high-severity drug interaction alerts.

Factors influencing alert acceptance: a novel approach for predicting the success of clinical decision support

Table 6  Association of independent variables with providers’ alert acceptance in the stratum of interruptive alerts, analyzed by binary logistic regression

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge quality</td>
<td>1.05 (0.82 to 1.35)</td>
<td>0.711</td>
</tr>
<tr>
<td>Display of the alert</td>
<td>4.75 (3.87 to 5.84)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Textual information</td>
<td>1.04 (0.91 to 1.19)</td>
<td>0.554</td>
</tr>
<tr>
<td>Setting (inpatients vs outpatients)</td>
<td>2.63 (2.32 to 2.97)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

the univariate analyses. However, if an alert did not require acknowledgment, it was only accepted in 1.4% of cases, indicating that alerts are overridden almost completely if no acknowledgment is required. Accordingly, the fact, that an alert...
Physiological monitors: “Generations”
Standard (threshold based) alarms in adult ICU

- False-positive: 86%
- True, significant alarm: 6%
- True, clinically irrelevant: 8%

Alarms in ICU

Detection life-threatening situations

Threshold based alarms (hardware)

"Notification" alarms

Rule based alarms - "Sniffers"

Support Treatment

Decision support systems

Support Diagnostics
NOT a smart alerts

EMR → Cool algorithm → Alert(s)
Smart alert

EMR

Simple(r) algorithm

Alert

Provider’s action
Recognition of the context

Who?

From “Time” magazine - Aug. 10, 2009

PHOTO-ILLUSTRATION FOR TIME BY ARTHUR HOCHSTEIN. HEAD: BRENDAN HOFFMAN/EPA. BODY: BRAD WILSON/GETTY.
Recognition of the context

Where?

"Nurse, get on the internet, go to SURGERY.COM, scroll down and click on the 'Are you totally lost?' icon."
Recognition of the context

When?
Diagnostics alarms or electronic surveillance

- Can do routine calculation
- Can notify provider
- Can analyze providers interventions
- **Should be smart to be not annoying**
Overloaded…
Alarms
Cases
Acute lung injury sniffer. Motivation

- ALI and ARDS represent major health problems

7% of ICU admissions

40% mortality rate
ALI/ARDS sniffer

Start algorithm every hour

Arterial blood gas

PaO2/FiO2 < 300

NO

YES

Chest Radiograph report

"Bilateral" AND "Infiltrate" OR "Edema"

NO

YES

Alert
## ALI sniffer: performance

<table>
<thead>
<tr>
<th></th>
<th>ALI +</th>
<th>ALI -</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screened positive</td>
<td>313</td>
<td>367</td>
<td>680</td>
</tr>
<tr>
<td>Electronic tool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screened negative</td>
<td>12</td>
<td>3103</td>
<td>3115</td>
</tr>
<tr>
<td>Electronic tool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>325</td>
<td>3470</td>
<td>3795</td>
</tr>
</tbody>
</table>

- **Sensitivity** (95% CI): 96.3% (93.6-98.1)
- **Specificity** (95% CI): 89.4% (88.4-90.4)
- **Positive predictive value** (95% CI): 46.0% (42.2-49.9)
- **Negative predictive value** (95% CI): 99.6% (99.3-99.8)
- **Likelihood ratio +** (95% CI): 9.1 (8.3-10.1)
- **Likelihood ratio -** (95% CI): 0.04 (0.02-0.07)
### Table 3 The performance of the ALI sniffer and routine clinical assessment in different ICUs

<table>
<thead>
<tr>
<th>Name</th>
<th>Total patients (n)</th>
<th>ALI (n)</th>
<th>Prevalence %</th>
<th>Alerted (n)</th>
<th>ALI sniffer</th>
<th>Routine clinical assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac surgery ICU</td>
<td>476</td>
<td>44</td>
<td>9.2</td>
<td>124</td>
<td>100 (92–100)</td>
<td>2 (1–12)</td>
</tr>
<tr>
<td>Medical cardiac ICU (CCU)</td>
<td>452</td>
<td>34</td>
<td>7.5</td>
<td>82</td>
<td>97 (85–99)</td>
<td>18 (7–35)</td>
</tr>
<tr>
<td>Medical ICU</td>
<td>617</td>
<td>97</td>
<td>15.7</td>
<td>148</td>
<td>97 (91–99)</td>
<td>30 (21–40)</td>
</tr>
<tr>
<td>Mixed medical-surgical ICU</td>
<td>474</td>
<td>52</td>
<td>11.0</td>
<td>90</td>
<td>89 (77–96)</td>
<td>90 (863–92)</td>
</tr>
<tr>
<td>Neuro ICU</td>
<td>645</td>
<td>16</td>
<td>2.5</td>
<td>45</td>
<td>100 (79–100)</td>
<td>19 (4–46)</td>
</tr>
<tr>
<td>Pediatric ICU</td>
<td>216</td>
<td>4</td>
<td>1.9</td>
<td>9</td>
<td>100 (40–100)</td>
<td>25 (4–80)</td>
</tr>
<tr>
<td>Thoracic and vascular surgery ICU</td>
<td>365</td>
<td>40</td>
<td>11.0</td>
<td>74</td>
<td>100 (91–100)</td>
<td>28 (15–44)</td>
</tr>
<tr>
<td>Heart and lung transplant ICU</td>
<td>162</td>
<td>11</td>
<td>6.8</td>
<td>45</td>
<td>100 (71–100)</td>
<td>9 (2–41)</td>
</tr>
<tr>
<td>Trauma and general surgery ICU</td>
<td>388</td>
<td>27</td>
<td>6.9</td>
<td>63</td>
<td>93 (76–99)</td>
<td>30 (14–50)</td>
</tr>
</tbody>
</table>
Validation of an electronic surveillance system for acute lung injury

Vitaly Haseевич
Murali Yilmaz
Hasrat Khan
Rolf D. Huhnuyr
Ogjen Gajic

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Abstract Objective: Early detection of acute lung injury (ALI) is essential for timely implementation of evidence-based therapies and enrollment into clinical trials. We aimed to determine the accuracy of computerized syndrome surveillance for detection of ALI in hospitalized patients and compare it with routine clinical assessment. Design: Using a near-real time copy of the electronic medical records, we developed and validated a custom ALI electronic alert (ALI “sniffer”) based on the European-American Consensus Conference Definition and compared its performance against provider-derived documentation. Patients and setting: A total of 2,795 consecutive critically ill patients admitted to nine multidisciplinary intensive care units (ICUs) of a tertiary care teaching institution were included. Measurements and main results: ALI developed in 325 patients and was recognized by bedside clinicians in only 86 (26.5%). Under-recognition of ALI was associated with not implementing protective mechanical ventilation (median tidal volumes of 9.2 vs. 8.0 mL/kg predicted body weight, P < 0.001). ALI “sniffer” demonstrated excellent sensitivity of 96% (95% CI 94–98) and moderate specificity of 89% (95% CI 88–90) with a positive predictive value ranging from 24% (95% CI 13–40) in the heart–lung transplant ICU to 64% (95% CI 55–71) in the medical ICU. Conclusions: The computerized surveillance system accurately identifies critically ill patients who develop ALI syndrome. Since the lack of ALI recognition is a barrier to the timely implementation of best practices and enrollment into research studies, computerized syndrome surveillance could be a useful tool to enhance patient safety and clinical research.

Keywords Respiratory distress syndrome - Adult - Syndrome surveillance - Database - Datamart - Diagnosis

Introduction

Acute lung injury (ALI) and its more severe form, acute respiratory distress syndrome (ARDS), represent a major health problem with an estimated prevalence of 7% of intensive care unit (ICU) admissions [1, 2] for which the appropriate treatment is commonly instituted too late or not at all [3, 4]. Timely recognition of ALI syndrome is an important determinant of outcome of critical illness and is essential for appropriate enrollment into research studies. However, recognizing specific patterns of ICU syndromes is difficult [3]. This is particularly true in elderly patients with multiple comorbidities in whom the incidence of ALI is particularly high [2]. Under-recognition of ALI is an important barrier to a timely instigation of specific treatment (i.e., low tidal
Not smart enough?

The hospital where I work has recently turned to an electronic medical record system—EPIC. Literally every time you enter a medication for a patient, multiple alerts pop up. Most of these are absurd and needless, for instance warning you of exceeding maximum recommended daily doses for medications that have no maximum recommended daily dose, and so on and so on. Over time, the multiple needless repeated warnings very much risk distracting you from any potential meaningful warning buried in their midst. In other words, the systems are only as good as their programming. And the programming for most of these systems, in my experience, is very much wanting.

— Ed

http://bits.blogs.nytimes.com/2009/03/18/the-doctor-will-brms-you-now/?emc=eta1
"Failure to rescue" concept

SPEED LIMIT 25

Actual speed 20
“Failure to rescue” concept

SPEED LIMIT 25

Actual speed 20

GPS
Ventilator induced lung injury sniffer: motivation

Lung protective mechanical ventilation\(^1,4\)

Adherence \(~\)80\% (Tv <8 mL/kg PBW)\(^2\)

Lack of recognition

In 70\% of patients who did not receive appropriate treatment\(^3\)

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Calculation

Men: $50+0.91 \times \text{height (cm)} - 152.4 \text{ or } 50+2.3 \times \text{height (inches)} - 60$

Women: $45.5+0.91 \times \text{height (cm)} - 152.4 \text{ or } 45.4+2.3 \times \text{height (inches)} - 60$

Height and gender are known to be better predictors of lung size than is actual body weight.
Modern ventilators

No VILI alert embedded
Sniffer algorithm

- Arterial blood gas analysis: \( \frac{\text{PaO}_2}{\text{FiO}_2} \) < 300
- Chest radiograph report: Evidence of lung injury

OR

- Peak pressures > 35 H₂O
- Tidal volume > 8 mL/kg predicted body weight, based on patient’s gender and height
- Plateau airway pressure > 30 cm H₂O

Institution paging system

- ICU 1
- ICU 2
- ICU 3

Hospital databases

METRIC Datamart
VILI sniffer study timeline

Simultaneous paging notification of RT and critical care fellow on call in the 3 ICUs
## Ventilator practice and outcomes (means±SD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline (n=186)</th>
<th>After VILI sniffer implementation (n=304)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of potentially injurious ventilation (hours)</td>
<td>40.6±74.6</td>
<td>26.9±77.3</td>
<td>0.0042</td>
</tr>
<tr>
<td>Tidal volume preset (max)</td>
<td>480±97</td>
<td>456±82</td>
<td>0.0092</td>
</tr>
<tr>
<td>Plateau pressure (max)</td>
<td>45.8±13.6</td>
<td>43.0±12.0</td>
<td>0.038</td>
</tr>
<tr>
<td>Tidal volume per PBW (mean)</td>
<td>6.1±1.7</td>
<td>6.3±1.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Plateau pressure (mean)</td>
<td>21.6±7.1</td>
<td>21.8±5.6</td>
<td>0.96</td>
</tr>
<tr>
<td>Ventilator-free days (days)</td>
<td>21.7±7.2</td>
<td>22.0±6.7</td>
<td>0.2</td>
</tr>
<tr>
<td>ICU mortality (%)</td>
<td>30.6</td>
<td>27.3</td>
<td>0.47</td>
</tr>
<tr>
<td>Hospital mortality (%)</td>
<td>39.8</td>
<td>39.5</td>
<td>0.94</td>
</tr>
<tr>
<td>ICU length of stay (days)</td>
<td>11.8±8.4</td>
<td>10.9±9.7</td>
<td>0.06</td>
</tr>
<tr>
<td>ICU-free days (days)</td>
<td>16.6±7.4</td>
<td>17.7±7.1</td>
<td>0.06</td>
</tr>
<tr>
<td>Hospital length of stay (days)</td>
<td>27.4±24.0</td>
<td>26.3±25.3</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Response to pager

Out of 111 alerts sent during study period expert co-investigator confirmed 65 cases of VILI risk (positive predictive value of 69%).

- Pulse alerts: 46 (32%)
- Decreased tidal volume: 8 (12%)
- Changed the mode of ventilation: 9 (14%)
- Increased sedation or neuromuscular blockade: 17 (26%)
- No intervention: 17 (26%)
- Other intervention: 14 (22%)
Provider satisfaction: survey

- Among 65 Respiratory Therapists 40 answered the survey questions (response rate 61%). 68% of them received VILI pages.

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I found the electronic alert for detecting potentially injurious mechanical ventilation in patients with ALI/ARDS useful</td>
<td>4 (15%)</td>
<td>9 (33%)</td>
<td>9 (33%)</td>
<td>5 (19%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>False alarms are common and annoying</td>
<td>1 (4%)</td>
<td>4 (15%)</td>
<td>15 (55%)</td>
<td>7 (26%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
In conclusion
Steps to develop intelligent alerts or “sniffers”

1. Patterns need to be **recognized**: machine learning techniques or by experienced clinicians in the field or from evidence-based literature.

2. Patterns need to be **algoritmized**.

3. Algorithm need to be **tested** on large databases.

4. EMR need to be **programmed** to recognize these patterns by using tested algorithm.

5. **Real-time testing** then needs to be used to ensure that sensitivity and specificity is adequate for clinical usage.
Key Elements for Successful Implementation of Informatics tools

- Simplicity
- Wide distribution
- No requirement for major changes
- The endorsement by local leaders
- Sense of ownership among staff
- Frontline use of proposed tools by bedside providers involved in research and QI is essential for meaningful impact
Acknowledges

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Team Work

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