Advanced Capabilities for Emergency Medical Monitoring
A Strategy for Combat Casualty Triage Decision Support on the Battlefield

VA Convertino[1], CA Rickards[1,2], SL Glorsky[1], RT Gerhardt[1], JG McManus[1], KL Ryan[1]

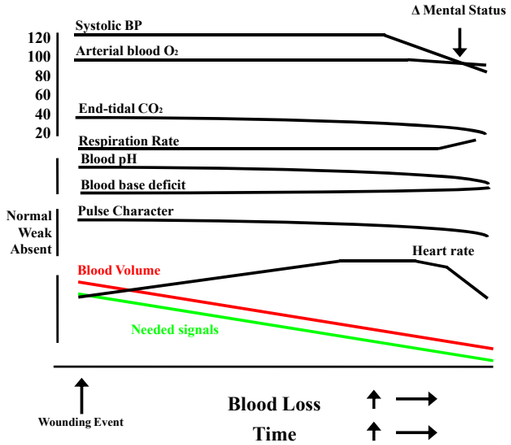
[1]US Army Institute of Surgical Research, Fort Sam Houston, TX 78234; [2]University of Texas at San Antonio, San Antonio, TX 78249

The use of Army medical and/or other Army records in the preparation of this material is acknowledged, but is not to be construed as implying official Department of the Army approval of the conclusions presented.

INTRODUCTION

- Hemorrhage accounts for > 80% (> 600) of 'potentially survivable' deaths on the battlefield [Kelly et al., J Trauma 64:S21-S27, 2008].
- Standard vital signs currently used for triage either change relatively late or are non-specific (e.g., heart rate) in the course of reduced blood volume due to autonomic compensation, making them less useful in determining the severity of hemorrhage in injured patients (Figure 1).
- Early intervention improves patient outcomes from hemorrhage [Gerhardt, J Trauma 62:S11-S12, 2007].
- New physiological signals need to be identified for earlier indication of blood volume loss and patient status.

Figure 1. Illustration of need for early signals of blood loss.



PROGRAM OBJECTIVES

- Identify new physiological signals that reflect early reductions in central blood volume resulting from hemorrhage for use in:
  - remote triage
  - advanced medical monitoring devices during en route transport and in the emergency room
- Develop multivariate, machine-learning algorithms for real-time, decision-support monitors.

METHODS

- Level 1 Trauma Patient Databases - pre-hospital civilian trauma patients
- Lower body negative pressure (LBNP) - laboratory model of hemorrhage in healthy human subjects

Trauma Patients **Laboratory Model**

Figure 2. Databases used for identifying early physiological indicators of hemorrhage in humans are derived from clinical vital signs and other physiological measures obtained from patients during transport to Level 1 trauma centers (left panel) and exposure of healthy human subjects to LBNP (right panel).

RESULTS

Table 1. Evidence for ineffective decision support provided by standard vital sign monitors.

Standard Vital Sign	Changes early during central hypovolemia?	Reference(s)
SBP	No	Convertino et al, J Trauma 61: 629-634, 2006; Cooke et al, J Trauma, 60: 363-370, 2006; Parks et al., Am J Surg 192:727-731, 2006
DBP	No	Convertino et al, J Trauma 61: 629-634, 2006 Convertino et al, J Trauma 64: S342-S353, 2008
MAP	No	Convertino et al, J Trauma 61: 629-634, 2006 McManus et al, Prehosp Emerg Care 12: 199-205, 2008
HR	Yes, but not specific	Cooke et al, J Trauma, 60: 363-370, 2006 Brasel et al., J Trauma 62:812-817, 2007
Shock Index (HR/SBP)	Yes, but not specific	Convertino et al, J Trauma 64: S342-S353, 2008
O_2 Saturation (Pulse Oximeter)	No	Convertino et al, J Trauma 64: S342-S353, 2008 Soller et al, JAP 104: 475-481, 2008
Capillary Refill	?	-----
Radial Pulse	No	Ryan et al, Prehosp Emerg Care 12: 192-198, 2008
End-tidal CO_2	Yes, but limited info	McManus et al, Prehosp Emerg Care 12: 199-205, 2008
Respiratory Rate	No	McManus et al, Prehosp Emerg Care 12: 199-205, 2008
GCS	No	Ryan et al, Prehosp Emerg Care 12: 192-198, 2008
Blood pH	No	Convertino et al, J Trauma 64: S342-S353, 2008
Blood [Lactate]	No	Convertino et al, J Trauma 64: S342-S353, 2008
Blood Base Excess	No	Convertino et al, J Trauma 64: S342-S353, 2008

Figure 3. We need to fill the 'Data Gap' of medical monitoring, i.e., we need the capability to integrate the meaning of physiological responses during the compensatory phase of hemorrhagic shock.

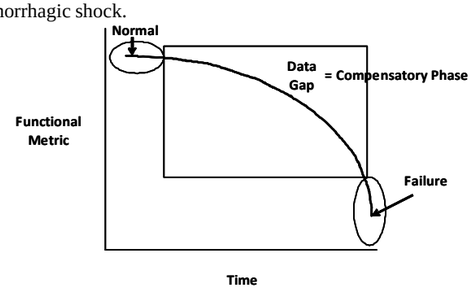


Figure 4. Testing usefulness of machine-learning algorithm that tracks circulating volume status when added to standard vital signs.

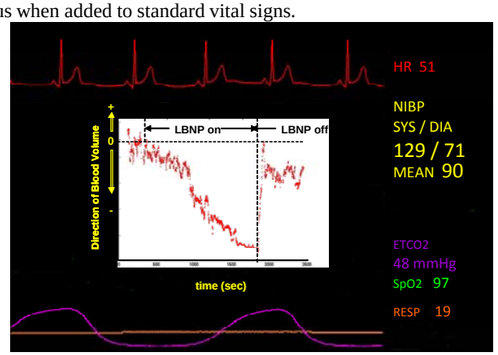
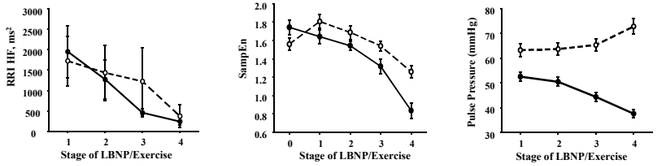


Figure 5. Strategy for tracking circulating blood volume during Remote Triage. Comparison of responses to central hypovolemia (LBNP) and exercise demonstrate that heart rate variability metrics respond in the same direction (RRI HF and SampEn), while pulse pressure can distinguish the two conditions.



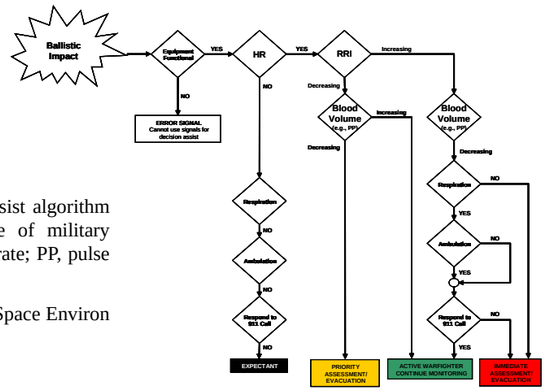


Figure 6. Decision-assist algorithm for the remote triage of military casualties (HR, heart rate; PP, pulse pressure).

Rickards et al., Aviat Space Environ Med 79: 670-6, 2008

CONCLUSIONS

- We propose that an advanced algorithm for early diagnosis of severity of bleeding will be multivariate and incorporate measures that reflect complex physiological compensations, including:
  - hemodynamic responses (e.g., arterial waveforms, waveform oscillations)
  - autonomic compensations (e.g., RR interval)
  - changes in tissue oxygenation (e.g., near-infrared spectroscopy)
- A machine-learning algorithm that provides real-time continuous integration of these signals will prove instrumental in filling the 'Data Gap' of medical monitoring.