

# Proceedings of the 2013 U.S. Military Health System Research Symposium

*September 2014  
Publication Preview*

The Journal of  
Trauma and  
Acute Care  
Surgery



# PREFACE

## Military trauma research: Answering the call

**Todd E. Rasmussen, MD, Terry M. Rauch, PhD,  
and Dallas C. Hack, MD, *Fort Detrick, Maryland***

**M**ilitary medicine has long served as a vital platform for fostering lines of investigation and innovation and advancing patient care, both in military and civilian contexts. Historically, however, medicine has reaped its gains from the battlefield haphazardly. Unlike the terminal phases of any other war, the U.S. now approaches the drawdown of combat in Afghanistan with an intentional and harmonized approach to trauma care and research. During the last decade the nation's investment has produced a continuously learning medical or trauma system. This system is capable of assiduous collection of clinical observations and data from the battlefield conducted in concert with process improvement mechanisms and focused lines of research. In turn, these support the implementation of evidence-based guidelines, often adapted and applied in a pragmatic way to inherently unpredictable settings. The end goal of the military's trauma system is to reduce combat-related morbidity and mortality, especially that which may be avoidable. As noted in last year's Military Health System Research Symposium supplement, the programmed investment has resulted in a beneficial return – the lowest case fatality rate in the history of war.<sup>1</sup> While a challenge remains to translate lessons learned from the battlefield to the street, it is also incumbent upon us to address unresolved gaps in care and maintain the momentum of investigation. To that end, we are pleased to present this year's compendium of research first presented at the Military Health System Research Symposium of 2013.

# HISTORICAL FOREWORD

Vietnam (1972) to Afghanistan (2014): The state of military trauma care and research, past to present

**Basil A. Pruitt, Jr, MD and Todd E. Rasmussen, MD**  
*Fort Detrick, Maryland*

“Those who cannot remember the past are condemned to repeat it...” George Santayana



**Figure 4.** Aerial view of the 332 Expeditionary Medical Group/Air Force Theater Hospital, a level III surgical facility at Balad Air Base, Iraq. Note the current state-of-the-art construction and improved design to increase efficiency of operation.



**Figure 3.** Aerial view of the 12th Evacuation Hospital at the base camp of the 25th Infantry Division near Cu Chi Vietnam (1967). Note the pavilion-style organization of the Quonset huts (elongated white structures with the red crosses on top) adapted for use as receiving areas, laboratories, operating rooms, and patient wards.

# SPECIAL REPORT

## Initial UK experience of prehospital blood transfusion in combat casualties

**David J. O'Reilly, FRCS, Jonathan J. Morrison, MRCS, Jan O. Jansen, FRCS, FFICM, Giles Nordmann, MB, FRCA, Todd E. Rasmussen, MD, Mark J. Midwinter, MD, FRCS, and Heidi Doughty, FRCP, FRCPath, Birmingham, United Kingdom**

The decade of conflict in the Middle East and Central Asia has driven a significant number of improvements in the medical care of military casualties.<sup>1</sup> Exsanguination remains a potentially preventable cause of battlefield mortality and, consequently, the treatment of hemorrhage has been a significant focus trauma care innovation. The last decade has seen the rehabilitation of tourniquets,<sup>3</sup> the development of hemostatic dressings,<sup>4</sup> improvements in paramedical training and the development of deployed trauma systems.<sup>5</sup>

Experience derived from the field hospital resuscitation of severely injured patients has led to the development of damage control resuscitation (DCR), which has transformed the treatment of patients with hemorrhagic shock, in both military and civilian practice.<sup>6,7</sup> DCR combines damage control surgery<sup>8</sup> with hypotensive resuscitation,<sup>9</sup> balanced transfusion therapy,<sup>10,11</sup> and limited use of crystalloid fluids.<sup>12</sup> DCR has been shown to reverse the triad of coagulopathy, acidosis, and hypothermia, even during the index operation.<sup>13</sup>



**Figure 1.** Prehospital blood transfusion during retrieval of a combat casualty to the medical treatment facility at Camp Bastion by the UK MERT-E aboard a Royal Air Force CH-47 Chinook helicopter.

# SPECIAL REPORT

## Role I trauma experience of the Israeli Defense Forces on the Syrian border

Avi Benov, MD, MHA, Elon Glassberg, MD, MHA, Roy Nadler, MD, Sami Gendler, MD, Tomer Erlich, MD, Tarif Bader, MD, MHA, Todd E. Rasmussen, MD, and Yitshak Kreiss, MD, MHA, MPA, Ramat Gan, Israel

Israel has been in a state of conflict with the bordering country of Syria since 1948. Beginning in February 2011, Syria has been in a state of civil war that has taken the lives of civilians and resulted in more than a million refugees.<sup>1</sup> In February 2013, casualties from the fighting in Syria arrived at the Israeli border seeking medical assistance. Despite the challenging scenario, members of the Israeli Defense Forces (IDF) provided care to this group of injured civilians. Since that time, such medical care was available to men, women, and children who arrive at the Syrian border. In contrast to endeavors in which the IDF-Medical Corps (MC) has deployed to sites of calamities around the globe, this operation began as one of expediency to provide humanitarian care on its own domestic border.<sup>2</sup>

**TABLE 1.** Demographics and Injury Severity

	Value	n
Age, median (IQR)	24 (20–27)	155
Male/female	147/17 (90%/10%)	164
Injury severity*		166
Mild	60 (33.7%)	
Moderate	54 (30.3%)	
Severe	45 (25.2%)	
Dead	7 (3.9%)	

\*As was determined in the emergency department or the Role 2+ facility.

# ORIGINAL ARTICLE

## A laparoscopic swine model of noncompressible torso hemorrhage

James D. Ross, PhD, Christopher J. Burns, MD, Eileen M. Sagini, Lee-Ann Zarzabal, MS,  
and Jonathan J. Morrison, MRCS, San Antonio, Texas

**BACKGROUND:** Hemorrhage persists as the leading cause of potentially preventable civilian and military death. Noncompressible torso hemorrhage (NCTH) is a particularly lethal injury complex, with few contemporary prehospital interventions available. Various porcine models of hemorrhage have been developed for civilian and military trauma research. However, the predominant contemporary models lack key physiologic characteristics including the natural tamponade provided by an intact abdominal wall.

To improve physiologic and clinical relevance, we developed a laparoscopic model of NCTH. This approach maintains both the integrity of the peritoneum and the natural tamponade effect of an intact abdominal wall while preserving the intrinsic physiologic responses to hemorrhage. Furthermore, we present data quantifying the contribution of the swine contractile spleen in the context of uncontrolled hemorrhage.

**METHODS:** Anesthetized adult male Yorkshire swine underwent a laparoscopic Grade V liver injury, with or without open preinjury splenectomy. Animals were observed without intervention for a total of 120 minutes after injury to simulate point of injury, transport time, and arrival at hospital.

**RESULTS:** Shed blood-to-body weight ratio did not differ among groups; however, mortality was higher in splenectomized animals (67% vs. 33%). Cox regression modeling demonstrated a critical time point of 45 minutes and blood pressure as significant predictors of mortality.

**CONCLUSION:** This study describes a model of NCTH that reflects clinically relevant physiology in trauma and uncontrolled hemorrhage. In addition, it quantitatively assesses the role of the swine contractile spleen in the described model. (*J Trauma Acute Care Surg*. 2014;77: S77-S82. Copyright © 2014 by Lippincott Williams & Wilkins)

**KEY WORDS:** Noncompressible torso hemorrhage; splenectomy; swine.

# ORIGINAL ARTICLE

## Rat model of brain injury caused by under-vehicle blast-induced hyperacceleration

Julie L. Proctor, MS, William L. Fourney, PhD, Ulrich H. Leiste, PhD,  
and Gary Fiskum, PhD, *Baltimore, Maryland*

---

**BACKGROUND:** More than 300,000 US war fighters in Operations Iraqi and Enduring Freedom have sustained some form of traumatic brain injury (TBI), caused primarily by exposure to blasts. Many victims are occupants in vehicles that are targets of improvised explosive devices. These underbody blasts expose the occupants to vertical acceleration that can range from several to more than 1,000 G; however, it is unknown if blast-induced acceleration alone, in the absence of exposure to blast waves and in the absence of secondary impacts, can cause even mild TBI.

**METHODS:** We approached this knowledge gap using rats secured to a metal platform that is accelerated vertically at either 20 G or 50 G in response to detonation of a small explosive (pentaerythritol tetranitrate) located at precise underbody standoff distances. All rats survived the blasts and were perfusion fixed for brain histology at 4 hours to 30 days later.

**RESULTS:** Robust silver staining indicative of axonal injury was apparent throughout the internal capsule, corpus callosum, and cerebellum within 24 hours after blast exposure and was sustained for at least 7 days. Astrocyte activation, as measured morphologically with brains immunostained for glial fibrillary acidic protein, was also apparent early after the blast and persisted for at least 30 days.

**CONCLUSION:** Exposure of rats to underbody blast-induced accelerations at either 20 G or 50 G results in histopathologic evidence of diffuse axonal injury and astrocyte activation but no significant neuronal death. The significance of these results is that they demonstrate that blast-induced vertical acceleration alone, in the absence of exposure to significant blast pressures, causes mild TBI. This unique animal model of TBI caused by underbody blasts may therefore be useful in understanding the pathophysiology of blast-induced mild TBI and for testing medical and engineering-based approaches toward mitigation. (*J Trauma Acute Care Surg.* 2014;77: S83–S87. Copyright © 2014 by Lippincott Williams & Wilkins)

**KEY WORDS:** Axonal injury; astrocyte; inflammation; internal capsule; cerebellum.

---

# ORIGINAL ARTICLE

## Effect of cold storage on shear-induced platelet aggregation and clot strength

Prajeeda M. Nair, MS, Heather F. Pidcoke, MD, PhD, Andrew P. Cap, MD, PhD,  
and Anand K. Ramasubramanian, PhD, *San Antonio, Texas*

- 
- BACKGROUND:** Platelets (PLTs) participate in hemostasis and save lives following trauma. PLTs for transfusion are maintained at room temperature (RT, 22°C), limiting viability to 5 days because of metabolic compromise and high risk of bacterial contamination. RT storage may result in weaker clots, delaying hemorrhage control, whereas cold storage (4°C) could permit longer PLT shelf life and result in a more hemostatic product. In this study, we characterized the effect of storage temperature on shear-induced PLT aggregation, clot formation, and strength.
- METHODS:** PLTs obtained from phlebotomized blood or by apheresis were stored at RT or 4°C for 5 days, and PLT aggregation and clot strength were assessed at 37°C. We studied PLT aggregation at steady and complex patterns of shear rates (500–2,500 per second) by flow cytometry, and the kinetics of clot formation and strength were measured using turbidity and dynamic mechanical analysis, respectively.
- RESULTS:** PLT aggregation was higher in 4°C-stored samples on Day 5 compared with fresh or RT-stored samples at all shear rates tested (fresh vs. 4°C and RT vs. 4°C,  $p < 0.05$ ). PLTs stored at 4°C for 5 days formed significantly stronger clots compared with fresh or RT-stored samples as quantified by turbidity and elastic moduli measurements (fresh vs. 4°C and RT vs. 4°C,  $p < 0.05$ ).
- CONCLUSION:** Our results show that cold-stored PLTs are more responsive to aggregation stimuli and form stronger clots, presumably because of thicker fibrin strands. These data suggest that the superior functionality of cold-stored PLTs may support faster hemostasis for acutely bleeding in trauma patients compared with RT-stored PLTs. (*J Trauma Acute Care Surg.* 2014;77: S88–S93. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** Platelet storage; refrigeration; SIPA; clot strength; hemorrhage.
-

# ORIGINAL ARTICLE

## Platelet activation using electric pulse stimulation: Growth factor profile and clinical implications

**Andrew S. Torres, PhD, Antonio Caiafa, PhD, Allen L. Garner, PhD, Steve Klopman, Nicole LaPlante, Christine Morton, Kenneth Conway, Alan D. Michelson, MD, Andrew L. Frelinger, III, PhD, and V. Bogdan Neculaes, PhD**

---

**BACKGROUND:** Autologous platelet gel therapy using platelet-rich plasma has emerged as a promising alternative for chronic wound healing, hemostasis, and wound infection control. A critical step for this therapeutic approach is platelet activation, typically performed using bovine thrombin (BT) and calcium chloride. However, exposure of humans to BT can stimulate antibody formation, potentially resulting in severe hemorrhagic or thrombotic complications. Electric pulse stimulation using nanosecond PEFs (pulse electric fields) is an alternative, nonbiochemical platelet activation method, thereby avoiding exposure to xenogeneic thrombin and associated risks.

**METHODS:** In this study, we identified specific requirements for a clinically relevant activator instrument by dynamically measuring current, voltage, and electric impedance for platelet-rich plasma samples. From these samples, we investigated the profile of growth factors released from human platelets with electric pulse stimulation versus BT, specifically platelet-derived growth factor, transforming growth factor  $\beta$ , and epidermal growth factor, using commercial enzyme-linked immunosorbent assay kits.

**RESULTS:** Electric pulse stimulation triggers growth factor release from platelet  $\alpha$ -granules at the same or higher level compared with BT.

**CONCLUSION:** Electric pulse stimulation is a fast, inexpensive, easy-to-use platelet activation method for autologous platelet gel therapy. (*J Trauma Acute Care Surg.* 2014;77: S94-S100. Copyright © 2014 by Lippincott Williams & Wilkins)

**KEY WORDS:** Platelet activation; thrombin; platelet-rich plasma; pulse electric field.

---

# ORIGINAL ARTICLE

## Long-term effects of Combat Ready Clamp application to control junctional hemorrhage in swine

Bijan S. Kheirabadi, PhD, Irasema B. Terrazas, MS, Nahir Miranda, MS, J. Scot Estep, DVM, Benjamin T. Corona, PhD, John F. Kragh, Jr, MD, and Michael A. Dubick, PhD, *San Antonio, Texas*

- 
- BACKGROUND:** Groin application of Combat Ready Clamp (CRoC) in pigs elicits an acute inflammation in underlying ischemic tissues. This study examined functional recovery of pigs' hind leg(s) following 2 hours of CRoC application.
- METHODS:** Left femoral arteries were isolated and injured in anesthetized pigs. Following 25% hemorrhage, CRoC was applied on the inguen for 2 hours (n = 6), and wounds were covered with combat gauze (CG). Bleeding was treated in the control animals (n = 5) with CG only. Next, CRoC and CG were removed, arteries were repaired and reflowed, and animals were recovered. The legs' mobility was scored daily, and their neuromuscular functions were measured on Days 7 and 14. Computed tomographic angiography and blood analysis were performed on Days 0, 2, 7, and 14. Pigs were then euthanized, and tissues were collected for histology. Umbilicus application of CRoC was also tested in four pilot experiments.
- RESULTS:** Inguinal application of CRoC with  $524 \pm 12$  mm Hg pressure occluded iliac arteries and collateral circulation. Following surgical repair, blood flow to the arteries was restored, and five of six CRoC-applied legs recovered full mobility within 9 days. Control-treated legs recovered full function in 3 days ( $p = 0.001$ ). At 2 weeks, muscle strength of CRoC-applied legs was diminished ( $p < 0.05$  vs. baselines or controls). Injury biomarkers in the CRoC group increased severalfold compared with the controls on Day 2 but returned to baseline afterward. Histologic changes were mostly mild and indicative of ischemia in the CRoC group. Umbilical application of CRoC required higher pressure ( $625 \pm 8$  mm Hg) and caused gross ischemic necrosis of lumbar muscles with significant disabilities.
- CONCLUSION:** Two-hour inguinal application of CRoC caused mild and reversible ischemic injuries, which delayed full recovery of the limb function by a few days. In contrast, 2-hour umbilicus application of CRoC resulted in extensive muscle necrosis with functional disabilities. While CRoC seems safe and effective for inguinal application, other tourniquets should be evaluated for treating bilateral junctional bleeding. (*J Trauma Acute Care Surg.* 2014;77: S101–S108. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** Combat Ready Clamp; hemorrhage control; junctional bleeding; junctional tourniquet; swine.
-

# ORIGINAL ARTICLE

## Optimal training for emergency needle thoracostomy placement by prehospital personnel: Didactic teaching versus a cadaver-based training program

**Daniel Grabo, MD, Kenji Inaba, MD, Peter Hammer, MD, Efstathios Karamanos, MD, Dimitra Skiada, MD, Matthew Martin, MD, Maura Sullivan, PhD, and Demetrios Demetriades, MD, PhD, Los Angeles, California**

---

<b>BACKGROUND:</b>	Tension pneumothorax can rapidly progress to cardiac arrest and death if not promptly recognized and appropriately treated. We sought to evaluate the effectiveness of traditional didactic slide-based lectures (SBLs) as compared with fresh tissue cadaver-based training (CBT) for placement of needle thoracostomy (NT).
<b>METHODS:</b>	Forty randomly selected US Navy corpsmen were recruited to participate from incoming classes of the Navy Trauma Training Center at the LAC + USC Medical Center and were then randomized to one of two NT teaching methods. The following outcomes were compared between the two study arms: (1) time required to perform the procedure, (2) correct placement of the needle, and (3) magnitude of deviation from the correct position.
<b>RESULTS:</b>	During the study period, a total of 40 corpsmen were enrolled, 20 randomized to SBL and 20 to CBT arms. When outcomes were analyzed, time required to NT placement was not different between the two arms. Examination of the location of needle placement revealed marked differences between the two study groups. Only a minority of the SBL group (35%) placed the NT correctly in the second intercostal space. In comparison, the majority of corpsmen assigned to the CBT group demonstrated accurate placement in the second intercostal space (75%).
<b>CONCLUSION:</b>	In a CBT module, US Navy corpsmen were better trained to place NT accurately than their traditional didactic SBL counterparts. Further studies are indicated to identify the optimal components of effective simulation training for NT and other emergent interventions. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S109–S113. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Care management, level II.
<b>KEY WORDS:</b>	Prehospital needle thoracostomy; tension pneumothorax; simulation training; education; cadaver-based training.

---

# ORIGINAL ARTICLE

## Prehospital blood transfusion in the en route management of severe combat trauma: A matched cohort study

David J. O'Reilly, FRCS, Jonathan J. Morrison, MRCS, Jan O. Jansen, FRCS, FFICM,  
Amy N. Apodaca, PhD, Todd E. Rasmussen, MD,  
and Mark J. Midwinter, MD, FRCS, Birmingham, United Kingdom

---

<b>BACKGROUND:</b>	The value of prehospital blood transfusion (PHBTx) in the management of severe trauma has not been established. This study aimed to evaluate the effect of PHBTx on mortality in combat casualties.
<b>METHODS:</b>	This is a retrospective cohort study of casualties admitted to the field hospital at Camp Bastion, Afghanistan, by the Medical Emergency Response Team from May 2006 to March 2011. Participants were divided into two consecutive cohorts by the introduction of PHBTx. Paired groups of patients were chosen by combining propensity score methodology with detailed matching of injury profile. Thus recipients of PHBTx were matched with nonrecipients who would have received it had it been available.
<b>RESULTS:</b>	A total of 1,592 patients were identified. Of the 1,153 patients to whom PHBTx was potentially available, 310 received it (26.9%). The rate of severe injury (Injury Severity Score [ISS] > 15) rose from 28% before PHBTx was available to 43% thereafter ( $p < 0.001$ ). Mortality in the latter group was higher (14% vs. 10%, $p = 0.013$ ) but not in the severely injured patients (32% vs. 28%, $p = 0.343$ ). Ninety-seven patients were paired. The mortality of matched patients who received PHBTx, compared with those with similar injury patterns who did not, was less than half (8.2% vs. 19.6%, $p < 0.001$ ). However, matched recipients had more prehospital interventions, reached hospital more quickly, and had lower heart rate at admission (all $p < 0.05$ ). Matched recipients received more red blood cells within 24 hours (median, 4 U; interquartile range [IQR], 2–10 U) than nonrecipients (median 0 U; IQR, 0–3.5 U) and more fresh frozen plasma (median, 2 U; IQR, 2–9 U vs. median, 0 U; IQR, 0–1 U) (both $p < 0.001$ ).
<b>CONCLUSION:</b>	An aggressive approach to damage control resuscitation including the use of PHBTx was associated with a large improvement in mortality. However, because of confounders resulting from changes in practice, the isolated contribution of PHBTx cannot be determined from this study. ( <i>J Trauma Acute Care Surg.</i> 2014;77:S114–S120. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic study, level IV.
<b>KEY WORDS:</b>	Combat injury; shock; hemorrhage; blood products; military trauma.

---

# ORIGINAL ARTICLE

## Evaluation of standard versus nonstandard vital signs monitors in the prehospital and emergency departments: Results and lessons learned from a trauma patient care protocol

Nehemiah T. Liu, MS, John B. Holcomb, MD, Charles E. Wade, PhD, Mark I. Darrah, PhD,  
and José Salinas, PhD, San Antonio, Texas

---

<b>BACKGROUND:</b>	This study aimed to determine the effectiveness of using a wireless, portable vital signs monitor (WVSM) for predicting the need for lifesaving interventions (LSIs) in the emergency department (ED) and use a multivariate logistic regression model to determine whether the WVSM was an improved predictor of LSIs in the ED over the standard of care monitor currently being used.
<b>METHODS:</b>	This study analyzed 305 consecutive patients transported from the scene via helicopter to a Level I trauma center. For 104 patients in the study, a WVSM was also attached to the patient's arm and used to record and display prehospital and hospital physiologic data in real time on a handheld computer and in the trauma bay. Multivariate logistic regression analyses were performed for accuracy in predicting needs for LSIs in control and WVSM subjects. In addition, receiver operating characteristic curves were obtained to examine the discriminating power of the models for the outcome of one or more LSIs in the ED.
<b>RESULTS:</b>	Of the 305 patients, 73 underwent 109 LSIs in the ED. Of these, 21 patients wore the WVSM during transport in addition to the standard monitor. Logistic regression analysis revealed that heart rate, respiratory rate, and systolic blood pressure were significantly associated with an increased risk for LSIs in the ED ( $p < 0.05$ ). Receiver operating characteristic curve analysis also demonstrated better prediction for LSIs performed in the ED in WVSM subjects than in control subjects (area under the curve, 0.86 vs. 0.81, respectively).
<b>CONCLUSION:</b>	The WVSM system leads to improved LSI accuracy in the ED. In addition, many important lessons have been learned in preparation for this study. Adoption of nonstandard vital signs monitors into critical care/trauma medicine may require a new paradigm of personnel education, training, and practice. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S121–S126. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic/care management, level IV.
<b>KEY WORDS:</b>	Prehospital physiologic data; lifesaving interventions; vital signs; signal quality; automatic data processing.

---

# ORIGINAL ARTICLE

## Self-expanding foam for prehospital treatment of intra-abdominal hemorrhage: 28-day survival and safety

Adam P. Rago, MS, Michael J. Duggan, DVM, John Beagle, Miroslav P. Peev, MD, John Marini, John O. Hwabejire, MD, Patricia Hannett, Greg Zugates, PhD, Rany Busold, BS, Marc Helmick, George Velmahos, MD, PhD, Marc A. Demoya, MD, Daniel Dante Yeh, MD, Peter J. Fagenholz, MD, Upma Sharma, PhD, and David R. King, MD, Boston, Massachusetts

- 
- BACKGROUND:** Intracavitary noncompressible hemorrhage remains a significant cause of preventable death on the battlefield and in the homeland. We previously demonstrated the hemostatic efficacy of an in situ self-expanding poly(urea)urethane foam in a severe, closed-cavity, hepatoportal exsanguination model in swine. We hypothesized that treatment with, and subsequent explantation of, foam would not adversely impact 28-day survival in swine.
- METHODS:** Following a closed-cavity splenic transection, animals received either fluid resuscitation alone (control group, n = 6) or resuscitation plus foam treatment at doses of 100 mL (n = 6), 120 mL (n = 6), and 150 mL (n = 2). Foam was allowed to polymerize in situ and was explanted after 3 hours. The animals were recovered and monitored for 28 days.
- RESULTS:** All 18 animals in the 100-mL, 120-mL, and control groups survived to the 28-day endpoint without complications. The 150-mL group was terminated after the acute phase (n = 2). En bloc explantation of the foam took less than 2 minutes and was associated with millimeter-sized remnant particles. All foam animals required some level of enteric repair (imbrication or resection). Excluding the aborted 150-mL group, all animals survived, with no differences in renal or hepatic function, serum chemistries, or semiquantitative abdominal adhesion scores. Histologic analysis demonstrated that remnant particles were associated with a fibrotic capsule and mild inflammation, similar to that of standard suture reaction. In addition, safety testing (including genotoxicity, pyrogenicity, and cytotoxicity) was performed consistent with the ISO-10993 standard, and the materials passed all tests.
- CONCLUSION:** For a distinct dose range, 28-day recovery after foam treatment and explantation for noncompressible, intra-abdominal hemorrhage is not associated with significant physiologic or biochemical evidence of end-organ dysfunction. A foam volume exceeding the maximum tolerable dose was identified. Bowel repair is required to ensure survival. (*J Trauma Acute Care Surg.* 2014;77: S127–S133. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** Noncompressible; abdominal hemorrhage; survival; safety; swine.
-

# ORIGINAL ARTICLE

## Accuracy of noninvasive hemoglobin monitoring in patients at risk for hemorrhage

Betty J. Tsuei, MD, Dennis J. Hanseman, PhD, Michael J. Blakeman, Thomas C. Blakeman, RRT, Sung H. Yang, MD, Richard D. Branson, RRT, and Travis S. Gerlach, MD, Cincinnati, Ohio

---

<b>BACKGROUND:</b>	Monitoring for acute blood loss is critical in surgical patients, and delays in identifying hemorrhage can result in poor outcomes. The current standard of care for monitoring patients at risk for bleeding is serial measurement of hemoglobin (Hgb) by standard laboratory complete blood count (CBC). Point-of-care testing (i.e., iSTAT) can be a rapid method of evaluating Hgb, and spectrophotometry-based devices (i.e., Radical-7) offer the advantages of being continuous and noninvasive. We sought to evaluate the accuracy of Radical-7 and iSTAT in measuring Hgb and assessing for blood loss when compared with the criterion standard CBC.
<b>METHODS:</b>	Adult patients at risk for hemorrhage admitted to the surgical intensive care unit of a tertiary referral, Level I trauma center were eligible for this study. Serial CBC Hgb measurements were drawn as clinically indicated. The Radical-7 device was placed on the patient for noninvasive Hgb measurements (SpHb), and at each CBC measurement, concurrent iSTAT Hgb measurements were obtained. Bland-Altman analysis was used to compare the three methods of measuring Hgb with accuracy defined as measurements within 1.0-g/dL CBC Hgb. Concordance measurements were also performed to compare trends between values.
<b>RESULTS:</b>	Eighty-eight patients were enrolled and underwent 572 CBC measurements. Bland-Altman analysis of SpHb versus CBC resulted in an estimated bias of 1.49 g/dL, with 95% limits of agreement of -2.2 g/dL to 5.0 g/dL. iSTAT versus CBC resulted in an estimated bias of -0.63 g/dL, with 95% limits of agreement of -3.4 g/dL to 2.2 g/dL. Changes in SpHb had concordance with CBC Hgb 60% of the time, compared with 76% for iSTAT versus CBC.
<b>CONCLUSION:</b>	Radical-7 SpHb was inaccurate when compared with CBC Hgb levels, and serial SpHb achieved concordance with CBC Hgb 60% of the time. As such, the clinical utility of Radical-7 as a rapid, noninvasive predictor of acute hemorrhage may be limited. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S134-S139. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Care management, level II.
<b>KEYWORDS:</b>	Hemorrhage; noninvasive monitoring; hemoglobin.

---

# ORIGINAL ARTICLE

## Use of an impedance threshold device in spontaneously breathing patients with hypotension secondary to trauma: An observational cohort feasibility study

David Wampler, PhD, LP, Victor A. Convertino, PhD, Shannon Weeks, EMT-P, Michael Hernandez, EMT-P, Jacob Larrumbide, and Craig Manifold, DO, San Antonio, Texas

---

<b>BACKGROUND:</b>	An impedance threshold device (ITD) intended for use in the spontaneously breathing patient has been shown to raise blood pressure in hypotensive patients. This device has not been evaluated in patients with hypotension secondary to trauma. This study focused on changes in key vital signs when the ITD was added to the paramedic treatment protocol for hypotensive patients with prehospital traumatic injury.
<b>METHODS:</b>	A 6-month prospective nonrandomized observational cohort study was conducted of 200 spontaneously breathing symptomatic adult patients with prehospital hypotension due to multiple causes; the patients of primary interest experienced a traumatic injury. Upon determination of hypotension (systolic blood pressure of approximately $\leq 90$ mm Hg), standard therapy was initiated by application of the mask-style ITD. Vital signs were documented every 2 minutes to 5 minutes after intervention. A change in mean arterial pressure (MAP) with ITD use was the primary study endpoint.
<b>RESULTS:</b>	Of the 200 hypotensive subjects treated, 29 (3 were excluded because of incomplete data sets and 3 patients treated with the ITD were excluded because their blood pressure did not meet inclusion criterion) were hypotensive secondary to trauma. Their MAP increased from 60 mm Hg (SD, 11 mm Hg; 95% confidence interval [CI], 8.17–15.432) to 78 mm Hg (16 mm Hg; 95% CI, 12.43–23.46) ( $p = 0.001$ ), without significant change in mean heart rate. Approximately 75% of the patients reported moderate to easy tolerance. Similar increases in MAP were observed in the nontraumatic patients, from 60 mm Hg (10 mm Hg; 95% CI, 9.4–11.5) to 70 (15; 95% CI, 13.4–16.7) ( $p = 0.0001$ ).
<b>CONCLUSION:</b>	In this observational cohort study of patients with hypotension secondary to trauma, the ITD was well tolerated, and MAP as well as systolic and diastolic blood pressure were improved. The patients were not overresuscitated with this intervention. On the basis of these findings, additional studies in patients with hypotension secondary to traumatic injury should be performed to better define the need and benefit of additional fluid resuscitation when the ITD is used. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S140–S145. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic study, level IV.
<b>KEY WORDS:</b>	Permissive hypotension; impedance threshold device; prehospital; noninvasive therapy.

---

# ORIGINAL ARTICLE

## Tranexamic acid at the point of injury: The Israeli combined civilian and military experience

Roy Nadler, MD, Sami Gendler, MD, Avi Benov, MD, MHA, Refael Strugo, MD, Amir Abramovich, MD,  
and Elon Glassberg, MD, MHA, Ramat Gan, Israel

---

<b>BACKGROUND:</b>	Accumulating evidence established the benefit of tranexamic acid (TXA) for traumatic bleeding in the hospital setting. TXA use in the field (at or near the point of injury [POI]) was described in the military setting but not in the civilian one. The current study describes the Israeli combined experience (civilian and military) of administering TXA in the field.
<b>METHODS:</b>	The Israel Defense Forces (IDF) and Magen David Adom (MDA) (the national Israeli civilian emergency medical service) protocols for giving TXA at the POI are presented. We then review all trauma patients who received TXA in the field in accord with either protocol. Data were abstracted from the IDF Trauma Registry and from the MDA database.
<b>RESULTS:</b>	Data regarding casualties treated with TXA by the IDF Medical Corps and MDA between December 2011 and August 2013 are presented. One hundred three casualties who received TXA in the field were identified. The median age was 26.5 years, and 83 (88%) were male. The mechanism of injury was penetrating in 48 cases (51%). POI data indicate slightly higher injury severity for the group of patients treated by MDA compared with patients treated by the IDF (systolic blood pressure, 90 mm Hg vs. 110 mm Hg; Glasgow Coma Scale [GCS] score, 11 vs. 15; hemoglobin, 11.9 vs. 13.3; $p < 0.05$ ).
<b>CONCLUSION:</b>	On the basis of our combined data, it appears that administering TXA in the field is feasible in the civilian and the military setting. Lessons learned in military settings are applicable to civilian medical systems. Action investigations and comparison of the different protocols may further improve treatment at or near the POI. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S146–S150. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic study, level V.
<b>KEY WORDS:</b>	TXA; tranexamic acid; point of injury; military; prehospital.

---

# ORIGINAL ARTICLE

## Performance of portable ventilators at altitude

**Thomas Blakeman, MSc, Tyler Britton, Dario Rodriguez Jr, MSc,  
and Richard Branson, MSc, Cincinnati, Ohio**

**BACKGROUND:** Aeromedical transport of critically ill patients requires continued, accurate performance of equipment at altitude. Changes in barometric pressure can affect the performance of mechanical ventilators calibrated for operation at sea level. Deploying ventilators that can maintain a consistent tidal volume (VT) delivery at various altitudes is imperative for lung protection when transporting wounded war fighters to each echelon of care.

**METHODS:** Three ventilators (Impact 731, Hamilton T1, and CareFusion Revel) were tested at pediatric (50 and 100 mL) and adult (250–750 mL) tidal VTs at 0 and 20 cm H<sub>2</sub>O positive end expiratory pressure and at inspired oxygen of 0.21 and 1.0. Airway pressure, volume, and flow were measured at sea level as well as at 8,000, 16,000, and 22,000 ft (corresponding to barometric pressures of 760, 564, 412, and 321 mm Hg) using a calibrated pneumotachograph connected to a training test lung in an altitude chamber. Set VT and delivered VT as well as changes in VT at each altitude were compared by *t* test.

**RESULTS:** The T1 delivered VT within 10% of set VT at 8,000 ft. The mean VT was less than set VT at sea level as a result of circuit compressible volume with the Revel and the 731. Changes in VT varied widely among the devices at sea level and at altitude. Increasing altitudes resulted in larger VT than set for the Revel and the T1. The 731 compensated for changes in altitude delivered VT within 10% at the adult settings at all altitudes.

**CONCLUSION:** Altitude compensation is an active software algorithm. Only the 731 actively accounts for changes in barometric pressure to maintain the set VT at all tested altitudes. (*J Trauma Acute Care Surg.* 2014;77: S151–S155. Copyright © 2014 by Lippincott Williams & Wilkins)

**KEY WORDS:** Portable ventilators; altitude performance; aeromedical evacuation.

# ORIGINAL ARTICLE

## The use of rigid eye shields (Fox shields) at the point of injury for ocular trauma in Afghanistan

Robert A. Mazzoli, MD, Kirby R. Gross, MD, and Frank K. Butler, MD, Tacoma, Washington

---

<b>BACKGROUND:</b>	Unlike hemorrhagic injuries in which direct pressure is indicated, any pressure placed on the eye after penetrating trauma can significantly worsen the injury by expelling intraocular contents. The accepted first response measure for obvious or suspected penetrating ocular injury is placement of a rigid shield that vaults the eye so as to prevent accidental iatrogenic aggravation during transport to the ophthalmologist. Patching and placing intervening gauze between the shield and the eye are both contraindicated. Anecdotally, compliance with these recommendations is poor in the military and civilian communities alike; however, published studies documenting compliance are uniformly lacking. This study was undertaken to provide such an evaluation.
<b>METHODS:</b>	In this retrospective observational study, the Department of Defense Trauma Registry was reviewed to identify eye injuries in Afghanistan from 2010 to 2012 and to examine compliance with eye shield recommendations. One hundred fifty-seven records of eye casualties were identified and categorized according to diagnostic codes, noting use of a shield. A subset of 30 records was further analyzed for compliance with other core treatment measures specified by the operant Clinical Practice Guideline. Because comparative studies do not exist, simple statistical analysis was performed.
<b>RESULTS:</b>	Overall, 39% of eye injuries received a shield at the point of injury (61% failure), ranging from 0% to 50% between diagnostic subgroups. Subset analysis revealed that only 4.2% of injuries were successfully mitigated at the point of injury (95.8% failure).
<b>CONCLUSION:</b>	In one of the few studies documenting the use of eye shields after ocular trauma, anecdotal reports of poor, inadequate, or incorrect compliance with basic recommendations were substantiated. Several factors may account for these findings. Corrective efforts should include enhanced educational emphasis and increased shield availability. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S156–S162. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Epidemiologic study, level IV. Therapeutic study, level IV.
<b>KEY WORDS:</b>	Eye injuries; eye shields; eye trauma; combat injuries; casualty care.

---

# ORIGINAL ARTICLE

## Modified Augmented Renal Clearance score predicts rapid piperacillin and tazobactam clearance in critically ill surgery and trauma patients

Kevin S. Akers, MD, Krista L. Niece, PhD, Kevin K. Chung, MD, Jeremy W. Cannon, MD, Jason M. Cota, PharmD, and Clinton K. Murray, MD, *San Antonio, Texas*

---

<b>BACKGROUND:</b>	Recent evidence suggests that current antimicrobial dosing may be inadequate for some critically ill patients. A major contributor in patients with unimpaired renal function may be Augmented Renal Clearance (ARC), wherein urinary creatinine clearance exceeds that predicted by serum creatinine concentration. We used pharmacokinetic data to evaluate the diagnostic accuracy of a recently proposed ARC score.
<b>METHODS:</b>	Pharmacokinetic data from trauma/surgical intensive care unit patients receiving piperacillin/tazobactam were evaluated. We combined intermediate scores (4–6 points) into a single low score ( $\leq 6$ ) group and compared pharmacokinetic parameters against the high ( $\geq 7$ ) ARC score group. Diagnostic performance was evaluated using median clearance and volume of distribution, area under the antibiotic time-concentration curve (AUC), and achievement of free concentrations greater than a minimum inhibitory concentration (MIC) of 16 $\mu\text{g/mL}$ for at least 50% of the dose interval ( $fT > \text{MIC} \geq 50\%$ ). Alternative dosing strategies were explored in silico.
<b>RESULTS:</b>	The ARC score was 100% sensitive and 71.4% specific for detecting increased clearance, increased volume of distribution, decreased AUC, and $fT > \text{MIC} < 50\%$ at an MIC of 16 $\mu\text{g/mL}$ . The area under the receiver operating characteristic curve was 0.86 for each, reflecting a high degree of diagnostic accuracy for the ARC score. Serum creatinine less than 0.6 mg/dL had comparable specificity (71.4%) but was less sensitive (66.7%) and accurate (area under the receiver operating characteristic curve, 0.69) for detecting higher clearance rates. Monte Carlo pharmacokinetic simulations demonstrated increased time at therapeutic drug levels with extended infusion dosing at a drug cost savings of up to 66.7% over multiple intermittent dosing regimens.
<b>CONCLUSION:</b>	Given its ability to predict antimicrobial clearance above population medians, which could compromise therapy, the ARC score should be considered as a means to identify patients at risk for subtherapeutic antibiotic levels. Adequately powered studies should prospectively confirm the utility of the ARC score and the role of antimicrobial therapeutic drug monitoring in such patients. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S163–S170. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Diagnostic tests, level III.
<b>KEY WORDS:</b>	Augmented Renal Clearance; ARC score; sensitivity and specificity; antimicrobial pharmacokinetics and pharmacodynamics; trauma critical care.

---

# ORIGINAL ARTICLE

## Nontherapeutic laparotomy in American combat casualties: A 10-year review

Thomas A. Mitchell, MD, Tara Hutchison, Tyson E. Becker, MD, James K. Aden, PhD,  
Lorne Blackbourne, MD, and Christopher E. White, MD, MSc, San Antonio, Texas

---

<b>BACKGROUND:</b>	The civilian literature has expanded the indications for selective nonoperative management (SNOM) for abdominal trauma to minimize morbidity from nontherapeutic laparotomies (NTLs); however, this treatment modality remains controversial and rare in austere settings. This study aimed to quantify the percentage of NTL and incidence of failed SNOM performed in theater and to define each of their respective intra-abdominal-related morbidities.
<b>METHODS:</b>	A retrospective evaluation of all patients who underwent a laparotomy from 2002 to 2011 during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) was performed for patients who survived a minimum of 24 hours. With the use of DRG International Classification of Diseases—9th Rev. procedure codes, a therapeutic laparotomy was defined by the presence of a defined intraperitoneal or retroperitoneal procedure; an NTL was defined by the absence of a defined intraperitoneal or retroperitoneal procedure. Second, patients transferred from North American Treaty Organization Role II to Role III medical treatment facilities to be operated on were deemed failed SNOM. Finally, intra-abdominal complications and mortality were identified for patients undergoing therapeutic laparotomy, NTL, and failed SNOM.
<b>RESULTS:</b>	Blunt, bum, and penetrating injuries accounted for 38.5% (n = 490), 1.1% (n = 14), and 60.4% (n = 769) of all laparotomies in the OEF and OIF, respectively. Thirty-two percent of all laparotomies performed during the OEF and OIF campaigns were NTL; specifically, the NTL rates in OEF and OIF were 38.2% and 28.6%, respectively. In addition, 31.6% and 32.2% of all penetrating and blunt injury mechanisms resulted in an NTL, respectively. The percentage of all patients identified as failing SNOM was 7.5% (n = 95). The early intra-abdominal complication rate for failed SNOM and for all patients undergoing NTL was 2.1% and 1.7%, respectively.
<b>CONCLUSION:</b>	The OIF and OEF combined NTL rate was 32.1%, with an associated 1.7% intra-abdominal early complication rate. The infrequent application of SNOM in a deployed military environment is likely secondary to unpredictable fragmentation trajectories and related blast injury patterns, limited medical resources including computed tomography, and a complex aeromedical evacuation system preventing serial observation. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S171–S175. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Epidemiologic study, level IV.
<b>KEY WORDS:</b>	Laparotomy; nontherapeutic laparotomy; Operation Enduring Freedom; Operation Iraqi Freedom.

---

# ORIGINAL ARTICLE

## Injury tolerance of the wrist and distal forearm to impact loading onto outstretched hands

Jason Forman, PhD, Brandon Perry, Aaron Alai, Aaron Freilich, Robert Salzar,  
and Tim Walilko, Charlottesville, Virginia

- 
- BACKGROUND:** The wrist/forearm complex is one of the most commonly fractured body regions, yet the impact tolerance of the wrist is poorly understood. This study sought to quantify the injury tolerance of the adult male forearm-wrist complex under loading simulating axial impact to an outstretched hand.
- METHODS:** Fifteen isolated cadaveric forearm/wrist specimens were tested. Loading was applied via an instrumented drop tower device designed to impact the palmar surface of the hand with the wrist extended to approximately 90 degrees. Impact severity was modulated by adjusting the boundary condition of the elbow. Elbow reaction force and deformation of the specimen (deflection of the palmar surface of the hand toward the elbow) were measured. Bone-implanted strain gauges were used to detect the time of fracture. Injury risk functions were developed using parametric survival analysis with a cumulative Weibull distribution.
- RESULTS:** Of 14 specimens, 10 exhibited a fracture to the wrist or forearm after test (one specimen was excluded from the analysis). Injury severities varied from nondisplaced fractures of the radius to severely displaced fractures and/or fracture-dislocations of the carpal bones. Of the potential predictors studied, the specimen deflection expressed as a percentage of the initial specimen length produced the injury risk model of best fit (50% risk of fracture at 1.69% deflection; 95% confidence interval, 1.38–2.07% deflection). The value of the elbow reaction force corresponding to a 50% risk of injury was 4.34 kN (3.80–4.97 kN).
- CONCLUSION:** These results provide information for the prediction of wrist and forearm injury in biomechanical models simulating impacts in the field and provide tolerance information for the development of injury mitigation countermeasures. (*J Trauma Acute Care Surg.* 2014;77: S176–S183. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** Wrist; forearm; fracture; tolerance; biomechanics.
-

# ORIGINAL ARTICLE

## Automated inhaled nitric oxide alerts for adult extracorporeal membrane oxygenation patient identification

Slava M. Belenkiy, MD, Andriy I. Batchinsky, MD, Timothy S. Park, MD, David E. Luellen, MBA, Maria L. Serio-Melvin, MSN, Leopoldo C. Cancio, MD, Jeremy C. Pamplin, MD, Kevin K. Chung, MD, José Salinas, PhD, and Jeremy W. Cannon, MD, *San Antonio, Texas*

---

<b>BACKGROUND:</b>	Recently, automated alerts have been used to identify patients with respiratory failure based on set criteria, which can be gleaned from the electronic medical record (EMR). Such an approach may also be useful for identifying patients with severe adult respiratory distress syndrome (ARDS) who may benefit from extracorporeal membrane oxygenation (ECMO). Inhaled nitric oxide (iNO) is a common rescue therapy for severe ARDS which can be easily tracked in the EMR, and some patients started on iNO may have indications for initiating ECMO. This case series summarizes our experience with using automated electronic alerts for ECMO team activation focused particularly on an alert triggered by the initiation of iNO.
<b>METHODS:</b>	After a brief trial evaluation, our Smart Alert system generated an automated page and e-mail alert to ECMO team members whenever a nonzero value for iNO appeared in the respiratory care section of our EMR. If iNO was initiated for severe respiratory failure, a detailed evaluation by the ECMO team determined if ECMO was indicated. For those patients managed with ECMO, we tabulated baseline characteristics, indication for ECMO, and outcomes.
<b>RESULTS:</b>	From September 2012 to July 2013, 45 iNO alerts were generated on 42 unique patients. Six patients (14%) met criteria for ECMO. Of these, four were identified exclusively by the iNO alert. At the time of the alert, the median PaO <sub>2</sub> -to-FIO <sub>2</sub> ratio was 64 mm Hg (range, 55–107 mm Hg), the median age-adjusted oxygenation index was 73 (range, 51–96), and the median Murray score was 3.4 (range, 3–3.75), indicating severe respiratory failure. Median time from iNO alert to ECMO initiation was 81 hours (range, –2–292 hours). Survival to hospital discharge was 83% in those managed with ECMO.
<b>CONCLUSION:</b>	Automated alerts may be useful for identifying patients with severe ARDS who may be ECMO candidates. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S184–S189. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Care management study, level V.
<b>KEY WORDS:</b>	Adult respiratory distress syndrome; extracorporeal membrane oxygenation; automated alert; inhaled nitric oxide.

---

# ORIGINAL ARTICLE

## Subcutaneous depth in a traumatized lower extremity

Mellisa Roskosky, MSPH, Gillian Robinson, PhD, William Reisman, MD, Bruce Ziran, MD, Michael S. Shuler, MD, and Brett Freedman, MD, Athens, Georgia

---

<b>BACKGROUND:</b>	Acute compartment syndrome is a rare but serious consequence of traumatic leg injury. Near-infrared spectroscopy (NIRS) is able to measure oxygenation to a depth of 2 cm to 3 cm below the skin, raising concerns over the ability of NIRS to accurately determine oxygenation of injured leg compartments in the presence of swelling and in the obese. The purpose of this study was to measure the thickness of the subcutaneous tissue overlying the posterior muscle compartment in subjects with tibia fractures to determine if it might compromise rSO <sub>2</sub> measurement in the muscle.
<b>METHODS:</b>	Data were analyzed on 50 patients with severe leg injuries. Distance from the skin to the fascia in the superficial posterior compartment of both legs was measured on each patient using a portable ultrasound device.
<b>RESULTS:</b>	Subject age ranged from 18 years to 65 years (mean, 39 years), with 43 male and 7 female patients. The mean (SD) subcutaneous adipose tissue thickness (ATT) was 6.98 (3.17) mm for the injured leg and 7.06 (3.37) mm for the uninjured leg, and the mean body mass index for the group was 27.08 kg/m <sup>2</sup> . No significant correlation was found between the ATT of the injured or uninjured legs and body mass index. Mean comparison testing revealed no difference in ATT between the injured and uninjured legs (null hypothesis: equal means, $p > 0.05$ ). Of the 50 subjects analyzed, no subject had a subcutaneous depth of more than 2 cm on the injured or uninjured leg.
<b>CONCLUSION:</b>	These data suggest that, within this traumatically injured population, symptoms associated with leg injury (such as swelling and edema) do not significantly affect the distance from the skin to the fascia. It is also notable that subcutaneous depth beyond the 2-cm mark (validated in previous studies) is a rare occurrence in this population. These results further support the use of continuous NIRS monitoring for diagnosis of acute compartment syndrome. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S190–S193. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic study, level IV.
<b>KEY WORDS:</b>	Near-infrared spectroscopy; acute compartment syndrome; subcutaneous; monitoring; diagnostic test.

---

# ORIGINAL ARTICLE

## Infection reduces return-to-duty rates for soldiers with Type III open tibia fractures

Matthew A. Napierala, MD, Jessica C. Rivera, MD, Travis C. Burns, MD, Clinton K. Murray, MD,  
Joseph C. Wenke, PhD, Joseph R. Hsu, MD,  
and Skeletal Trauma Research Education Consortium (STReC), San Antonio, Texas

---

<b>BACKGROUND:</b>	Infection is a potentially devastating complication following severe lower extremity trauma, but its impact on the outcomes of combat casualties remains unclear. We hypothesize that orthopedic infectious complications will have a negative impact on holistic patient outcome as measured by return-to-duty (RTD) and disability ratings among wounded soldiers.
<b>METHODS:</b>	We reviewed the medical records for 115 wounded soldiers who sustained a Type III open tibia fracture and tabulated the prevalence of infectious complications. We searched the Physical Evaluation Board database to determine the disability ratings of soldiers with and without an infection and how many of each group was able to return to active duty service. The average percent disability rating and RTD rates between groups were compared using an unpaired <i>t</i> test and $\chi^2$ test, respectively.
<b>RESULTS:</b>	Overall, 40% of our cohort had an infectious complication of their fractured limb. Twenty-one soldiers were able to RTD, while 94 could not and were medically retired. Of those medically retired, 44% had an infection. The average percent disability among soldiers with infection was 55%, compared with 47% for those who were not infected ( $p = 0.1407$ ). Soldiers who experienced any type of infectious complication ( $p = 0.0470$ ) and having osteomyelitis ( $p = 0.0335$ ) had a lower chance of RTD compared with those who had no infection. Having a deep soft tissue infection alone showed a strong trend toward decreased RTD rate ( $p = 0.0558$ ).
<b>CONCLUSION:</b>	Infectious complications following severe lower extremity trauma significantly decrease the rate of RTD. In addition, the presence of infectious complications demonstrates a trend toward higher disability ratings in the combat wounded. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S194–S197. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Prognostic study, level III.
<b>KEY WORDS:</b>	Infection; return to duty; open tibia fracture; type III.

---

# ORIGINAL ARTICLE

## A dose-finding study of sufentanil sublingual microtablets for the management of postoperative bunionectomy pain

Neil K. Singla, MD, Derek D. Muse, MD, Mark A. Evashenk,  
and Pamela P. Palmer, MD, PhD, Redwood City, California

---

<b>BACKGROUND:</b>	Sufentanil sublingual microtablets (SSMs) at a dose of 15 µg per tablet have been studied for postoperative patient-controlled analgesia with a 20-minute lockout via a bedside handheld system over 2 days to 3 days of use. For more short-term (<24 hours) management of acute moderate-to-severe pain, such as in the ambulatory surgical setting, a single, higher-strength SSM dose administered via a health care provider would be of benefit as it would require less frequent administration and avoid the setup of a drug delivery system.
<b>METHODS:</b>	This study was a two-center, randomized, double-blind, placebo-controlled trial for 12 hours in patients 18 years to 80 years of age who were undergoing bunionectomy alone or with hammertoe repair. Patients were randomly assigned at a 2:2:1 ratio to treatment with SSM 20 µg, SSM 30 µg, or placebo. The primary endpoint was time-weighted summed pain intensity difference to baseline over 12 hours (SPID12). Patients had to have a pain intensity score of 4 or higher just before initial microtablet dosing. Additional doses were administered when requested by the patient, with a minimum redosing interval of 1 hour.
<b>RESULTS:</b>	One hundred patients were randomized and received study drug. The SSM 30 µg was superior in the treatment of post-bunionectomy surgical pain compared with placebo as demonstrated by the SPID12 score (6.53 vs. -7.12, respectively; $p=0.003$ ) as well as all other secondary efficacy end points. The SSM 20-µg dosage strength was not superior to placebo for primary or secondary efficacy measures. Adverse events were similar among the three groups with the exception of nausea, vomiting, and somnolence, which demonstrated a dose-dependent increase in occurrence.
<b>CONCLUSION:</b>	The SSM 30 µg may be an effective, noninvasive alternative to health care provider-administered intravenous, intramuscular, or oral opioids for the management of moderate-to-severe acute pain. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S198-S203. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Therapeutic study, level I.
<b>KEY WORDS:</b>	Therapeutic index; plasma-central nervous system equilibration half-life; context-sensitive half-time.

---

# BRIEF REPORT

## Efficacy of medical grade honey against multidrug-resistant organisms of operational significance: Part I

**Damaris J. Tirado, MT, Nolan Ryan Hudson, CT,**  
*and Carlos J. Maldonado, PhD, Travis Air Force Base, Fairfield, California*

- 
- BACKGROUND:** MEDIHONEY (Derma Sciences, Inc., Toronto, Ontario M1S 3S4, Canada) was cleared by the Food and Drug Administration for use on traumatic wounds, diabetic ulcers, and second-degree burns against normal skin flora but not necessarily against multidrug-resistant organisms (MDROs) infecting these wounds or its associated recovery and healing rate.
- METHODS:** Here, we report on the efficacy of this medical grade honey treatment against two MDROs (*Acinetobacter baumannii*, methicillin-resistant *Staphylococcus aureus* [MRSA]). In this initial phase (Part I), an in-laboratory validation and characterization of the efficacy against antibiotic-resistant bacteria were performed in vitro.
- RESULTS:** The antimicrobial resistance of both MDROs was confirmed in vitro using standard microbiology techniques and species' DNA signatures. The minimum inhibitory concentration of the MEDIHONEY was determined to be 3.5% for MRSA and 8.5% for *A. baumannii*. The minimum bactericidal concentrations determined against MRSA and multidrug-resistant *A. baumannii* were shown to be 9.5% and 10.5%, respectively.
- CONCLUSION:** Our in vitro findings support the efficacy of MEDIHONEY against MRSA and *A. baumannii* as requested by first responders. We also conducted screening assays using other “supermarket brands” of honey. All cultures from the latter showed bacterial and fungal growths. The use of supermarket brand honey for wound treatment is discouraged. (*J Trauma Acute Care Surg.* 2014;77: S204–S207. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** MEDIHONEY; multiple-drug resistant bacteria; medical grade honey.
-

# BRIEF REPORT

## Continuous noninvasive respiratory volume monitoring for the identification of patients at risk for opioid-induced respiratory depression and obstructive breathing patterns

Christopher J. Voscopoulos, MD, Colin Marshall MacNabb, MS, Jenny Freeman, MD, Samuel M. Galvagno, Jr., DO, PhD, Diane Ladd, DNP, and Edward George, MD, PhD, *Waltham, Massachusetts*

---

<b>BACKGROUND:</b>	Opioid-induced respiratory depression (OIRD) and postoperative apnea (POA) can lead to complications after surgery or traumatic injury. Previously, real-time monitoring of respiratory insufficiency and identification of apneic events have been difficult. A noninvasive respiratory volume monitor (RVM) that reports minute ventilation (MV), tidal volume, and respiratory rate is now available. The RVM was used to report the effect of opioids on respiratory status as well as demonstrate apneic breathing patterns in a hospital postanesthesia care unit.
<b>METHODS:</b>	RVM traces were collected from 132 patients. Predicted MV ( $MV_{PRED}$ ) for each patient was used to calculate and the “percent predicted” MV ( $MV_{MEASURED} / MV_{PRED} \times 100\%$ ) before opioid administration. Patients were stratified into two categories: “at risk,” MV of less than 80% $MV_{PRED}$ , and “not at risk,” MV of 80% $MV_{PRED}$ or greater. After opioid dosing, patients with MV of less than 40% $MV_{PRED}$ were categorized as “unsafe.” POA was defined as more than five apneic or hypopneic events per hour.
<b>RESULTS:</b>	Of the 132 patients, 50 received opioids. Baseline MV was $7.2 \pm 0.5$ L/min. The MV-based protocol classified 18 of 50 patients as at risk before opioid administration. After the first opioid dose administration, at-risk patients experienced an average MV decrease ( $36.7\% \pm 8.5\% MV_{PRED}$ ) and 13 of 18 decreased into unsafe; the 32 not at-risk patients experienced a lesser average MV decrease ( $76.9\% \pm 6.3\% MV_{PRED}$ ). Only 1 of 32 not at-risk patients had a decrease in MV to unsafe. The proposed protocol had a sensitivity of 93% and a specificity of 86%. Of the 132 patients, 26 displayed POA. Of the 26 patients, 12 experienced POA without receiving opioids. Of the 26 patients with POA, 14 also received opioids, and of those, 6 were classified as unsafe.
<b>CONCLUSION:</b>	This investigation indicates that at risk and unsafe respiratory patterns occur frequently after procedure. RVM provides continuous noninvasive objective measurements of OIRD and POA. The RVM may prove a useful tool in opioid dosing and in recognition and management of POA and strong potential value in the rapid detection of OIRD and apnea in the contemporary combat casualty environment. ( <i>J Trauma Acute Care Surg.</i> 2014;77: S208–S215. Copyright © 2014 by Lippincott Williams & Wilkins)
<b>LEVEL OF EVIDENCE:</b>	Diagnostic test, level V.
<b>KEY WORDS:</b>	Noninvasive respiratory volume monitoring; opioid-induced respiratory; depression; postoperative apnea; identification.

---

# REVIEW ARTICLE

## Hemoglobin-based oxygen carriers: An update on their continued potential for military application

**Clayton J. Lewis, MD** and **James D. Ross, PhD**, *Joint Base San Antonio, Lackland, Texas*

**H**emoglobin-based oxygen carriers (HBOCs) have a storied history. The 1980s and 1990s were a period of significant investment and development in the oxygen therapeutic market, and generations of HBOCs continue to evolve for potential use in myriad clinical settings. Early clinical trials on HBOCs focused on end points such as reduction in the transfusion of allogenic packed red blood cells. It was hoped that, had HBOCs been successful in this niche, the need for human blood products and their associated medical and logistical complexities could be reduced.

# REVIEW ARTICLE

## Early identification of uncontrolled hemorrhage after trauma: Current status and future direction

Stacy A. Shackelford, MD, Katharine Colton, Lynn G. Stansbury, MD, MPH,  
Samuel M. Galvagno, Jr, DO, PhD, Amechi N. Anazodo, MD, Joseph J. DuBose, MD,  
John R. Hess, MD, MPH, and Colin F. Mackenzie, MBChB, *Baltimore, Maryland*

**D**uring the last decade, advanced trauma care surgical and transfusion teams have achieved remarkable gains in the rapid identification and effective response to potentially lethal hemorrhage, and these improvements are now demonstrable in improved survival and decreased blood product use.<sup>1,2</sup> However, uncontrolled hemorrhage remains the most common cause of potentially preventable death after both civilian and military trauma,<sup>3,4</sup> and of those who survive to reach advanced care, half will die in the first 2 hours after admission.<sup>3</sup> Changes in the types and proportions of blood product requirements are also driving changes in blood banking procedures for product testing, release, and delivery.<sup>5</sup> It is likely that the next evolution in improved survival from traumatic injury will occur in the realm of

en route care through the introduction of advanced capabilities at the point of injury and during aeromedical transport. However, the ability to move a rapid, accurate, and practical diagnostic capability into the field medical response and the aviation transport process remains an unrealized goal in modern trauma care. In this review, using large-scale transfusion requirements (so-called *massive transfusion* [MT]) as a surrogate marker for uncontrolled hemorrhage, we will examine the history and current status of efforts to rapidly identify bleeding casualties and predict the need for immediate hemorrhage control procedures and transfusion.

# REVIEW ARTICLE

## State of the science review: Advances in pain management in wounded service members over a decade at war

**John L. Clifford, PhD, Marcie Fowler, Jacob J. Hansen, Bopiah Cheppudira, Jennifer E. Nyland, Margaux M. Salas, Laura L. McGhee, Lawrence N. Petz, and Dayna R. Loyd, San Antonio, Texas**

---

**ABSTRACT:** The pain conditions and comorbidities experienced by injured service members and the challenge of pain management by the military medical system offer a unique opportunity to inform pain management and medical research. In this article, acute and chronic pain issues, current treatment options and limitations, as well as novel approaches to pain management are discussed within the context of combat casualty care, from the battlefield to hospitalization and rehabilitation. This review will also highlight the current pain management limitations that need to be addressed in future clinical and basic science research to improve care for our nation's injured service members. (*J Trauma Acute Care Surg.* 2014;77: S228–S236. Copyright © 2014 by Lippincott Williams & Wilkins)

---

# CURRENT OPINION

## A perspective on the 2014 Institute of Medicine report on the long-term effects of blast exposures

**Todd E. Rasmussen, MD, Eric A. Elster, MD, Terry M. Rauch, PhD,  
and Kelley A. Brix, MD**

In February 2014, the Institute of Medicine (IOM) published a report titled “Long-term effects of blast exposures.”<sup>1</sup> The report, which was commissioned by the US Department of Veterans Affairs (VA), was produced by the IOM’s Committee on Gulf War and Health and was released as volume 9 of the IOM’s “Gulf War and Health” series. Billed as an evidence-based evaluation of the multisystem response to blast exposures and subsequent acute and long-term health consequences in US service personnel, the report provides a considerable amount of important information. However, the committee fell well short of its charge to “evaluate what is known about health effects of exposure to blast, including the blast waves and other blast mechanisms, such as blunt-force trauma and projectiles” and draw conclusions regarding the evidence. The report also lacks in its ability to direct or “develop a research agenda to provide the Department of Veterans Affairs with guidance in addressing the deficiencies in the evidence base.”

# PROCEDURES & TECHNIQUES

## Managing endotracheal tube cuff pressure at altitude: A comparison of four methods

Tyler Britton, RRT, Thomas C. Blakeman, MSc, RRT, John Eggert, RN, Dario Rodriguez, MSc, RRT, Heather Ortiz, RN, and Richard D. Branson, MSc, RRT, Cincinnati, Ohio

- 
- BACKGROUND:** Ascent to altitude results in the expansion of gases in closed spaces. The management of overinflation of the endotracheal tube (ETT) cuff at altitude is critical to prevent mucosal injury.
- METHODS:** We continuously measured ETT cuff pressures during a Critical Care Air Transport Team training flight to 8,000-ft cabin pressure using four methods of cuff pressure management. ETTs were placed in a tracheal model, and mechanical ventilation was performed. In the control ETT, the cuff was inflated to 20 mm Hg to 22 mm Hg and not manipulated. The manual method used a pressure manometer to adjust pressure at cruising altitude and after landing. A PressureEasy device was connected to the pilot balloon of the third tube and set to a pressure of 20 mm Hg to 22 mm Hg. The final method filled the balloon with 10 mL of saline. Both size 8.0-mm and 7.5-mm ETT were studied during three flights.
- RESULTS:** In the control tube, pressure exceeded 70 mm Hg at cruising altitude. Manual management corrected for pressure at altitude but resulted in low cuff pressures upon landing (<10 mm Hg). The PressureEasy reduced the pressure change to a maximum of 36 mm Hg, but on landing, cuff pressures were less than 15 mm Hg. Saline inflation ameliorated cuff pressure changes at altitude, but initial pressures were 40 mm Hg.
- CONCLUSION:** None of the three methods using air inflation managed to maintain cuff pressures below those associated with tracheal damage at altitude or above pressures associated with secretion aspiration during descent. Saline inflation minimizes altitude-related alteration in cuff pressure but creates excessive pressures at sea level. New techniques need to be developed. (*J Trauma Acute Care Surg.* 2014;77: S240–S244. Copyright © 2014 by Lippincott Williams & Wilkins)
- KEY WORDS:** Artificial airway; enroute care; altitude. hypobarism; cuff pressure.
-