
Craig Manifold, DO
EMS Medical Director

Primary presentation by:
Vic Convertino, PhD
Senior Scientist
Tactical Combat Casualty Care Research
victor.a.convertino.civ@mail.mil

Disclaimer: The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense
What’s the Problem?

Hemorrhagic Shock Due to Trauma

• ~40% of Civilian Deaths
• 5281 Total military KIA in OIF / OEF (2001 to present)
  • >90% are pre-hospital
  • ~25% or 1660 classified as “potentially survivable” deaths on the battlefield
  • >80% or >930 “potentially survivable” of these deaths due to hemorrhage
What clinical parameters do you currently use to identify hemorrhage shock?

What do you think you will use in the future?

How soon will compensatory risk index (CRI) be available to you?
Pre-hospital Study of Severe Hemorrhage

Cooke WH et al, *J Trauma* 60:363-370, 2006
What if . . .

• What if we had technology that could indicate a patient’s progression toward ‘shock’ well in advance of changes in vital signs?

• What if we had technology that could provide guidance for accurate resuscitation?
What do we need?

• Physiological (human) model predictive of shock (hemorrhage, sepsis, etc.)

• Reproducible clinical outcome (i.e., hemodynamic compensation)

• Identify signals that represent integrated physiology of hemodynamic compensation

• Large a data ‘library’ for algorithm development

• Algorithm(s) designed to recognize each INDIVIDUAL patient
Human Model of Hemorrhage
Lower Body Negative Pressure (LBNP)

Need for Early Signals of Hypovolemia

- Systolic BP
- Arterial blood $O_2$
- Respiration Rate
- Pulse Character
- Blood Volume
- Heart rate

Blood Loss

Time

$\Delta$ Mental Status

Normal
Weak
Absent

Needed signals
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

Baseline

60 mmHg LBNP (> 1,000 ml Blood Loss)

Time (sec)

Arbitrary Units

Convertino, Aviat Space Environ Med 83:614--619, 2012
Requirement for Improved Diagnosis of Hypovolemic Shock

What should we measure?

- continuous feature changes in the arterial waveform
- arterial waveform oscillations
Arterial Pulse Waveform
Compensatory Reserve

How CRI Works

Input 30 Heartbeats of Patient’s Arterial Waveform

Compare to Waveforms at CRI = 1

Compare to Waveforms at CRI = 0.5

Compare to Waveforms at CRI = 0

How CRI Works

New Decision-Support Monitor Display

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

Video of ‘Tracking’ CRI

Time (min): 1

CRI 0.9

HR 63
NIBP SYS / DIA 140 / 87
MAP 104
SpO2 95
RESP 18
Time to Recognize Unstable Patient

Monitor Decision Support

† 95% CI
P < 0.001

Muniz et al, J Trauma 75:S184-S189, 2013
Algorithm Specificity
Blood Withdrawal Model of Hemorrhage

Subject 1

Subject 2

Compensatory Reserve

Blood Loss, ml

0 200 400 600 800 1000 1200 1400

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Blood Loss, ml

0 200 400 600 800 1000 1200 1400

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Convertino et al, Shock 2015 (in press)
• Admitted after significant blunt trauma, but CT abdomen negative

• Bowel injury detected ~24 hours after admission, required resection
Algorithm Specificity
Dengue Fever Model of Hemorrhage

Patient 1

CRI

Patient 2

CRI

Patient 3

CRI
Algorithm Specificity
Tracking Trauma Patient Status

Compensatory Reserve Index

<table>
<thead>
<tr>
<th></th>
<th>Compensatory Reserve Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trauma No Hemorrhage</td>
<td>N = 30</td>
</tr>
<tr>
<td>Trauma + Hemorrhage</td>
<td>N = 12</td>
</tr>
</tbody>
</table>

† Statistically significant difference.
New CRI Monitor Screen
Summary diagnostic new tool benefits

- Early marker of patient status
- Provides time to act
- Not just point in time; continuous
- Based upon complex physiological relationships (i.e., reserve)
- Specific to the individual patient
Hemorrhagic Shock = ‘Zero’ Compensatory Reserve
Effective Resuscitation = Restoration of the Compensatory Reserve
Tracking Blood Loss & Resuscitation

Δ Blood Volume, ml

Time, min

Baseline

6.25%

12.5%

18.75%

25%