“You ain’t seen nothin’ yet”
Critical care informatics

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DISCLAIMER

“I DID NOT PICK THE TITLE”
"You need educatin'
You got to got to school“ (BTO)
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Current generation monitors present data that are
• Not predictive; and
• Do not offer decision assistance capability
None of these is predictive
None offers decision-assist
One is closed loop
“TMI”
When Gertrude Stein was being wheeled into the operating room for surgery on her stomach, she asked Alice B. Toklas, "What is the answer?"

When Toklas did not answer, Stein said, "In that case, what is the question?"

*Portrait of Gertrude Stein* by Pablo Picasso
Metropolitan Museum of Art, New York City.
In that case, what is the question?
In that case, what is the question?

Given current circumstances (condition & interventions), will the patient recover?
In that case, what is the question?

Given current circumstances (condition & interventions), will the patient recover?

If not, what can/should/must be changed?
Current State
- Examination
- Bedside physiology and labs
- Imaging

Processes
- Physical interventions (drains, vents, IABP,...)
- Medicines

Desired State
- Parameterized goals
- Processes tightly linked to goals

Change/Do
- Targeted interventions
- Stop ineffective/harmful actions
“System: Neuro”

Current State
- Neuro exam, Sedation Score,...
- Osmolality, [Na⁺], ICP = 24 torr, CPP = 75 torr
- CT scan

Processes
- Ventricular drain
- Mannitol 0.5 mg/kg Q 4 hr... (or hypertonic saline)
- ...

Desired State
- CPP > 70 torr, ICP < 15 torr

Change/Do
- ↑ Mannitol 1 mg/kg Q 4 hr
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New Approaches to Physiological Informatics in Neurocritical Care

Marco D. Sorani,1 J. Claude Hemphill III,2,5 Diane Morabito,3,5 Guy Rosenthal,4,5 and Geoffrey T. Manley4,5,*

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<table>
<thead>
<tr>
<th>Source</th>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viridia bedside monitor</td>
<td>MAP</td>
<td>mean arterial blood pressure</td>
</tr>
<tr>
<td></td>
<td>ABP – systolic</td>
<td>systolic arterial blood pressure</td>
</tr>
<tr>
<td></td>
<td>ABP – diastolic</td>
<td>diastolic arterial blood pressure</td>
</tr>
<tr>
<td></td>
<td>ICP</td>
<td>intracranial pressure</td>
</tr>
<tr>
<td></td>
<td>ETCO₂</td>
<td>end tidal CO₂</td>
</tr>
<tr>
<td></td>
<td>SvO₂</td>
<td>oxygen saturation of venous blood from brain</td>
</tr>
<tr>
<td></td>
<td>HR</td>
<td>heart rate</td>
</tr>
<tr>
<td></td>
<td>CTP</td>
<td>cerebral perfusion pressure</td>
</tr>
<tr>
<td></td>
<td>SpO₂</td>
<td>oxygen saturation in capillaries</td>
</tr>
<tr>
<td></td>
<td>Core Temp</td>
<td>body temperature</td>
</tr>
<tr>
<td></td>
<td>P1O₂</td>
<td>brain tissue oxygen</td>
</tr>
<tr>
<td>Licor tissue oxygen monitor</td>
<td>Brain Temp</td>
<td>brain tissue temperature</td>
</tr>
<tr>
<td>Draeger ventilator</td>
<td>Plateau pressure</td>
<td>pressure applied to small airways and alveoli</td>
</tr>
<tr>
<td></td>
<td>PEEP breathing pressure</td>
<td>positive pressure applied at the end of expiration</td>
</tr>
<tr>
<td></td>
<td>Peak breathing pressure</td>
<td>pressure measured by ventilator in major airways</td>
</tr>
<tr>
<td></td>
<td>Tidal volume</td>
<td>tidal volume during normal breath</td>
</tr>
<tr>
<td></td>
<td>Spontaneous minute volume</td>
<td>tidal volume x respiratory rate - (patient breathing)</td>
</tr>
<tr>
<td></td>
<td>Minute ventilation</td>
<td>tidal volume x respiratory rate - (ventilator)</td>
</tr>
<tr>
<td></td>
<td>Respiratory rate</td>
<td>respiratory rate</td>
</tr>
<tr>
<td></td>
<td>Inspired O₂</td>
<td>fraction of inspired oxygen</td>
</tr>
</tbody>
</table>
Geometries of Biological Time
Stress Test

- Indirect reflection of arterial blood flow to heart during exercise
- 1\textsuperscript{st} test 1929, now standardized
- Authentic exercise (or drug, dobutamine)
  - (a way to get from health to stress, at least for study)
State and velocity of change

Some frames to keep an eye on (seem to identify transitions)
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Assumes Complete Description

Data-Based Prediction
Characterizing the Dose-Response Relationship between Mannitol and Intracranial Pressure in Traumatic Brain Injury Patients Using a High-Frequency Physiological Data Collection System

MARCO D. SORANI, DIANE MORABITO, GUY ROSENTHAL, KATHLEEN M. GIACOMINI, and GEOFFREY T. MANLEY

B

![Graph showing dose-response relationship and intracranial pressure changes over time.](image-url)
“Natural Clinical Experiment”:
Spontaneous Breathing Trial (SBT)

BEFORE

Controlled Ventilation:
auxiliary control (A/C)
Frequency: \(12-18\) min\(^{-1}\) = \((0.2-0.3)\) Hz
Tidal Volume: \((6-10)\) mL/kg

SBT

Spontaneous Breathing

Continuous positive airway pressure (CPAP)

AFTER

Controlled Ventilation:
auxiliary control (A/C)
Frequency: \(12-18\) min\(^{-1}\) = \((0.2-0.3)\) Hz
Tidal Volume: \((6-10)\) mL/kg
Fluctuation-Dissipation Theorem (FDT) Provides a Simple Analytical Relationship between Post-Perturbation Heart Rate Recovery (HRR) and Heart Rate Variability (HRV) During the Stress

Fluctuation-Dissipation Theorem

FDT is a powerful tool for predicting the **relaxation behavior** of a system from its **reversible fluctuations** in **thermal equilibrium**.

The theorem states a general relationship between the response (**response function**) to an external disturbance and the internal fluctuation (**correlation function**) of the system in equilibrium.

Often that linear response takes the form of one or more **exponential decays**.
Our first-pass approach: apply equilibrium statistics to the far-from-equilibrium problem

- **Heart Rate Variability (HRV)** - microscopic fluctuations of HR at rest (I or IV);
- **Heart Rate Recovery (HRR)** – macroscopic change of HR after SBT;
- **Stress B (off vent)** - perturbation

\[ B(t) = B_0 \theta (- (t - t_0)) = B_0 \theta (t_0 - t) \]
Math hides two assumptions:

- Gaussian Distribution (but it's really a Lévy 'fat-tailed' dist'n)
- Equilibrium

Fluctuation-Dissipation Theorem (FDT):

\[ <f(t_k)>_{III} = <f>_IV + \frac{B_0}{kT} \langle \delta f(t) \delta f(t + t_k) \rangle_{II} \]

\[ C(t_k) = \langle \delta f(t) \delta f(t + t_k) \rangle_{II} \text{ autocorrelation function} \]

\[ C(t_0) = \langle \delta f^2 \rangle = \sigma_f^2 \]

Assumptions:

1. \( B_0 \approx \Delta f = \langle f \rangle_{II} - \langle f \rangle_{IV} \) - Stress Intensity
2. \( kT \sim \sigma_f^2 = \langle \delta f^2 \rangle \) - "Thermal Energy"

\( \sigma_f \sim \sqrt{kT} \) (width of the distribution)

These two assumptions are not independent:

\[ f_0 = <f>_IV + \frac{B_0}{kT} \cdot \sigma_f^2 \]

Recovery time after SBT is related to the correlation coefficient of heart rate fluctuations during the stress-SBT

\( T_{\infty} = \frac{\Delta t}{\ln[1 - r_f(\Delta t)\langle \delta f(t) \rangle]} \)

\( r_f(\Delta t) = \frac{\langle \delta f(t - \Delta t) \delta f(t) \rangle}{\langle \delta f^2 \rangle} \)

(patient relaxation time)
Heart Rate Prediction
under Gaussian Assumption

\[ R(x_{i+1} | x_i) = \frac{p(x_{i+1}, x_i)}{p(x_i)} = \frac{\sqrt{\chi(0)}}{\sqrt{2\pi | M |}} \exp \left[ -\frac{1}{2} (\delta x_i, \delta x_{i+1})^T M^{-1} (\delta x_i, \delta x_{i+1}) + \frac{1}{2} \delta x_i^2 \right] \]

\[ p(t_n) = R^n p(t_0) \quad \text{Prediction:} \quad \langle HRF(t_n) \rangle = \sum_i \text{state}(i) \ast p(i; t_n) \]
Relaxation Time: Prediction vs. Exponential Fit

Failure of Prediction?
Poorly sedated, altered
Neuro status...
Developing the capability to do this in real time...
Summary

Patient Data Acquisition

- ICE Interface Adapters
- Monitors
- Research Front End
- Patient
- Phenotypic Data
- Physiologic Data
- Data Aggregator (ICE Network Controller)

Current state

Processes

Decision Support and Visualization

- Database and Query Tools
  - Physio-MIMI
- Visualization Tools
- Decision Support
  - Prediction tools
- Tele-ICU

Desired State

Change/Do
Questions?