Improving Patient Outcomes Through Continuous Predictive Analytics Monitoring

The PM-IMPACCT Trial and Application on the Acute Care Floor

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CoMET Creator
PM-IMPACCT Co-Investigator
Disclosures

Jamieson Bourque (no relevant disclosures)
• Consulting: Pfizer, GE
• Equity: Locus Health

Randall Moorman
• Equity: Advanced Medical Predictive Devices, Diagnostics, and Displays (AMP3D)
Learning Objectives

1. Recognize the incidence and impact of unanticipated clinical deterioration in floor and ICU patients.

2. Describe predictive analytic models that identify patient decompensation prior to obvious significant changes in clinical status.

3. Identify the impact of continuous predictive analytics in the ICU and the rationale for use on the acute care cardiology floor.

4. To interpret continuous predictive analytics monitoring results in the acute care cardiology setting in the context of the PM-IMPACCT trial.
Case – Ms. H

• 85 year-old female
• Known CAD, PVD s/p ICA 14 days ago for NSTEMI with right groin hematoma
• Admitted for R SFA occlusion s/p femoral angioplasty and stenting
• Hospital Course
  – Day 4 morning – no concern for infection
  – Day 4 evening – pneumonia and sepsis -> respiratory failure
  – Transfer to MICU
  – Palliative care
HOW CAN WE DO BETTER?
Roadmap

• Clinical deterioration on the acute care floor is a problem
• What is predictive analytics monitoring?
• UVa algorithm development and validation
• Ms. H revisited
• IMPACT trial
Development of Clinical Decision Support

What is the important, tractable clinical problem?

Which patients really had events?

Are we analyzing all the useful features of all the data?

How do we best report findings and present to the clinicians?

Does a clinical trial show improved outcomes?

Patient → Data → Data mining → Clinical decision support
Development of Clinical Decision Support

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Deterioration on the Acute Care Floor

• Floor patients are at risk for unexpected clinical decompensation, 7% or more develop:
  – Respiratory failure
  – Cardiogenic shock
  – Hemorrhage
  – Sepsis

• And require urgent intervention and potential escalation in level of care

Moss TJ et al., Cardiorespiratory dynamics measured from continuous EKG improves detection in acute care patients. PLoS One, 2017
Events with major negative impact

- MICU hemorrhage
- SICU hemorrhage
- MICU sepsis
- SICU sepsis
- MICU intubation
- SICU intubation
- Atrial fibrillation in ICU
- Failed extubation
- ED to ward to ICU
- Ward to ICU

Length of stay (days)

Moss ... Moorman *Critical Care Medicine* 2016
Moss ... Moorman *PLoS One* 2017
Events with major negative impact

- MICU hemorrhage
- SICU hemorrhage
- PICU sepsis
- MICU sepsis
- SICU sepsis
- MICU intubation
- SICU intubation
- Atrial fibrillation in ICU
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Moss ... Moorman *Critical Care Medicine* 2016
Moss ... Moorman *PLoS One* 2017
Background: Critical deterioration on acute care wards

- Up to 30% of admissions to medical-surgical ICUs are floor patients who deteriorate emergently \(^1\)
- When clinical deterioration goes unrecognized on the floor and ICU transfer is delayed, the need for emergent resuscitation can be as high as 67\(^2\)
- Early detection -> high impact

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(1) Escobar, G J Hosp Med 2011 (2) Wellner, B et al., JMIR Med Inform 2017
HOW CAN PREDICTIVE ANALYTICS HELP?
What is predictive analytics monitoring?

– Continuously updated estimation of the risk of imminent events
– Based on real-time data from the patient
– That gives clinicians a heads-up on who is getting sick
– And allows them to see the patient early in the course of illness
– And initiate diagnostic and therapeutic measures earlier
When once the diseased skin begins to swell, you will see men asking in vain for treatment.

*Meet the disease on its way to attack you.*

This is the goal of predictive analytics monitoring

Juvenal, *Satires*, 1st century
Predictive analytics monitoring at UVa

• Neonatal Intensive Care Unit:
  – Heart rate characteristics monitoring
• Neonatal sepsis is preceded by characteristic changes in the heart rate pattern

• We developed a new predictive monitor based on time series metrics

• In a very large RCT, we showed that NICU mortality was reduced by >20% with display of predictive monitor

Moorman et al., Mortality reduction in a randomized trial of heart rate characteristics monitoring *J Peds* 2011

One of University of Virginia’s top 12 research discoveries in the past 50 years
Predictive analytics monitoring at UVa

• Neonatal Intensive Care Unit:
  – Heart rate characteristics monitoring
• Surgery Trauma ICU
  – CoMET monitoring
• 3\textsuperscript{rd} floor
  – RAMP (Voss, Clay)
• 4\textsuperscript{th} floor
  – CoMET monitoring – upcoming RCT
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Does a clinical trial show improved outcomes?
**TP:** SEPTIC, and classed as SEPTIC

**TN:** NOT septic, and classed as NOT septic

**FN:** SEPTIC, and classed as NOT septic

**FP:** NOT septic, and classed as SEPTIC

Iwashyna *Med Care* 2014
Rhee *JAMA* 2017
8111 admissions to a cardiac floor
457 deteriorated and went to ICU
Clinical presentations were complicated
Clinical profiles varied in deteriorating patients
There is no one-size fits-all model

- The most common forms of deterioration leading to ICU transfer present clinically in very different ways:
- All these culprit organ systems suggests that there are multiple signatures of deterioration, not necessarily detectable using a single model

- We have developed >300 predictive models that are specific for units, patients, diagnoses ...
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Data analysis

• Data sources
  – EKG, respiratory and arterial waveforms (60-240Hz)
  – Vital signs – HR, RR, O2 saturation, BP (0.5Hz)

• Calculations
  – Time domain – moments, correlations
  – Frequency and wavelet domain measures
  – Phase and other non-linear dynamical measures, e.g., entropy estimation

• Statistical pattern recognition
  – Regression, HMM, RF, kNN, SVM...

• We have a very large legacy data set of signals and adjudicated clinical events for further R&D
Time series mathematics we developed

- 2000 Sample entropy (SampEn) (Richman, Moorman) (>5000 citations)
- 2001 SampEn changes in neonatal sepsis (Lake, Moorman) (>1000 citations)
- 2005 SampEn is asymptotically Gaussian (Richman)
- 2006 Quadratic entropy rate (Lake)
- 2011 Coefficient of sample entropy (Lake, Moorman)
- 2012 Apnea detection with wavelets (Flower ... Moorman, Delos)
- 2013 Cardiorespiratory interaction (Clark ... Moorman)
- 2013 Time-warped filtering for apnea detection (Lee ... Moorman, Delos)
- 2014 Local dynamics score (Moss ... Moorman)
- 2015 Markov models of illness (Clark ... Moorman)
- 2015 Periodic breathing detection with wavelets (Mohr, Moorman ... Delos)
- 2015 Improved atrial fibrillation detection (Carra ... Moorman)
- 2018 Quantitative neonatal breathing record (Dennery ... Moorman)
- 2019 Model-based O₂ sat to SOFA score (Gadrey ... Moorman)
Our papers 2015-2020

- Critical Care Medicine 2020
- Pediatrics 2020
- J Neonatal Perinatal Medicine 2019
- Physiological Measurement 2019
- Pediatric Research 2019
- Journal of Clinical Monitoring and Computing 2019
- Applied Clinical Informatics 2019
- Pediatric Research 2019
- Pediatric Research 2019
- Journal of Perinatology 2019
- Journal of Clinical Monitoring and Computing 2018
- Physiological Measurement 2018
- Journal of Perinatology 2018
- American Journal of Perinatology 2018
- Critical Care Nursing Clinics of North America 2018
- Surgery 2018

- PLoS One 2017
- Critical Care Medicine 2017 Featured article, with editorial
- IEEE J Biomedical Health Informatics 2017
- Pediatric Research 2017
- Surgery 2017
- Critical Care Medicine 2016 Featured article, with editorial
- Europace 2016
- Pediatric Research 2016
- Physiological Measurement 2016
- Pediatric Research 2016
- Physiological Measurement 2015
- J Electrocardiology 2015
- Physiological Measurement 2015
- J Applied Physiology 2015
- J Electrocardiology 2015
About 300 data points in 2 days...

MIMIC-III, a freely accessible critical care database.
About 300 data points in 0.2 seconds...
About 300MB in 2 days
Predictions of Deep Learning models on >200,000 data points per patient, half from before the admission

Predictions of logistic regression models on much smaller data sets - <30 vital signs and lab tests

Big Data and Deep Learning did better.
Which was it – the 1000-fold Bigger Data, or the Deep Learning models?
**It wasn’t the Deep Learning...**

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CoMET in STICU
(Continuous Monitoring of Event Trajectories)
What does CoMET do?

- CoMET causes a paradigm shift in care
  - We know how to *REACT* to the crashing patient
  - We need to know when and how to be *PROACTIVE*
- The purpose of CoMET is to give you a heads-up on who might be deteriorating
- CoMET is designed to get you to see the patient early in the illness (before they crash)
  - Your clinical expertise will take over from there
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CoMET in the STICU

- Implemented in 2015 as a research study
- Now a standard of care
- Part of scripted rounds
- Has protocolized responses
Impact of CoMET in STICU

50% reduction in septic shock cases in the SICU after display of CoMET

CoMET display

No display

Ruminski, C et al., Journal of Clinical Monitoring and Computing 2018
Ms. H Revisited

- 85 year-old on the acute care cardiology ward
- Recovering from R SFA stenting
- No evidence of infection
- Early intervention key
- Retrospective review
  - How would our continuous predictive analytics model have performed?
CoMET: Morning of Event
1300 July 7
CardioRespiratory >5
CardioVascular >2
No S&S of critical illness
0100 July 8
CoMET CR risk >5
Pt now dyspneic, tachypneic, hypoxic

CXR (RML, RLL PNA)
Blood cultures
Antibiotics started
July 8 0200
DX of Sepsis
>12 hours after CoMET’s first warning
Ms. H – CoMET Hypothetical

- 12 hours of advance warning
- BEFORE clinical signs/symptoms
- Early intervention possible
- Unknown effects on acute outcomes
Health Care Analytics Storyboard

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PM-IMPACCT Trial

Predictive Monitoring - IMPact in Acute Care Cardiology Trial (PM-IMPACCT)

2-year randomized controlled trial of continuous predictive analytics monitoring on the acute care cardiology wards (4th floor).
Key Personnel:

**Steering Committee**
- Jamie Bourque, MD Study PI
- Jess Keim-Malpass, RN, PhD Co-PI
- Sarah Ratcliffe, Ph.D. – Biostatistician
- Randall Moorman, MD Co-I, CMO AMP3D
- Katy Krahm, CRC Manager
- Matthew Clark, Ph.D., CSO AMP3D
- Liza Prudente Moorman MSN, ACNP-BC, CIO AMP3D

**Clinical Partners**
- Karen Forsman, Administrator, Heart and Vascular Center
- Bob Anthony, Director, In-patient Cardiovascular Services

**Sponsors**
- Frederick Thomas Fund ($$)
- AMP3D (hardware, software, technical and education support)
Cluster Randomization

- $4^{th}$ floor divided into 14 – 4-room clusters
- Each cluster randomized every 2 months
- Monitoring versus no monitoring

2 months later...
PM-IMPACCT Trial: CoMET on the walls

Central Ward
TV Display Cluster

Rooms 1-4

Rooms 5-8

Rooms 9-12

Rooms 13-16

Workroom
Display
PM-IMPACCT Trial: Education and Assistance Plan

• Extensive nursing education prior to implementation
  – Lectures, In-services, CBLs – ongoing education

• Onboarding for housestaff
  – CBLs, User Manual, case-study videos available

• Research team readily available for in-the-moment learning
  – Study CRC embedded on rounds
  – Study PIs available, will round when possible, will liaise with medical and nursing leadership
Nursing Response Protocol

CardioRespiratory Axis

- CoMET rise ≥2
- Go see the patient
- Document CoMET score
- Take full VS, Assess patient
- Consider context and course of pt illness

CardioVascular Axis

- CoMET rise ≥2
- Go see the patient
- Document CoMET score
- Take full VS, Assess patient
- Consider context and course and course of pt illness

2-3 on 4th floor per 24-hour period

Page Resident: CoMET Score, assessment

Write a note
# MD /NP CoMET Decision Guide

<table>
<thead>
<tr>
<th>Rise in CoMET by ≥ 2:</th>
<th>Look for:</th>
<th>Think about:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardio-Respiratory axis</td>
<td>Tachycardia, Tachypnea, Hypoxemia, Hypovolemia, Altered mental status</td>
<td>Sepsis, Cardiogenic shock, Pulmonary embolism, Pneumonia</td>
</tr>
<tr>
<td>Cardio-Vascular axis</td>
<td>Hypotension, Tachypnea, Hyperkalemia, Fever or hypothermia</td>
<td>Cardiogenic shock, Acute kidney injury, Sepsis</td>
</tr>
<tr>
<td>Both axes</td>
<td>Tachypnea, Hyperkalemia, Hypotension</td>
<td>Sepsis, Cardiogenic shock</td>
</tr>
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</table>
Rising CoMET Score

See the patient

Determine:
• Ongoing clinical suspicion
• New issue (consider DDx)

Potentially:
• Complete sepsis/hemorrhage workup sooner
• Consider MET evaluation
Outcomes

• Primary
  – Number of hours free of clinical deterioration
    • Emergent ICU transfer
    • Intubation
    • Cardiac arrest/death

• Secondary
  – In those transferred to ICU, outcomes better?
  – Time to proactive clinical response (i.e. culture and lactate drawn, MET team activation, etc.)
  – Rates individual events
  – Cost of care (what is impact on system?)
Thank you!

QUESTIONS