

# Buying More Time: Innovations in the Early Detection and Treatment of Shock

(Compensatory Reserve, The vital sign of the future)

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# CRI: a New Parameter for Hemorrhage Detection and Resuscitation Monitoring

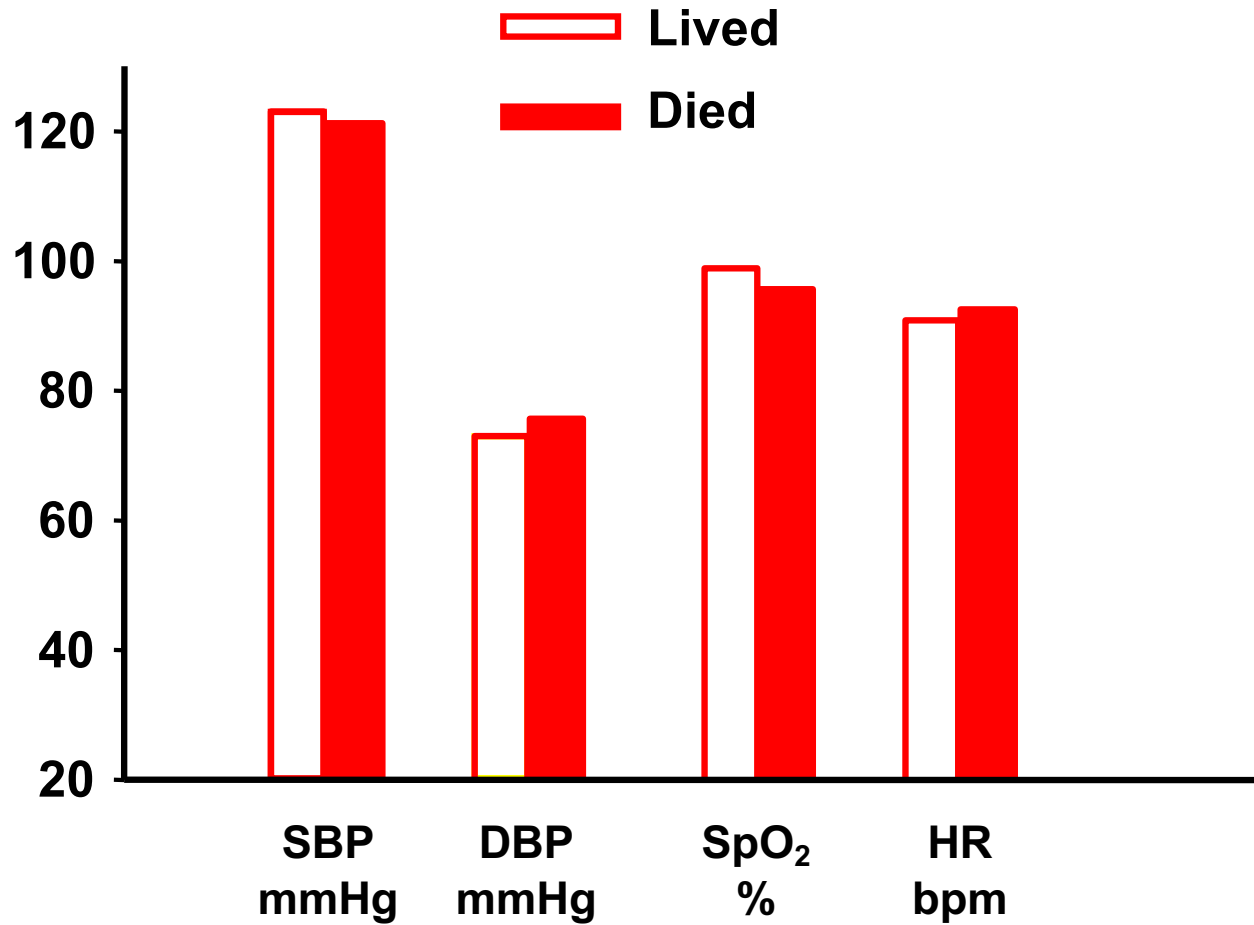
- Standard vital signs do not deteriorate with hemorrhage until the patient is near collapse due to a variety of compensatory mechanisms.
- The Compensatory Reserve Index (CRI™) is a new, simple to use, parameter that provides a unique window into human hemodynamics.
- **CRI measures an individual's 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.**

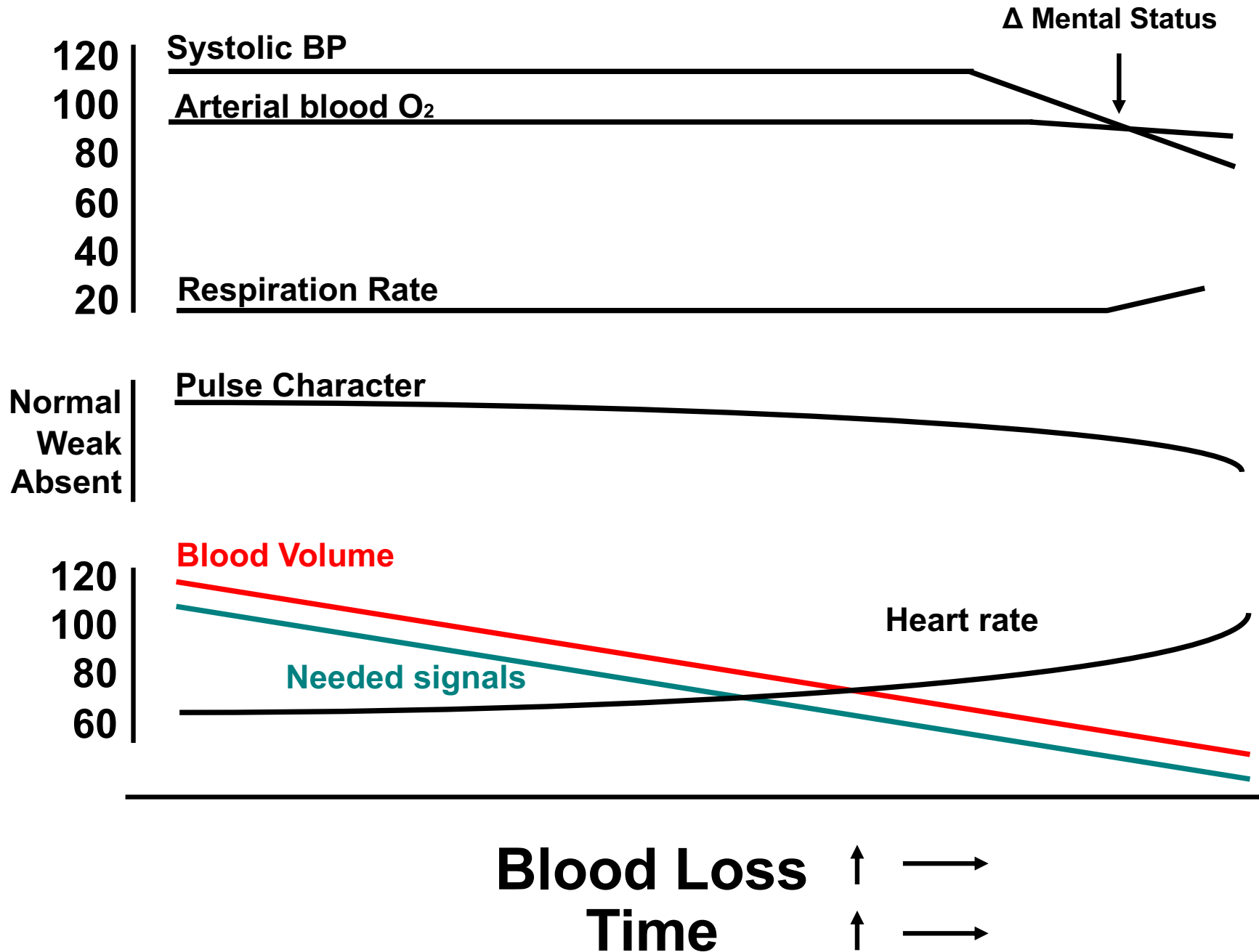


- CRI values between**
- **1: Normovolemia (“full tank of gas”)** and
  - **0: Hypovolemia/ decompensation (“empty tank of gas”)**

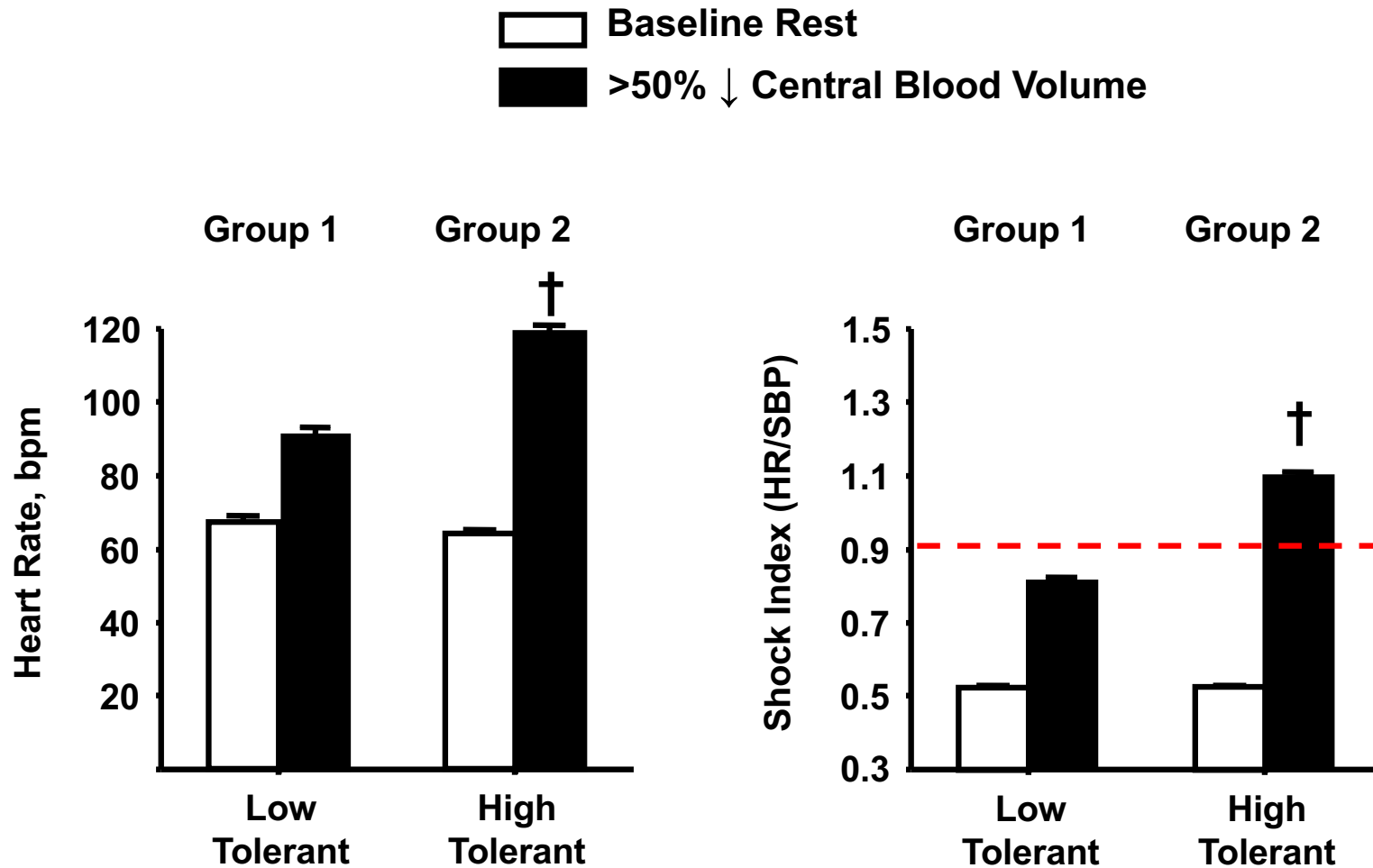
# Pre-hospital Study of Severe Hemorrhage



# Need for Early Signals of Hypovolemia



# 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)

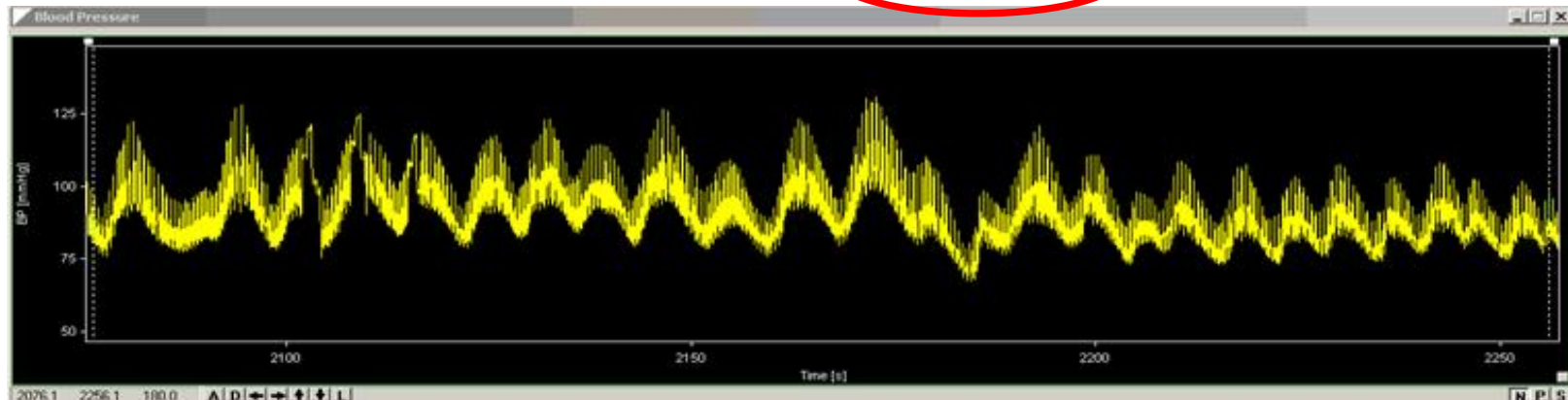
Average SBP = 116 mmHg

Decompensation

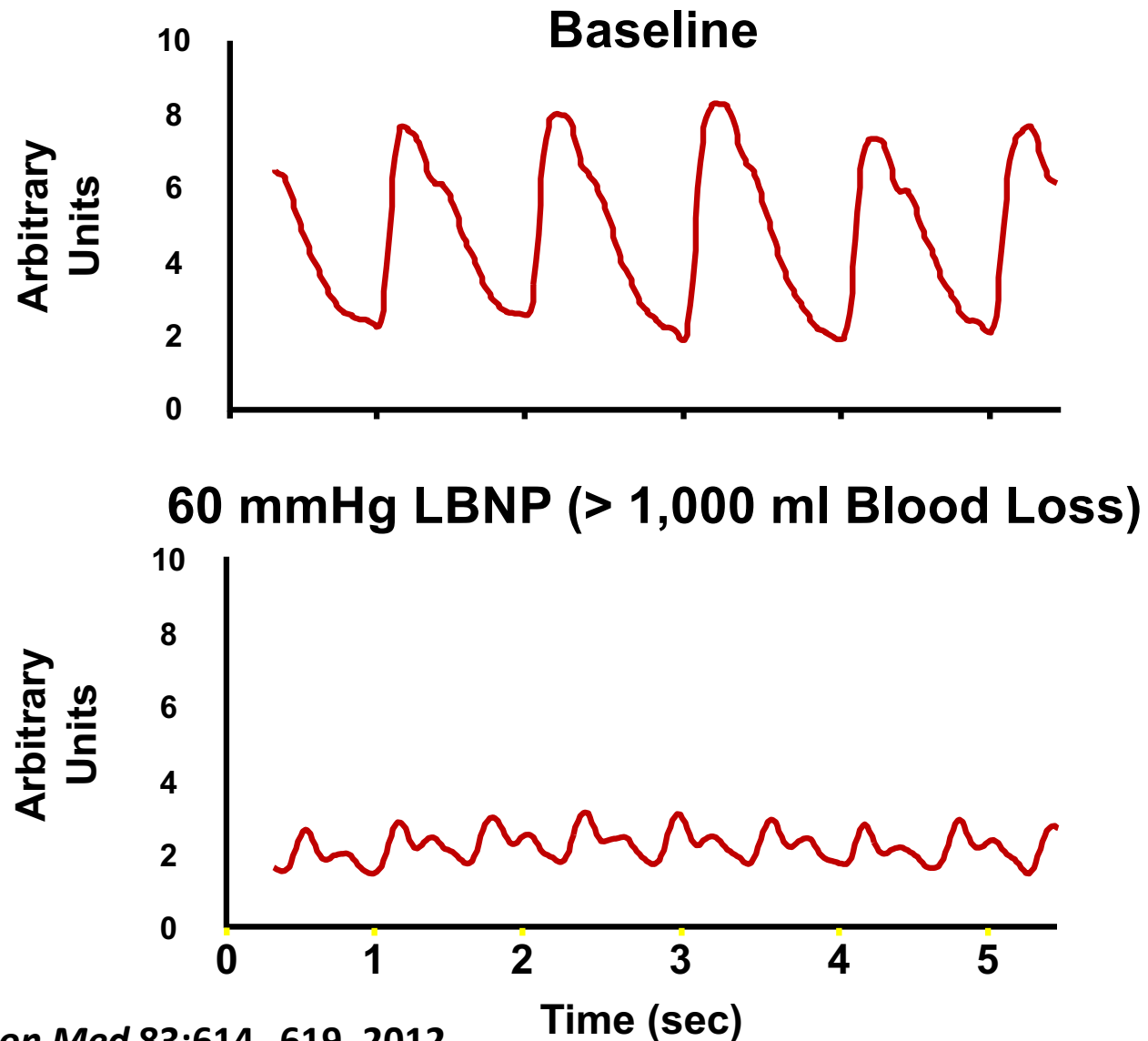
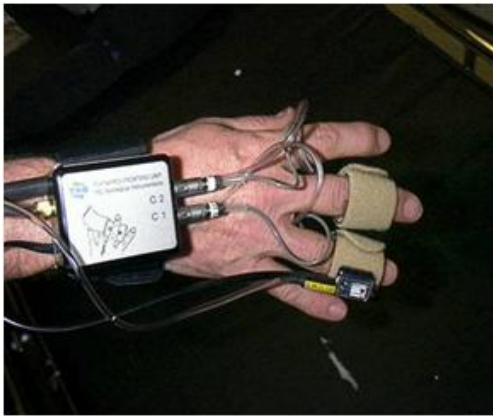


High Tolerant (max LBNP = -80 mmHg = ~1,200 ml)

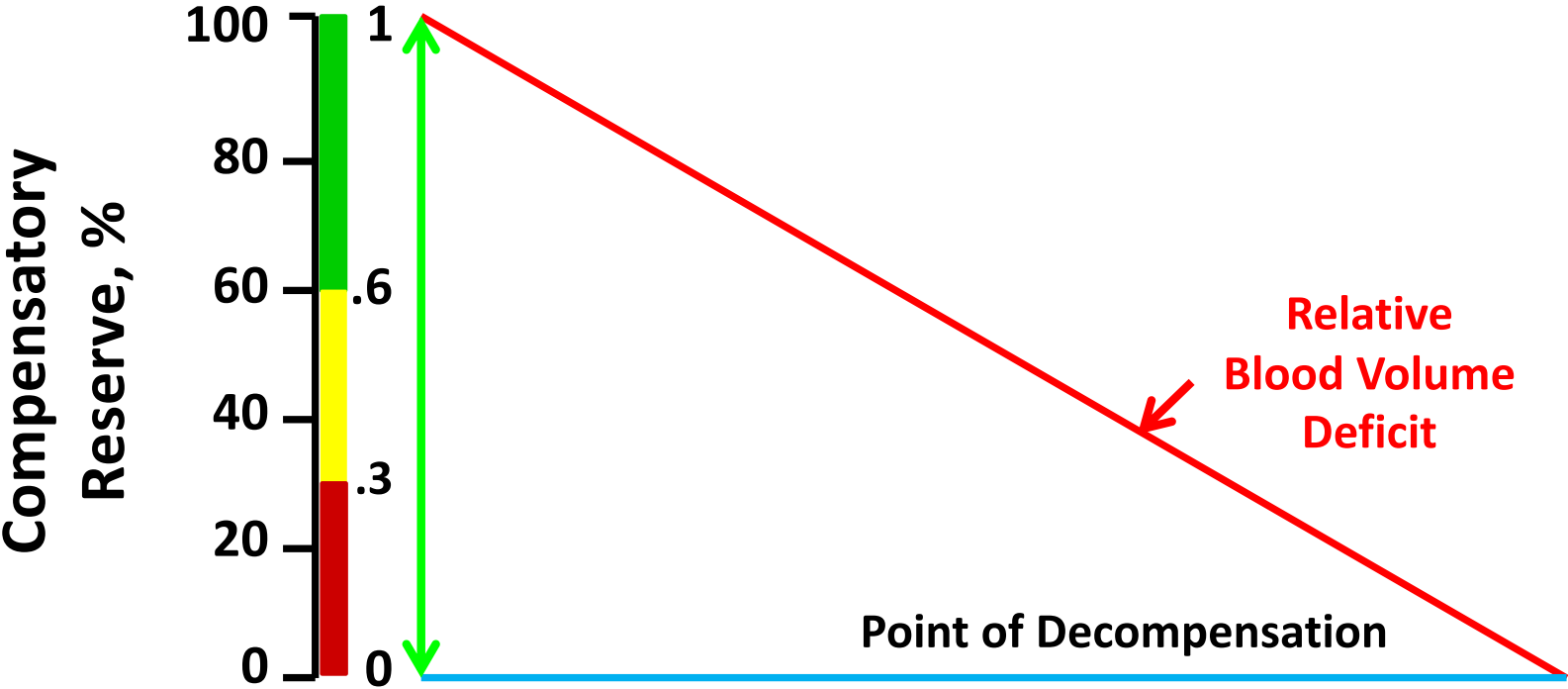
Average SBP = 104 mmHg



# Arterial Waveform Features as a Marker of Compensatory Reserve



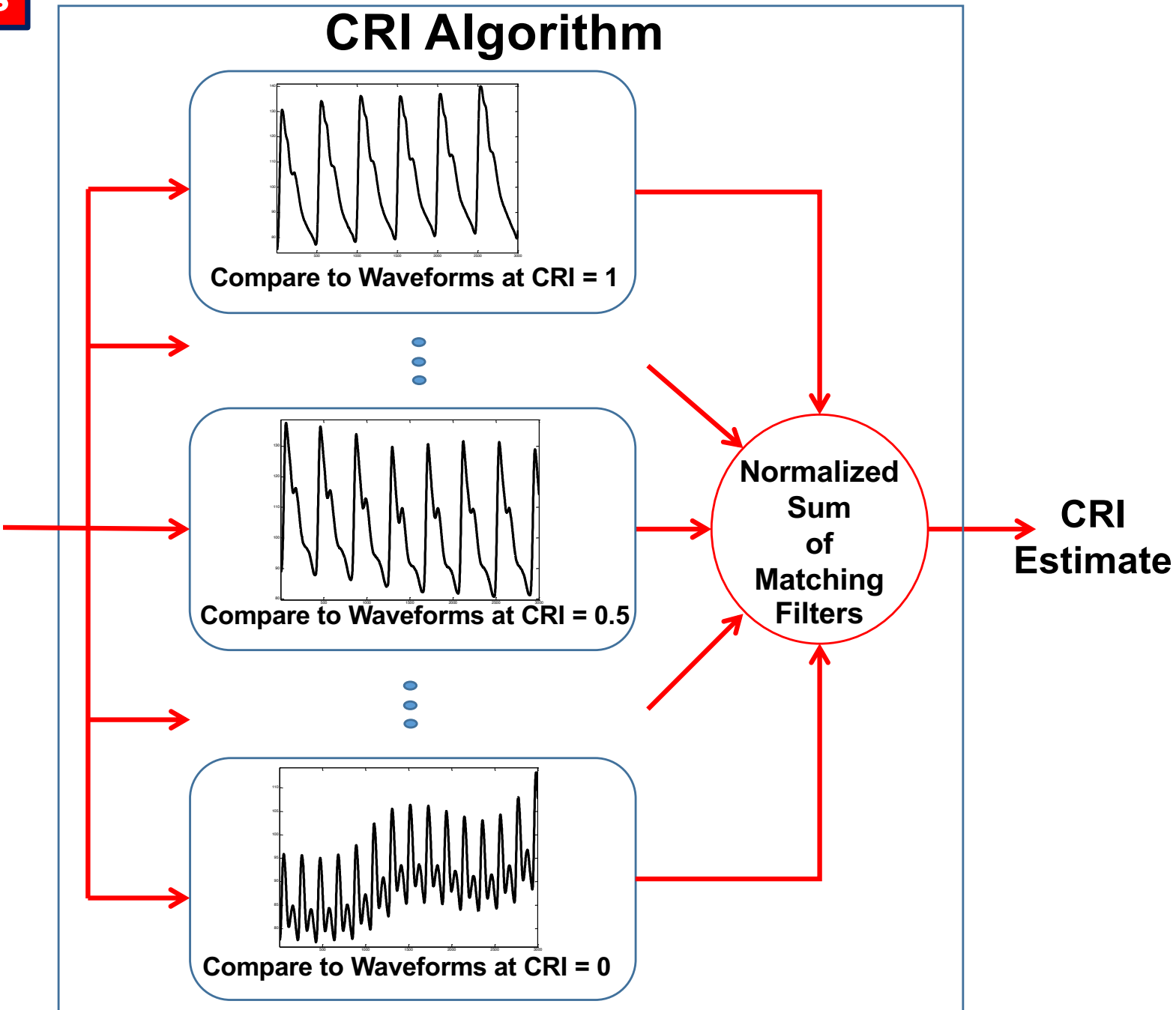
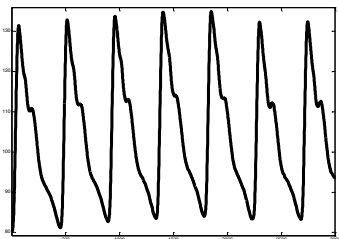
# Compensatory Reserve





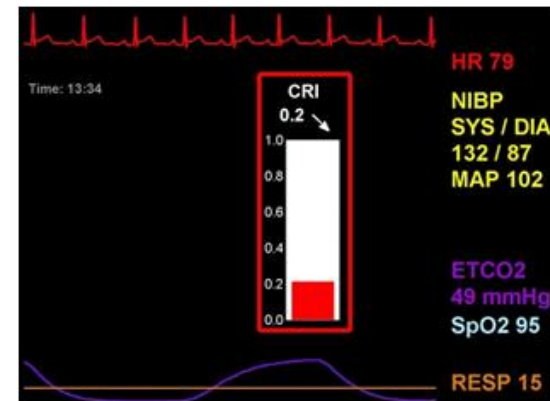
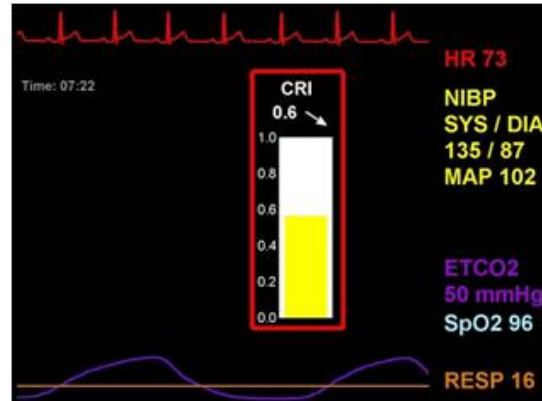
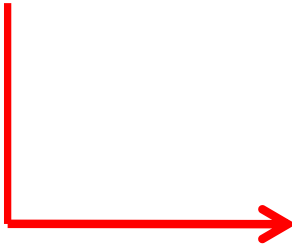
# How CRI Works

Input 30  
Heartbeats  
of  
Patient's  
Arterial  
Waveform

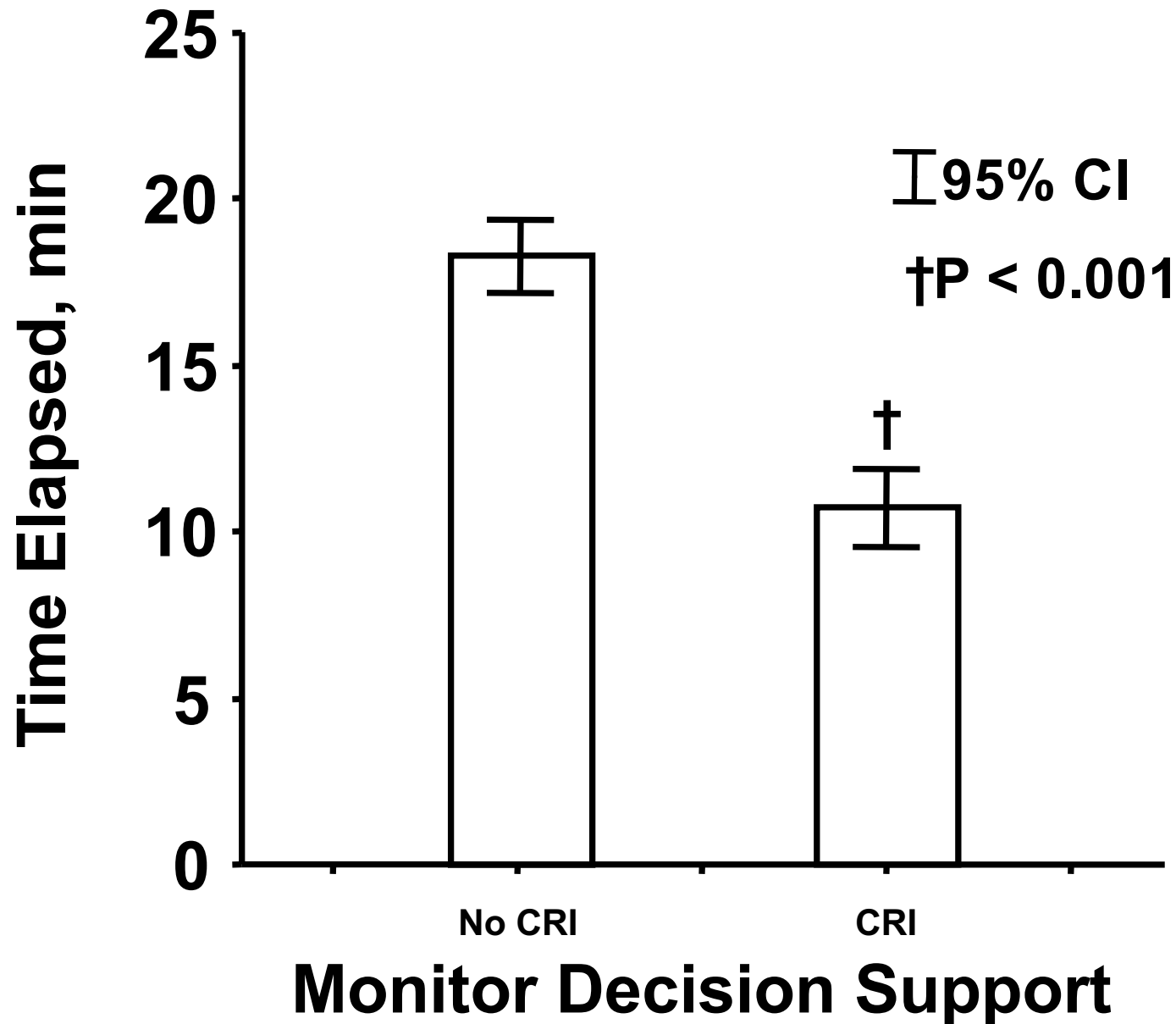


# New Decision-Support Monitor Display

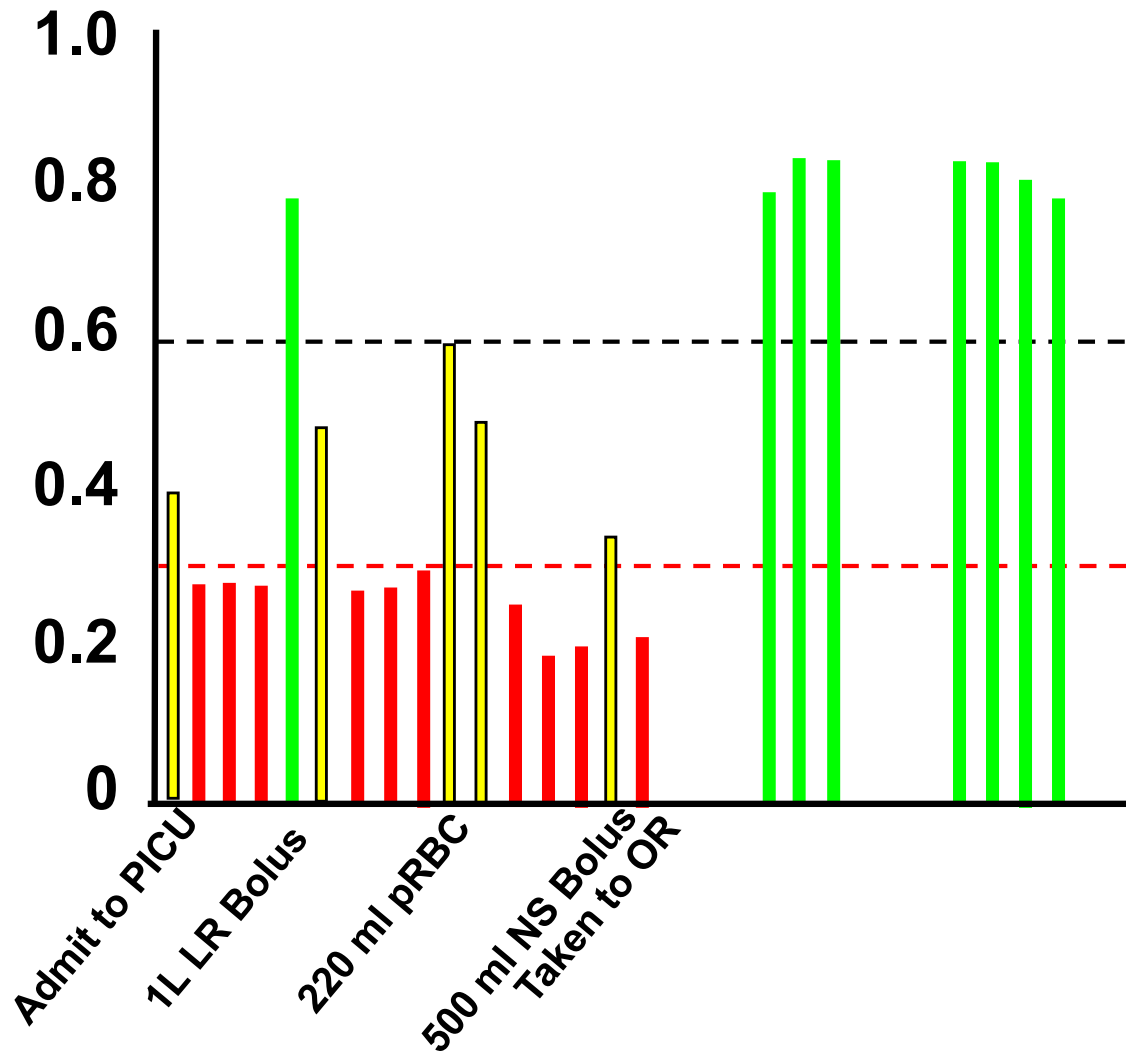
## Compensatory Reserve Index (CRI) or 'Fuel Tank' Concept



# Time to Recognize Unstable Patient



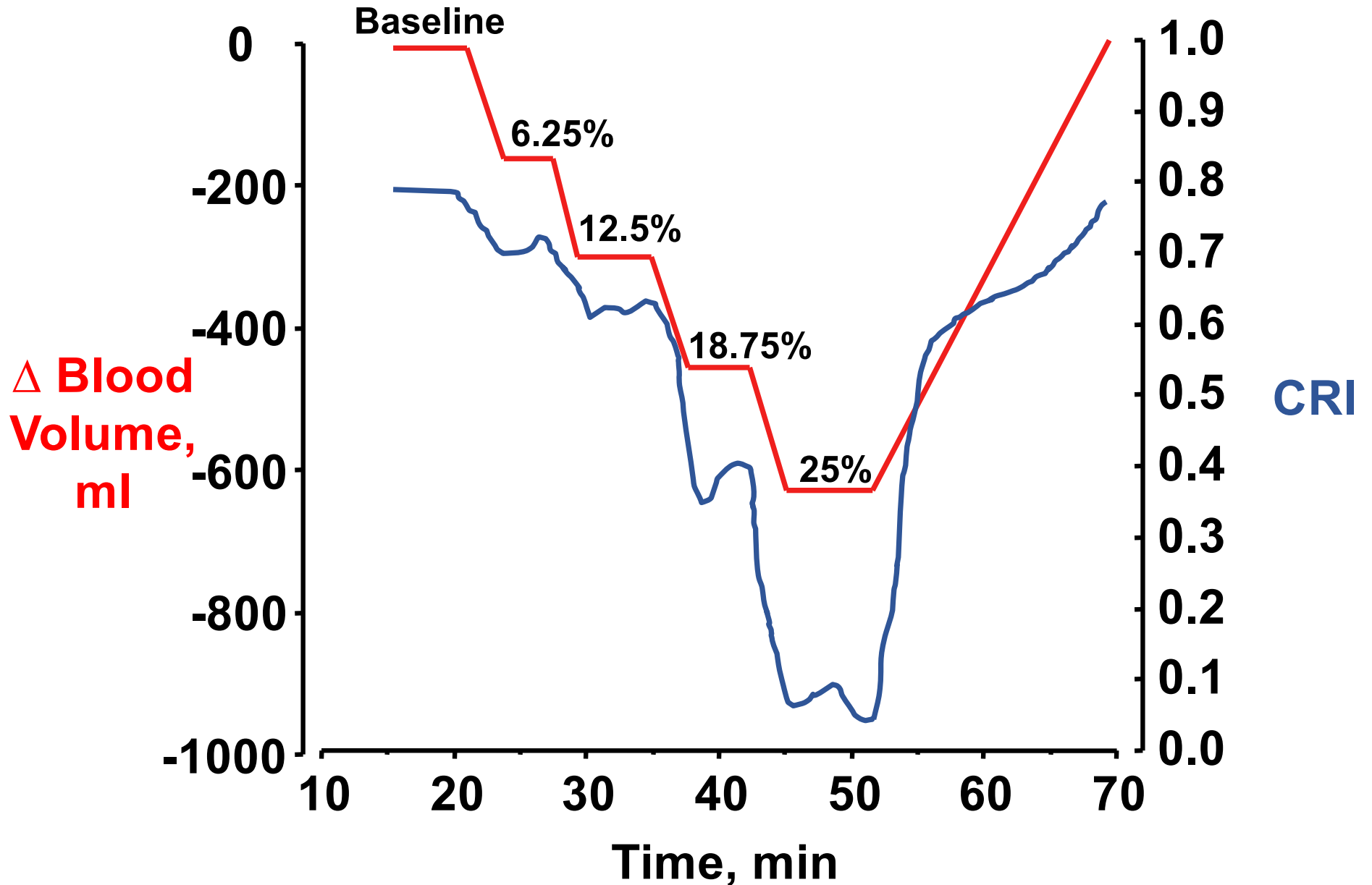
# Tracking Patient Status during ICU Care



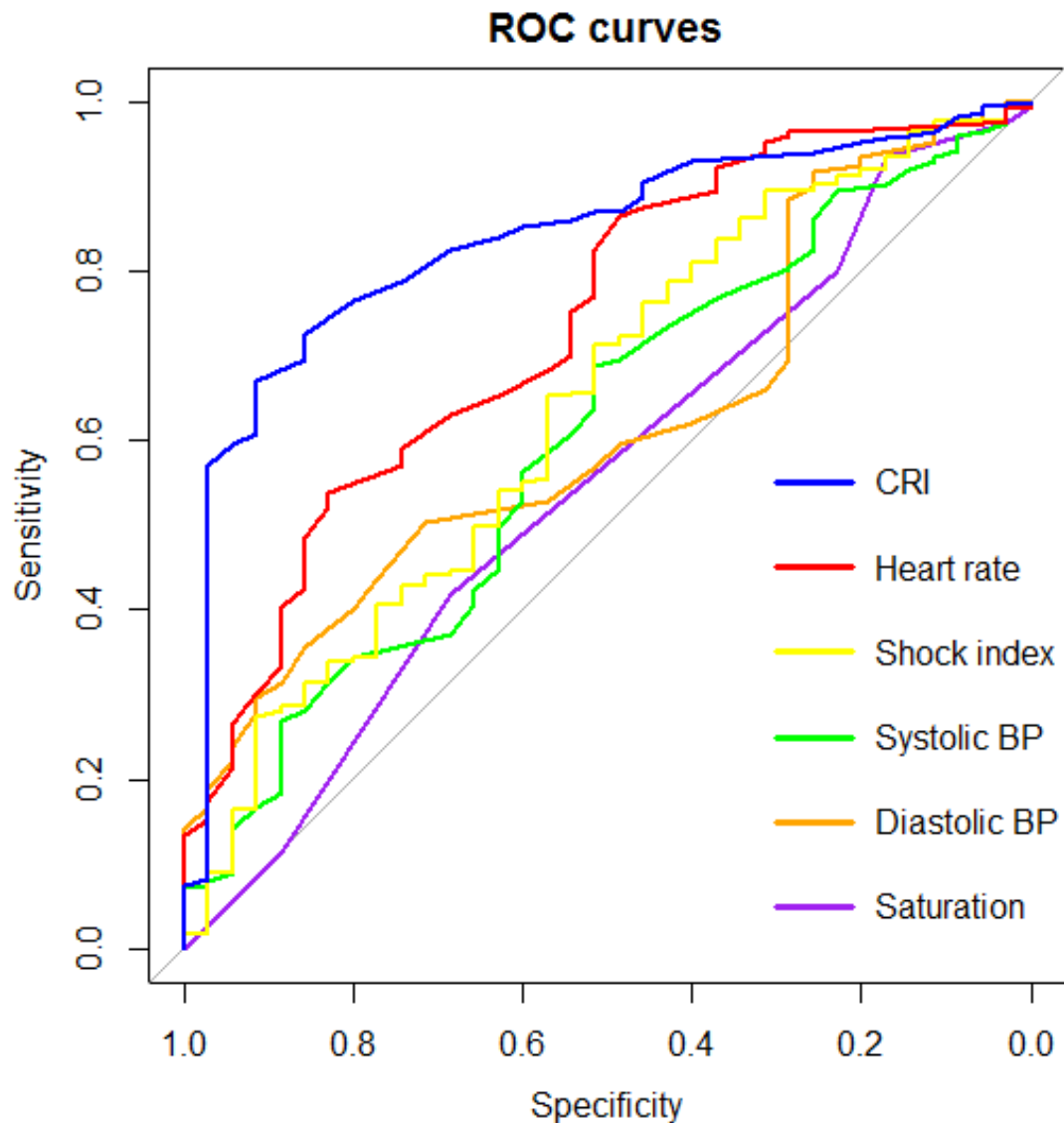
- Admitted after significant blunt trauma, but CT abdomen negative
- Bowel injury detected ~24 hours after admission, required resection

**Hemorrhagic Shock =  
'Zero' Compensatory Reserve**

# Tracking Blood Loss & Resuscitation



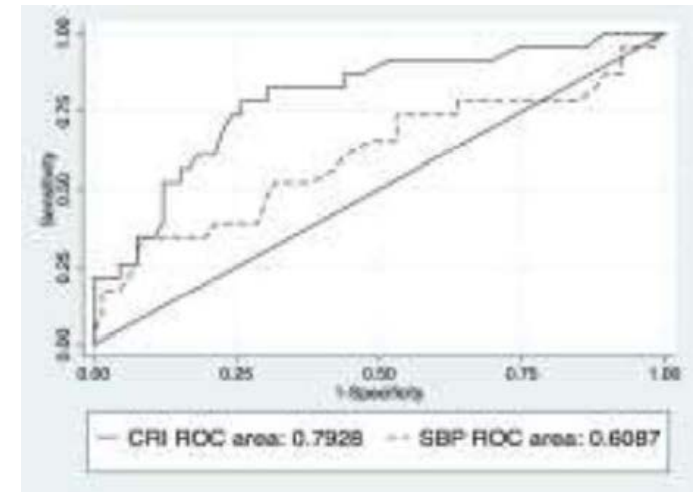
# CRI Monitoring During Blood Donation



Index	AUC
Saturation	0.55
Diastolic BP	0.61
Systolic BP	0.60
Shock index	0.64
Heart rate	0.73
CRI	0.84

# 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 ( $p < 0.05$ ).**



**AUC values of  $CRI=0.793$   
and  $SBP=0.609$**



## Specificity of CRI and Standard Vital Signs During Controlled Hemorrhage in Humans

Vital Sign	Specificity
Systolic BP	0.17
Diastolic BP	0.53
Mean Arterial BP	0.33
Heart Rate	0.02
SpO <sub>2</sub>	0.00
Stroke Volume	0.33
Cardiac Output	0.02
Vascular Resistance	0.35
Perfusion Index	0.29
Pulse Pressure Variability	0.69
<b>Compensatory Reserve</b>	<b>0.90</b>

# **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

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**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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