Use of Near-Infrared Spectroscopy to Assess the Adequacy of Resuscitation in Trauma

The long term objective is to develop and evaluate new monitoring strategies in clinically-relevant laboratory models of civilian and military trauma then translate the laboratory findings to the bedside. The short term primary objective was to assess the value of a new portable, noninvasive, continuous monitoring device (near-infrared spectroscopy, NIRS) in establishing the adequacy of resuscitation after trauma in an experimental model. That objective was achieved earlier than expected and is now being tested in patients. We are now evaluating proof of concept of other non-invasive monitoring strategies in both animals and patients. Some of these novel strategies could permit minimally-trained medics or other EMS personnel to provide care of trauma patients in the combat or civilian prehospital setting; others provide new perspectives on the diagnosis of injury severity.

Key terms: near-infrared spectroscopy, post-trauma resuscitation, non-invasive monitoring, heart rate variability
Scientific and Technical Objectives
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Approach
Anesthetized, instrumented swine receive a traumatic injury to the head, chest, abdomen, or extremity. After a 10-60 min shock period, the animal receives initial resuscitation with crystalloid, colloid, or novel test fluid, supplemented with various pharmacologic agents to mimic pre-hospital care. This is followed by resuscitation with standard of care cardiopulmonary support. After a 2-72 hr post trauma observation period, the outcome is graded on the basis of mortality, physiologic changes, neurologic function, biochemical/metabolic changes, and/or histologic changes. Similar observations are then made in trauma patients.

Concise Accomplishments
Three fundamentally different monitoring strategies were developed to monitor the status of trauma patients.

1. Near infrared spectroscopy can be used to non-invasively monitor changes in the peripheral circulation and the severity of shock in both animals and patients
2. Heart rate variability can be used to non-invasively monitor changes in the activity of the autonomic nervous system and the severity of traumatic brain injury in patients
3. Systemic catheter placement was found to produce a hypercoagulable state in both animals and patients
Expanded Accomplishments

1. Three different experimental protocols tested the hypothesis that hindlimb muscle tissue O2 saturation (StO2), measured non-invasively with NIRS is as reliable as invasive systemic oxygenation indices to guide fluid resuscitation. In Series 1, StO2 tracked mixed venous O2 saturation (SvO2), but discriminated between three survivor groups better than SvO2, arterial lactate, or arterial base excess. In Series 2, StO2 tracked SvO2 but discriminated between two survivor groups better than SvO2, arterial lactate, or arterial base excess. In series 3, animals survived to extubation when resuscitated to an StO2 target. Therefore, NIRS-determined muscle StO2 was more reliable than invasive oxygenation variables as an index of shock. Since muscle StO2 can be easily monitored in emergency situations, it may represent an improved method to gauge the severity of shock or the adequacy of fluid resuscitation after trauma. To determine clinical relevance, NIRS was used to establish: 1) the normal range of thenar StO2 in humans, and 2) the relationship between shock state and StO2 in trauma patients. This was a prospective, non-randomized, observational, descriptive, study in normal human volunteers (n=707) and patients admitted to the resuscitation area (n=150) of our Level I trauma center. Thenar StO2 was as follows: Normals, 87 ± 6%, Mild Shock 83 ± 10%, Moderate Shock 80 ± 12%, and Severe Shock 45 ± 26%. Therefore, decreased StO2 reflects the presence of severe hypoperfusion and 2) NIRS may be a novel method for rapidly and non-invasively assessing changes in tissue dysoxia.

2. Heart rate is neither periodic nor stationary in physiological conditions. Instead, there are neurogenically regulated beat-to-beat variations. Changes in heart rate variability (HRV) reflect autonomic dysfunction in patients in several pathologic states, including traumatic brain injury (TBI). Nevertheless, the clinical utility has been limited by data acquisition, off-line algorithms, and interpretation of complex statistical results. We report the design and first test of a versatile, user friendly portable system that provides an on-line HRV index. The module interfaces with a bedside monitor or uses a built-in amplifier to acquire/digitize the ECG signal at 250Hz via 12 bit conversion. Electrical/motion artifacts are filtered before real time sinus beats are detected with a QRS algorithm. Instantaneous heart rate (HR), variation in RR intervals (SDNN), and other derivatives of HRV over a user defined timescale are displayed and dynamically updated. The user can adjust the sampling frequency, digital filtering and the QRS detection parameters. The data showed that this novel HRV monitoring strategy is safe, easy to use, continuous, and non-invasive; 2) HRV index was reduced >90% in sedated TBI patients; 3) Further work is needed but HRV monitoring might improve outcome after TBI by allowing early detection of intracranial pathology and/or treatment effectiveness.

3. A higher rate of pulmonary embolism has been associated with pulmonary artery (PA) catheters, however no mechanism has been described. Conventional coagulation monitoring reveal no changes related to PA catheterization. The purpose of this study was to determine whether PA catheterization resulted in a hypercoagulable state detectable by thrombelastography (TEG). The data from healthy swine, and critically-ill patients, showed that 3 hrs after PA catheter placement, clotting time was reduced by half, which suggests that systemic catheters may enhance thrombin formation and fibrin polymerization. This may explain why PA catheters are associated with an increased risk of pulmonary emboli.

Work Plan

1. Determine the accuracy, specificity, and precision of heart rate variability monitoring as a non-invasive index for the severity of traumatic brain injury.
2. Determine whether catheters placed in site other than the pulmonary artery evoke a systemic hypercoagulable condition.
Problems/Issues
No problems are anticipated.

Peer-Reviewed Journal Articles

Status Text

In Press

In Press

In Press

In Press

In Press

In Press

Published

Published
14) Majetschak M, Cohn SM, Obertacke U, Proctor KG: Therapeutic potential of exogenous ubiquitin during resuscitation from severe trauma J Trauma 2004:May;56(5):991-1000

Published

Published

Published

Published

Published
Published

Published

Books or Book Chapters
Status Text
Published

Published

Technical Reports (Non-refereed Publications)
No technical reports reported.

Abstracts/Presentations/Posters/Conference Proceedings


Patel MB, Busby L, Proctor KG, Majetschak M: Assessment of 26S proteasome activity in skeletal muscle after trauma. Accepted for presentation at 60th Annual Surgical Forum, American College of Surgeons, San Francisco, CA Oct 2005

  a. Presented at American College of Surgeons Florida Committee on Trauma Resident Paper Competition, Miami Beach, FL Nov 2004 (* First place Research Award)
  b. Presented at American College of Surgeons Region IV Committee on Trauma Resident Paper Competition, Lexington, KY Nov 2004 (* First place Research Award)
  c. Presented at American College of Surgeons National Committee on Trauma
  a. Presented at American College of Surgeons Florida Committee on Trauma Resident Paper Competition, Miami Beach, FL, Nov 2004

Feinstein AJ, Cohn SM, Sanui M, King DR, Proctor KG: Vasopressin prevents cardiopulmonary collapse after severe chest trauma.


King DR, Cohn SM, Proctor KG: Resuscitation with a hemoglobin-based oxygen carrier after severe brain trauma.

Feinstein AJ, Beck G, Cohn SM, LeCroy DE, King DR, Proctor KG: Portable emergency ventilator that servo-controls inspired oxygen concentration;
  a. Presented at 64th Annual Meeting of American Assoc. for the Surgery of Trauma, Maui, HI, Sep 2004

Majetschak M, Proctor KG: Ubiquitin and ubiquitin-related molecules for treatment and prevention of harmful activation of the immune system.
  a. Presented at First Annual Florida Tech Transfer Conference, St. Petersburg, FL, May 2004
  c. Presented at ATACC2004, Advanced Technology Applications to Combat
Casualty Care, St. Pete Beach, FL Aug, 2004.
  b. Presented at Florida Society of Anesthesiologists, Miami, FL, Jul, 2004 (* First place Research Award)
  c. Presented at the Research and Technology Organisation (RTO) Human Factors and Medicine (HFM) symposium on “Combat Casualty Care in Ground Based Tactical Situations: Trauma Technology and Emergency Medical Procedures”, held in St. Pete Beach, FL Aug 2004


King DR, Cohn SM, Blackbourne LH, Benjamin RE, Proctor KG: Novel hemostatic dressing in coagulopathic patients with visceral injuries: preliminary findings.
  b. Presented at American College of Surgeons Florida Committee on Trauma Resident Paper Competition, Jacksonville, FL Nov 2003

Awards/Honors/Invention Disclosure
Heart rate variability index to predict severity in patients with traumatic brain injury; KG Proctor and SA Atapattu; invention disclosure to Univ of Miami Miller School of Medicine; http://www.miami.edu/techtransfer

Ara J. Feinstein, MD won the American College of Surgeons Committee on Trauma 2004 Florida Resident Paper Competition, and 2004 Region IV Resident Paper Competition for a study on the beneficial effects of vasopressin during resuscitation from trauma

Masamitsu Sanui, MD won the 2004 Florida Society of Anesthesiologists Resident Paper Competition for a study on the actions of vasopressin after traumatic brain injury

David R. King, MD won the 2005 Alexander Award from the Eastern Association for the Surgery of Trauma for the best paper by a resident or fellow for his study on coagulation changes caused by PA catheters

Bruce A. Crookes, MD won the 2004 Alexander Award from the Eastern Association for the Surgery of Trauma for the best paper by a resident or fellow for his study on near infrared spectroscopy in trauma patients
Patents Submitted
Heart rate variability index to predict severity in patients with traumatic brain injury; KG Proctor and SA Atapattu; US patent application filed Jan 2005 by Univ of Miami; http://www.miami.edu/techtransfer

Patents Issued
No patents issued reported.

Technology Transfer
During the past several years of ONR funding, we have evaluated several compounds that were being developed by bio-pharmaceutical companies for possible use in combat casualty care or civilian trauma. Many of these products are, or have been, used by other DOD-funded investigators, including:

- Polynitroxylated dextran & hemoglobin from Synzyme Technologies, LLC, Irvine, CA.
- 6% hetastarch in balanced electrolyte solution from BioTime Inc, Berkeley, CA
- HBOCs from Baxter Hemoglobin Therapeutics, Boulder, CO and Biopure Corp, Cambridge, MA
- ATL-146e from Adenosine Therapeutics, Charlottesville, VA
- RDH bandage from Marine Polymer Technologies, Cambridge MA

In addition, we have evaluated several different monitoring devices that have potential usefulness in emergency or field situations:

- Bispectral EEG analysis from Aspect Medical Systems, Inc., Newton, MA
- Non-invasive cardiac output monitoring from Novametrix NICO, Wallingford, CT
- Heart rate variability from Medical Automation Systems, Charlottesville, VA
- Near infrared (NIR) spectroscopy by Hutchinson Technologies (Hutchinson, MN)
- Thromboelastograph from Haemoscope, Inc, Niles, IL
- Sub-lingual CO2 sensor, Nellcor, Ballwin, MO
- Portable, automatic ventilator, Impact Instrumentation, West Caldwell, NJ

Several companies provided us with their products at no cost, or reduced cost, because they are interested in the results of the experiments. Several other critical care manufacturers provide us with supplies for our studies, including:

- Cerebral oximeter, Somanetics, Troy, MI
- Mechanical ventilators from Impact Instrumentation, West Caldwell, NJ
- Cardiac output computers and fiberoptic catheters from Edwards Critical-Care Division, Irvine, CA
- IV catheters and introducers from Arrow International, Inc., Reading, PA
- Instruments and reagents from Nova Biomedical (Waltham, MA)
- Monitors, probes and fiberoptic catheters from Camino Neurocare Group (Pleasant Prairie, WI)

Several DOD-funded investigators visited our lab in the last grant period to learn or to compare techniques. In addition, the U.S. Army trains Forward Surgical Teams (FST) at the Ryder Trauma Center. During a one month rotation, these individuals receive intensive training on the latest techniques. As part of the training, U.S. Army conducts mass casualty drills and skills tests in our lab each month with each new FST. These individuals are then deployed throughout the world.