(Compensatory Reserve, The vital sign of the future)

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CRI: a New Parameter for Hemorrhage Detection and Resuscitation Monitoring

• Standard vital signs do not deteriorate with hemorrhage until the patient is near collapse due to a variety of compensatory mechanisms.
• The Compensatory Reserve Index (CRI™) is a new, simple to use, parameter that provides a unique window into human hemodynamics.
• CRI measures an individual’s ability to compensate for additional fluid volume loss prior to reaching cardiovascular collapse.
• CRI can be calculated from a range of continuous sensors which capture the pulsatile component of the cardiac cycle.

Within 30 seconds, CRI is able to indicate the level of concern for bleeding and hemodynamic collapse.

CRI values between
- 1: Normovolemia (“full tank of gas”) and
- 0: Hypovolemia/decompensation (“empty tank of gas”)
Pre-hospital Study of Severe Hemorrhage

Cooke WH et al, *J Trauma* 60:363-370, 2006
Need for Early Signals of Hypovolemic Shock

- **Systolic BP**
  - 120
  - 100
  - 80
  - 60
  - 40
  - 20

- **Arterial blood O₂**

- **Respiration Rate**

- **Pulse Character**
  - Normal
  - Weak
  - Absent

- **Blood Volume**

- **Heart rate**

**Needed signals**

**Blood Loss**

**Time**

**Δ Mental Status**
Heart Rate and Shock Index Responses are Associated with Tolerance to Reduced Blood Volume

Tolerance to Reduced Central Blood Volume is Associated with Blood Pressure Oscillations

Low Tolerant (max LBNP = -30 mmHg = ~450 ml)
Average SBP = 116 mmHg

High Tolerant (max LBNP = -80 mmHg = ~1,200 ml)
Average SBP = 104 mmHg

Arterial Waveform Features as a Marker of Compensatory Reserve

Compensatory Reserve

Moulton et al, J Trauma 75:1053-1059, 2013
How CRI Works

Input 30 Heartbeats of Patient’s Arterial Waveform

CRI Algorithm

Compare to Waveforms at CRI = 1

...  

Compare to Waveforms at CRI = 0.5

...  

Compare to Waveforms at CRI = 0

Normalized Sum of Matching Filters

CRI Estimate

New Decision-Support Monitor Display

Compensatory Reserve Index (CRI)
or
‘Fuel Tank’ Concept

Time to Recognize Unstable Patient

Monitor Decision Support

Time Elapsed, min

<table>
<thead>
<tr>
<th>No CRI</th>
<th>CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

95% CI, †P < 0.001

Muniz et al, J Trauma 75:S184-S189, 2013
Tracking Patient Status during ICU Care

- Admitted after significant blunt trauma, but CT abdomen negative
- Bowel injury detected ~24 hours after admission, required resection
Hemorrhagic Shock = ‘Zero’ Compensatory Reserve
Tracking Blood Loss & Resuscitation

\[ \text{Baseline} \]

\[ \text{6.25\%} \]

\[ \text{12.5\%} \]

\[ \text{18.75\%} \]

\[ \text{25\%} \]

\[ \text{\(\Delta\) Blood Volume, ml} \]

\[ \text{Time, min} \]

\[ \text{CRI} \]
CRI Monitoring During Blood Donation

CRI in Trauma (Johnson et al. 2016)

• 89 subjects that met trauma center activation criteria at a single level I trauma center
• For predicting hemorrhage, CRI demonstrated a sensitivity of 0.83 and a negative predictive value (NPV) of 91% for threshold CRI<0.7
• Sensitivity to detect hemorrhage for SBP 0.26 (p < 0.05) and SI 0.39 (p < 0.05)
• SBP had sensitivity of 0.26 and NPV of 78% while SI had sensitivity of 0.39 and NPV of 81%
• ROC curves generated from admission measures demonstrated AUC values of CRI=0.793 and SBP=0.609
• CRI identified significant hemorrhage requiring therapy more reliably than SBP or SI (p < 0.05).
Specificity of CRI and Standard Vital Signs During Controlled Hemorrhage in Humans

<table>
<thead>
<tr>
<th>Vital Sign</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP</td>
<td>0.17</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>0.53</td>
</tr>
<tr>
<td>Mean Arterial BP</td>
<td>0.33</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>0.02</td>
</tr>
<tr>
<td>SpO$_2$</td>
<td>0.00</td>
</tr>
<tr>
<td>Stroke Volume</td>
<td>0.33</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td>0.02</td>
</tr>
<tr>
<td>Vascular Resistance</td>
<td>0.35</td>
</tr>
<tr>
<td>Perfusion Index</td>
<td>0.29</td>
</tr>
<tr>
<td>Pulse Pressure Variability</td>
<td>0.69</td>
</tr>
<tr>
<td>Compensatory Reserve</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Ongoing Clinical Data Collection

- Trauma Patients
- Dengue Hemorrhagic Fever
- Blood Donation
- Renal Dialysis
- Orthostatic Challenges
- Child Birth
- Appendicitis
- Burn Injury
- Sepsis
- Cardiopulmonary Resuscitation
- Pre-hospital Use by IDF
Summary diagnostic benefits

- Early marker of patient status
- Provides time to act
- Not just point in time; continuous
- Goal-directed resuscitation
- Based upon complex physiological relationships (i.e., reserve)
- Specific to the individual patient
Social Media/Contact

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Colorado Springs EMS

CRI

STUDY IN THE CIVILIAN PRE-HOSPITAL ARENA

E. Stein Bronsky, MD
Chief Medical Director
Colorado Springs FD
El Paso County AMR
What does CRI Looks Like Today
What Are We Studying

• How can CRI help evaluate and potentially treat trauma patients in the field?

• All age ranges

• Evaluation of confounding factors:
  • Position of patient (orthostatics)
  • Comorbidities
  • Medications
Other Considerations

• Sepsis

• Other hypovolemic states

• Cardiopulmonary resuscitation
Applicability To Clinical Practice

• Can we use the new CRI metric to detect which patients benefit from blood transfusion?

• Can CRI help answer elusive blood product deployment questions?

• Can CRI help optimize fluid resuscitation?

• Can CRI help guide OHCA resuscitation?
Contact

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