Physiological Monitoring in the Waiting Areas of an Emergency Room

Dorothy Curtis, MIT
Jason Waterman, MIT
Jacob Bailey, BWH
Eugene Shih, MIT
Thomas O. Stair, MD, BWH
John Guttag, PhD, MIT
Robert A. Greenes, MD, PhD, BWH
Lucila Ohno-Machado, MD, PhD, BWH

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Problem: Unmonitored Patients

• Where
  – Disaster situations
  – Emergency room waiting areas

• Why
  – Lots of patients
  – Not a lot of caregivers to do monitoring
  – Patients can deteriorate
Approach

• Design a patient monitoring system
  – Vital signs
  – Location
  – Take advantage of wireless networking
• Evaluate it in an Emergency Room Waiting Area
• SMART: Scalable Medical Alert and Response Technology
Patient Monitoring
Patient Monitoring
Patient Monitoring
SMART Central
### SMART Central

<table>
<thead>
<tr>
<th>#</th>
<th>ON</th>
<th>Name</th>
<th>SPO2</th>
<th>HR</th>
<th>EKG HR</th>
<th>ESI</th>
<th>HEART</th>
<th>ZONE</th>
<th>ALARM</th>
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<tr>
<th>Name</th>
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<th>Sent To</th>
<th>Time</th>
<th>Utility</th>
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<td>Thu 19:05:33</td>
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<td>STE, W</td>
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<td>CARE 1</td>
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<td>~</td>
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<td>~</td>
<td>Thu 19:02:03</td>
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</table>

**W STE**

- **Age:** 60
- **Gender:** M
- **ESI:** 3
- **Complaint:** C/P, SOB
- **Allergies:**
- **Precautions:** HCT=26.9
- **MRN:** 800000008
- **THR: High HR**: 100
- **THR: Low HR**: 60
- **THR: Low SPO2**: 90
- **SMART Time:** 00:11

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**EKG PLOT**

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**Enter Notes:** [ ] [Submit]
Sonitor Indoor Location:
Tags and Detectors
Indoor Location Tracking
Caregiver PDA
Caregiver PDA Screenshots
Architecture
Under the Hood: Smart Central

• ECG Analysis: Medical
  – Beat detection
  – Absence of beats detection (Asystole)
  – Irregular
  – Tachycardia
  – Bradycardia
  – Ventricular Fibrillation
  – Ventricular Tachycardia
Under the Hood: Smart Central

• ECG Analysis: Technical
  – Leads Off
  – Noise
  – No Signal
  – Mismatch
Smart Central, cont’d

- **SpO$_2$**
  - Low level of Oxygen Saturation
  - Low Heart Rate
  - High Heart Rate
  - Sensor Off (Technical)
Smart Central, cont’d

• Location
  – Consolidate detector readings to get a zone

• Battery
  – Low

• Away Without Leave (AWOL)
How to Evaluate SMART?

• Conduct a study
  – Patient Acceptance (via a survey)
  – Caregiver Acceptance (not possible)

• Reportable Episodes
Study Results

• Demographics
• Data Collection
• Patient Survey
• Reprioritizing Patients
The Study

- June, 2006 - December, 2007
- 224 Patients approached
- 44 Refusals
- 180 Consents
- 8 Consents without wearing equipment
- 172 Patients Monitored
- 4 Returned the equipment
- 91 Surveys Completed

- 152hr 47min of data
- Average of 53 minutes per patient
The Study: The Patients

Average Age: 51
Range of Ages: 18 to 87
Patient Survey: Comfort

Was the monitoring system comfortable?

- Didn’t bother at all: 70%
- A little uncomfortable: 10%
- Very uncomfortable: 3%
- No response: 7%
Patient Survey: Safety

Did the monitoring system make you feel safer?

- Yes, for sure: 20%
- A little: 30%
- No Effect: 20%
- No, less safe: 10%
- No response: 0%
Patient Survey: Value of Monitoring Vital Signs

Value of vital signs monitoring

- Very important
- A little
- Not important
- Not important and actually annoying
- No response
Patient Survey: Value of Location Monitoring

Value of having location known

- Very important: 60%
- A little: 20%
- Not important: 10%
- Not important and actually annoying: 5%
- No response: 5%
Patient Survey: Effect on Wait

Effect of SMART on length of wait

- Shortened it a lot
- Shortened it a little
- No effect
- Increased it a little
- Increased it a lot
- No response
Patient Survey: Effect on Care

Effect of SMART Monitoring on Care

- Improved it a lot
- Improved it a little
- No effect
- Impaired it a little
- Impaired it a lot
- No response
Patient Survey: Wear Again?

Would you wear a SMART pouch again?

- Yes, for sure: 50%
- Probably: 30%
- No: 0%
- No response: 20%

79/91 (87%) positive responses
Survey Conclusions

• Good Patient Acceptance
  – 87% would wear the SMART pouch again
  – 79% said the monitoring system was comfortable
Reportable Episodes

- Pace Maker Working?
- Intermittent Premature Ventricular Contractions (PVC’s)
- Suspected Atrial Fibrillation
Is Pace Maker Working?

• 75 year old female
• Complaint of ringing noise from her pacemaker
Yes, Pace Maker is Working
Chest Pain

• 30 year old female
• Had just witnessed a distressing accident
• Intermittent runs of PVCs (premature ventricular contractions)
Reprioritization due to PVC’s
“No Symptoms”

- 74 year old male
- History:
  - Irregular heart beats
  - Using beta blockers
- Sent to ED from physician’s office due to heart rate of 120 bpm
- At triage, no symptoms
  - No chest pain, no shortness of breath, no palpitations, no dizziness
Reprioritization due to Possible AFIB
Future Work

• Distributed Monitoring
• Assisted Living
• Hydration and Temperature sensors
Closing

• Thanks to the National Library of Medicine for sponsorship
• Thanks to the Decision Systems Group at the Brigham and Women’s Hospital for collaborating with us
• Thanks to the Emergency Department for supporting the study
• Thanks to Sonitor for the location system
• Thanks to many contributors
  Esteban Pino, Staal Vinterbo, Rosa Figueroa, Stephen Nelson & Stratus Center at BWH
Spare Slides
### SpO2 Alarm Results

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Total</th>
<th>True Positive</th>
<th>False Positive</th>
<th>Unclear</th>
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<tbody>
<tr>
<td>High HR (SpO2 sensor)</td>
<td>79</td>
<td>75</td>
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<tr>
<td>Low HR (SpO2 sensor)</td>
<td>21</td>
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<td>Low SpO2</td>
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## ECG Alarm Results

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<tr>
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<td>61</td>
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<td>32</td>
<td>Noise often mistaken for tachycardia</td>
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<td>Bradycardia (ECG)</td>
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<td>12</td>
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<tr>
<td>Irregular rhythm</td>
<td>116</td>
<td>43</td>
<td>34</td>
<td>39</td>
<td>Noise often mistaken for irregular</td>
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</table>
### More ECG Alarm Results

<table>
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<tr>
<th>Alarm</th>
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<td>Asystole</td>
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<td>Ventricular Fibrillation</td>
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<td>46</td>
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<tr>
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# More ECG Alarm Results

<table>
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<th>Alarm</th>
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<tr>
<td>Irregular rhythm</td>
<td>116</td>
<td>43</td>
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<td>Noise often mistaken for irregular</td>
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<td>Mismatch</td>
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<td>Noisy</td>
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<td>Leads Off</td>
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<td>No Signal</td>
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## Technical Alarms

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<td>SpO2 Sensor Off</td>
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<td>AWOL</td>
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<td>309</td>
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<tr>
<td>Battery</td>
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SMART from an Ambulance
SMART from an Ambulance
Ambulance Bridge
SMART Central with GPS Location
Medical Alarms: Oximeter

- **SpO₂ High HR**
  - default threshold is 100bpm
- **SpO₂ Low HR**
  - default threshold is 60bpm
- **SpO₂ Low SpO₂**
  - default threshold is 90%
Medical Alarms: ECG

- Tachycardia – High Heart Rate
- Bradycardia – Low Heart Rate
- Irregular
  - ECG QRS complexes are irregularly spaced
- Asystole
  - No beat detected in 3 seconds
Medical Alarms: ECG (cont’d)

- **Ventricular Fibrillation**
  - ECG shows artifacts, abnormal skewness, wide waves or no waves, lacks QRS complexes, and the SpO$_2$ heart rate is missing or below 20bpm or above 150bpm

- **Ventricular Tachycardia**
  - ECG has wide QRS complexes and heartrate is over 100bpm
Technical Alarms: ECG

- **Mismatch**
  - ECG alarm, but SpO$_2$
- **Leads Off**
  - ECG lead is off (signal is saturated)
- **Nosignal**
  - No ECG data received
Technical Alarms: $\text{SpO}_2 + \text{misc}$

• Technical $\text{SpO}_2$
  – Oximeter sensor removed from finger

• AWOL (away without leave)
  – No communication between PDA and SMART Central

• Battery
  – Low battery (below 20%)
The Future of SMART

• Analytical/Exploratory
• Practical
Analytical/Exploratory Options

• Analysis of wireless network behavior during deployment in a large auditorium
• Improved ECG processing to reduce false alarms
Practical

- Could be used in low end ambulances or vans
  - Would require hardening of gear
  - Would require hospital or ambulance company cooperation/interest
- Could do another study with sicker patients
- Could do another study in context with more patients