Monitoring Trauma Patients in the Prehospital and Hospital Environments: The Need for Better Monitors and Advanced Automation

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### Monitoring Trauma Patients in the Prehospital and Hospital Environments: The Need for Better Monitors and Advanced Automation

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*Standard Form 298 (Rev. 8-98)*  
*Prescribed by ANSI Std Z39-18*
• Diagnosis in the prehospital and/or hospital environments is often inaccurate for trauma patients

• Current prehospital monitors measure vital signs that are not predictive of outcome in many instances
  – Systolic Blood Pressure
  – Heart Rate
  – SpO2

Cooke, et al., Heart Rate Variability in Pre-Hospital Trauma patients. J Trauma, 2005
**Standard Vital Signs**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lived (n = 15)</th>
<th>Died (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic pressure, mmHg</td>
<td>120±20</td>
<td>100±20</td>
</tr>
<tr>
<td>Mean pressure, mmHg</td>
<td>100±20</td>
<td>80±20</td>
</tr>
<tr>
<td>Diastolic pressure, mmHg</td>
<td>80±20</td>
<td>60±20</td>
</tr>
<tr>
<td>Arterial O2 Saturation, %</td>
<td>100±10</td>
<td>80±10</td>
</tr>
<tr>
<td>Pulse Rate, bpm</td>
<td>100±10</td>
<td>80±10</td>
</tr>
</tbody>
</table>
Grouped Vital Signs Do Not Predict Need for Life Saving Interventions

- Considered 3 data sets based on instrument requirements
  - Manual (MG)
  - Semi-Automated (SG)
  - Automated (AG)

- Demographics (Age, Sex)
- Pulse Character (Radial, Femoral, Carotid)
- GCS Motor, GCS Verbal
- Capillary Refill
- SpO₂
- Automated Respiration Rate
- Automated NIBP (Systolic, Diastolic)
- Heart Rate
- EtCO₂

Problem

Manual Vital Signs
Physical Exam

Electronic Vital Signs

No difference in prediction of outcome
Triage Problem

- **Civilian:**
  - Consistent overtriage and undertriage problem in the prehospital trauma environment
  - Not unusual to have a 50% overtriage within a large urban area

- **Military:**
  - Inability to effectively predict evacuation requirements balanced with tactical considerations

**Cause:**

Inability to accurately determine patient status using current methodologies/technologies.
Environment: Medic Injured Trying to Save Fallen Comrade
Bottom Line

Current monitors present data that is not predictive of eventual physiologic decompensation and are thus inadequate!
Solution

• We need a new type of monitor!

• Requirements
  – Accurate diagnosis of patient status
  – Small/Lightweight
  – Remote/wireless operation
  – Intelligent Decision assist technology
  – Autonomous/closed loop technology for long term care
Accurate Diagnosis of Trauma Patients

- Need to use new/advanced vital signs
  - Pulse Pressure
  - Shock Index

- Explore combinations of vital signs to enhance probability of correct diagnosis

- Make use of vital sign trends

- Use characteristics of high frequency waveforms
  - Heart Rate Variability
  - Heart Rate Complexity
  - Non Linear ECG Dynamics
Pulse Pressure

- Statistically significant for tracking stroke volume

$r^2 = 0.99$
Combination Vital Signs

Combination of Shock Index, Shock Index Trend, Respiratory Rate

![Graph showing sensitivity and 1-specificity for No Physical Exam and Physical Exam]

- Green line: No Physical Exam
- Red line: Physical Exam
Waveform HR variability

Measures Sympathetic/Parasympathetic activity based on the frequency distribution of the RRI values.
Waveform Complexity

Quantifies the regularity of the HR signal through entropy calculations with in the RRI values.

Prediction of LSI
Addition of more parameters

- **Parameter** | **Survival ROC**
- Single Vital Signs | 0.75
- Physiology and Trends | 0.80
- Physiological Variability | 0.85
- Physiology, Coagulation, and Immunology | 0.96

*The more significant data we get, the more predictive we can be!*
Problem

• Monitoring can be enhanced to further improve patient care…However:

“We keep monitoring patients to death”

-- Anonymous
Now What?

• Use enhanced prediction algorithms and inputs into intelligent medical systems to better assist medical providers
  – Decision Support Systems
  – Advanced Triage Systems

• Move validated medical systems into full automation for closed loop care of patients
Decision Assist (support) Technology

- Decision support systems are a class of computer-based information systems that support decision making activities
  - Type of intervention
    - What intervention to use based on the expertise of the user
  - When do we apply intervention?
  - Where should a patient be taken based on readings?
  - Where should a patient be transported to?
Benefits

- Helps to remind experts on proper patient care during critical procedures and/or mass casualty situations
- “Pushes” the expertise built into the software to non-expert providers
  - i.e. burn standard of care procedures for field use
- Maintains the open loop concept – Not a replacement for good clinical judgment
Types of DSS

- **Model Driven**
  - Used for statistical data manipulation
  - Example: Expected response of a company’s stock to a selloff
- **Communication Driven**
  - Used for coordination of tasks between users
- **Data Driven**
  - Used for manipulation of time series data
- **Document Driven**
  - Manipulation of unstructured information from documents
- **Knowledge Driven**
  - Most appropriate for medical systems
  - Emphasizes problem solving skills
USAISR DSS Examples

• ICU DSS Framework
  – Decision support framework for management of burn patients admitted to the USAISR Burn Center ICU
    • Resuscitation – Implemented
    • Tight glucose control - Implemented
    • Hypotension management – Working
    • Albumin use - Working
    • Abdominal compartment syndrome diagnosis and management - Working

• Mobile Burn Resuscitation
  – Decision support for burn resuscitation in a mobile/handheld system for field resuscitation
Automation and Closed Loop

- Use accurate inputs to control therapy for patient care
  - Examples:
    - Resuscitation
    - Ventilation
    - Pain Control
    - Hemorrhage
- Feedback system allows for more accurate delivery of therapy
Action Shots of DSS (ICU Version)
Action shots of DSS (Mobile)
The Future

• Full Automation
  – Closed loop
    • Computer control of sensors and actuators
  – Automated patient management
Lightweight Trauma Module (LTM), Impact Instrumentations

**Integral**
- Ventilator
- 12-lead ECG
- Pulse-Ox
- NIBP
- Data I/O
- Electronic med. record

**Modules**
- Aspirator
- I.V. pumps
- Multipatient monitor (SpO₂, ECG, NIBP)
- Patient controlled analgesia
- Spirometer
- O₂ concentrator
- Patient warming
- Stress test
- Anesthesia Module
- Ultrasound imaging
- Visualization
  - Oto/ophthalmoscope
  - Macrolens camera

- CO₂
- AED
- Temperature
- Invasive pressure
- Remote C²
- Smart help
- Closed-loop control

- Respiratory mechanics
  - Pulse Pressure, Shock Index, HRV
Wireless Vital Signs Monitor (WVSM), Athena GTX

An Automated Wireless, Battery Powered Medical Tool to Assist the Medical Personnel in the Field and Hospitals in Tracking and Monitoring Patients’ Vital Signs Continuously.....in a small and affordable package using WLAN and MS Windows O/S
Closed-Loop Resuscitation of Burn Injury

Sheep + IV access & bladder catheter

IV Pump

PC-Visual Basic controller

Bard® Urine Monitor

* G. Kramer, University of Texas Medical Branch
Hourly Urinary Outputs:
on-target, under-target and over-target

<table>
<thead>
<tr>
<th>Group</th>
<th>on-target</th>
<th>under-target</th>
<th>over-target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 sheep, 508 measurements</td>
<td>198</td>
<td>122</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>p = 0.23</td>
<td>p = 0.02</td>
<td>p = 0.65</td>
</tr>
<tr>
<td></td>
<td>1.31 (CI 0.85, 2.0)</td>
<td>0.58 (CI 0.36, 0.89)</td>
<td>1.10 (CI 0.74, 1.65)</td>
</tr>
<tr>
<td>CLR controlled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 sheep, 475 measurements</td>
<td>214</td>
<td>73</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>47%</td>
<td>16%</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>p = 0.23</td>
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</tr>
</tbody>
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Target range defined as 1.0 – 2.0 mL/hr target

*G Kramer, University of Texas Medical Branch
Conclusion

• Need better monitoring technologies
  – New vital signs
  – Combinations of standard, new, and trended vital signs
  – Advanced complexity vital signs
• Need to develop decision support systems
  – Additional tools to expert users
  – Better care for non-expert care providers
  – Open loop concept
• Future: Closed loop and automation
  – Computer control of sensors and actuators