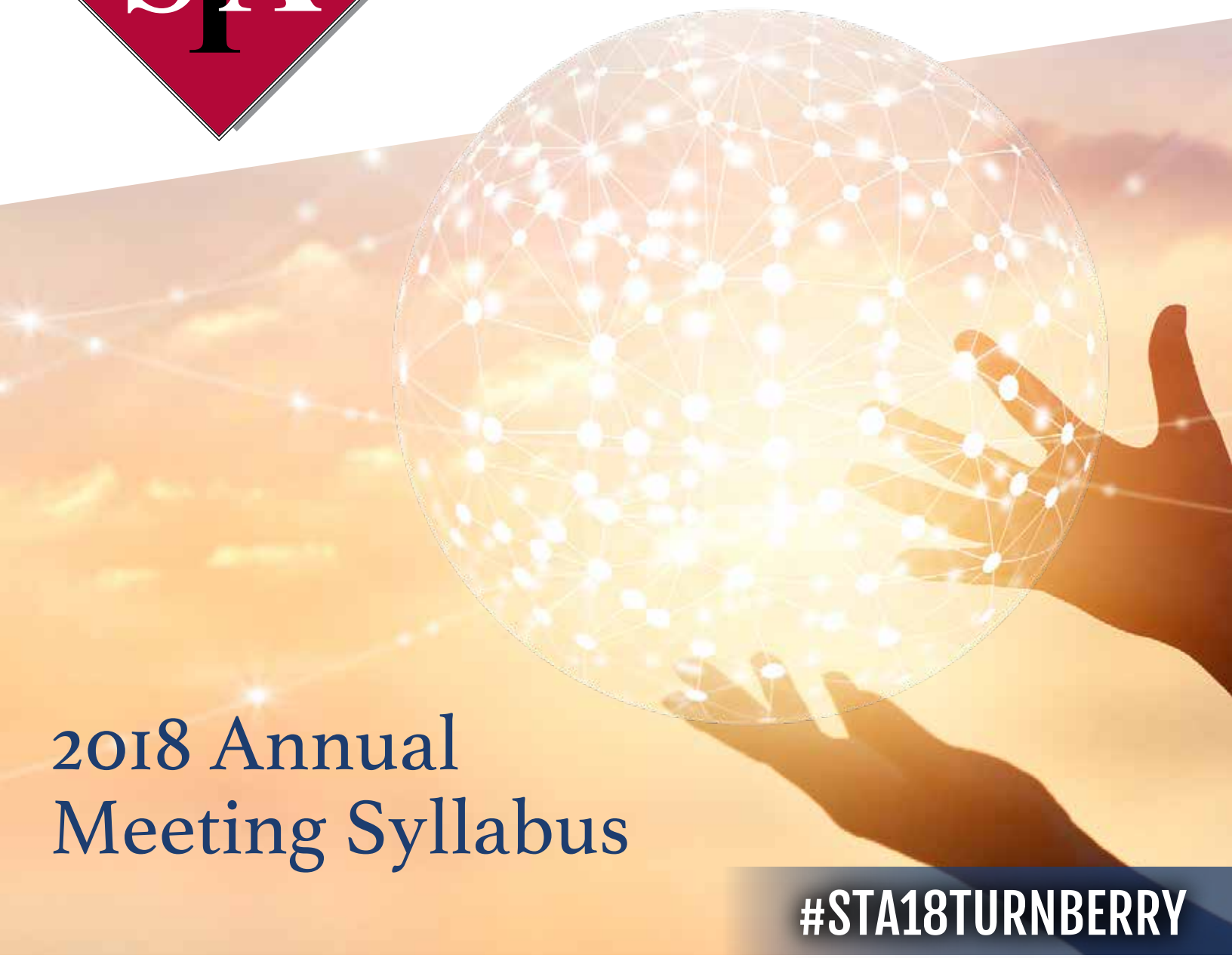
Data Driven Innovation and Technology in Anesthesia



2018 Annual Meeting Syllabus

#STA18TURNBERRY

January 10-13, 2018
Turnberry Isle Miami
Aventura, Florida

Annual Meeting
Program Co-Chairs
Lara Brewer, PhD
Jonathan M. Tan, MD, MPH

Society for Technology in Anesthesia
6737 W. Washington St., Suite 4210 • Milwaukee, WI 53214
(P) 414-389-8600 • (F) 414-276-7704 • www.stahq.org • stahq@stahq.org

FAER
Foundation for Anesthesia Education and Research

Featuring a Joint Session with the Foundation for Anesthesia Education and Research

WELCOME

Welcome to the 2018 Society for Technology in Anesthesia (STA) Annual Meeting! We have a wonderful, star-studded program prepared by Annual Meeting Co-Chairs Drs. Lara Brewer, PhD and Jonathan Tan, MD, MPH, and Abstract Co-Chairs Drs. Charlene Blake, MD, PhD, and Matthew Levin, MD. Also, of course, the STA staff who orchestrate everything so well: Marie, Rachel, and Jane. Please be sure to thank them for the success that we all enjoy.

In addition to a variety of informatics, data science, technology, and clinical topics, the meeting has been extended this year to accommodate Foundation for Anesthesia Education and Research (FAER) co-sponsorship, emphasizing development of young researchers, multi-center data collaboration, and entrepreneurship as the lifeblood of progress in anesthesia. The diversity in the posters and engineering challenge complement the formal agenda, showcasing the emerging ideas shaping the future of anesthesia.

Enjoy the unique character of this uniquely collaborative, interdisciplinary meeting. Clinicians and non-clinicians are purposefully on an equal footing in this venue. We are especially grateful for the continued sponsorship of our industry partners. We depend on their financial support for this meeting and perpetuation of the unique value of STA and FAER. Please engage with them to provide great return on their investments, making their participation and financial support worthwhile today and for years to come.

Enjoy the meeting and develop new mutually beneficial friendships!

S. Mark Poler, MD
President, Society for Technology in Anesthesia

INVITED FACULTY

Luis M. Ahumada, MSCS, PhD
Children's of Hospital of Philadelphia

J. Mark Ansermino, MBBCh
University of British Columbia

George Arndt, MD
University of Wisconsin School of Medicine and Public Health

Stephane Bibian, PhD
NeuroWave Systems, Inc

Charlene Blake, MD, PhD
Annual Meeting Abstract Co-Chair
University of California, San Francisco

Lara Brewer, PhD
Annual Meeting Program Co-Chair
University of Utah

Maxime Cannesson, MD, PhD
University of California, Irvine

Lane Desborough, MASc
Bigfoot Biomedical

Guy Dumont, PhD
University of British Columbia

Dustin Dunsmuir, MSc
University of British Columbia

Jesse Ehrenfeld, MD, MPH
Vanderbilt University Medical Center

Thomas P. Engel, MD
Loma Linda University School of Medicine

David Feinstein, MD
Beth Israel Deaconess Medical Center

Anura Fernando
Underwriters Laboratories

Jorge Galvez, MD, MBI
Children's Hospital of Philadelphia

Seth Goldenberg, PhD
GOLIN

Julian M. Goldman, MD
Massachusetts General Hospital

Matthias Gorges, PhD
University of British Columbia

Thomas Hemmerling, MD, MSc, DEAA
McGill University

Orlando Hung, MD, FRCPC
Dalhousie University

Patrick Kolbay, BS
University of Utah

Matthieu Komorowski, MD, MRes
Charing Cross Hospital

Samsun Lampotang, PhD
University of Florida

Barrett Larson, MD
Stanford University School of Medicine

Christine Lee, MS
University of California, Irvine

Matthew Levin, MD
Annual Meeting Abstract Co-Chair
Icahn School of Medicine at Mount Sinai

Amer Majeed, MBBS
King Faisal Specialist Hospital and Research Center

Jeffrey Mandel, MD, MS
University of Pennsylvania

Clyde Matava, MBChB, DA, MMed
Hospital for Sick Children

Jason Maynes, MD, PhD
University of Toronto

John Pawlowski, MD, PhD
Beth Israel Deaconess Medical Center

S. Mark Poler, MD
Geisinger Medical System

Catherine Price, PhD, ABPP-CN
University of Florida

Christopher Quartararo, MD
Winchester Anesthesia Associates

Parisa Rashidi, PhD
University of Florida

Mohamed Rehman, MD
John Hopkins All Children Hospital

Joseph Rinehart, MD
University of California, Irvine

Sean Runnels, MD
University of Utah

Norma Sandrock, MD
Beth Israel Deaconess Medical Center

Steven Shafer, MD
Stanford University

George Shorten, MD, PhD
University College of Cork, Ireland

Allan Simpao, MD, MBI
Children's Hospital of Philadelphia

Jonathan M. Tan, MD, MPH
Annual Meeting Program Co-Chair
Children's Hospital of Philadelphia

Patrick Tighe, MD, MS
University of Florida

Arthur Wallace, MD, PhD
University of California, San Francisco

Matthew B. Weinger, MD
Vanderbilt University

Sandy Weininger, PhD
FDA/CDRH/OSEL

Elizabeth Zambricki, MD, MBA
Palo Alto Medical Foundation

MEETING ACCREDITATION INFORMATION

Activity Overview

The Society for Technology in Anesthesia (STA) 2018 Annual Meeting will provide a forum for discussion of emerging innovations and technology in anesthesia with a particular emphasis on how data and data science are being used to drive and support these innovations. Topics covered throughout the program include how data driven innovation is informing automated drug delivery, perioperative medicine, academic innovation and cybersecurity in healthcare.

Target Audience

This live activity is designated for a national and international audience of physicians, engineers and industry members, as well as other practitioners in the field of anesthesia seeking an update on the current and future state of anesthesia technology.

Educational Objectives

As a result of participation in this CME activity, learners should be able to:

- Describe examples of innovations in anesthesia and perioperative medicine.
- Explore the current state of automated drug delivery and closed loop systems.
- Understand the importance and complexity of cyber security and interoperability in modern anesthesia and health care practice.
- Discuss how data science can be applied to EHRs to create more effective multicenter research and improve perioperative medicine.
- Describe how anesthesiologists in academic medicine are creating innovation and technology to drive both research and entrepreneurial missions.
- Discuss how young researchers can further their careers through mentorship and opportunities in anesthesia technology research and entrepreneurship.
- Summarize current research presentations from anesthesiologists, engineers, scientists and industry in anesthesiology technology and innovation.

Barriers to change:

- Harnessing new knowledge and applications of technology in a healthcare space that traditionally rewards routine and incremental changes.

Accreditation Statement

This activity has been planned and implemented in accordance with the accreditation requirements and policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of Amedco and the Society for Technology in Anesthesia (STA). Amedco is accredited by the ACCME to provide continuing medical education for physicians.

Credit Designation Statement

Amedco designates this live activity for a maximum of **21.25** ***AMA PRA Category 1 Credits™***. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

MOC LLSA Credit

The American Board of Preventive Medicine (ABPM) has approved this activity for a maximum of 9.25 LLSA credits towards ABPM MOC Part II requirements. Course ID#1544.

PRE-CONFERENCE SESSION

Challenges and Opportunities in Developing Anesthesia Products (for Industry)

Wednesday, January 10, 2018 • 0800 - 1200

The Challenges and Opportunities Course started over ten years ago as an introduction to the practice of anesthesia for non-clinical STA members. Through the years it has evolved to its current form where STA industry members and anesthesiologists meet to discuss current trends in anesthesia practice and product development.

This half day course is planned for industry by the scientist and researcher members of the STA involved in designing, testing and marketing new developments and products to anesthesiologists. Basic talks will provide participants with an understanding of the practice of anesthesiology and how to recognize opportunities for new products. The session will include mini descriptions and group discussions on key aspects of the clinical specialty, including anesthesia work-flow: what works and what's needed.

Discussions are driven by participant interests regarding all aspects of anesthesia care and practice. Faculty for the course are board-certified anesthesiologists from multiple geographic locations, practice settings and varieties of anesthesia care. Prior sessions have focused on the anesthesia machine, infusion pumps, AIM systems and Big Data, as well as the basics for those who are just getting acquainted with the specialty.

Work groups of anesthesiologists and participants will address challenges in the design process and how these can be overcome to market a successful product. This will be a highly interactive and stimulating workshop. **OPEN TO INDUSTRY PARTICIPANTS ONLY.**

SCHEDULE OF EVENTS

Wednesday, January 10, 2018

0700-0800 *Veranda East*
Challenges and Opportunities Registration *(FOR INDUSTRY ONLY)*

0800-1700 *Garden II*
Exhibitor Registration & Setup

0800-1200 *Veranda East*
Challenges and Opportunities in Developing Anesthesia Products
(FOR INDUSTRY ONLY)
David Feinstein, MD, Norma Sandrock, MD, John Pawlowski, MD, PhD, Jesse Ehrenfeld, MD, MPH, Christopher Quartararo, MD

1800-2000 *Garden II*
Registration & Welcome Cocktail Reception

Thursday, January 11, 2018

0700-0800 *Garden Foyer*
Registration & Breakfast

0800-0815 *Garden I*
Welcome Address
S. Mark Poler, MD, Lara Brewer, PhD & Jonathan M. Tan, MD, MPH

Session 1: Keynote Address
Moderator: Lara Brewer, PhD & Jonathan M. Tan, MD, MPH

0815-0930 *Garden I*
Challenges of Anesthesia During Future Interplanetary Space Missions
Matthieu Komorowski, MD, MRes

0930-1000 *Garden II & Salon I/II*
Break with Exhibitors & Abstract Posters

Session 2: A Road Less Traveled: Successful Innovations from Academic Institutions
Moderator: Clyde Matava, MBChB, DA, MMed

1000-1030 *Garden I*
Builders and Carers – Inventors Divided by a Common Language
George Shorten, MD, PhD

1030-1100 *Garden I*
Patient-Centered Anesthesia and Learner-Centered Training
Samsun Lampotang, PhD

1100-1130 *Garden I*
Using Stems Cells to Predict Drug Effect
Jason Maynes, MD, PhD

1130-1200 *Garden I*
Panel Discussion

1200-1315 *Bourbon Steak Restaurant*
Luncheon

Session 3: Automated Drug Delivery is Here!
Moderator: J. Mark Ansermino, MBBCh

1315-1345 *Garden I*
Closed Loop for Diabetes: Challenges and Opportunities
Lane Desborough, MASc

1345-1415 *Garden I*
Closed Loop TIVA for Combat Casualty Care
Stephane Bibian, PhD

1415-1445 *Garden I*
Closed Loop Anesthesia: Can We Make it Safe by Design?
Guy Dumont, PhD

1445-1515 *Garden I*
Panel Discussion

1515-1545 *Garden II & Salon I/II*
Break with Exhibitors & Abstract Posters

1545-1615 *Garden I*
Posters in a Minute: Moderated Poster Summaries (Group A)
Moderator: Charlene Blake, MD, PhD

Session 4: Abstract Awards & Presentations
Moderator: Thomas Hemmerling, MD, MSc, DEAA

1615-1640 *Garden I*
Excellence in Technology Award Presentation
Patrick Kolbay, BS

1640-1705 *Garden I*
Best Clinical Application Award Presentation
Dustin Dunsmuir, MSc

1705-1730 *Garden I*
Best of Show Award Presentation
Matthias Gorges, PhD

1730-1745 *Garden I*
2018 Junior Research Grant Recipient Awarded
Thomas Hemmerling, MD, MSc, DEAA

Friday, January 12, 2018

0700-0800 *Garden Foyer*
Registration & Breakfast

Session 5: Analysis of Big Data
Moderator: Patrick Tighe, MD, MS

0800-0830 *Garden I*
When Perioperative Data Get Tens(or)
Patrick Tighe, MD, MS

0830-0900 *Garden I*
Deep Analysis of Messy Perioperative Data
Parisa Rashidi, PhD

0900-0930 *Garden I*
Artificial Intelligence to Enhance Non-Artificial Cognitive Assessment
Catherine Price, PhD, ABPP-CN

0930-1000 *Garden I*
Panel Discussion

1000-1030 *Garden II & Salon I/II*
Break with Exhibitors & Abstract Posters

Session 6: Trust but Verify: Achieving the Medical Internet of Things
Moderator: Julian M. Goldman, MD

1030-1035 *Garden I*
Interoperability and Cybersecurity: What's the Connection?
Julian M. Goldman, MD

SCHEDULE OF EVENTS CONTINUED

Friday, January 12, 2018 continued

1035-1105 *Garden I*	**Medical Device Security and the Curse of the Internet of Things** *Thomas P. Engel, MD*
1105-1135 *Garden I*	**Technical Aspects of System Safety: Interoperability and Cybersecurity** *Sandy Weininger, PhD*
1135-1205 *Garden I*	**Decrypting the Cybersecurity Landscape** *Anura Fernando*
1205-1230 *Garden I*	**Panel Discussion**
1230-1345 *Ballroom III*	**STA Business Luncheon & 2018 J.S. Gravenstein Award Presentation** *S. Mark Poler, MD & Matthew Weinger, MD*
1345-1415 *Garden I*	**Posters in a Minute: Moderated Poster Summaries (Group B)** *Moderator: Matthew Levin, MD*
1415-1430 *Salon I/II*	**Break with Abstract Posters**

Session 7: STA & FAER Jointly Sponsored Concurrent Sessions

FAER Foundation for Anesthesia Education and Research

1430-1630 *Veranda West*	**Young Researchers Workshop** *Christine Lee, MS, Maxime Cannesson, MD, PhD, Joseph Rinehart, MD, Barrett Larson, MD*

The objective of this workshop is to bring together a community of young research scientists. In this community, researchers will share their individual research experiences, as well as develop collaborative relationships to further promote the advancement of technology in anesthesia. The focus of this year's workshop will be entrepreneurship.

1430-1630 *Veranda East*	**Multicenter Collaborative Data Research** *Mohamed Rehman, MD, Luis M. Ahumada, MSCS, PhD*

The objective of this workshop is to help groups work together and share data that will help attendees understand and improve outcomes of rare events. The workshop will have four 15 minute presentations of projects, followed by a group discussion and conclusion of next steps.

1700-1900 *Cascata Pool*	**STA Cocktail Reception**

Saturday, January 13, 2018

0700-0800 *Garden Foyer*	**Registration & Breakfast**

Session 8: STA Engineering Challenge

Moderator: Jeffrey Mandel, MD, MS

0800-0930 *Garden I/II*	**Engineering Challenge** *Jeffrey Mandel, MD, MS*
0930-1000 *Garden I/II*	**Posters in a Minute: Moderated Poster Summaries (Group C)** *Moderator: Allan Simpao, MD, MBI*
1000-1030 *Salon I/II*	**Break with Abstract Posters**

Session 9: Entrepreneurial Innovation and Application of New Technology

Moderator: Jorge Galvez, MD, MBI

1030-1100 *Garden I/II*	**Crowdsourced Innovation: A Model for Accelerating Medical Technology Development** *Barrett Larson, MD*
1100-1130 *Garden I/II*	**Accelerating Medical Devices to Market: Strategies for Rapidly Supporting Unmet Clinical Needs** *Seth Goldenberg, PhD*
1130-1200 *Garden I/II*	**Technology in Anesthesia: Crystal Balling the Future** *Amer Majeed, MBBS*
1200-1230 *Garden I/II*	**Panel Discussion**
1230-1400 *Ballroom I/II*	**STA/FAER Luncheon**

Session 10: Successful Steps in Entrepreneurship – A FAER-Sponsored Session in Honor of Dr. Ted Stanley

Moderator: James Eisenach, MD

1400-1600 *Garden I/II*	**Success and Failure Travel Together**

Stories from four clinically driven entrepreneurs who have attempted commercialization of clinically-driven ideas.

- Early Innovation in Academia – *Lara Brewer, PhD*
- Innovation for the Established Academic – *Jeffrey Mandel, MD, MS*
- Building Long Term Relationships - *George Arndt, MD*
- Why "Can't Fail" Fails - *Steven Shafer, MD*

1600-1630 *Garden Foyer*	**Break**
1630-1815 *Garden I/II*	**FAER Swimming with Sharks – Technology Version** *Lara Brewer, PhD, Jeffrey Mandel, MD, MS, George Arndt, MD, Steven Shafer, MD*

Contestants: *Arthur Wallace, MD, PhD, Elizabeth Zambricki, MD, MBA, Sean Runnels, MD, Orlando Hung, FRCPC, Barrett Larson, MD*

Turning your academic hobby into game changing technology. Anesthesiology has a long history of innovation, entrepreneurship, and close interactions between academicians, private practitioners, and industry to bring new concepts to the clinical arena and better care for our patients. Using the entertaining format of Shark Tank™, this session will have participants pitch their ideas to a panel of innovation experts, and learn about the steps involved in the process of developing an idea to bring it to market.

1830-2000 *Cascata Pool*	**FAER Closing Cocktail Reception**

TURNBERRY MIAMI ISLE

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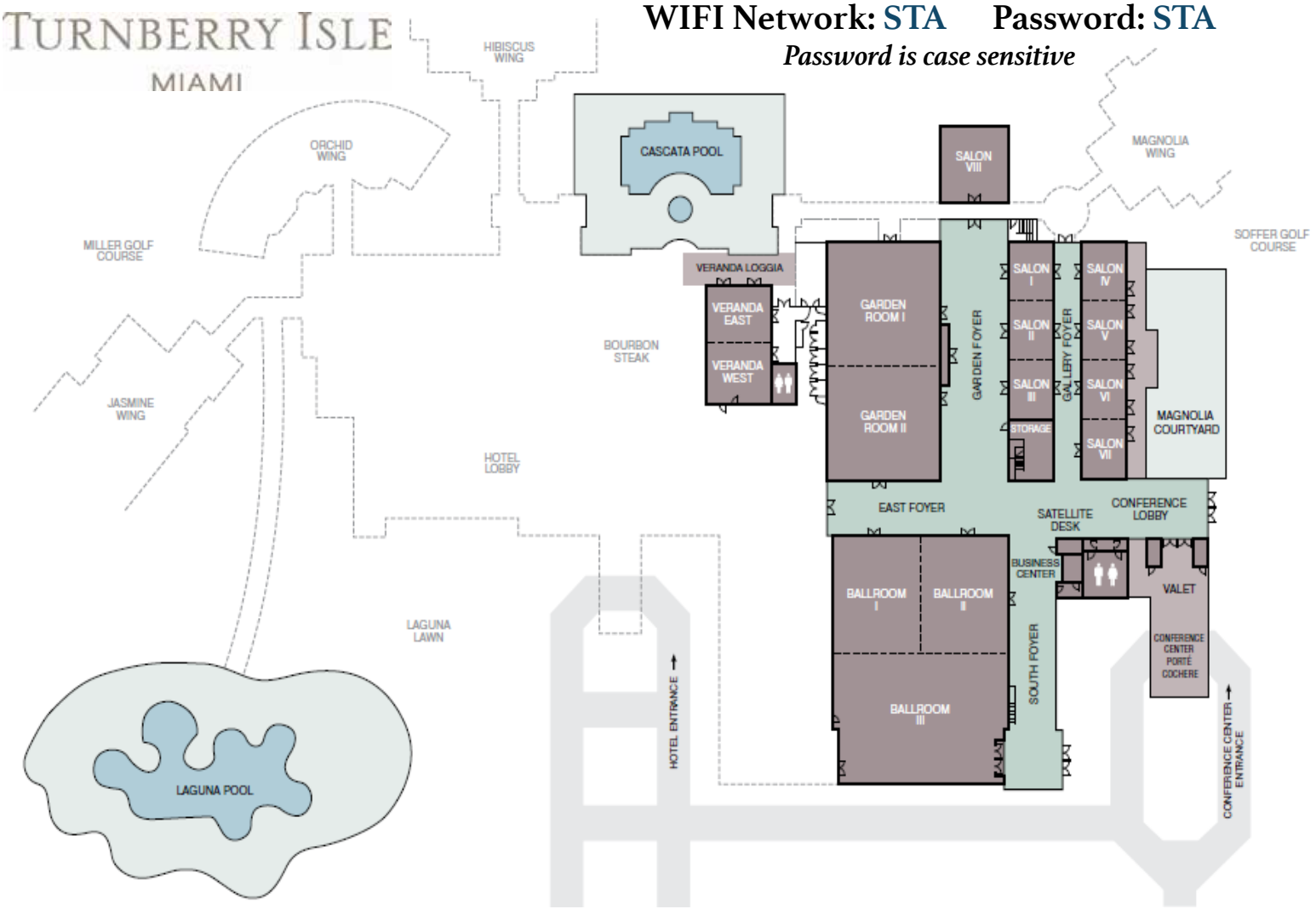

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- EHRC Technologies
- Respiratory Motion, Inc.
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Respiratory Motion, Inc .... www.respiratorymotion.com

SpiraLith Ca..... www.spiralith.com/micropore-inc

Vigilant Labels ..... www.vigilantlabels.com

COMPANY DESCRIPTIONS

AlertWatch

AlertWatch develops integrated decision support software to help anesthesiologists improve quality across the entire continuum of care. The software integrates device and medical record information to produce real-time alerts focused on improving outcomes and reducing length of stay.

Our newest product is AlertWatch:OB, the world's first electronic maternal surveillance system. The software facilitates the early recognition and management of maternal morbidity, including postpartum hemorrhage and severe hypertension. With maternal mortality on the rise in the United States, AlertWatch:OB will become a key part of your labor & delivery unit.

BD

BD is a global medical technology company that is advancing the world of health by improving medical discovery, diagnostics and the delivery of care. BD leads in patient and healthcare worker safety and the technologies that enable medical research and clinical laboratories. The company provides innovative solutions that help advance medical research and genomics, enhance the diagnosis of infectious disease and cancer, improve medication management, promote infection prevention, equip surgical and interventional procedures and support the management of diabetes.

COMPANY DESCRIPTIONS CONTINUED

ClearLine MD
ClearLine MD is founded and funded by forward-thinking device engineers based on first-hand knowledge of an avoidable adverse event, air embolism. The Company is delivering a new standard of care for eliminating reducing potentially dangerous Air Burden by reducing air from IV lines and avoiding the clinical complications associated with air embolism.

Codonics
Codonics Safe Label System (SLS) is the standard of care for medication preparation safety and compliance. Installed in over 5,000 ORs, SLS integrates with anesthesia dispensing carts (ADCs) to provide unparalleled safety and comprehensive barcode labeling. SLS labels integrate with Epic Anesthesia and Plexus Anesthesia Touch for AIMS/EHR documentation, offering a complete solution for barcode medication identification and verification of IV meds at the point of care. An FDA Class II device, the system ensures TJC compliance with best practices and standards to improve patient safety and workflow efficiency. SLS helps to eliminate human error and improves system integration to enhance clinical delivery.

DMF Medical, Inc
DMF Medical Incorporated (DMF) is a Canadian based company with the sole purpose of making anesthesia safer. The company's lead product – memsorb – is a next generation CO_2 filtration device for general anesthesia that uses membrane technology rather than traditional chemical absorption. DMF's filtration technology provides clinical, environmental, cost, and reliability benefits that cannot be achieved with chemical absorbents. This includes a game-changing solution to the known dilemma associated with current CO_2 absorbers and their use in ultra-low flow anesthesia.

Draeger Medical
For more than a century, clinicians have trusted Dräger's innovative anesthesia solutions to improve the practice and business of anesthesia care. To learn about how our anesthesia machines, patient monitors, clinical IT solutions, accessories, and services can make an impact, please stop by our booth at the STA 2018 Annual Meeting.

Edwards Lifesciences
Edwards Lifesciences, based in Irvine, Calif., is the global leader in patient-focused medical innovations for structural heart disease, as well as critical care and surgical monitoring. Driven by a passion to help patients, the company collaborates with the world's leading clinicians and researchers to address unmet healthcare needs, working to improve patient outcomes and enhance lives. For more information, visit Edwards.com and follow us on Twitter @EdwardsLifesci.

COMPANY DESCRIPTIONS CONTINUED

EHRC Technologies

We focus on selling an FDA approved medical device that repairs the skin. On the basis of LED Therapy Red light treatment is completely safe and has no reported side effects. The LED light is known to promote the production of cells & collagen and by doing that it's basically rejuvenating your skin. The red light also is known to reduce melanin (hormone) level in the skin and improve the appearance of age spot and dark spots. Today the LED technology is being also used by therapists for arthritis, joint pain relief, sports injuries of athletes and more. Research done by NASA, it was found that some common side effect of chemotherapy and radiation treatments can be reduced by using the LED light treatment NASA also found it to aid in the healing of human wounds, burns and Diabetic skin ulcers. The kit comes with a high-end skin care to complete the treatment

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GE Healthcare

GE Healthcare provides transformational medical technologies and services to meet the demand for increased access, enhanced quality and more affordable healthcare around the world. GE (NYSE:GE) works on things that matter - great people and technologies taking on tough challenges. From medical imaging, software & IT, patient monitoring and diagnostics to drug discovery, biopharmaceutical manufacturing technologies and performance improvement solutions, GE Healthcare helps medical professionals deliver great healthcare to their patients.

Masimo

Masimo is a global medical technology company that develops and manufactures innovative noninvasive monitoring technologies, including medical devices and a wide array of sensors that may enable earlier detection and treatment of potentially life-threatening conditions. A key medical technology innovator, Masimo is responsible for the invention of award-winning noninvasive technologies that are revolutionizing patient monitoring, including Masimo SET® pulse oximetry, Masimo rainbow® noninvasive and continuous hemoglobin (SpHb®), acoustic respiration rate (RRa™), Masimo Patient SafetyNet™, SedLine® (EEG-based) Brain Function Monitors, and Phasein™ respiratory monitors.

Medtronic

As a global leader in medical technology, services and solutions, Medtronic improves the health and lives of millions of people each year. We believe our deep clinical, therapeutic and economic expertise can help address the complex challenges — such as rising costs, aging populations and the burden of chronic disease — faced by families and healthcare systems today. But no one can do it alone. That's why we're committed to partnering in new ways and developing powerful solutions that deliver better patient outcomes.

COMPANY DESCRIPTIONS CONTINUED

Mindray North America
Mindray, founded in 1991, is a leading global developer, manufacturer, and supplier of medical devices whose mission is to deliver high-quality, richly featured medical products making healthcare more accessible and affordable around the world. Mindray provides solutions in three core businesses: Patient Monitoring and Life Support, Medical Imaging, and In-Vitro Diagnostics.

Neurowave Systems, Inc
NeuroWave is dedicated to improving patient safety, outcome and quality of life by creating innovative monitoring and drug delivery systems using advanced neurophysiological signal processing and control system engineering. In particular, the AutoTIVATM System is being developed for the military to allow for safe and effective delivery of Total Intravenous Anesthesia. This device integrates a proprietary infusion system and a brain monitor with a Physiological Closed-Loop Controller to automatically regulate the infusion rates of propofol and remifentanil based on a setpoint defined by the anesthesia care provider. The AutoTIVA represents a major step forward in Target Controlled Infusion technologies.

Respiratory Motion, Inc.
Respiratory Motion, Inc., brings New Technology to multiple clinical sites of care by non-invasively assessing if the patient is breathing sufficiently to support metabolism and respiration. ExSpironTM, a Minute Ventilation monitor provides Clinicians a superior solution for monitoring ventilation status, including life threatening hypoventilation. Hypoventilation often leads to respiratory failure. ExSpironTM is a technology that detects hypoventilation early than existing technologies including SpO2 and EtCO2.

SpiraLith Ca
Micropore, based in Elkton, MD and Newark, DE is a U.S. based ISO 9001 manufacturing company that produces advanced absorbent systems for the most critical rebreathing and life support applications, including military and commercial diving, submarines, medical devices, mining, and emergency response. Micropore's products, sold under the SpiraLith, ExtendAir, and MicroSep brand names, are manufactured to meet the most stringent and exacting standards for some of the world's most discerning clients including the U.S. Navy, NIOSH and NASA.

Vigilant Labels
Vigilant Labels solves for Anesthesia and PACU syringe labeling challenges through technology that fits the provider's workflow. The Click-to-Comply solution allows providers to print USP 797 compliant labels in just two clicks. Stop handwriting your syringe labels. Stop worrying about Joint Commission or AAAHC site visits. Implement Vigilant Labels Click-to-Comply and simplify the burdens of syringe labeling.

ABSTRACT TABLE OF CONTENTS

* *Best of Show Award*
** *Excellence in Technology Award*
*** *Best Clinical Application Award*
**** *Honorable Mention*

ABSTRACT TABLE OF CONTENTS CONTINUED

* *Best of Show Award*
** *Excellence in Technology Award*
*** *Best Clinical Application Award*
**** *Honorable Mention*

Abstract #	Full Abstract Title	Presenting Author	Institution
27	Applications of Tissue Oximetry in the Assessment of Endothelial Dysfunction-Pilot Study	Abdubadie Kutubi	Yale University School of Medicine
28	Development and Validation of the Integrated Positioning Index (IPI) for Pressure Injury Prevention	Barrett Larson, MD	Leaf Healthcare
29	Development of a Device to Improve the Safety of Video Laryngoscopy	Barrett Larson, MD	Leaf Healthcare
30	VITALDB, A Freely Accessible Intraoperative Vital Signs Database of Surgical Patients	Hyung-Chul Lee, MD	Seoul National University College of Medicine
31	Optimal Insertion Depth of Central Venous Catheter Through the Right Internal Jugular Vein, Verified with Transesophageal Echocardiography	Jiwon Lee, MD	Keimyung University Dongsan Medical Center, Keimyung University College of Medicine
32	Measuring Transient Heart Rate Changes During Noxious Stimulation in Laparoscopic Surgery	Yu-Ting Lin, MD	Taipei Veterans General Hospital
33	Blood Pressure Management Analysis on ICU and Surgical Patients Receiving Vasopressor Therapy	Michael Ma, BS	University of California Irvine
34	One Laryngospasm, Two Realities: The Impact of Data Granularity on Post Hoc Analysis of Perioperative Events	Annie Ma, BS	Children's Hospital of Philadelphia
35	Medication Bar-Code Scanning in AIMS: An Impact Study of Education Efforts and a User-Interface Error on Anesthesia Provider Compliance	Anil Marian, MD, FRCA	University of Iowa Hospitals & Clinics
36	Targeting Blood Pressure by Monitoring Cerebral Autoregulation: Gradient Adjusted Flow-Pressure Curves	Dean Montgomery, PhD	Medtronic
37	Monitoring at Home Before and After Tonsillectomy	Gabby Napoleone, BSc	Digital Health Innovation Lab
38	Comparison of Electromyography Derived Train-of-Four Ratios of the Adductor Pollicis and Abductor Digiti Minimi Muscles and Their Comparison to Acceleromyography Derived Train-of-Four Ratios	Reka Nemes, MD	Mayo Clinic, Jacksonville
39	Can You Turn It Down? Assessing Noise and Distractions from Music in the Operating Room	Daniel Orlovich, MD, PharmD	Stanford University
40	An Observational Study of Peripheral Muscle Oxygenation Using NIRS in a Cohort of Nourished and Malnourished Children with Pneumonia	Roberto Pagano, PhD	University of British Columbia
41	State of Validation Evidence for Computational Models Used for Design and Evaluation of Physiological Closed-Loop Mechanical Ventilation Devices	Bahram Parvinian	Food and Drug Administration
42	Feasibility and Utility of Continuous Noninvasive Hemoglobin Monitoring in the General Care Setting	Irina Perreard	Dartmouth-Hitchcock Medical Center
43	Development of a Method to Determine Geolocations for Anesthesia Specialty Coverage and Standby Call Allowing Return to the Hospital within a Specified Time Interval	Paul Potnuru, MD	University of Miami, Miller School of Medicine
44	Quality: Taking Action When it Matters	Rocky Reston, MD, PhD	Cognitive Medical Systems
45	Closed-Loop Vasopressor Controller Robustness Against Variability in Pharmacokinetics, Pharmacodynamics, and Infusion Line Delay	Joseph Rinehart, MD	University of California Irvine
46	The Effect of Ketamine on Depth of Hypnosis Indices During Total Intravenous Anesthesia – a Comparative Study Using a Novel Case Replay System	Stephanie Schüler	University of British Columbia
47	There's an App for That: Smartphone App Use Among Anesthesia Providers	Rayhan Tariq, MD	Drexel University College of Medicine
48	Automated Email Reminders Significantly Improve Faculty Compliance with Resident Evaluations	Zachary Turnbull, MD	Weill Cornell Medicine
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Extracting Video Heart Rate in Very Low Lighting Conditions

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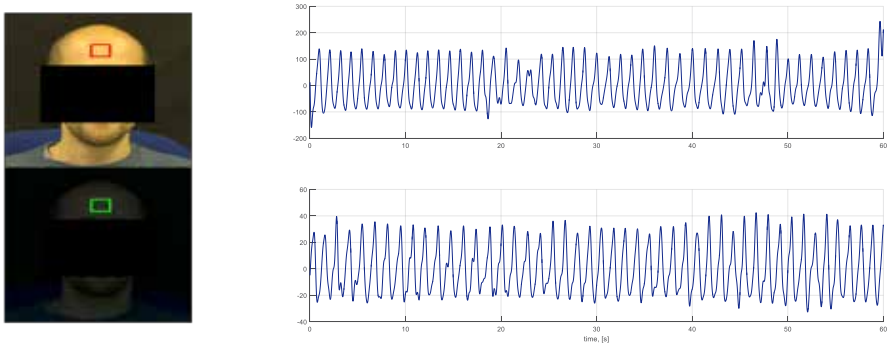
Co-Authors: Dominique Jacquel, PhD, David M.H. Foo, PhD. Medtronic, Minimally Invasive Therapies Group, Edinburgh, Scotland, UK.

Introduction: Video monitoring of the photoplethysmogram (video-PPG) has attracted significant attention in recent years [1]. However, it is susceptible to three main confounders: motion artefacts, lighting levels (both low levels and dynamic variations) and skin pigmentation. Following on from a recent study where we varied lighting conditions by switching on and off additional light sources during a porcine study of desaturation [2], we sought to measure the video-PPG in very low lighting conditions. Here we report on early results which indicate that with high resolution imaging equipment, the video-PPG can be detected in very low lighting conditions, which may mean that it could be suitable for physiological monitoring (e.g. heart rate and respiratory rate) during sleep.

Method: Video was acquired with a Basler RGB scientific camera under two light intensities with the subject in a relatively still position: a 300 lx intensity corresponding to a reasonably low room lighting condition; and 20 lx corresponding to a dark room with the lights off and the blinds closed. The lux measurements were taken at the forehead of the subject using a lux meter. Images from the video stream in each lighting condition are shown in figure 1a. We extracted video from the Region-of-Interest (ROI) on the forehead as shown in the figure. The signals shown in figure 1b were obtained from the average of the green channel in the ROI after band-pass filtering the video-PPG between 0.7 and 3 Hz.

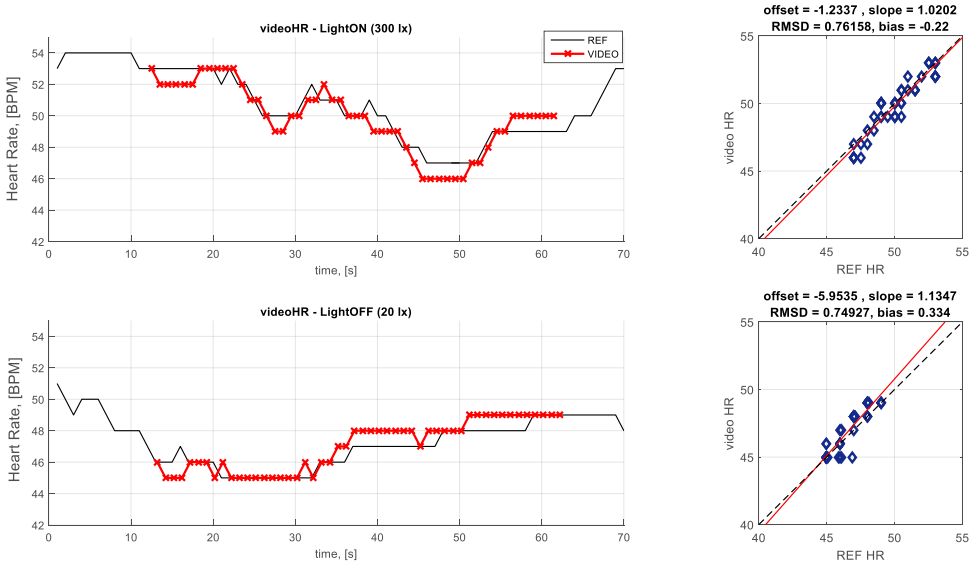


(a) (b)

Figure 1: a) De-identified image with the ROI used for video-PPG extraction (top: 300 lx, bottom: 20 lx). (b) Extracted video-PPG (band-pass filtering between 0.7 and 3 Hz) corresponding with the top and plots to the light levels.

Results:

The heart rates extracted from the two video-PPGs in figure 1b are shown in figure 2a with the corresponding reference heart rate from a Nellcor pulse oximeter (Medtronic, Boulder, CO) attached to the index finger of the subject. The corresponding scatter plots are shown in figure 2b. The root mean square difference (RMSD) between the extracted video heart rate (video-HR) and a reference pulse rate (ref-HR) for the 300 and 20 lx signals was calculated to be 0.76 and 0.74 bpm, respectively.



(a) (b)

Figure 2: (a) The extracted video-HR against the reference HR (b) scatter plots of the video-HR against the reference HR (top=300 lx, bottom=20 lx)

Conclusions:

Reports on video-based physiological monitoring studies are now prevalent in the literature as an increasing number of applications emerge. In a recent editorial in the journal Anesthesia and Analgesia [3], Thiele stated that such video based technologies 'may one day change our lives in ways we cannot imagine'. Our preliminary results demonstrate the determination of heart rate from the video-PPGs under very low lighting conditions. This indicates a potential use within darkened hospital environments without requiring external infrared light sources such as the monitoring of patients during sleep in wards with low level lighting.

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Pilot Study: Utilizing Finger Pulse Oximetry Waveform for Evaluating Endothelial Function

Presenting Author: Nadeem Elbetebsi[1]

Co-Authors: Abdubadie Kutubi[1], Aymen Alian[1], Kirk Shelley[1]

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Introduction: Endothelial dysfunction (ED) is a shift in the vascular endothelium towards vasoconstriction, producing a prothrombotic and pro-inflammatory state. ED is associated with cardiac disease, PVD, DM, and stroke; thus, it is important to screen for ED. The present non-invasive gold standard for assessment is Flow Mediated Ultrasound (FMD), but it is operator dependent, thus, peripheral arterial tonometry (PAT) is the next best method as it is operator independent.
We aim to assess endothelial function using finger pulse oximetry -photoplethysmographic (PPG)- waveforms. Pulse oximeters are cheaper and more readily available.

Methods:
Study Population: With IRB approval, the study was conducted in two parts; part #1 involved 12 healthy subjects, and part #2 involved 10 patients having endothelial dysfunction.
PAT is a non-invasive technique that measures changes in digital blood volume during post ischemic reactive hyperaemia (RH).
Pulse oximeter testing involved placing a probe on a digit in both hands. The RH test started with baseline readings for 6 mins, then the BP cuff was inflated above systolic pressure for 5 mins and then released where a reading of RH was taken for 5 mins.
Data Analysis:
PAT: The software analyses the data and calculates the RH Index (RHI) and its natural logarithm (LnRHI).
LnRHI scores of 0.51 indicates the cut-off point, where values below 0.51 are regarded as having ED.
Pulse oximetry (PPG) waveform processing: We used a high-pass filter of 2 Hz to eliminate the venous modulation of the waveforms. PPG RHI and LnRHI were calculated similarly to PAT.

Results: Comparing the readings of finger PPG to those of PAT established a cut-off point of PPG LnRHI > 0.40.
Part #1: In healthy subjects; 11 showed normal values of PAT LnRHI (above 0.51), with only one subject (#12) who had LnRHI of (0.32). The same was observed with PPG LnRHI. All subjects were above the critical level of (0.4), except subject #12.
Part#2: In patients; the same agreement between the PAT and PPG LnRHI was observed. (Figure 1).
Correlation of PAT LnRHI and PPG LnRHI for all subjects (n=22), $r = 0.713$, $p<0.01$ (figure 2).

Conclusion: When we consider the availability of pulse oximeters, we can see that if they were manufactured with the preceding calculations applied, they would be able to predict

conditions of endothelial dysfunction. Further trials need to be conducted to strengthen this statement.

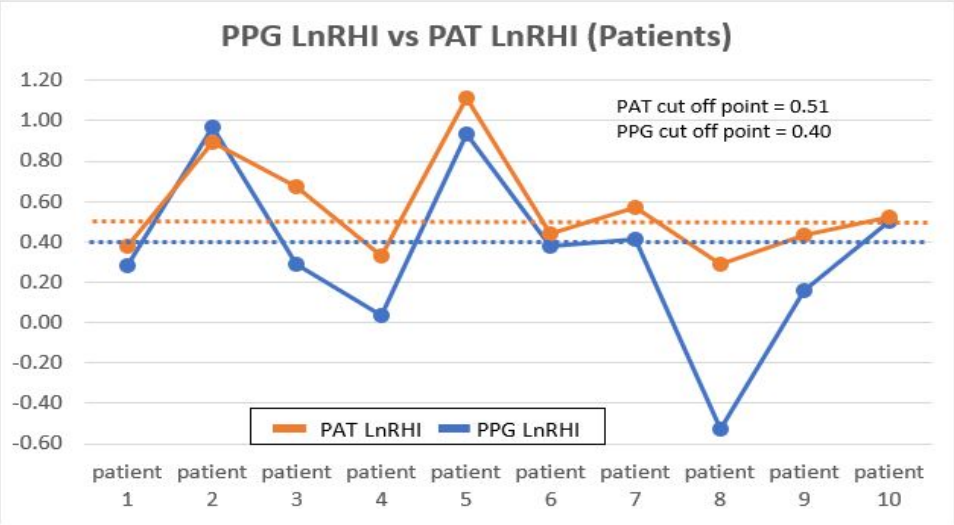

Figure 1 – Graph illustrating the comparison of the PPG and PAT LnRHIs of the Patient group, also delineating a cut-off point of 0.40 for the PPG device

Passive Leg Raise (PLR) Test as a Predictor of Tolerence to Lower Body Negative Pressure (LBNP)

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Co-Authors: Hesham Ezz, MBChB, Yale University, department of Anesthesiology, Jose Chavez, MD, Yale University, department of Anesthesiology, Nadeem Elbetebsi, MBChB, Yale University, department of Anesthesiology, Sophisa Sophonphattana, MD, Yale University, department of Anesthesiology, Kirk Shelley, MD, PhD, Yale University, department of Anesthesiology.

Introduction: Fluid responsiveness (FR) is reported to be the ability to increase stroke volume (SV) in response to fluid administration[1]. Passive leg raising (PLR) creates a transient increase in biventricular preload and has shown the capability to predict fluid responsiveness[2]. LBNP creates a reversible hypovolemic state by sequestrating blood in the lower extremities[3]. This study sought to examine the ability of stroke volume percent change during (PLR) to predict the extent of tolerance to hypovolemia during Lower body negative pressure (LBNP).

Methods: With IRB approval 12 subjects underwent PLR at 45° angle for 2 min followed by progressive LBNP protocol at -15 mmHg, -30 mmHg, -45 mmHg, -60 mmHg, -75 mmHg and -85 mmHg. Each patient was monitored for heart rate (HR), continuous noninvasive arterial blood pressure (CNAP) (CNSystems, Austria), Noninvasive CO monitor (NICOM) (Cheetah medical, MA, USA) streaming stroke volume (SV), cardiac index (CI) noninvasively at 8s intervals. These parameters were measured at baseline, during LRT and during progressive LBNP, Subjects were classified as high tolerance (HT) and low tolerance (LT) based upon the development of symptoms of hypovolemia such as lightheadedness, nausea, diaphoresis and shortness of breath at LBNP -75 mmHg or earlier. Unpaired t-test was used to assess the difference in the mean percent change in SV (ΔSV%), CI (ΔCI%) and HR (ΔHR%) with PLR between the HT and LT groups, *p*-value of < 0.05 was accepted statistically significant. ROC curve was constructed to examine the accuracy of SV change in response to PLR in predicting tolerance to LBNP.

Results: During LBNP 6 out of 12 were (LT) and 6 were (HT). There was a statistically significant difference between the HT and LT groups in terms of ΔCI% and ΔSV% during PLR, while difference in ΔHR% wasn't significant (table-1). Using ΔSV% ROC curve (figure-1) yielded cut-off of (ΔSV% = 12.8%) with 100% sensitivity, 95% CI (54-100%) and 83% specificity, 95% CI (36-99%). AUC is 0.89, 95% CI (0.67-1.1) ($p = 0.025$) to predict tolerance to LBNP-induced hypovolemia.

Discussion: LRT is associated with 300 cc of auto transfusion[4]. Thus, even small volume of fluid will have a great impact on CI attributed to changes in SV and not the HR. A threshold of ≥ 12.8% increase in SV with PLR predicted with great sensitivity the tolerance to central hypovolemia induced by the LBNP model.

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Figure 1:

Table 1	**HT**	**LT**	***p-value***
ΔCI% mean ±SD	9.4 ±8.8	21.8 ±6.3	*0.018*
ΔSV% mean ±SD	8.8 ±7.6	19.1 ±6.7	*0.046*
ΔHR% mean ±SD	0.8 ±3.5	1.9 ±3.3	0.58

Study of the Finger PPG Width During Lower Body Negative Pressure

Co-Authors: Aymen Alian, Hesham Ezz, Jose Gabriel, Abdubadie Kutubi, Kirk Shelley, Anesthesia Department, Yale University School of Medicine.

Introduction: The pulse oximeter waveform reflects volume changes in skin microcirculation. The finger is a more useful and responsive site when compared to the ear when measuring the activity of the sympathetic system. [(1)] The pulse width is more sensitive than other parameters on the PPG waveform in detecting changes in systemic vascular resistance. [(2)] Blood pressure measurements and heart rate (HR) are commonly used for the assessment of hypovolemia. [(3)] Lower body negative pressure (LBNP) creates a reversible hypovolemia by sequestrating blood in the lower extremities. This study sought to determine if finger PPG width, SBP, DBP, MAP and HR measurement will be different between symptomatic (low tolerance to hypovolemia) and asymptomatic (high tolerance to hypovolemia) subjects during LBNP.

Methods: With IRB approval 17 subjects underwent progressive LBNP. Heart rate (HR), continuous noninvasive arterial pressure (CNAP) to determine SBP, DBP and MAP, and finger pulse oximeter were monitored. These parameters were measured during baseline, -30, -45, -60 and -75 mmHg LBNP. The width of the PPG waveform was calculated using Labchart 7. Subjects were divided into low tolerance (LT) and high tolerance (HT) groups based on the development of symptoms of hypovolemia (diaphoresis, lightheadedness, nausea) during progressive LBNP. Subjects that developed symptoms at LBNP of -60 mmHg were assigned to the (LT) group and subjects who did not develop symptoms or developed symptoms at LBNP lower than -75 mmHg were assigned to the (HT) group (high tolerance to hypovolemia). PPG, SBP, DBP, MAP and HR percent change was calculated using: percent change from baseline = 100*((LBNP value – baseline value)/baseline value) and t-test was used. Data was reported as mean ± SD and $p<0.05$ was considered significant.

Results: 2 out of the 17 subjects were excluded from the study due to insufficient data, 9 out of 15 subjects were assigned to the (LT) group and 6 subjects to the (HT) group. Finger PPG width showed significant difference between (LT) and (HT) group at LBNP of -45 and -60 mmHg, as shown in (table 1). There were no significant differences in MAP and SBP variability between (LT) and (HT) groups at any phase during LBNP, results summarized in (table 1). Heart rate showed significant difference between (LT) and (HT) group at LBNP -60 mmHg, as shown in (table 1). Changes from baseline for finger PPG width, blood pressure and heart rate are shown in figures (1 –A) and (1-B) for (LT) and (HT) groups respectively.

Discussion: Early recognition of hypovolemia can be complicated by compensatory mechanisms such as systemic vasoconstriction and blood flow redistribution. Our data shows that SBP and MAP were maintained even with ~1300 cc blood loss (LBNP -60 mmHg). Tachycardia, the first clinical sign of significant hypovolemia, was only seen at ~1000 mL blood loss (LBNP -45 mmHg), and there were no changes in blood pressure detected. On the other hand, the finger PPG width showed significant reduction at LBNP -45 and -60 in the LT group while no changes in blood pressure were detected.

Conclusion: the PPG waveform width could be a reliable tool for early detection of hypovolemia.

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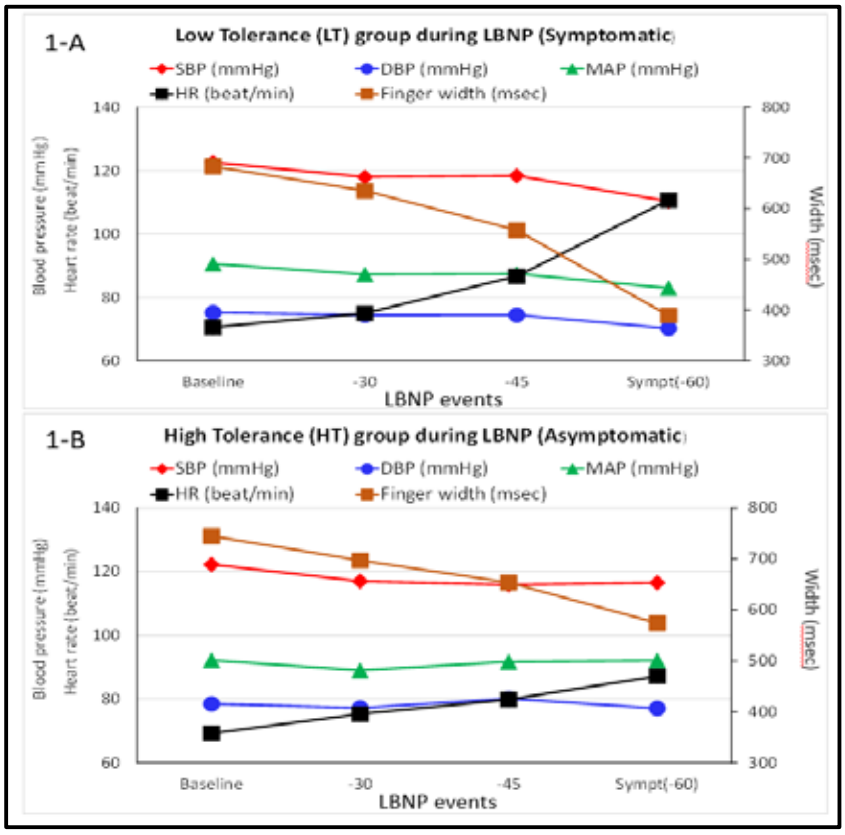
Table 1: summarized the average ±(SD) of finger PPG width, SBP, DBP, MAP and HR during different phases of LBNP (baseline, -30 mmHg, -45 mmHg, and -60 mmHg). LT: low tolerance for LBNP (symptomatic at LBNP -60 mmHg), HT: high tolerance for LBNP (Asymptomatic at LBNP =-60 mmHg). SBP: Systolic blood pressure, DBP: diastolic Blood pressure, MAP: mean arterial pressure, HR: heart rate.

* P value < 0.05. % change = 100*((LBNP value – baseline value)/baseline value)

Figure 1.

			LBNP events				% Change		
	Variables		Baseline	-30	-45	Sympt(-60)	-30	-45	-60
LT	SBP (mmHg)	Average	123	118	118	110	-4	-4	-10
		SD	17	20	21	25	7	10	15
LT	DBP (mmHg)	Average	75	74	74	70	-1	-1	-7
		SD	9	8	10	12	6	6	13
LT	MAP (mmHg)	Average	91	87	87	83	-4	-4	-8
		SD	10	9	11	14	4	5	13
LT	HR (beat/min)	Average	71	75	87	111 *	6	23	58
		SD	11	12	15	19	6	10	20
LT	Finger width (msec)	Average	683	635	558*	389 *	-6	-18	-42
		SD	73	88	94	116	13	16	20
HT	SBP (mmHg)	Average	122	117	116	117	-4	-5	-5
		SD	12	10	11	15	3	6	7
HT	DBP (mmHg)	Average	79	77	80	77	-2	2	-2
		SD	9	9	12	11	2	11	6
HT	MAP (mmHg)	Average	92	89	92	92	-3	0	0
		SD	10	11	13	13	2	9	9
HT	HR (beat/min)	Average	69	75	80	87	9	16	27
		SD	9	10	9	7	5	5	13
HT	Finger width (msec)	Average	745	697	654	574	-6	-12	-22
		SD	102	131	92	131	15	11	17

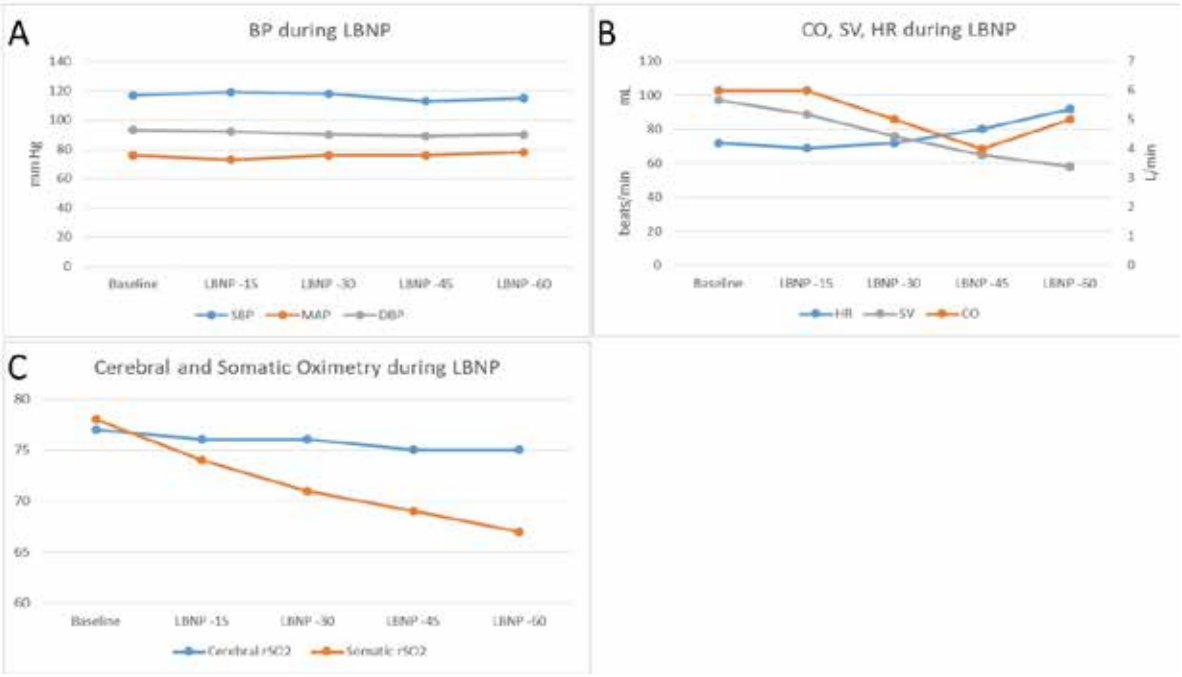

1-A
Low Tolerance (LT) group during LBNP (Symptomatic)
SBP (mmHg)
DBP (mmHg)
MAP (mmHg)
HR (beat/min)
Finger width (msec)
Blood pressure (mmHg)
Heart rate (beat/min)
Width (msec)
140
120
100
80
60
800
700
600
500
400
300
Baseline
-30
-45
Sympt(-60)
LBNP events
1-B
High Tolerance (HT) group during LBNP (Asymptomatic)
SBP (mmHg)
DBP (mmHg)
MAP (mmHg)
HR (beat/min)
Finger width (msec)
Blood pressure (mmHg)
Heart rate (beat/min)
Width (msec)
140
120
100
80
60
800
700
600
500
400
300
Baseline
-30
-45
Sympt(-60)
LBNP events

Cerebral vs Somatic Oxygenation as an Early Detector of Hypovolemia

Presenting Author: Aymen Alian, MD - Yale University School of Medicine
Co-Authors: Christopher Choi, MD; Hesham Ezz, MBBCh; Nadeem Elbetebsi, MBBCh; Kirk Shelley, MD,PhD - Yale University School of Medicine

Abstract Content: Technology for measuring tissue oxygen saturation based upon near infrared spectroscopy (NIRS) has become more sophisticated, allowing for reliable measurements of cerebral and regional circulations. Whereas the traditional pulse oximeter monitors peripheral oxygen saturation in pulsatile (arterial) blood, NIRS can identify tissue hypoxia in the absence of macrocirculatory changes (1). We hypothesized that continuous tissue oximetry can detect early changes in local perfusion secondary to hypovolemia that are not reflected by systemic hemodynamic variables alone. 22 healthy volunteers underwent a lower body negative pressure (LBNP) protocol, a well-known method for simulating hypovolemia (2). Cerebral and somatic sensors, five-lead EKG, finger pulse oximetry, blood pressure (BP) and non-invasive cardiac output monitors were applied to all subjects. BP, cardiac output as well as oxygen saturation were maintained during progressive hypovolemia (A). Somatic oxygenation decreased significantly (P≤0.006) from baseline starting at -15 mmHg and with progressive increases in LBNP, whereas cerebral oxygenation was maintained until -45 mmHg (C). HR showed significant changes only at -45 and -60 mmHg (B). Recognition of hypovolemia can be complicated by compensatory mechanisms such as systemic vasoconstriction and blood flow redistribution. Indeed, in our data, BP and cardiac output were maintained with progressive hypovolemia. Tachycardia, the first clinical sign of significant hypovolemia, was only seen at ~1000 mL blood loss. In contrast, somatic tissue oxygenation was significantly decreased starting at ~333 mL blood loss. Our data shows somatic tissue oxygenation as a promising perfusion-based tool for early recognition of hypovolemia.

Images:



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2. J Appl Physiol 2004;96:1249-61

The Effect of Ketamine on EEG and WAV_{CNS} During Induction of Anesthesia

Presenting Author: J. Mark Ansermino, FRCPC*

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Background: The processed electroencephalogram (EEG) depth-of-hypnosis (DoH) indices may not be reliable when multi-modal anesthesia, particularly when ketamine is used. Low dose ketamine administered as a sole anesthetic agent introduces high β- and low γ-band oscillations (25-32 Hz) [1]. The WAV_{CNS} (NeuroSENSE, NeuroWave Systems) DoH index is predominantly determined by EEG in the γ-band (32–64 Hz), and may therefore be affected by ketamine. If ketamine is co-administered with propofol, the EEG signature resembles the propofol signature, where ketamine shifts the peak of α spindles to higher frequencies [4]. Ketamine had limited effect on the WAV_{CNS} index during steady-state propofol-remifentanil anesthesia [5]. Conflicting results on the effect of ketamine on other pEEG monitors have been reported. The aim of this study was to evaluate the validity of the WAV_{CNS} index to guide propofol infusion in the presence of analgesic ketamine dosing as recommended by guidelines on the management of postoperative pain (*recommended dose*) [2]. We examine the effect of ketamine with propofol-remifentanil anesthesia on the WAV_{CNS} index and on the raw EEG during induction of anesthesia.

Methods: Following research ethics board approval and written informed consent, 30 ASA I-II adults aged 18-54 years were randomized to one of three groups. Group 0.5 received the *recommended dose* of ketamine; a bolus of 0.5 $mg \cdot kg^{-1}$ immediately before induction of anesthesia, followed by a 10 $mcg \cdot kg^{-1} \cdot min^{-1}$ infusion until last suture. Group 0.25 received a bolus of 0.25 $mg \cdot kg^{-1}$ followed by a 5 $mcg \cdot kg^{-1} \cdot min^{-1}$ infusion. The control group received no ketamine. All participants received a bolus of 1.0 $mcg \cdot kg^{-1}$ remifentanil and a bolus of 1.5 $mg \cdot kg^{-1}$ propofol for induction of anesthesia. Additional propofol doses (0.5 $mg \cdot kg^{-1}$) were administered as required. Anesthesiologists were blinded to the WAV_{CNS}, but not to the ketamine dose. The attending anesthesiologist evaluated adequacy of anesthesia using standard clinical signs. The EEG power spectral density was evaluated using the multi-taper method [3]. Results are expressed as median [Q_1, Q_3] and compared to the control group using a two-tailed Wilcoxon rank-sum test.

Results: EEG data were available for 28 cases (22 males, 29 [26, 37] years, 84.0 [74.5, 95.8] kg, 180.2 [175.3, 185.4] cm). Total propofol induction dose was 1.5 [1.5,2.5] $mg \cdot kg^{-1}$ in Group 0.5 ($p=0.27$), 2 [1.5,2] $mg \cdot kg^{-1}$ in Group 0.25 ($p=0.41$) and 2 [2,2] $mg \cdot kg^{-1}$ in the control group. The peak of the α-spindles (8–16 Hz) shifted to higher frequencies with increasing doses of ketamine (Fig 1A). Normalized power in the β- (16–32 Hz) and γ-band (32–64 Hz) also increased with increasing ketamine doses (Fig 1A). The WAV_{CNS} trends in Group 0.5 showed temporarily elevated values with a median of over 60 (Fig 1B), while individual blood pressure and heart rate trends showed no significant response to stimulation during airway instrumentation. The

elevated WAV_{CNS} values coincided with peak frequency (Fig 1C) and normalized γ-power (not shown) exceeding their respective steady-state values during maintenance of anesthesia. Transient increases were not observed in Group 0.25, where interpatient variability was large (not shown).

Conclusion: The *recommended dose* of ketamine, with propofol-remifentanil anesthesia, does not introduce high β- and low γ-band oscillations seen with ketamine when used as a sole agent. We did observe a dose-dependent shift in the peak frequency, consistent with previous reports [4]. We speculate that the recommended bolus of 0.5 mg/kg of ketamine (Group 0.5) introduces a peak in ketamine EEG effect following induction of anesthesia, which exceeds the effect of the corresponding maintenance infusion of 10 $mcg \cdot kg^{-1} \cdot min^{-1}$. This observation needs to be confirmed in a larger study. The median of the corresponding WAV_{CNS} values in Group 0.5 was also above the recommended [40-60] range.

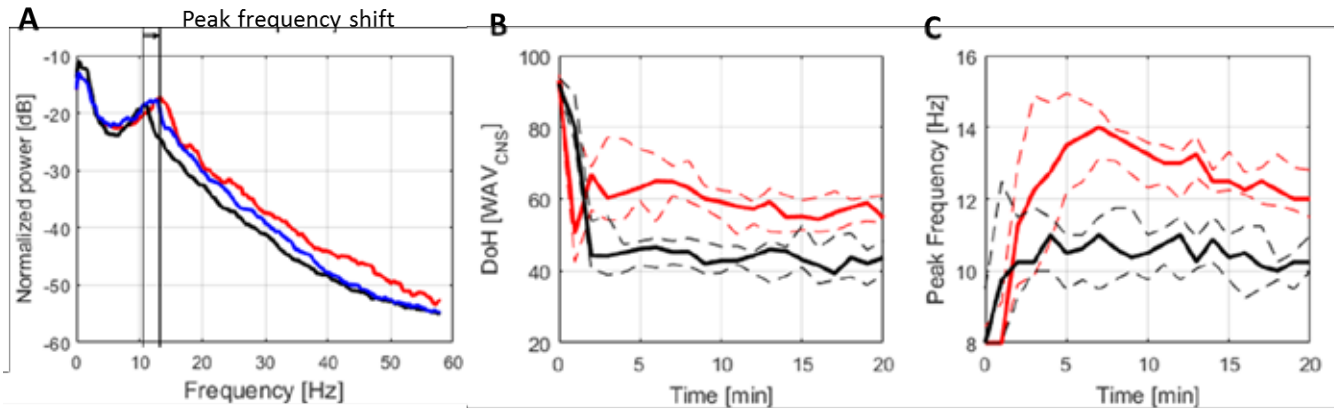

Figure 1. WAV_{CNS} trends and EEG spectral characteristics for Group 0.5 (red), Group 0.25 (blue) and the Control group (black). Fig1A shows EEG power, normalized over the 0-64 Hz frequency range, at 5 min after the start of propofol infusion. Fig1B and 1C show the WAV_{CNS} and peak frequency trends. Median values are indicated by solid lines, IQR is indicated by dashed lines (10 second averages shown each minute).

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PVP Variability During Leg Raise Test to Predict Hypovolemia During Lower Body Negative Pressure

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Introduction: The venous system is a low pressure highly compliant system that can accommodate large changes in volume with only minimal changes in pressure[1]. The impact of respiratory and cardiac pulse on PVP waveforms during hypovolemia can be isolated by frequency analysis and could identify hypovolemia before detectable hemodynamic changes[2]. During leg raise test(LRT) there is an auto-transfusion of 300 cc of blood from the lower limbs to the central circulation. Lower body negative pressure(LBNP) chamber creates a reversible hypovolemia by sequestrating blood in the lower extremities. We were interested to study the impact of LRT on PVP and whether the change in PVP during LRT may be used as a predictive tool to determine the tolerance to hypovolemia during LBNP.Our hypothesis is that subjects who have low tolerance to progressive LBNP will be associated with lower PVP and higher PVP variability during LRT.

Methods: 17 subjects underwent LRT and LBNP. Each onewas monitored for heart rate (HR), CNAP, PVP waveforms and NICOM to measurecardiac output(CO)at baseline, during LRT for 2 min and during progressive LBNP at -15, -30, -45, -60, -75 and -85 mmHg. 7subjects were excluded because of insufficient data.Subjects who developed symptoms of hypovolemia at LBNP of -60 mmHg were classified as having low tolerance(LT) to LBNP and subjects who developed symptoms at LBNP lower than -75 mmHg or did not develop symptoms, as having high tolerance(HT) to LBNP. The PVP variability was calculated using ΔPVP% =100*((LRT value – baseline value)/baseline value). Results were reported as mean±SD, t-test wasused to determine the differences in PVP and ΔPVP% between (HT) and (LT) groups.ROC curve of ΔPVP% was made to determine the ability of ΔPVP% during LRT to predict tolerance during progressive LBNP.

Results: 5 out of 10 subjects were (LT) and 5 were (HT).There were no significant differences in BP, HR and CO between groups. WithLRT, there was a significant increase in the PVP. The average PVP values were 10 ±4 and 17 ±2 mmHg for (LT) and (HT) groups respectively ($p < 0.05$), as shown in figure 1(A and B). The ΔPVP% were 61±26 and 21±16 for (LT) and (HT) subjects respectively ($p < 0.05$). The ΔPVP% ROC curve at a cutoff point of ≥30% had a sensitivity of 100% and specificity of 60% (figure 2).

Discussion: All (LT) subjectshad a ΔPVP% ≥ 30%.(LT) group had lower meanPVPand higher ΔPVP% during LRT.(HT) group had higher PVP values at baseline and lower ΔPVP% during LRT. These results support our theory that (LT) subjects had a more compliant venous system.

Conclusion: PVP changes during LRT maybe a useful tool to be used for the prediction of tolerance to LBNP induced hypovolemia.

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2. Alian AA, Galante NJ, Stachenfeld NS, Silverman DG, Shelley KH. Impact of lower body negative pressure induced hypovolemia on peripheral venous pressure waveform parameters in healthy volunteers.Physiol Meas. 2014 Jul;35(7):1509-20.

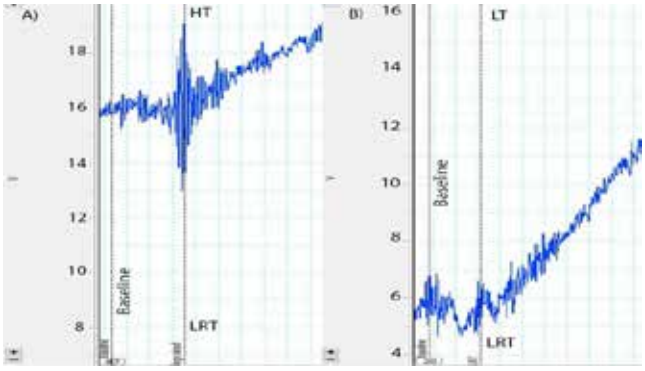

Figure 1. PVP tracing before and after LRT from (HT) subject (1-A) and (LT) subject (1-B).

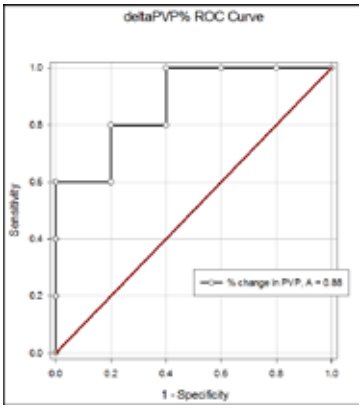

Figure 2: ROC curve of PVP variability, ΔPVP% ≥30% with sensitivity of 100% and specificity of 60%.

Communicating with Anesthesia Technicians in the 21st Century: An App-Based Approach to Supply-Chain Management

Presenting Author: Rohit Choudhary, MD

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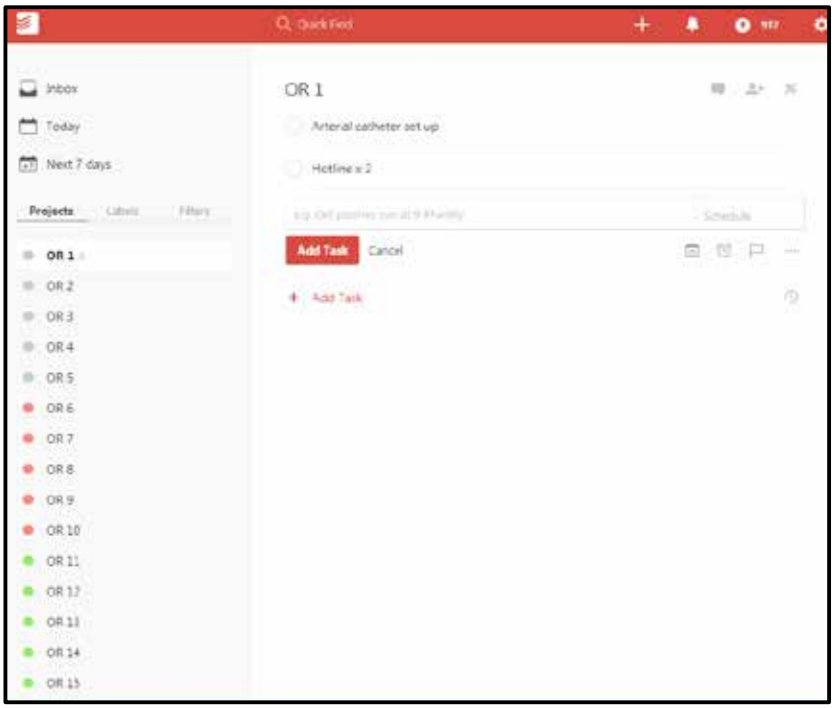
Background: Primary methods of communicating between anesthesia providers and technicians include the use of telephones, paging systems, written notes, etc. Effective, efficient, and accurate means of communication between providers and technicians is crucial to optimizing operating room turn over and enhancing productivity. There are numerous free third party, web based applications for Windows, Mac, Android, and iOS platforms which offer the ability to create instant, auto-syncing lists of tasks that can be updated and tracked in real time. Integrating this type of application with the already existing internet enabled Local Area Network (LAN) is simple and would allow for a cost-effective method to improve supply and equipment management within the operating room environment.

Methods: *Todoist* is a multiplatform, customizable, auto-syncing web based application that allows one to create and organize lists of tasks. The application was initially setup in a way to include all of the hospital operating rooms from 1-20 as well as all off-site locations such as the GI, IR, and MRI suites. The application itself can be readily accessed with a web browser on Windows and Mac computers and can viewed via the *Todoist* mobile application on Android and iOS platforms. The anesthesia provider simply selects the desired location and then free-texts items that he needs for the first case of the day or next case. The anesthesia technicians check the application and see if there are any pending items associated with any location before case start. The technicians would then select and complete the items as they are finished. In an effort to facilitate use of the application, an iPad was hardwired and mounted on the wall next to the anesthesia stock room so the technicians would be able to easily access the information within *Todoist*. Both anesthesia providers and technicians were given a pre- and post-survey regarding the usefulness of the new application. Likert scales were developed to survey ease of use, convenience, and overall satisfaction.

Results: The pre-survey indicated that both anesthesia providers and technicians believed that the former method of calling or leaving notes could be improved upon. Users of the *Todoist* application reported that it was easy to use and served as a better and more accurate way to communicate between the two groups. The anesthesia providers could update the app the night before and the technicians could start completing their tasks when they arrived early the next morning without having to wait for a call or page. Also, the application could be easily updated between cases in order to facilitate efficient anesthesia operating room turnover.

Conclusion: Auto-syncing, multiplatform, web based task manager applications such as *Todoist* offer a cost-effective and simple way to easily improve communication between anesthesia providers and technicians in the context of improving anesthesia OR room setup ready time and

Figure 1: Screenshot of *Todoist* web-based portal



OR turnover. Having a hard-wired, wall mounted iPad with the *Todoist* application installed near the anesthesia supply room did allow the technicians to fulfill the requested tasks that were updated via the application. Additionally, technicians also were able to install the application on their personal mobile devices to further help facilitate their work. One complaint was the lack of push notifications when updating the application with new tasks/items. Future work will aim to create an application de novo with this functionality and have it readily available on all OR computers. Also, a study will be done analyzing any difference with respect to anesthesia ready times before and after the integration of this *Todoist*.

Honorable Mention

3D Printed Thermal Powered Laryngoscope

Presenting Author: Michael Dinsmore B.Sc, PhD, MD, FRCPC, Clinical Fellow Department of Anesthesia, Toronto Western Hospital

Co-Authors: Vivian Sin, Lab Research Project Manager (CIGITI group), Hospital for Sick Children, Clyde Matava MB ChB, MMed, Department of Anesthesia, Hospital for Sick Children

Introduction: Laryngoscopes are a fundamental and necessary piece of equipment used by every anesthetist on a regular basis. They are a mechanically simple piece of medical equipment, but rely heavily on a properly functioning light source. Current models consist of a metal/plastic handle that encases a halogen/LED light powered by a disposable/rechargeable battery. The handle is designed to allow the attachment of multiple different blades for intubating patients of various ages and anatomical differences. Although laryngoscopes are often available in developing countries, antidotal evidence suggests they are often missing a functional light source. Anesthesia in developing countries must take into account local conditions and whether reliable supplies such as batteries or electricity are readily available. Only 34% of hospitals have reliable electricity access in sub-Saharan African countries and therefore Laryngoscopes with rechargeable batteries would not be a reliable option[1]. Alternatively, lower cost LED laryngoscopes are becoming much more widely available, but batteries are expensive, often difficult to attain and deteriorate through use and over time. In addition, used batteries that are not properly recycled lead to toxic effects on the environment and potentially harmful consequences to the surrounding communities. Therefore, the aim of this research is to develop a low cost 3D printed laryngoscope with a completely green, clean and renewable light source that is powered only by thermal energy produced by the user's hand when holding the laryngoscope.

Materials and Methods: The device contains an external 3D printed shell that is designed to contain at least one thermoelectric generator (Peltier Tile) extending through an open portion of the exterior for direct contact with the users hand in order to extract the maximum heat from the users left hand. The inner surface of the thermoelectric generator is attached to an aluminum heat sink with multiple cooling channels in order to optimize the temperature gradient across the thermoelectric generator. Integrated circuitry consisting of a commercially available step-up transformer and transistor oscillator in direct electrical communication with both the thermoelectric generators and the light source are housed within the handle.

Results: Optimization has included increasing the number of tiles in sequence in order to reach a maximum brightness of 204.1 ± 11.7 Lux using 4 tiles. Time decay was linear with the average initial brightness of 193.8 ± 40.1 Lux decreasing to 142.3 ± 27.3 and 103.4 ± 20.7 at 60 sec and 120 sec respectively. Further optimization includes handle design and heat sink optimization.

Reference:

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Best Clinical Application Award

Feasibility of Panda, a Pediatric Post-Discharge Pain Management Smartphone Application for use by Parents

Presenting Author: Dustin Dunsmuir[1,2] MSc

Co-Authors: Helen Wu[1,2], Terri Sun[1] MD, Nicholas West[1,2] MSc, Matthias Görges[1,2] PhD, Gillian R Lauder[1,3] FRCA, J Mark Ansermino[1,2,3] FRCPC.
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Introduction: As the number of pediatric outpatient surgeries increases [1], it is important to empower families to adequately manage their children's pain in the days following surgery. Some families poorly manage their child's postoperative pain at home [2], and this can cause significant behavioural issues such as eating problems and anxiety [3]. The reasons for poor post-operative pain management include inadequate discharge instructions, failure to appropriately assess pain [2], inability to recall medication instructions [2], and underestimation of a child's pain [3]. To address these problems, we have developed Panda, a smartphone application (app) that alerts parents when to give medication and provides a standardized and validated tool for parents to assess their child's pain (Figure 1). This study evaluated the feasibility of providing the Panda app to parents for use at home, based on their compliance and satisfaction with the app.

Methods: Following ethical approval and informed consent, families used Panda for 1-7 days at home after their child's surgery. With assistance from a research assistant, parents set up user preferences and a medication schedule on either a research device or their own personal Apple or Android phone. At each scheduled notification, the parents used validated pain assessment tools and safety checks before completing the administration of medications. Data collection consisted of an audit function recording all actions within the app, responses to app alerts (pain scores and medication given), feedback through a post-study structured telephone interview, and the completion of the Computer Systems Usability Questionnaire (CSUQ) [4].

Results: Twenty-nine families were recruited to use the app and completed a post-study interview. Recruitment was done in 3 rounds with small improvements, such as graphics and alert noises, made between rounds. Families received an average of 13 alerts during the study period, 46% were responded to within an hour and 74% were responded to before the next alert occurred. The CSUQ was completed by 22/29 (76%) families. The median (interquartile range [IQR]) CSUQ approval rating was 2 (1-3) "agree". The most highly rated statement "It was easy to learn using this interface" had a median (IQR) rating of 1.5 (1-2) "strongly agree to agree". In interviews, participants reported the app as easy to use and useful for those who are forgetful, but suggested many ways to expand its functionality and improve its usability. Parents wanted more flexibility and control within the app, including more dynamic medication schedules, custom alerts, and the addition of numeric (adult) pain scales.

Conclusion: We have shown that with minimal help from a research assistant, it is feasible for parents to use this app at home in a real world setting. There are several suggestions to improve the app, which we are currently reviewing. We hope to incorporate the app into standard discharge instruction for outpatient surgeries and to add a healthcare provider communication component in the near future, which will include a hospital-based patient recovery information dashboard receiving pain and medication details from Panda.

References: [1] Pain Res Manage. 2012; 17(5): 328–34. [2] Paediatr Anaesth. 2013; 24(3): 239–48. [3] Arch Dis Child. 2012; 97(10): 879–84. [4] Int J Hum Comput Interact. 1995; 7: 57-78.

Figure 1: The two-step process of responding to a Panda alert is performing a pain check and then safety checks for medication(s).

Comparison of a Wide Respiratory Rate Range Reported from Seven Sensors in Non-Intubated, Spontaneously Breathing Volunteers

Co-Authors: Sean Ermer, B.S.[1], Lara Brewer, Ph.D[1], Joe Orr, Ph.D[1], Talmage D. Egan, M.D.[1,] Ken Johnson, M.D.[1]
[1]University Of Utah, Department of Anesthesia

Introduction: Growing concern over opioid-induced respiratory depression in the post-operative environment has led many experts and consensus guidelines to suggest that all patients receiving opioids be monitored for respiratory rate. Though many potential monitors have been described in the literature, in-depth details regarding the breath detection algorithms are usually scarce. This dearth of information makes comparisons between sensors difficult. The goal of this research project was to create a single algorithm capable of identifying breaths in a multitude of potential monitors. The respiratory rate range analyzed included apnea (zero breaths per minute) to normal (21 breaths per minute) ranges.

Methods: With IRB approval, data were collected from 26 volunteers who were administered target controlled infusions of remifentanil and propofol in order to induce low respiratory rates. Data were collected from a suite of sensors which were analyzed using a single, custom breath detection algorithm. Breath rates derived from a capnometer, oronasal thermistor, nasal pressure transducer, abdomen accelerometer, microphone, photoplethysmogram, and impedance respiratory sensor were compared against breath rates derived from the reference standard of respiratory inductance plethysmography bands (RR range: 0-21 BPM). A Bland-Altman analysis was performed for each signal.

Results: 877 minutes of data were collected and analyzed (For the case of the microphone for which 828 minutes were analyzed). The results of the Bland-Altman analysis are reported in the table below. Of the data analyzed, 407 minutes were at a respiratory rate of 10 BPM or fewer.

	Accelerometer	Nasal Pressure	Thermistor	Impedance	Capnometer	PPG	Microphone
Bias (BPM)	-0.30	-0.40	-0.20	-1.40	0.00	-2.00	-1.70
Std (BPM)	1.89	2.76	2.34	4.95	1.25	4.87	4.52
Upper 95% Confidence Interval (BPM)	3.40	5.00	4.40	8.30	2.50	7.50	7.20
Lower 95% Confidence Interval (BPM)	-4.00	-5.80	-4.80	-11.10	-2.50	-11.50	-10.60

Table 1: Bland-Altman statistics for seven sensors. Values are reported as breaths per minute and are calculated as 'test-signal' minus 'reference signal'. For example, a positive bias means

that the test signal identified more breaths than the reference signal, on average. 877 minutes of data were used for this analysis, except in the case of the microphone where some data became corrupted during the course of the study. As a result, 828 minutes of data were used for that comparison. PPG indicates photoplethysmogram.

Discussion: Creating a single algorithm to identify breaths across multiple signals has both advantages and disadvantages. The primary advantage is that it allows us to perform a more constant comparison among signals by holding algorithm performance constant. It also allows us to analyze a large number of signals relatively quickly instead of developing individual algorithms for each. On the other hand, the algorithm may not be perfectly suited for all signals. The PPG and microphone for example have fundamentally different signal morphologies from the rest. Overall, the results were in line with our expectations. The capnometer and abdomen accelerometer had the best agreement with the reference signal. Most signals displayed a negative bias because sections of low signal amplitude (poor signal quality) in a given signal will heavily underreport respiratory rate. Signals for which this was more common had more negative bias compared to the others. Ignoring these sections, most signals showed relatively standard distributions with low bias to the reference signal.

Comparison of Hypopneic Respiratory Rates Reported from Seven Sensors in Non-Intubated, Sedated Volunteers

Co-Authors: Sean Ermer, B.S.[1], Lara Brewer, Ph.D[1], Joe Orr, Ph.D[1], Talmage D. Egan, M.D.[1,] Ken Johnson, M.D.[1]
[1]University Of Utah, Department of Anesthesia

Introduction: Growing concern over opioid-induced respiratory depression in the post-operative environment has led many experts and consensus guidelines to suggest that all patients receiving opioids be monitored for respiratory rate. Though many potential monitors have been evaluated in the literature, differences in study populations, algorithms, and statistical methods make comparisons between these monitors difficult. To date, no true standard for non-intubated respiratory rate monitoring has emerged in the clinical setting. The goal of this research project was to collect respiratory rate data from a wide set of sensors and perform a comparative analysis while holding as many variables constant as possible. Specifically, we aimed to analyze these sensors' performance in the hypopneic range in order to best understand how they might detect adverse events.

Methods: With IRB approval, data were collected from 26 volunteers who were administered target controlled infusions of remifentanil and propofol in order to induce low respiratory rates. Data were collected from a suite of sensors which were analyzed using a single, custom breath detection algorithm. Breath rates derived from a capnometer, oronasal thermistor, nasal pressure transducer, abdomen accelerometer, microphone, photoplethysmogram, and impedance respiratory sensor were compared against breath rates derived from the reference standard of respiratory inductance plethysmography bands at low breath rates (RR<=10 BPM). A Bland-Altman analysis was performed for each signal.

Results: 407 minutes of data were collected and analyzed. The results of the Bland-Altman analysis are reported in the table below.

	Accelerometer	Nasal Pressure	Thermistor	Impedance	Capnometer	PPG	Microphone
Bias (BPM)	0.10	0.00	0.50	0.60	0.20	0.40	0.20
Std (BPM)	1.08	2.49	2.07	3.92	1.17	3.03	2.15
Upper 95% Confidence Interval (BPM)	2.20	4.90	4.60	8.30	2.50	6.30	4.40
Lower 95% Confidence Interval (BPM)	-2.00	-4.90	-3.60	-7.10	-2.10	-5.50	-4.00

Table 1: Bland-Altman statistics for seven sensors. Values are reported as breaths per minute and are calculated as 'test-signal' minus 'reference signal'. For example, a positive bias means that the test signal identified more breaths than the reference signal, on average. 407 minutes of data were used for this analysis.

Discussion: Through evaluating all seven sensors using the same methods—including the same algorithm, study population, and statistical analyses—we can better compare reported respiratory rate. The abdomen accelerometer and capnometer had the best agreement with the reference. The impedance and PPG sensors had the lowest agreement, as both were subject to a high degree of cardiac noise. Though the nasal pressure and thermistor signals generally showed a high signal-to-noise ratio, they also occasionally suffered from overall low signal amplitude which led to their middling results. The primary hurdle with the microphone was the biphasic nature of the signal which would occasionally cause one breath to be double counted. Overall, an understanding of how these devices perform in the low respiratory rate range may help influence clinical decisions about patient monitoring in the post-operative period.

Closed Circuit Anesthesia is Justified Despite Marginal Cost of Co2 Absorbent

Presenting Author: Christopher Lo, University of Pennsylvania – Wharton School, Philadelphia, PA

Co-Author: Jeffrey M Feldman, MD, MSE, University of Pennsylvania-Perelman School of Medicine, Children's Hospital of Philadelphia. Philadelphia, PA.

Introduction: Closed circuit anesthesia is a method of anesthetic administration where fresh gas flow (FGF) equals oxygen consumption and anesthetic vapors are completely rebreathed. It is the ideal approach to minimizing anesthetic consumption as all of the exhaled gas returns to the patient providing the greatest drug cost savings and minimizing the environmental impact of wasted anesthetic vapor. However, the closed circuit condition also maximizes the utilization of CO_2 absorbent since all of the exhaled CO_2 passes through the absorbent. Given the varying cost and efficiency of CO_2 absorbents, it is possible that the marginal benefit of reducing drug costs in a closed circuit condition is limited by the marginal cost of CO_2 absorbent. This project develops a mathematical model to determine the optimal FGF defined as that FGF where the marginal benefit of reducing anesthetic usage equals the marginal cost of absorbent utilization.

Methods: The mathematical model is designed to calculate the cost per minute of both anesthetic vapor (VCM) and CO_2 absorbents (ACM) as a function of fresh gas flow (FGF). Factors in the model include choice and cost of anesthetic drug, choice and cost of CO_2 absorbent formulation, patient weight and CO_2 absorbent efficiency. VCM is calculated as:

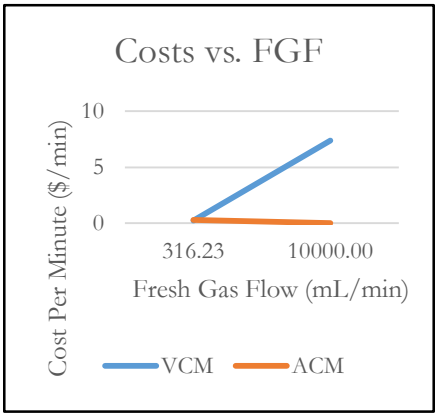
$$VCM = VAP \times FGF \times VL \times V\$$$

where VAP is vaporizer setting in %, FGF is mls/min, VL is mls of liquid/mls of vapor and V$ is the cost of anesthetic in dollars per ml of liquid. The CO2 absorbent cost per minute (ACM) is calculated as:

$$ACM = \frac{CAM \times A\$}{CAG \times A_{eff}}$$

where CAM is the CO_2 absorbed per minute in mls/min, A$ is the absorbent cost in $/g, CAG is the CO_2 absorbed per gram of absorbent in mls/g, and Aeff is the efficiency of the absorbent in %. A closed circuit condition was defined as FGF equal to oxygen consumption (VO_2) as determined by the Brody equation. The maximum FGF was set at minute ventilation assuming this represented an open circuit condition. CAM was based upon CO_2 production (VCO_2) determined by oxygen consumption and a respiratory quotient of 0.8 and estimated as a linear relation from 100% of CO_2 absorbed for a closed circuit and 0% for an open circuit. Conditions that maximize the marginal cost of absorbent and minimize the marginal benefit of vapor savings were based upon cost data for anesthetics and absorbents from our hospital purchasing agent, and published data on absorbent capacity and efficiency.(1,2) Worst case assumptions

that would maximize absorbent cost and minimize vapor savings included a 100 Kg patient, Isoflurane at $0.125/ml and MAC of 1.15%, A$ at $.05/g, CAG of 73 mls/g, Aeff of 50%.



Results: In this worst case scenario, the marginal cost of CO2 absorbent exceeded the marginal benefit of vapor savings by $0.11 per minute or $6.60 per hour when using a closed circuit anesthetic.

Discussion: This model is intended to determine the theoretical maximum cost of CO_2 absorbent and minimum vapor cost savings under closed circuit conditions and showed that the marginal absorbent cost is not very great. Real world results would yield lower absorbent costs and greater vapor savings indicating that closed circuit anesthesia is economically justifiable. There are strategies for minimizing absorbent cost including the choice of absorbent material, and delaying absorbent replacement until inspired CO2 is present. In addition to the economic benefits, the environmental benefits of closed circuit anesthesia are also compelling but are not addressed in this analysis.

References:

1) Knolle et. al. Anesth Analg 2002;95:650.
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Oxygen Reserve Index: Utility as Early Warning For Desaturation in Morbidly Obese Patients

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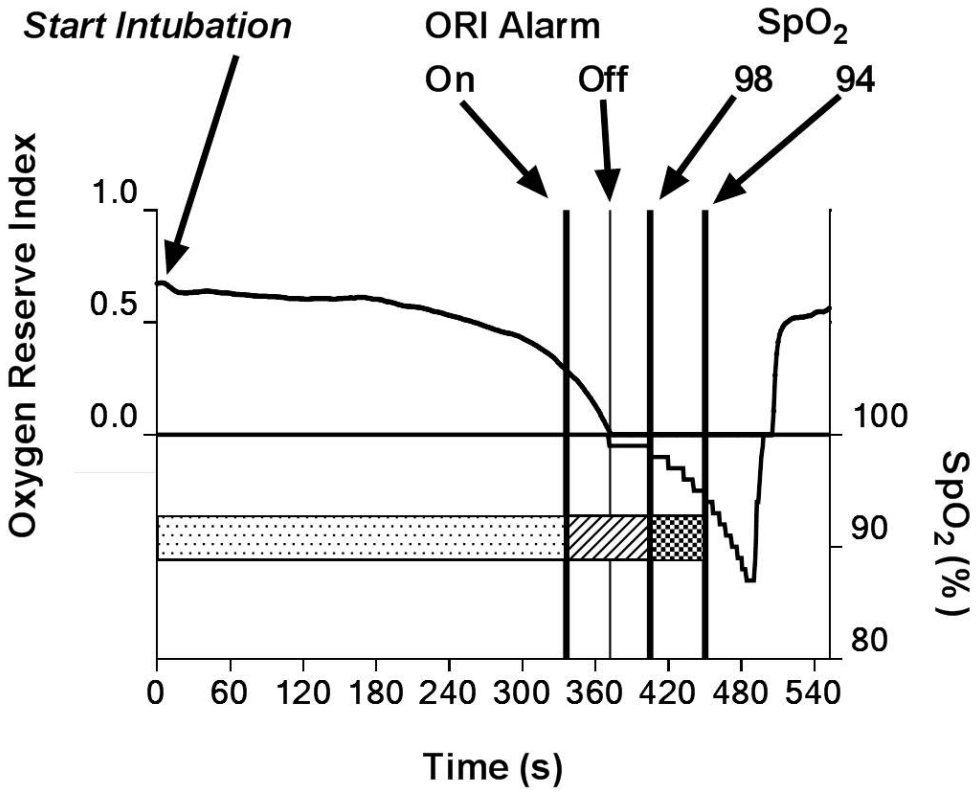
Co-Authors: Sebastian Ayala, BS, Amrik Singh, MD, Richard Applegate II, MD, Department of Anesthesiology & Pain Medicine, UC Davis School of Medicine

Introduction: Expansion of infrared transmission pulse oximetry technology to include multiple wavelengths (7+) provides additional information that has been shown to correlate with moderately hyperoxic arterial oxygen concentrations.[1] This information is characterized as the Oxygen Reserve Index (ORI), a unit-less scale between 0 and 1, that correlates with P_aO_2 values between 100 and 200mmHg. ORI has been shown to provide a clinically useful advanced warning of arterial hemoglobin desaturation in pediatric[2] and critically ill patients.[3] Obese patients are an additional high risk group presenting with increasing frequency for both elective and emergent surgical procedures. Airway management in these patients presents problems associated with both physical and physiological changes of obesity. Pre-oxygenation is more difficult and unpredictable[4], maintenance of a patent airway can be more difficult[5] and obese patients desaturate more rapidly during periods of apnea[6]. As a consequence, arterial oxygen desaturation is more common and more severe in this patient population[7]. This protocol was designed to determine the amount of early warning of impending arterial hemoglobin desaturation provided by ORI in obese patients.

Methods: Written, informed consent was obtained from patients with a BMI>30,<40 m/kg^2 who were scheduled for an elective surgical procedure requiring general anesthesia and endotracheal intubation. Following the placement of standard monitors plus an additional sensor capable of measuring ORI, baseline values were recorded. Patients were then pre-oxygenated with 100% oxygen. When ORI plateaued, general anesthesia was induced with a combination of amnestics, narcotics, intravenous induction agents and muscle relaxants. Endotracheal intubation was accomplished under direct visualization using a GlideScope. When the arterial hemoglobin saturation reached 94% ventilation was initiated with 100% oxygen. Both ORI and arterial hemoglobin saturation were recorded continuously by an automated data capture system.

Results: 40 patients provided written, informed consent. In four patients the ORI sensor failed initial calibration. For the remaining 36 patients there were 19 females and 17 males with an average age of 59±14 years and average BMI of 34±3 (range 30 to 39). The time from the initiation of endotracheal intubation (onset of apnea) to the activation of the ORI alarm, triggered by the value and the rate of change, averaged 4.1±1.3 minutes (range 1.0 to 6.8). The average time to the decrease in arterial hemoglobin saturation to 98% was 4.8±1.5 minutes (range 1.5 to 7.7). The average increase in warning time provided by the ORI (time between ORI alarm start and 98%) was 42±49 seconds (range 5 to 255 seconds). Elimination of two outliers (>2SD) changed the average increase in warning time provided by the ORI to 33±23 seconds (range 5 to 107 seconds).

Conclusion: This study demonstrates the ability of ORI to provide advanced warning of arterial desaturation as an adjunct to SpO_2 in this high risk patient population. This additional warning time can potentially translate to improved patient safety by allowing earlier calls for help, assistance from a more experienced person, or modification of airway management. For this analysis we defined the advance warning to end at 98% SpO_2, with a defined trigger for intervention of 94% SpO_2. In clinical situations where 98% SpO_2 might not be considered to be critical, using a lower SpO2 as the alarm level would increase the advance warning provided by ORI. Further analysis of the correlations of ORI and P_aO_2, the use of ORI as a guide to pre-oxygenation, and its utilization in either ideal body weight or the super morbidly obese patients are areas for future study.



Quantification of Flow-Volume Loops Using a Non-Invasive Respiratory Volume Monitor

Presenting Author: Jenny Freeman, MD, Respiratory Motion, Inc.

Co-Authors: Wael Saasouh, MD, Detroit Medical Center, Jasmin Imsirovic, PhD, Respiratory Motion, Inc.

Introduction: Pulmonary function tests utilize flow-volume loops (FVLs) to help detect, diagnose, and monitor the long-term progression lung disorders such as COPD and asthma. Spirometry is the gold standard for generating FVLs via a forced vital capacity test, which measures the amount of air a subject can forcefully exhale. This test requires the patient to be awake, alert, and cooperative which is not always possible, especially for pediatric or geriatric patients. In addition, tidal breathing FVLs have been used to analyze respiratory function under baseline conditions and monitor real time changes in breathing using respiratory inductance plethismography (RIP) bands. Monitoring tidal breathing FVLs has been proposed as means of monitoring disease progression, responsiveness to therapy, reaction to broncho-constrictive agents, and changes in breathing during exercise, but has not been widely adopted due to technology limitations. The objective of this study was to demonstrate the utility of a non-invasive respiratory volume monitor (RVM) in measuring continuous tidal FVLs in healthy volunteers breathing at a variety of breathing rates in lieu of RIP bands or a spirometer.

Methods: Continuous respiratory data including volume traces were collected using an RVM (ExSpiron 1Xi, Respiratory Motion, Inc., Waltham, MA) from volunteer subjects. Each subject performed 6 breathing trials at 3 different prescribed respiratory rates. In trials 1 and 6, subjects were instructed to breathe normally. In the middle four trials, the subject alternated between fast (25 bpm) and slow (5 bpm) breathing as set by a metronome. Flow traces were generated by taking the first derivative of the volume traces. To reduce breath-to-breath variability, individual breaths were aligned at the start of inhalation with volume and flow set to "zero". For each breathing trial, breaths were divided into equal time segments and averaged across all breaths within each trial to generate an average "representative" FVL. We assessed the characteristics of the shape of FVLs for different breathing trials.

Results: 48 subjects (15 females/33 males, age: 46.1 ± 14.3 years; BMI: 27.6 ± 6.2 kg/m^2, mean ± SD) completed the study. Respiratory rates for the normal, fast, and slow breathing trials were 12.6 ± 0.6 min^{-1}, 24.6 ± 0.1 min^{-1}, and 6.9 ± 0.3 min^{-1} (mean ± SEM), respectively. Figure 1 depicts representative volume (top row), flow (middle row), and FVLs (bottom row) for normal, fast, and slow breathing trials. The FVLs display all breaths during the breathing trials as well as the average inspiratory (green) and expiratory (red) curves. For the normal breathing trial (left column), the FVL has a convex shape with a steady flow during the second half of the expiratory limb. The FVLs during the fast breathing trial are elliptical with a major axis with a steep slope. During the slow breathing protocol, a concave expiratory limb is observed near the end of expiration indicating an expiratory flow limitation which is observed in patients with obstructive lung diseases such as COPD.

Conclusion: In this study we demonstrated the capability of the non-invasive RVM in generating continuous tidal FVLs in healthy volunteers. We observed distinctive shapes of the FVLs when the subjects varied their respiratory rate. While this study was done in healthy volunteers, the results indicate that FVLs generated by the RVM have sufficient sensitivity to be able to identify abnormalities observed in patients with lung diseases. The RVM eliminates the need for a spirometer and vastly expands the potential applications in which FVL can be measured.

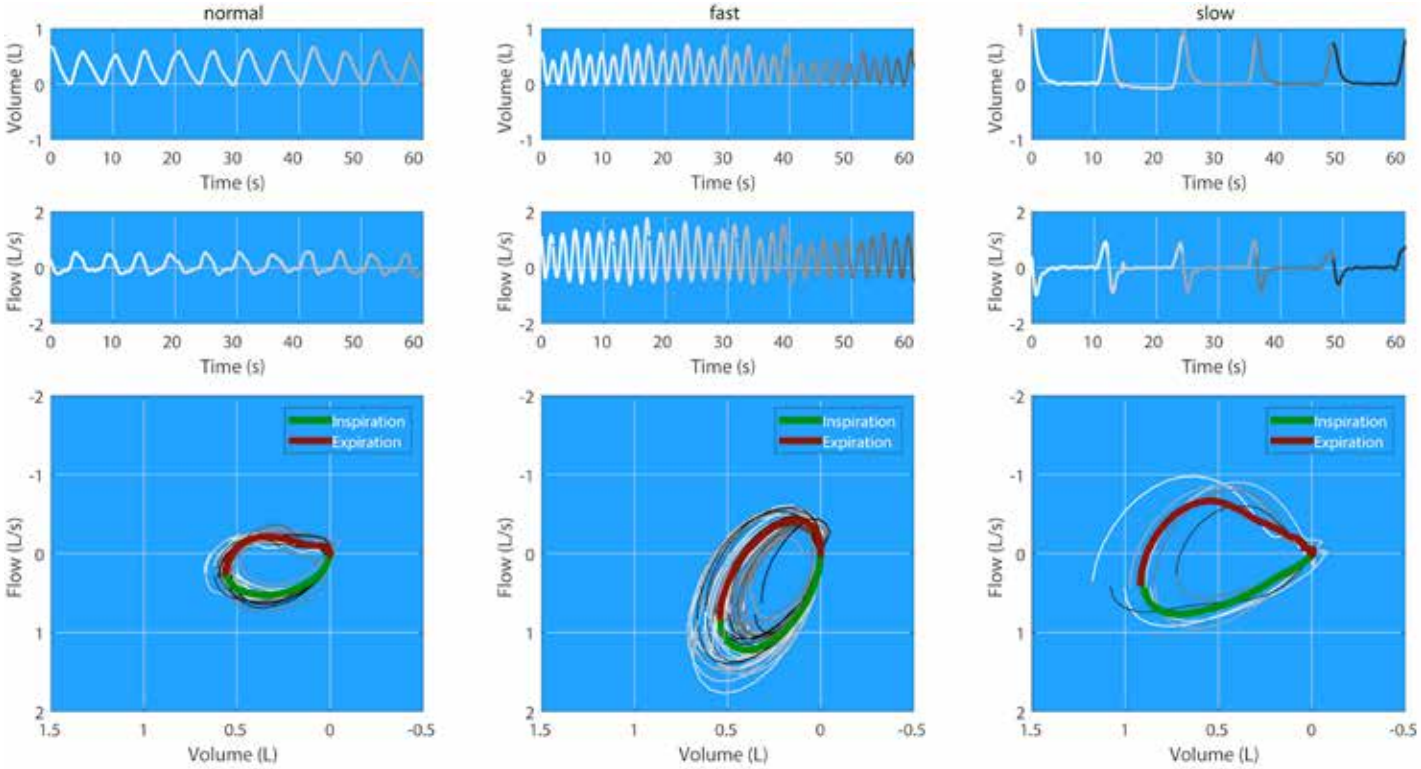


Figure 1. Representative volume (top row), flow (middle row), and flow-volume loops (bottom row) for normal (left column), fast (middle column), and slow (right column) breathing trials. The flow-volume loops display all breaths during the breathing trials as well as the average inspiratory (green) and expiratory (red) curves. Note that both axes are reversed in accordance with common presentation of flow-volume loops.

Pediatric Difficult Airway Diagnoses Mapping to SNOMED CT Terminology

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Introduction: The Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT) is a recognized standard of medical terminology around the world. SNOMED CT describes concepts in relationships to other concepts and in various hierarchies, classifying them in common disease categories. SNOMED CT allows for evolution by allowing multiple synonimcs to be mapped to one unique concept. [1,2]

Pediatric anesthesiologists rely on patient history and physical exam to identify patients that may experience difficult airway management during anesthesia care. The Society for Pediatric Anesthesia's Pedi-R special interest group that maintains a multi-institution registry of patients with known difficult airways and associated conditions.[3] In this study, problems associated with difficult airways were mapped to existing SNOMED CT terms. We present the results of the SNOMED CT term mapping and number of patients with matching diagnoses as well as the incidence of difficult airway diagnoses in this cohort from a single institution cohort.

Methods: We retrieved the list of diagnoses associated with difficult airway from the REDCap database in use by the Society for Pediatric Anesthesia's Pedi-R Special Interest Group. Two authors (Galvez JA, and Cha YM) reviewed the diagnoses and matched them to existing SNOMED CT terms using the International Edition SNOMED CT Browser (4). We retrieved a de-identified dataset from the clinical data warehouse at The Children's Hospital of Philadelphia between January 1, 2016, and December 10, 2017, for patients with an active or resolved diagnosis matching the SNOMED CT terms compiled. My study satisfies the requirements of my institution or organization regarding the use of human subjects in scientific research.
We reported patients with active or completed difficult airway problem, active or completed critical airway, history of general anesthesia, history of tracheostomy, or history of an endotracheal tube. Difficult airway is defined as known difficulty with intubation in the past or anticipated challenges in securing a stable airway. Critical airway is defined as a patient whose airway is unable to be ventilated due to anatomic or other abnormalities if an artificial airway is dislodged, tracheostomy less than 7 days, or airway stent in place.

Results: We matched 141 diagnoses with SNOMED CT codes, of which 52 codes were matched 710 patients in the clinical data warehouse during the study period. 25 diagnoses were linked with difficult airway in active or resolved state (Table 1). Tracheostomy rates ranged from 0-100%.

Discussion: The true incidence of difficult airway for the individual patient populations remains unknown. Mapping the conditions found in the Pedi-R database with a medical terminology standard such as SNOMED CT is one of the necessary steps to study these populations. Furthermore, a validated list of SNOMED CT terms can be organized into a hierarchical grouping of pediatric difficult airway syndromes. This grouping can be applied to population-based studies as well as clinical decision support applications in electronic health record systems around the world. The authors are continuing to work with SNOMED CT international and the Society for Pediatric Anesthesia to achieve this goal.

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Table 1 – Prevalence of SNOMED CT difficult airway terms at The Children's Hospital of Philadelphia

SNOMED CT	Patients (n)	Hx Anesthesia (%)	Difficult Airway		Critical Airway		Tracheostomy		Hx Endotracheal Tube (%)
			Active (%)	Resolved (%)	Active (%)	Resolved (%)	Active (%)	Resolved (%)	
Congenital web of larynx	1	100%	100 %	100%	100 %	0%	100 %	0%	0%
Microstomia	1	100%	100 %	0%	0%	0%	0%	0%	0%
Stenosis of trachea	36	86%	50%	11%	31%	55%	28%	50%	53%
Mucopolysaccharidosis type II	6	50%	50%	0%	0%	0%	0%	0%	0%
Anomaly of chromosome pair 18	2	50%	50%	0%	0%	0%	0%	0%	0%
Ring chromosome 18 syndrome	2	100%	50%	0%	0%	0%	0%	0%	0%

Supernumerary der(22)t(11;22) syndrome	2	100%	50%	0%	0%	0%	0%	0%	0%
Tracheal stenosis following tracheostomy	2	50%	50%	0%	0%	0%	0%	0%	0%
Treacher Collins syndrome	7	29%	29%	0%	14%	100%	29%	50%	14%
Goldenhar syndrome	20	60%	25%	20%	5%	100%	0%	0%	0%
Mucopolysaccharidosis type I-H	4	100%	25%	0%	0%	0%	0%	0%	0%
Robin sequence	47	57%	23%	46%	13%	50%	13%	33%	19%
Acrocephalosyndactyly type V	5	60%	20%	0%	0%	0%	0%	0%	0%
Coloboma, heart malformation, choanal atresia, retardation of growth and development, genital abnormalities, and ear malformations association	23	48%	17%	0%	4%	100%	26%	17%	17%
Complete trisomy 21 syndrome	6	83%	17%	0%	0%	0%	17%	0%	33%
Laryngeal web	8	63%	13%	100%	25%	100%	13%	100%	13%
Complete trisomy 18 syndrome	21	24%	10%	0%	5%	100%	5%	0%	19%
Vallecular cyst	11	82%	9%	0%	0%	0%	9%	100%	9%
Congenital cleft larynx	23	70%	9%	0%	4%	100%	9%	0%	0%
Klippel-Feil sequence	26	35%	8%	0%	0%	0%	0%	0%	0%
Beckwith-Wiedemann syndrome	81	30%	7%	67%	1%	100%	1%	0%	4%

Rubinstein-Taybi syndrome	15	53%	7%	100%	0%	0%	0%	0%	0%
DiGeorge sequence	31	71%	3%	100%	3%	100%	7%	0%	23%
Noonan's syndrome	50	44%	2%	0%	2%	100%	2%	0%	14%
Congenital hypothyroidism	131	25%	1%	0%	2%	100%	2%	0%	9%

Medical Device Cybersecurity Preparedness and Response: Lessons from WannaCry

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Background: On May 12, 2007, the WannaCry ransomware "cyber worm" began attacking Microsoft Windows operating systems, including Electronic Health Record Systems and medical devices, affecting 300,000 users in 150 countries. [1] Sixteen hospitals in the U.K. were affected. [2] Initially, the transmission method and virulence of WannaCry was unknown, therefore the susceptibility of medical devices to WannaCry and the risk of interfering with patient care was uncertain. The need to rapidly assess this risk and develop a response plan was recognized by our healthcare system.

Methods: Although the magnitude of the threat was uncertain, vigilance and preparedness for an impending attack was mandatory. A preliminary Partners HealthCare (an 18-hospital system) emergency Medical Device Cybersecurity Response plan (MD-CRP) was developed and executed.

The emergency MD-CRP included:

Internal Communications

- Identify biomedical engineering (BME) leadership with medical equipment management responsibilities, establish daily meeting schedule.
- Liaise with Information System (IS) leadership and technical experts that are responsible for managing and protecting the hospitals IT network. They have access to real-time threat data and technical expertise to assist with medical device responses.
- As technical details about WannaCry emerged, we hypothesized how and to what extent our medical devices could be affected (i.e. we performed "threat modeling").

External Communications

- Contact medical device manufacturers to inquire about WannaCry vulnerabilities and validate threat models and mitigations.
- Obtain information from HHS Critical Infrastructure Protection briefings and web (ASPR-TRACIE) [3,4]
- Use available information to maintain our situational awareness of the progression of WannaCry

Results: Initiating a multi-hospital MD-CRP on an emergency basis over a weekend was challenging. We established team meetings with leadership responsible for critical patient monitoring, infusion, and anesthetic equipment. We noted that management of medical

devices may be distributed beyond centralized BME. For examples, individual departments may manage their own fleets of ventilators and point-of-care test equipment.

Government information-sharing calls implied that WannaCry attacks were occurring at US hospitals, but specific device types were not disclosed, thus actionable information was not available. Congress held a hearing "Lessons Learned from WannaCry" and refinements to the government's response planning is underway. [5]
We are expanding the medical device cybersecurity-related capabilities of our MD PnP Lab/testbed to support medical device cybersecurity preparedness and response for hospitals systems in collaboration with MITRE and the FDA, and to provide data to researchers in the IMPACT community under a DHS research grant. [6,7] We will hold a "lessons learned" workshop with regional hospitals in January 2018.

Conclusion: The experience of responding to the WannaCry Cyberworm underscores the importance for every hospital system to develop an MD-CRP before it is needed to respond to a cybersecurity threat. Key experts and stakeholders should be included in the MD-CRP. Efficient preparedness and response requires (the elusive) database of all installed medical device and associated systems, including network configurations.

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7. https://www.dhs.gov/csd-impact

BEST IN SHOW

The Feasibility of Anesthetic Drug Delivery by a Valve-Less Micro-Pump

Co-Authors: Kirsten Allen, Christian L Petersen, J Mark Ansermino, Matthias Görges, Digital Health Innovation Lab, The University of British Columbia, Vancouver, Canada

Introduction: Globally, one of the biggest health inequalities is the lack of access to essential surgical services in low resource settings [1]. Safe delivery of anesthesia is crucial to address the need for increased surgical services. Intravenous administration of agents such as ketamine requires less complicated equipment (i.e. syringe pumps) than the administration of volatile agents that need gas delivering anesthesia machines fitted with vaporizers. Even so, conventional syringe pumps remain large, complex and costly. In this study, an alternative method of drug delivery by disposable valve-less diffuser micro-pumps [2] is explored.

Method: A valve-less diffuser pump is realized by the 3D printing of the pump body in resin with 25 µm resolution stereolithography (Fig. 1a). The body is a 6.4 mm thick disc, 25.4 mm in diameter. The driving element is a 20 mm brass disc with piezoelectric coating (a widely available piezo “buzzer”). The disc is driven by an off-the-shelf audio power amplifier causing large oscillations at ~300Hz (Fig. 1b). The difference in flow resistance at ingress and egress of the pump chamber below the disc results in liquid being forced through the pump. The pumped liquid (water was used during testing) is measured by a precision scale as a function of time.

Results: The prototype demonstrated the ability to pump at a rate of 0.85 ml/min (51 ml/h) in the absence of back-pressure, and displayed a linear infusion profile over time (Fig. 1c). This rate is adequate for maintenance of anesthesia but insufficient for induction and bolus action. In addition, the prototype is currently not able to overcome the back-pressure observed in drug delivery when connected to a patient. More optimization is needed to determine whether these shortcomings are fundamental to the valve-less design, or if a more accurate pump body design and a dedicated high-voltage piezo driver can increase rates and overcome the back-pressure.

Conclusion: With further development, it may be possible to realize a coin-sized, disposable anesthetic delivery system, which can be manufactured for a few cents and provide safe drug delivery in resource constrained environments around the world. Such a system might also prove useful for delivering other medications, such as oxytocin.

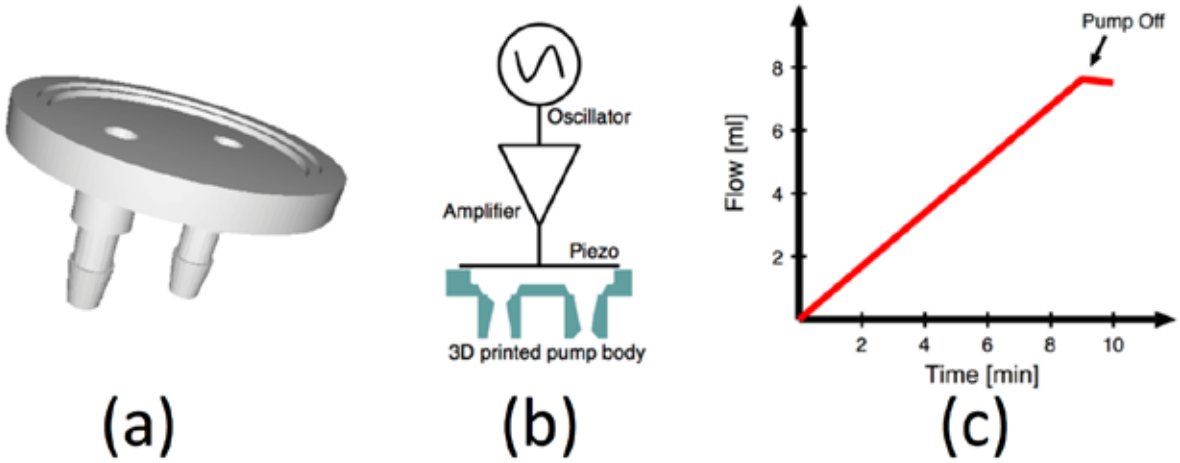

Fig.1: 3D printed micro-pump body (a), system diagram (b) and infusion profile using initial measurements (c).

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Evaluation of a Combined PPG/MPG Sensor in Healthy Volunteers

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Background: Conventional pulse oximetry uses light absorption to detect volumetric changes in arterial blood over time, captured in the photoplethysmogram (PPG) [1]. Complementary data, from a change in blood pressure, will allow for the exploration of the pressure-volume relationships in the cardiac cycle. We previously reported how a brass disk with a ceramic piezoelectric coating can be integrated into a regular pulse oximeter finger boot [2] to obtain a mechano-plethysmogram (MPG). The aim of this work is to refine this prototype and record pilot data in a variety of both positions and vasotonic conditions.

Methods: The optical elements of a Nellcor pulse oximeter clip sensor were mounted in a custom 3D printed shell, allowing a piezo disc to be suspended directly under the photodiode for co-located measurements of PPG and MPG. With research ethics board approval and written informed consent, ten healthy volunteers were recruited. The combined PPG/MPG clip was attached to the index finger of the dominant hand. Participants were seated in a chair. Measurements were taken under five conditions; three positional measurements (a, b and c; performed for 60 seconds each), and two conditions studying vasoconstriction (d) and vasodilation (e).

a) Baseline: sensor slightly below the heart level on a flat surface.
b) Minimum height: hand hanging by the side of the chair.
c) Maximum height: sensor elevated maximally above the head.
d) Cooling: after immersion in ice water (for 60 seconds or as long as tolerated), the hand was placed at baseline height and data was collected for 120 seconds.
e) Warming: after rewarming using a forced air warming blanket (for 5 minutes), the hand was placed at baseline height and data was collected for 60 seconds.

Data from both PPG/MPG were collected with a Datex-Ohmeda S/5 multi-parameter patient monitor synchronously through two identical invasive pressure interfaces at 100Hz. PPG and MPG amplitudes were extracted using MATLAB; their phase delays were calculated using peak time differences; and MPG-PPG loops [3] were created for each position. Comparisons in amplitude and phase were performed using Wilcoxon signed-rank tests, without adjustments for multiple comparisons. To estimate noise, spectrograms of the MPG segments were compared to segments of the first derivative of the PPG.

Results: The data from 10 volunteers show that the MPG is similar, but not identical to, the PPG first derivative. It was possible to determine key features of the cardiac cycle in the MPG waveform including systole, diastole, and the dicrotic notch. Compared to Baseline, MPG amplitude decreased for the Minimum height position (median difference [MD]: -39.0), but not the Maximum height position; vasodilation increased the MPG amplitude (MD: 59.5), but no changes in PPG amplitude were observed (Fig. 1 left). The phase shift between the MPG and PPG was small and did not change with position or vasotonic condition. MPG/PPG loops grew in size with warming and showed additional features (peaks) in the MPG component (Fig. 1 right).

MPG was significantly noisier than PPG, as seen by higher amounts of power across the entire frequency spectrum, particularly in frequencies over 30Hz.

Conclusion: There may exist untapped physiological information about the cardiac cycle (e.g. cardiac valve opening/closing) in the MPG waveform as some peaks and troughs are cleaner and more reproducible in the MPG waveform than the first derivative of the PPG. Future work, including a sensor redesign aimed at improving the signal-to-noise ratio, will explore this opportunity further.

References: [1] Electronics. 2014; 3:282-302. [2] Anesth Analg. 2017;124(5S_Suppl):110-1. [3] J Clint Monit. 1997;13(4):223-8.

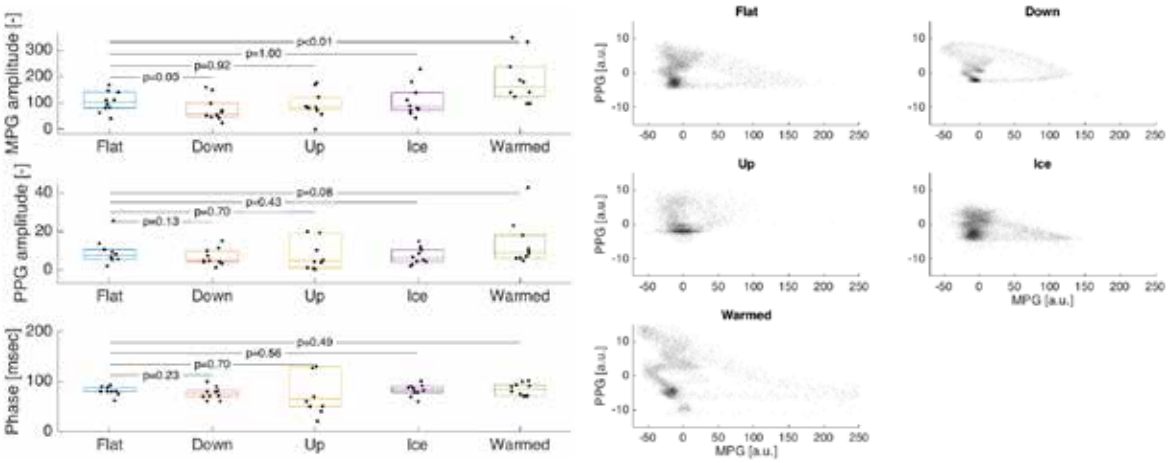

Figure 1: MPG and PPG comparison. The left subplot shows MPG amplitude (top), PPG amplitude (middle) and phase delay of MPG and PPG (bottom) in the three positions (a, Baseline/Flat; b, Minimum/Down; c, Maximum/Up) and (d) vasoconstriction (after cooling in Ice) and (e) vasodilation (after being Warmed); the right subplot shows MPG-PPG-Loops, with MPG waveform values plotted against PPG waveform values for the five conditions (data shown as a heatmap with log-transformed intensity).

Active Air Removal Device Reduces Intravenous Air Burden Introduced by Warmed Fluids

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Background/Introduction: To avoid perioperative hypothermia and possibility of related adverse outcomes the intraoperative use of fluid warmers has become routine. One of the risks of fluid warming is "outgassing" of dissolved air since solubility of air in fluids decreases with warming.[1] The result is an iatrogenic air burden with varying adverse consequences depending upon the size and location of the embolism. To estimate the amount of air burden (outgassing) that occurs in a typical infusion of packed red blood cells, we measured the volume of air liberated from refrigerated bovine blood after warming. The goal is to simulate the clinical situation where human blood is maintained refrigerated and then warmed in a fluid warmer during infusion.

Methods: 500mL of bovine blood (Lampire Biological, Pipersville, PA), chilled to 8^0C, was infused through a Y connector to two separate infusion lines. The cold blood bag output line was split into 2 lines using a Y connector so that the same source of fluid entered each test setup. The output lines from the y-set are fed separately through an Alaris infusion pump (BD, Franklin Lakes, NJ) and then through Smiths Hotline H-90 fluid warmers (Smith's Medical, Minneapolis, MN) programmed at 41^0C. One of the fluid warmers was connected directly to an air collection cylinder (Qosina, Ronkonkoma, NY). The other was connected to the ClearLine IV air removal device (ClearLineMD, Woburn, MA). The ClearLine IV output was connected to the air collection cylinder. The collection tubes were configured for easy weighing on a calibrated scale. All tubing was primed so as to eliminate air in the tubing. Three separate runs were conducted at infusion rates of 100, 150 and 200 ml/hr. A FLIR IR gun (FLIR, Wilsonville, OR) was used to document the fluid temperature at the CLIV input and output and fluid warmers inputs and outputs. Temperature was +/- 2^0 C.
Air that is generated by the outgassing of the warmed blood cells makes its way to the collection tube and the air displaces the fluid in the filled collection tube. The air volume of air was determined using the weight change of the liquid filled collection tube. Each collection tube was weighed at the beginning of each test run (full capacity), and at the end of each test run, after infusion of 250mL of blood. The collection vessel change in weight in grams was used to determine the volume in cc or ml of air generated in the warming process assuming the density of the blood to be 1gm/cc.

Results: An average of 4cc of air per 250mL infused blood was found in the air cylinder using the Hotline fluid warming system, compared to an average of 0cc of air in the air cylinder after the ClearLine IV device. Temperature readings were consistent in both setups and within the expected specifications.

	200mL/hour	150mL/hour	100mL/hour
Without ClearLine IV	3.0cc	3.5cc	5.7cc
With ClearLine IV	0cc	0cc	0cc

Conclusions: The data indicate that outgassing of air does occur during warming and further that the active air elimination device is effective for removing the outgassed air. Infusion rate alters the amount of outgassed air. These results are particularly relevant when large volumes of warmed fluids are administered and especially for small pediatric patients.

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1) Varga C, Luria I, Gravenstein N. Intravenous Air: The Partially Invisible Phenomenon. Anesth Analg. 2016 Nov;123(5):1149-1155. PubMed PMID: 27749346.

KEY WORDS. Fluid warmer, hypothermia, air embolus, gas, air bubbles, Clearline IV, patient safety

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[1] Varga C, Luria I, Gravenstein N. Intravenous Air: The Partially Invisible Phenomenon. Anesth Analg. 2016 Nov;123(5):1149-1155. PubMed PMID: 27749346

In Vitro Performance of CO_2 Absorbents

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Goals: CO_2 absorbent that scrubs CO_2 from rebreathed gas during low flow anesthesia is provided either as loose fill (to be used in refillable canisters) or in prepacked, disposable, and machine specific plastic canisters (prepacks). The absorbent contained in the canister (prefilled or refillable) is considered exhausted once the inspired CO_2 (F_ICO_2) reaches 0.5%. The performance of (CO_2 absorbent in) prepacks of different brands for 2 different anesthesia machines has recently been tested in vitro under standardized conditions [1,2]. However, the results of these studies cannot be used to directly compare the performance of the absorbent of the different brands per se because different canisters contain different amounts of absorbent and because the type of anesthesia machine and canister shape are confounding factors affecting performance themselves. We therefore compared CO_2 absorbent performance of 9 different brands of $Ca(OH)_2$ based absorbents using the same anesthesia machine and the same refillable canister in identical CO_2 loading conditions.

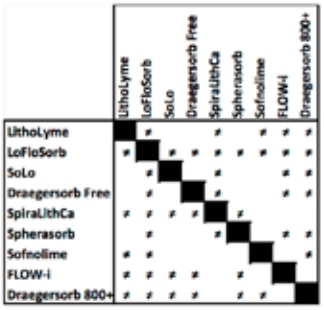
Methods: Nine absorbents (Table 1) obtained from either jars containing loose fill or from opening prepacks were tested as follows. A plastic cup (200 mL, measured by H_2O displacement) weighing 2.5 mg was filled with each absorbent and weighed (Mettler Toledo XP1002 Columbus, OH; accuracy 10 mg), and the weight (g) per 100 mL calculated. Next, the absorbent was poured into a refillable canister (700 mL internal volume) that was weighed before and after filling it up to determine the weight (g) of fresh absorbent; the volume of fresh absorbent was calculated using the weight/100 mL volume data. One brand, the SpiraLithCa, was tested in a separate plastic canister specifically molded for the product because it cannot be fitted into the other canister by nature of its composition, i.e. a synthetic polymer binder sheet (13.0 g) coated with absorbent wrapped around a central plastic hollow core (9.2 g), resulting in a cylinder bloc (cartridge) with preformed longitudinal channels. The filled canister was placed in a circle breathing system of an ADU anesthesia machine (GE, Madison, WI) that ventilated a 2L bag; 160 mL/min CO_2 (flow meter accuracy 2 mL/min; MEDEC, Aalst, Belgium) flowed into its tip. Tidal volume was 500 mL, rate 10/min, I:E 1:1, and fresh gas flow 300 mL/min O_2/air (60% O_2). Gases sampled by the gas analyzer (M-CAiOV module (GE, Madison, WI) were redirected into the expiratory limb. For each product, 4 test runs (all of the same lot)

were performed; the study ended when F_ICO_2 had reached 0.5% (defined as exhaustion). ANOVA was used to compare average CO_2 inflow, time to exhaustion, time to exhaustion per 100 g, and time to exhaustion per 100 mL of product, with $p < 0.05$ denoting a significant difference. Results are expressed as average (standard deviation).

Results: Table 1. One FLOW-i test was deleted (CO_2 inflow too low), and only 3 SpiraLithCa canisters were available.

Product	LithoLyme	LoFloSorb	SoLo	Draegersorb Free	SpiraLithCa	Spherasorb	Sofnolime	FLOW-i	Draegersorb 800+	Statistics
Manufacturer	Allied Healthcare	Intersurgical	Molecular Products	Draeger	MicroPore	Intersurgical	Molecular Products	Molecular Products	Draeger	
NaOH content	LiCl	+	+	+	+	+++	+++	+++	+++	
Granular shape	broken cylinders, heteromorph	round pellets	broken cylinders, heteromorph	disc	wrap with preformed channels	round pellets	broken cylinders, heteromorph	broken cylinders, heteromorph	disc	.
Number of test run	4	4	4	4	3	4	4	3	4	
CO2 inflow (mL/mi	161 (1)	161 (3)	161 (1)	160 (1)	160 (1)	161 (2)	161 (1)	162 (2)	161 (2)	A
Fresh volume (mL)	691 (26)	687 (7)	689 (21)	709 (12)	1069	686 (18)	721 (12)	684 (2)	702 (5)	B
Fresh weight (g)	464 (17) ∏	461 (5) ∏	444 (13) ∏	544 (9) * ##	805 (4)	517 (14) ‡	561 (9) v *	529 (2) ## ‡	578 (4) v	C
Min per 100 g until FICO2 = 0.5%	88 (4)	75 (3)	92 (9)	89 (3)	107 (5)	92 (1)	99 (2)	108 (2)	110 (0)	D
Min per 100 mL until FICO2 = 0.5%	59 (3) †	50 (2)	59 (5) †	69 (2) §	81 (3) ¶ #	69 (0) §	77 (1) #	83 (2) ¶	90 (0)	E

Table 1. Study results.
A: no difference between groups
B: SpiraLithCa differs (by study design)
C: all differ EXCEPT those with identical symbol beneath them
D: see inserted grid - the symbol ≠ indicates they differ
E: all differ EXCEPT those with identical symbol beneath them



Conclusions

CO_2 absorbents differ in the time until they exhaust. Results differ depending on whether time until exhaustion is calculated on a per weight or per volume basis. NaOH content and granular shape affect the time until exhaustion.

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Large Retrospective Clinical Database of Electroconvulsive Therapy Allows Investigation of Therapeutic Effects Associated with Postictal Suppression and Anesthesia Type

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Co-Authors: S. Mark Poler, Fatin Nahi, Wei Dar Lu, Sharon Larson, and Wendy Marie Ingram

Background/Introduction: Electroconvulsive therapy (ECT) is an effective and rapid treatment for severe depression. While seizure duration is commonly believed to predict clinical therapeutic response to treatment, it may not be optimal[1]. Small prospective studies suggest that other measurable electroencephalogram (EEG) parameters, specifically postictal suppression (the speed and degree of the EEG voltage drop at the end of the seizure) may be better correlated with therapeutic response to ECT treatment[2-4]. In addition, limited studies suggest that postictal suppression may be influenced by the type of anesthesia and duration of anesthesia prior to seizure induction[5]. A large number of electronic clinical records provided the opportunity to compare our retrospective experience with the smaller series reported in the literature.

Methods: We created a large clinical database of ECT treatments and related parameters over several weeks of part-time effort. Cases during a four-year period for a single treating psychiatrist at an integrated health care system were selected, from June 1st, 2013 – May 31st, 2017. A total of 127 patients received 2038 inpatient and outpatient ECT treatments. All data were available electronically, facilitating rapid compilation. Routinely recorded unstructured data including scans of EEG ictal parameters, Beck's Depression Inventories, and Mini-Mental Status Examinations were collected by retrospective chart review. These were merged with structured data acquired from electronic health records (EHR) including patient demographics, anesthetic medications and dosages for each ECT. These data were analyzed for associations between anesthetic medications and dosage with measured EEG parameters (e.g. seizure duration, post-ictal suppression index). Analyses involved mixed effect models, linear regression, and t-tests to test associations between anesthetic type and dosage, EEG parameters, and therapeutic clinical outcomes.

Results: Approximately 70.4% of ECT treatments resulted in detected seizures. Of those with detected seizure, postictal suppression indexes ranged from <10% to 98%, with a mean of 57.7% and a median of 60.7%. Only a quarter of ECTs with detected seizure resulted in a postictal suppression index of 77.6% or greater. Approximately 24.9% of ECTs with detected seizures were performed using propofol, 72.2% were performed using methohexital, and 2.9% were performed using other agents (e.g. ketamine, etomidate, etc.). Propofol has been reported to provide greater post-ictal suppression, however, our results show methohexital having a higher mean post-ictal suppression index (58.6%) than propofol (54.1%).

Conclusions: Postictal suppression has emerged as a compelling correlate for use in predicting therapeutic improvement in depression following electroconvulsive therapy. This retrospective study established a large database of anesthetic and EEG parameters from over 2,000 ECTs. Initial results show that methohexital produced a higher mean postictal suppression index than

propofol. To our knowledge, this is the largest study reported to date investigating the interaction of anesthesia, postictal suppression, and ECT therapeutic response.

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Target Controlled Inhalational Anesthestia- Isoflurane Consumption with Adequacy of Anesthesia Monitoring in Conventional and Multimodal Analgesia: A Comparative Study

Presenting Author: Litty John, MBBS D.A.

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Background: In this era of increased concern over environmental impact of chlorofluorocarbons, there is an impetus to minimize inhalational anesthetic consumption. This is possible with the practice of low flow anesthesia (LFA)[1,2] and multimodal analgesia (MMA)[3,4] techniques.

LFA is a closed system in which the fresh gas flow is 500-1000 ml/min.[2] It can be administered either by manually controlled anesthesia (MCA) or target controlled anesthesia, also known as end–tidal control anesthesia (EtCA). In MCA, the set target of end tidal oxygen and anesthetic gases are titrated by the anesthesiologists whereas in EtCA it is automatically adjusted by newer anesthesia work stations (GE Healthcare Aisys CS2). [5]

Even though LFA minimizes operation theater pollution, the gases vented out by the scavenging system has an impact on greenhouse gas emission[1] which could be minimized by practicing MMA, a rational approach to treat acute pain. In MMA, all four elements of pain processing, namely, transduction, transmission, modulation and perception, are targeted with specific drugs, whereas in conventional analgesic regimen (CAR) only one or two elements are targeted.[3]

During the conduct of tailor-made balanced anesthesia, patient monitoring with Adequacy of Anesthesia (AoA) concept is deemed appropriate by the anesthesiologist in order to minimize adverse events. An advanced non-invasive monitoring technology provides balanced view of the derived parameters: depth of amnesia, analgesia and muscle relaxation by Spectral Entropy (SE), Surgical Pleth Index (SPI) and frontal electromyography (FEMG) signals respectively.[6]

We aimed to assess the difference in isoflurane consumption between MMA and CAR for a given period of time using EtCA and AoA monitoring. We hypothesized that MMA using EtCA would significantly reduce the intraoperative isoflurane consumption.

Methods: A prospective randomized double blind study was conducted after obtaining approval from the Hospital Ethics Committee. After obtaining informed consent, 60 patients under ASA physical status I and II undergoing laparoscopic cholecystectomy were included. They were divided into study group (MMA group) and control group (CAR group). In the induction room, patients were attached with monitoring devices along with entropy leads. Both groups received 2% xyloadrenaline infiltration at the entry ports along with pre-emptive diclofenac sodium 75gm intravenously. In addition, the MMA group received intravenous acetaminophen 1gm and clonidine 0.75µg/kg. All patients were premedicated with intravenous midazolam 0.03mg/kg, ondansetron 4mg, glycopyrrolate 0.2mg and fentanyl 3µg/kg. They were then induced with propofol and paralyzed with atracurium 0.5mg/kg. Anesthesia was maintained with isoflurane in air and 30% oxygen along with atracurium. When inspired and expired minimum alveolar concentration of isoflurane was equilibrated, the mode was

switched over to EtCA. AoA was used to monitor the depth of balanced anesthesia (SE: 35-45, SPI: 30-40). The consumption of isoflurane and duration of anesthesia were documented before extubation. Patient was extubated when TOF T4/T1 ratio ≥0.9 and AoA Bal view in court 4 or 1 (Fig-1). Adverse effects of analgesic drugs were noted. Statistical significance of mean difference between the two groups was analyzed using Independent t-test. $p<0.05$ was considered statistically significant.

Results: Mean isoflurane consumption in MMA group was 8.9±4.1ml whereas in CAR group it was 12.7±5.3ml (p=0.002). Duration of anesthesia between the groups was not clinically significant (p=0.931). None of the patients had awareness under general anesthesia.

Conclusion: MMA with EtCA significantly reduces isoflurane consumption due to inhibition of nociception at all levels of pain processing along with its synergistic effect with isoflurane.

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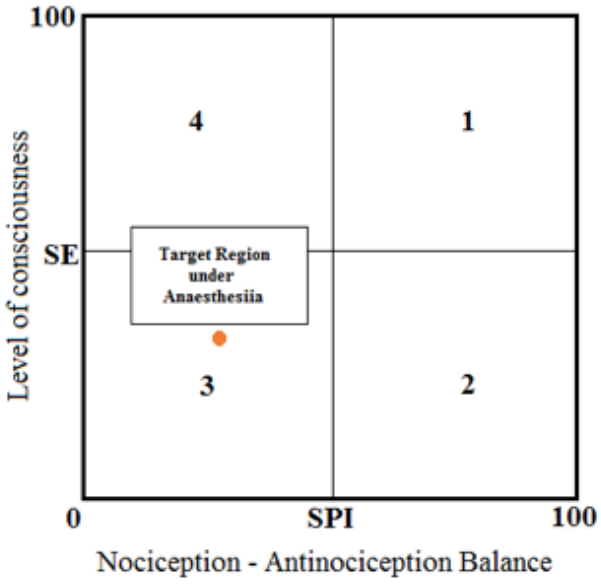


Fig-1: AoA split screen view.

SE (State entropy) Normal range 40-60, Deep anesthesia <40, needs adjusted titration >60.
SPI (Surgical pleth index) Normal range 25-50, Intense analgesia <25, Inadequate analgesia >50.
AoA Bal view indicates depth of analgesia and amnesia. Dot in court-1: patient is awake, court-2: adequately sedated but analgesia inadequate, court-3: towards center surgical plane and towards zero very deep plane, court-4: adequate analgesia in light plane of anesthesia.

Capnography Sample Line Design and Oxygen Delivery Influence ETCO2 Accuracy

Author: Ido Karpenkop, B.Sc., OEM application Engineer, Medtronic

Background: Capnography is a non-invasive method for monitoring continuous carbon dioxide in the respiration cycle to assess a patient's ventilatory status. This bench study investigates the effect of CO2 cannula design and oxygen flow on expired end-tidal CO2 accuracy (etCO2), as measured by a Microstream™ capnography monitor.

Differences in supplemental O2 flow rate and cannula design may impact dilution of expired air and etCO2 accuracy.[1]

The Microstream measurement system was designed and tested to be used exclusively with Microstream sampling lines for optimal results. Use of non-Microstream sampling lines is untested and may impact accuracy and quality of waveforms.

Method: A gas cylinder with 5% CO2 (34 mmHg) was connected to the trachea of the mannequin through a reducer and mass flow controller, to simulate steady-breathing exhaled mixed air. The non-invasive CO2 cannula sampling lines were applied to the mannequin's face with the integrated O2 tubing connected to a 100% O2 gas cylinder. A Microstream™ capnography monitor measured the simulated exhaled gas samples.

EtCO2 levels (mmHg) were measured with O2 flow in the range of 0-10 lpm. At every level of O2 delivery, the CO2 gas was delivered to match the O2 flow and then increased by 2 lpm with the O2 flow constant as follows:

First measurement: O2 flow= CO2 flow, second measurement: O2 flow = CO2 flow + 2lmp (O2= zero, one measurement at 6lpm CO2)

Each consumable cannula filterline was test for all O2 flow rates before replacement.
The test was done with 13 cannula filterline consumable designs 9 adult/4 pediatric) produced by seven different manufacturers, including nasal and oral-nasal cannula designs as descripted in the legend for Figure 1.

Test results: The etCO2 accuracy specifications (compared to a calculated reference) for the Medtronic Microstream™ enabled capnography is +/- 2mmHg.

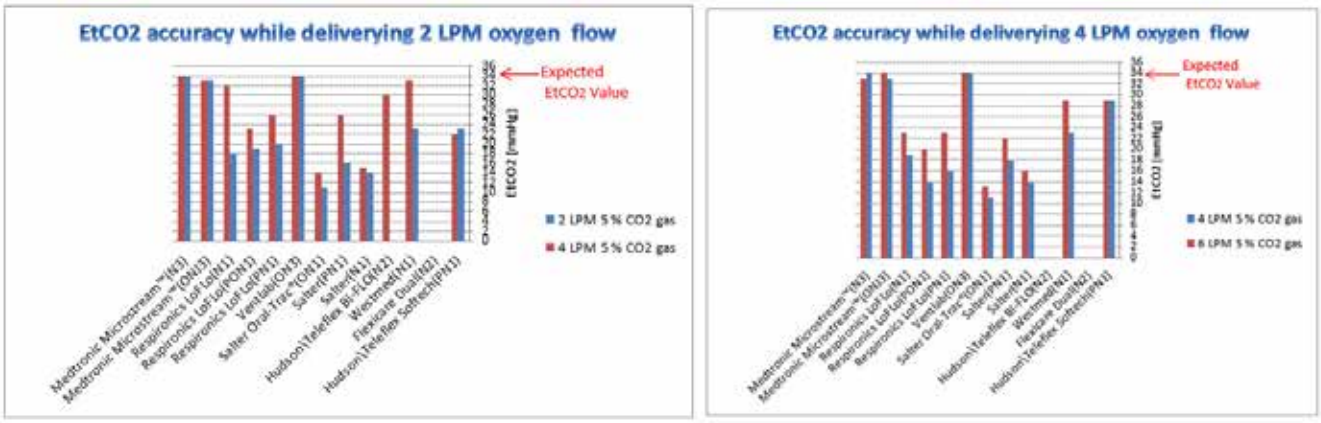
At zero O2 flow and CO2 flow at 6lpm, all cannula designs provided an etCO2 measurement with the mouth of the mannequin partially open for measurement.

[1] Ebert, Thomas J. MD, et al. The Effectiveness of Oxygen Delivery and Reliability of Carbon Dioxide Waveforms: A Crossover Comparison of 4 Nasal Cannula. Anesthesia & Analgesia: February 2015 - Volume 120 - Issue 2 - p 342–348.

At the lowest O2 flow rate (2 LPM) 5 out of the 13 tested consumables ((Ventlab(ON3), Medtronic Microstream™(ONJ3), Medtronic Microstream™ (N3), Westmed(N1) and Respironics LoFlo(N2)) met Microstream™ gas sample etCO2 accuracy requirements.

At O2 flow rates from 4 LPM to 10 LPM, only 3 out of 13 consumables ((Ventlab(ON3), Medtronic(ONJ3) and Medtronic (N3)) met the etCO2 accuracy requirements.

Figure 1. EtCO2 Measurements as a Function of O2 flow and Cannula Design



Legend on cannula design. Note: If no EtCO2 levels were shown in the graph, etCO2 levels of 0 mmHg were observed.
P: Pediatric; N: Nasal CO2 sampling; ON: Oral/nasal CO2 sampling; ONJ: Oral/nasal CO2 sampling with Uni-junctions;
1: Nare Bilateral Split with CO2 sampling in one nare and O2 delivery in opposite nare.
2: Nare prong split/stacked with CO2 sampling and O2 delivery in each nasal prong.
3. Separated O2 delivery via under nose vents

Conclusion: This test suggests that varying oxygen flow affects the etCO2 measurement accuracy when using Microstream™ capnography measurement technology. The results also indicated that using different cannula designs will affect etCO2 accuracy when delivering O2.

Limitation: Simulation bench testing on gas flow and mixing, further testing on humans is required.

Excellence in Technology Award

Development of an Anesthetic Reflection System

Presenting Author: Patrick Kolbay, B.S., University of Utah

Co-Authors: Joseph Orr, Ph.D., University of Utah; Kai Kück, Ph.D. University of Utah

Introduction: The World Health Organization declared climate change the defining issue for health systems in the modern century. Ironically, the health care industry itself is a leading emitter and accounts for 8% of the total carbon dioxide emissions alone [1]. In anesthesia, publications have brought growing concern about the global warming potential of emitted inhalational anesthetics. Previously we have demonstrated that activated charcoal has suitable sorption isotherm characteristics to absorb and desorb isoflurane, suggesting feasibility to reflect exhaled anesthetic gases back to a patient during sedation [2]. Building off this research, we have developed an anesthesia machine add-on that allows for traditional anesthesia delivery in tandem with a charcoal filter for gas reflection.

Methods: An initial proof-of-concept prototype was created to be fitted within the rebreathing circuit of a current anesthesia machine. This system consisted of a housing of two chambers printed with biocompatible acrylic (MED610, Stratasys, Eden Prairie, MN). One chamber was fitted with a charcoal cartridge (Oxpure 1220C-75, Oxbow Activated Carbon, West Palm Beach, FL), and the other remained open. A gear with a semicircular opening was actuated externally to direct gas flow between chambers. In addition, differential pressure sensors were attached at both chamber ends to determine direction of gas flow (simulated inhalation and exhalation). Anesthetic gas concentration measurements from a standard infrared gas bench (Datex-Ohmeda, Helsinki, Finland) was used for basic feedback control. A microcontroller controlled the gear valve to titrate a user give anesthetic concentration based on flow detection and anesthetic gas concentration using a rudimentary hysteresis controller. This device was tested between the breathing circuit of an anesthesia machine and a test lung.

Results and Discussion: Our proof-of-concept device was successful in meeting the basic criteria. During a mock induction, the device oscillated between the open chamber (inhalation) and the charcoal filter (exhalation) to initially saturate the activated charcoal (Figure 1). During this time, it took approximately 6 minutes for the charcoal filter to saturate. Fresh gas flow then primarily flowed bidirectionally through the charcoal filter, with the controller able to maintain average isoflurane concentrations within 0.2% by volume of the user set point (1 MAC). Given a cartridge with 40 grams of activated charcoal, the Anesthetic Reflection System would can reflect 1 MAC/hour of anesthetic gas at a fresh gas flow rating of 1 liter/minute.

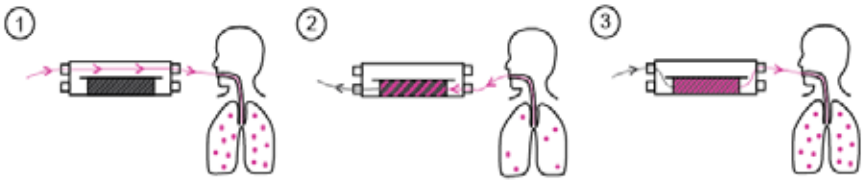


Figure 1 – (1) Patient inhales anesthetic gas directly from anesthesia machine during induction. (2) Patient exhales anesthetic gas into activated charcoal filter. (3) Anesthetic gas is supplied from filter to the patient during anesthetic maintenance.

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In Vitro Evaluation of a Novel Image Processing Device to Estimate Surgical Blood Loss in Suction Canisters

Presenting Author: Gerhardt Konig MD UPMC Magee-Women's Hospital, Department of Anesthesiology

Co-Authors: Jonathan H Waters MD, Eric Hsieh BS, Bridget Philip MD, Vicki Ting MD, Gaurav Abbi MD, Mazyar Javidroozi MD, PhD, Griffeth Tully MD, Gregg Adams MD

Background: Clinicians are tasked with monitoring surgical blood loss. Unfortunately, there is no reliable method available to assure an accurate result. Most blood lost during surgery ends up on surgical sponges and within suction canisters. A novel FDA-cleared device (Triton system, Gauss Surgical, Inc., Los Altos, CA) to measure the amount of blood present on sponges using computer image analysis has been previously described. This study reports on performance of a complementary FDA-cleared device (Triton Canister System, Gauss Surgical, Inc., Los Altos, CA), that uses similar image analysis to measure the amount of blood in suction canisters.

Methods: Known quantities of expired donated whole blood, packed red blood cells (PRBC), and plasma, in conjunction with various amounts of normal saline, were used to create 207samples representing a wide range of blood dilutions commonly seen in suction canisters. Each sample was measured by the Triton device under 3 lighting conditions (Bright, Medium and Dark), resulting in a total of 621 measurements. The measured hemoglobin mass in each sample was compared

Results: The Bland-Altman bias of total Hb mass measured by Triton versus reference method was 4.1 g (95% CI 3.6 to 4.5) with the corresponding lower and upper limits of agreements of -7.8 g (95% CI -8.6 to -6.9) and 15.9g (95% CI 15.1 to 16.7), falling well within the predetermined clinically significant limits of ± 30 g.[1] Repeated measurements of the samples under the various lighting conditions were highly correlated, with intraclass correlation coefficient (ICC) of 0.995 (95% CI 0.993-0.996, p<0.001).Hemoglobin mass bias was significantly associated with hemolysis level (Spearman's rho correlation coefficient -0.137, p=0.001) and total canister volume (Spearman's rho correlation coefficient 0.135, p=0.001), but not ambient illuminance.
Conclusion: The Triton Canister System was able to measure the Hb mass reliably with clinically acceptable accuracy in reconstituted blood samples representing a wide range of Hb concentrations, dilutions, hemolysis and ambient lighting settings.

Variable	Lighting Condition	Bias (Triton vs. Assay)	Lower Limit of Agreement	Upper Limit of Agreement
Assay Hb Mass (g)	Dark	4.7 (3.8 to 5.6)	-8.1 (-9.7 to -6.6)	17.6 (16.0 to 19.1)

	Medium	3.4 (2.6 to 4.1)	-7.4 (-8.7 to -6.1)	14.2 (12.9 to 15.5)
	Bright	4.1 (3.2 to 4.9)	-7.6 (-9.0 to -6.2)	15.7 (14.3 to 17.1)
Assay Hb Concentration (g/dl)	Dark	0.3 (0.2 to 0.3)	-0.4 (-0.5 to -0.3)	1.0 (0.9 to 1.0)
	Medium	0.2 (0.2 to 0.2)	-0.4 (-0.5 to -0.3)	0.8 (0.7 to 0.9)
	Bright	0.2 (0.2 to 0.3)	-0.4 (-0.5 to -0.3)	0.9 (0.8 to 1.0)
Assay EBL (ml)	Dark	37.8 (29.9 to 43.8)	-62.6 (-74.6 to -50.6)	136.3 (124.3 to 148.3)
	Medium	26.8 (20.9 to 32.8)	-58.7 (-69.0 to -48.4)	112.4 (102.1 to 122.7)
	Bright	32.0 (25.5 to 38.5)	-61.0 (-72.2 to -49.8)	124.9 (113.7 to 136.1)

Table: Hb mass, concentration and estimated blood loss in 207 study samples under 3 lighting conditions. The bias represents the mean difference between the Triton and Assay values. All values are provided with corresponding 95% confidence intervals.

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Applications of Tissue Oximetry in the Assessment of Endothelial Dysfunction-Pilot Study

Presenting Author: Abdubadie Kutubi, MS

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Introduction: Patients with Endothelial Dysfunction (ED) produce abnormal hemodynamic parameters as in diabetes mellitus and peripheral vascular disease [1] [2] [3]. Flow Mediated Ultrasound (FMD) is the gold standard non-invasive method for ED assessment [4], but is susceptible to observer bias and requires specialist training. The 2nd best method for ED assessment is peripheral arterial tonometry (PAT) which isn't readily available and is costly. This pilot study aims to investigate the potential of tissue oximetry to assess endothelial function in healthy subjects and diseased patients.

Methods: The study involved 13 subjects and 14 patients whose endothelial function was assessed using Tissue Oximetry (Nonin SenSmart OEM) and PAT (EndoPAT). The patient selection criteria involved diagnosed disorders linked with ED.
PAT captures beat-to-beat plethysmographic recordings of the finger arterial pulse wave amplitude with pneumatic probes and produces a Reactive Hyperaemia Index (RHI) score specifying endothelial health on a distribution of a non-selective population [5].
Tissue oximetry sensors were applied to both forearms. The experiments involved taking baseline tissue oximetry and PAT readings for 6 mins, followed by BP cuff inflation causing arterial occlusion for 5 mins, then BP cuff deflation inducing reactive hyperaemia for 5 mins. Readings were also simultaneously recorded from the control arm.

Data analysis: PAT measurements were analyzed with an algorithm, eliminating observer bias. RHI values were reported as the natural log (LnRHI) and indicated the critical value to be 0.51, values below which indicate ED.
Tissue Oximeter readings were graphed as figure (1) and the parameters calculated: Area of desaturation curve (dAUC) (metabolic reserve), area under of reperfusion curve (rAUC) (magnitude of reactive hyperaemia), desaturation slope (dSlope), reperfusion slope (rSlope) (rate of reperfusion), difference between baseline and peak (Delta) and ratio of peak to baseline.

Results: Analysis of tissue oximetry data showed significant differences between the ED and the healthy group with regards to Delta, rAUC, dAUC, rSlope and dSlope (table 1). P values in all variables were significant except for peak: baseline ratio.

Table 1: summary of the tissue oximetry variables. Data presented as Mean and SD.
SD: standard deviation. ED: endothelial dysfunction. * p value < 0.05

Tissue oximetry Variables	Mean		SD		Difference between normal and ED groups	P value
	ED Group	Normal Group	ED Group	Normal Group		
Delta (peak-baseline)	12.79	20.33	7.9	8.7	1.60	0.017 *
rAUC	0.13	0.28	0.012	0.013	2.15	0.002 *
dAUC	0.072	0.11	0.031	0.043	1.52	0.017 *
rSlope	14112	21769	4388	8933	1.54	0.009 *
dSlope	133451	219614	60486	82021	1.65	0.004 *
ratio of peak: baseline	1.23	1.31	0.15	0.18	1.07	0.117

Conclusion: Our data showed that somatic rSO_2 as a promising tool for assessment of endothelial function. Further study is needed to assess the fidelity of tissue oximetry against a gold standard test for endothelial dysfunction.

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Development and Validation of the Integrated Positioning Index (IPI) for Pressure Injury Prevention

Presenting Author: Barrett Larson, MD, Leaf Healthcare

Co-Authors: Annemari Cooley, MA, MBA, Leaf Healthcare ; Mark Weckwerth, PhD, Leaf Healthcare

Introduction: Patient immobility has been linked to a number of serious and costly hospital complications[1]. One of the most common complications of immobility is pressure injuries, which affect 2.5 million patients each year and drives up the cost of healthcare in the United States by up to $11 billion annually[2]. In order to prevent pressure injuries, the standard of care is to turn at-risk patients every two hours, day and night[3]. Historically, the quality of patient turning protocols has been based on an assessment of the frequency with which patients are repositioned by nursing staff, which is often referred to as the "compliance rate". However, studies have shown that the *magnitude* of patient turns[4] (i.e. turn angle) and the amount of tissue *reperfusion time*[56] (i.e. time elapsed between periods of tissue ischemia) are also important components to an effective pressure injury prevention program. Traditionally, there has not been a convenient means to reliably quantify patient turn angles and tissue reperfusion times. To help address the need for improved pressure injury prevention methods, we developed a wireless patient monitoring system (Leaf Healthcare) that continuously monitors the position, movements, and activity of hospitalized patients.

Methods: The Leaf Patient Monitoring System detects all patient turns (including unwitnessed self-turns), the magnitude of each of those turns, and the time that tissues are given to recover from a recent pressure insult. We developed an algorithm that integrates these three parameters into a single index value to give a simplified assessment of the patients' position distribution history. This index value, called the Integrated Positioning Index (IPI), is designed to provide additional insight into the quality of a pressure injury prevention program. The IPI ranges from 0-100, with higher numbers reflecting a higher level of in-bed mobility/movement. The Integrated Positioning Index (IPI) was clinically validated by correlating data from the Leaf sensor with clinical outcome data from 4 acute care hospitals.

Results: A total of 351,987 hours of sensor data was analyzed from 4,209 patients. The Integrated Positioning Index (IPI) was strongly correlated to pressure injury rates, with higher IPIs correlating to lower pressure injury rates. When the IPI was below 85, the incidence of pressure injuries was 5x higher than when the IPI was greater than 85.

Conclusion: The Integrated Positioning Index (IPI) correlates well with pressure injury rates. IPI provides a comprehensive assessment of the quality of a pressure injury prevention program and can be used as a tool to guide patient care.

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Development of a Device to Improve the Safety of Video Laryngoscopy

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Background/Introduction: Video laryngoscopy (VL) offers significant advantages over conventional direct laryngoscopy. However, despite the benefits afforded by this technique, video laryngoscopy does have some important limitations. There have been an increasing number of case reports of pharyngeal injuries associated with video laryngoscopes[1-11]. Pharyngeal injury associated with video laryngoscopy is thought to occur due to blind advancement of the styleted endotracheal tube. While the common teaching is to always look in the mouth when inserting the endotracheal tube, a natural inclination is to prematurely look at the video screen and wait for the endotracheal tube to appear. Given the frequency with which providers prematurely divert their visual attention away from the mouth during VL, and given that it's difficult to resist this natural tendency, some authors have suggested that we need explore fundamental changes to video laryngoscope technology[12].

Methods: To help overcome a fundamental limitation of video laryngoscopy and to improve the safety of this increasingly popular technique, we set out to develop a navigation system that lets providers know if the endotracheal tube is in a safe position and orientation during video laryngoscopy. The system is designed to help providers safely navigate the "blind spot" by automatically changing the color of the laryngoscopes' handle based on the measured trajectory of the endotracheal tube. If the endotracheal tube is determined to be in a safe position, close to the curve of the laryngoscope, the handle of the video laryngoscope will illuminate green. Once the navigation system determines the endotracheal tube has safely traversed the "blind spot", the handle *blinks* green to indicate that it's now safe to divert visual attention away from the mouth and towards the VL display. The intubation can then safely proceed under visual guidance. The navigation system utilizes an array of 3D magnetometers that are integrated into the optical cable of the video laryngoscope. The magnetometers detect the presence of an endotracheal tube stylet that has a magnetized distal tip. A microcontroller aggregates sensor data and controls a series of LEDs on the video laryngoscope handle to provide visual feedback. The device was tested on an intubation mannequin.

Results: A prototype device was successfully designed, developed and tested in a simulation environment. The navigation system accurately represented the 3-dimensional position, orientation, and trajectory of the endotracheal tube and accurately indicated when the "blind spot" had successfully been traversed.

Conclusion: A navigation system to help providers safely navigate the "blind spot" during video laryngoscopy was successfully developed. The components are inexpensive and the technology can be integrated into virtually any video laryngoscope. The technology does not require any changes to workflow and provides visual feedback in an easily-interpretable, unobtrusive

manner. Future studies will aim to determine the extent to which this technology improves the safety of video laryngoscopy.

Pictures

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VITALDB, A Freely Accessible Intraoperative Vital Signs Database of Surgical Patients

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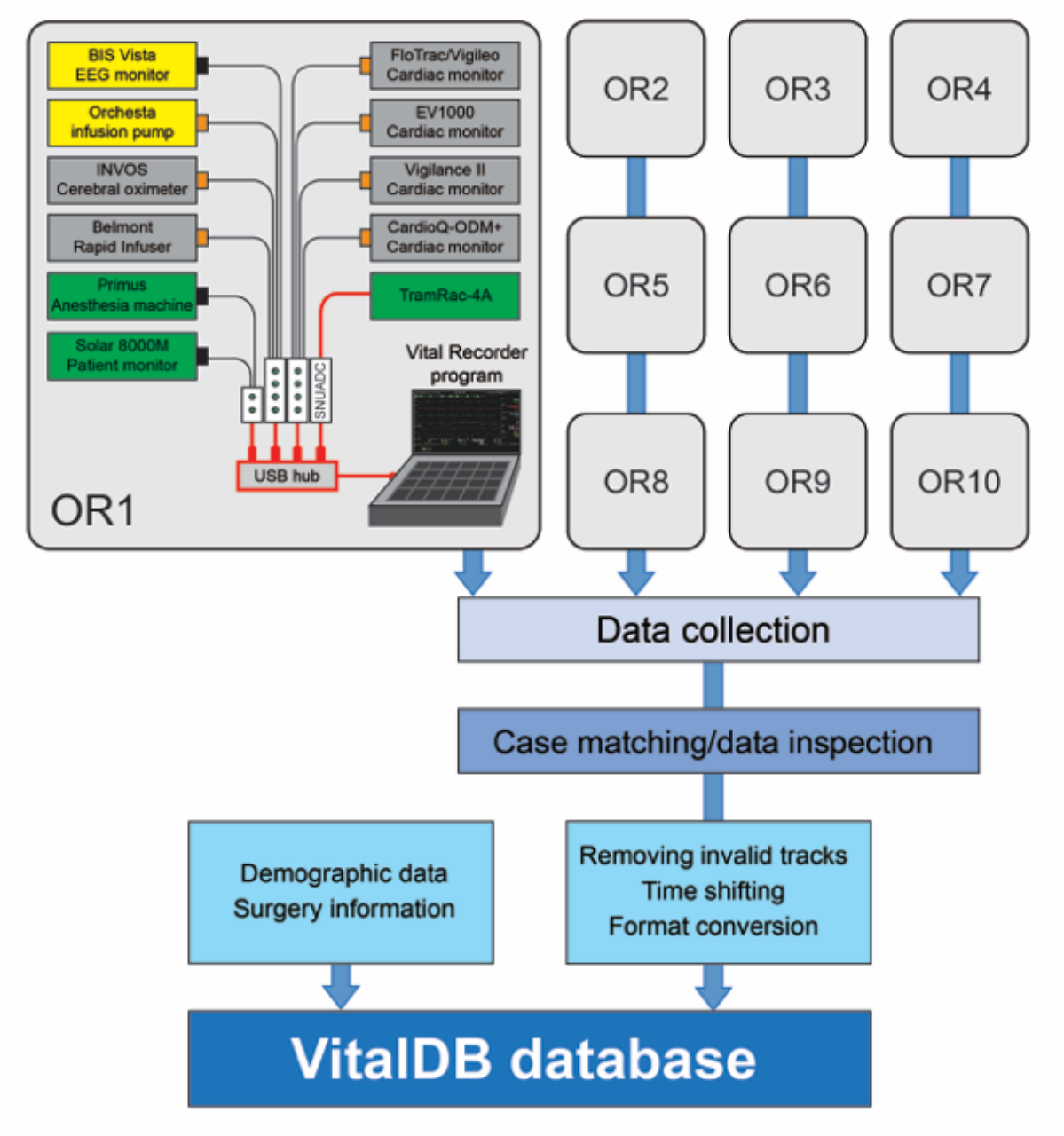
Co-Authors: Chul-Woo Jung, MD, PhD. Department of Anesthesiology and Pain Medicine, Seoul National University College of Medicine, Seoul, Republic of Korea.

Background/Introduction: Anesthesia information management system (AIMS) has been widely used to improve anesthesia practices and research. However, despite the growing demand for higher-level data for research and engineering, there are limitations in current systems in recording and providing detailed physiologic data.

Methods: We have developed the Vital Recorder, a Windows-based program to record high-resolution, time-synchronized physiologic data from various anesthesia equipment including patient monitors, anesthesia machines, brain monitors, cardiac monitors, and infusion pumps (https://vitaldb.net, accessed 29 NOV 2017). The Vital signs DataBase (VitalDB) was built using de-identified case files that were automatically recorded by the Vital Recorder program during daily surgery and anesthesia. Demographic and surgical information of patients and data track information are also provided in the database to enhance research.

Results: Using the Vital Recorder program, we developed the Vital signs DataBase (VitalDB), a single-center database that allows free access to high-resolution multi-device physiologic data recorded from surgical patients during anesthesia (https://osf.io/xv35a, accessed 29 NOV 2017). This dataset provides basic characteristics and 561,150 data tracks of 6,423 surgical patients recorded in 10 operating rooms of a tertiary, university hospital. For easy use of the data by medical researchers, we have prepared a summary of patient and surgery information as well as respective case files with a time resolution of 250 Hz.

Conclusion: This database is the first digital register of high-resolution integrated data generated from multiple anesthesia equipment. This dataset will provide valuable information to leading researchers who need high-quality vital signs data that is difficult to obtain from previous AIMSs, as well as to medical researchers and engineers who have difficulty acquiring the vital signs data required for research or development due to various environmental constraints.


BIS Vista
EEG monitor
Orchesta
infusion pump
INVOS
Cerebral oximeter
Belmont
Rapid Infuser
Primus
Anesthesia machine
Solar 8000M
Patient monitor
FloTrac/Vigileo
Cardiac monitor
EV1000
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Vigilance II
Cardiac monitor
CardioQ-ODM+
Cardiac monitor
TramRac-4A
Vital Recorder
program
SNUADC
USB hub
OR1
OR2
OR3
OR4
OR5
OR6
OR7
OR8
OR9
OR10
Data collection
Case matching/data inspection
Demographic data
Surgery information
Removing invalid tracks
Time shifting
Format conversion
VitalDB database

Optimal Insertion Depth of Central Venous Catheter Through the Right Internal Jugular Vein, Verified with Transesophageal Echocardiography

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Background: Previous studies have presented some guidelines for ideal depth for central venous catheterization through the right internal jugular vein. Some guidelines are formulas such as 'height(cm)/10' by Peres, 'height(cm)/10 – 1' by Czepizak et al., 'height(cm)/10 – 1.3' by Lum, or a fixed depth of 15 cm. Other guidelines recommended clinicians to check the depth of central catheter inserted with carina on X-ray as a landmark. However, there has been not consensus for the ideal depth yet. The purpose of this study was to measure ideal insertion depth of central venous catheter using transesophageal echocardiography and to find out an equation predicting the ideal depth on the basis of patient's height. The secondary aim was to compare a new simple formula from our data with guidelines introduced in previous studies.

Methods: Adult patients (> 18 years old) scheduled for elective open heart surgery requiring right internal jugular venous catheterization and intraoperative transesophgeal echocardiography (TEE) at Dongsan Medical Center were screened for eligibility. Before the initiation of trial, we defined that the optimal point of the catheter tip should be 2 cm above upper margin of crista terminalis. Also, we defined the optimal zone for the catheter tip should be within 1 cm from the optimal point. After induction of anesthesia, a probe for TEE was inserted through esophagus for evaluating the heart during the surgery. Next, central venous catheterization through the right internal jugular vein was performed by an anesthesiologist with the modified Seldinger's maneuver. When the catheter was being inserted, an investigator observed the tip of catheter using TEE on bicaval view. At first, the investigator confirmed the tip of catheter was located at the upper margin of crista terminalis using sterile agitated saline. Next, the anesthesiologist withdrew the catheter 2 cm backward. And then, depth of inserted part of the catheter inserted was recorded. After surgery, the length between the catheter tip and carina on chest X-ray was measured in each patient. The optimal depth was calculated, and an equation was derived through regression analysis. Also, we made a new formula from our data. And, we compared this new formula and some formulas introduced in previous studies to find out which formula would be best fit for optimal zone.

Results: Eighty-nine patients were enrolled in this trial. The mean (SD) of patient height was 160.4 cm (9.3). The mean (SD) of inserted depth of catheter was 14.5 cm (1.6). The optimal length for each patient could be predicted using the equation: optimal depth (cm) = 0.117 × height (cm) – 4.3 (r^2 = 0.494, P < 0.001). Also, we made a new formula of 'height(cm)/10 –

1.5 cm', named 'J-J formula'. The accuracy rates of each formula or guideline for optimal zone in our study population was 34.8% (Peres), 67.4% (Lum), 58.4% (Czepizak), 50.6% (15 cm), 40.0% (to carina), and 71.9% (J-J formula).
Conclusion: When the tip of inserted catheter was evaluated with real-time transesophageal echocardiography, it seemed that it would be difficult to find out a perfect formula or guideline for optimal depth of central venous catheter through the right internal jugular vein. In our study population, we found a new formula of 'heigt(cm)/10 – 1.5' for the optimal depth was better than other guidelines.

Measuring Transient Heart Rate Changes During Noxious Stimulation in Laparoscopic Surgery

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Introduction: Evaluating the surgical noxious stimulation in general anesthesia requires the interpretation of physiological signals. While the heart rate (HR) and blood pressure readings displayed on the patient monitor provide convenient information, those readings are too static to measure the transient response from dynamic noxious stimulation, in particular the transient change of beat-to-beat heart rate, which we referred to as *Instantaneous Heart Rate* (IHR).

Since opposite impacts of noxious stimulation on the autonomic system –sympathetic activation causes tachycardia, whereas noxious stimulation could elicit a transient bradycardia via vagal activation, the HR readings on the patient monitor is the averaging sum of both opposing effects on the heart rate, providing limited information. It requires one of the opposing effect greatly overpowers the others to make a notable change of HR value.

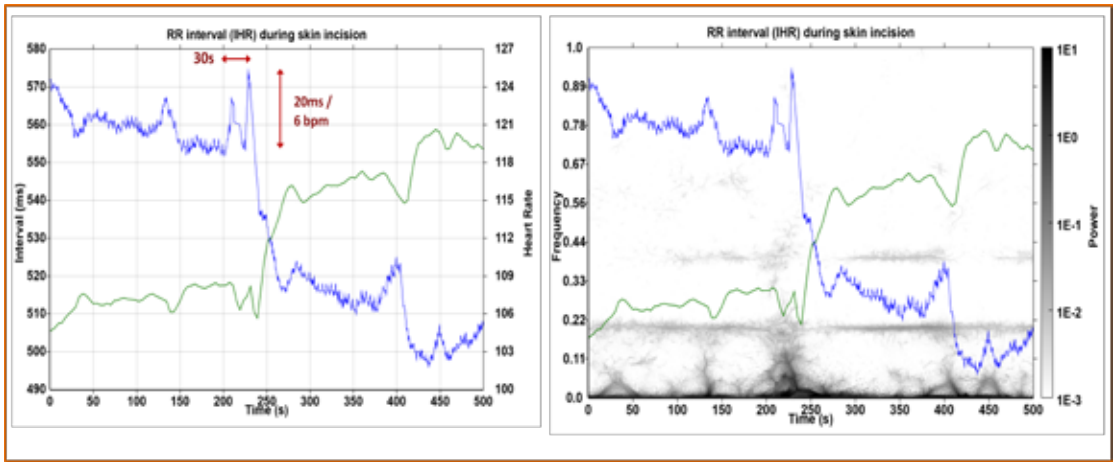
The analysis of IHR is traditionally known as heart rate variability (HRV) analysis, whose techniques are short of quantifying the dynamical information in IHR, particularly the transient change in response to the noxious stimulation. The recent development of time-frequency analysis could provide a functional “time-varying power spectrum” in high resolution to fulfill the above requirement. Our previous study has revealed the potential of the new method referred to as Concentration of Frequency and Time (ConceFT). Hence in the present study, we hypothesize that surgical noxious stimulation of different intensity and different location exhibits differential dynamic feature in IHR.

Method: The study was approved by the local institutional Research ethics Board and written consents were collected from subjects. We conducted a prospective observation study by enrolling patients undergoing laparoscopic cholecystectomy. The standard monitoring signals, including the electrocardiogram (ECG) in 500Hz sampling rate, was collected from the Philips IntelliVue^{TM} patient monitor. We registered the accurate timestamps of noxious stimulation events, including umbilical skin incision (10 mm), umbilical trocar penetration by laparoscopic trocar (10 mm), xiphoid skin incision (5 mm), xiphoid trocar penetration of xiphoid area (5 mm), subcostal skin incision (3 mm), subcostal

trocar penetration (3 mm). IHR was obtained by automatic R-peak detection from ECG waveform and cubic spline interpolation. ConceFT method was applied to analyze IHR data from the ECG recording.

Results: We enrolled data from 41 patients for analysis. From IHR, we used ConceFT as a scale to measure the intensity of noxious stimulation. The time-varying spectra also reveals that trocar penetration causing more transient bradycardia than skin incision in the corresponding area. We proposed an algorithm to measure the scale

Conclusion: We quantify the scale of transient HR change during noxious stimulation. Also we quantify the relative difference between noxious stimulation from superficial and deep structure. The two-dimensional measurement of noxious stimulation in laparoscopic surgery could help the management in clinical anesthesia.



Difficulty of observing the transient heart rate, which changes as 20ms difference in interval and appears within 30s, can be seen (left). Conceft as a time-varying power spectrum quantify this transient event in the heart rate (right).

Blood Pressure Management Analysis on ICU and Surgical Patients Receiving Vasopressor Therapy

Presenting Author: Michael Ma, BS[1]

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Background: Blood pressure management in the operating room and intensive care unit often requires vasopressor therapy, especially in high-risk surgical cases and critically ill patients. The current standard in vasopressor therapy is to manually titrate to a target mean arterial pressure, which can vary among different institutions. Ideally, changes in vasopressor infusion rates quickly follow changes in blood pressure. While too low of a blood pressure risks hypoperfusion and ischemia from too low driving pressure, too high of a blood pressure also risks ischemic injury via blood flow redistribution away from the visceral organs. In the ideal scenario, vasopressor infusions would be maintained at the minimum level sufficient to prevent hypotension. Few studies, if any, have examined blood pressure management under vasopressor infusion in a large sample of surgical and ICU patients receiving vasopressor therapy, however.

Methods: The data used in this study was obtained from two centers: Erasme Hospital in Brussels, Belgium and University of California, Irvine Medical Center (UCIMC) in Orange, California. At Erasme Hospital, 516 surgical patients were included in the data set. At UCIMC, 18,138 ICU visits were included. 1,302,221 minutes of ICU MAP data were included in the data set. At Erasme Hospital, patients on norepinephrine infusions with valid mean arterial blood pressure values (defined as values between 40 mmHg and 140 mmHg) were included. Norepinephrine was primarily used for blood pressure management at Erasme Hospital and therefore we did not examine blood pressure in the surgical setting during any other vasopressor. For the purpose of this analysis, the ideal MAP was considered to be 60-80 mmHg. The target MAPs in both data sets were unknown. We examined blood pressure during which vasopressors were used and also throughout the entire case/stay.

Results: Table 1. Surgical Patients from Erasme Hospital and ICU Visits from UCIMC

		Whole case	Under norepinephrine	Under phenylephrine
Surgical Patients from Erasme	Average MAP (mmHg)	76.17	75.08	
	Standard Deviation MAP (mmHg)	11.70	10.60	
	% time [60-80]	53.28	55.64	
	% time < 60 mmHg	11.18	10.65	
	% time > 80 mmHg	35.46	33.47	
ICU Visits from	Average MAP (mmHg)	84.54	76.90	79.90

UCIMC	Standard Deviation MAP (mmHg)	20.44	18.91	20.23
	% time [60-80]	34.65	53.24	46.32
	% time < 60 mmHg	6.60	10.63	9.46
	% time > 80 mmHg	58.75	36.13	44.22

Conclusion: These findings indicate a similar trend in blood pressure management under vasopressor infusion between an intensive care unit in the United States and an operating room setting in Europe. In both settings, patients spend significant time (>30%) with a MAP > 80 mmHg, and non-trivial time with MAP below 60 (about 10%). Given the growing evidence in the last few years that cumulative hypotension time contributes to worsened outcomes (1) and the substantial time in over-treatment, from this data, it is clear that there is room for improvement in accurate titration.

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One Laryngospasm, Two Realities: The Impact of Data Granularity on Post Hoc Analysis of Perioperative Events

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Background: Anesthesia information management systems (AIMS) record perioperative data in an automated fashion. Secondary uses of AIMS data include research and quality improvement efforts. Concerns, however, have been raised regarding data validity and artifacts in AIMS. This case highlights how different data sampling rates can significantly alter the analysis of perioperative events. Physiologic monitors can be configured to transmit data directly to an AIMS or a middleware medical device interface (MDI). AIMS and MDI data sampling rates can vary. For example, our institution's AIMS has a sampling rate of 1 minute, while our MDI stores most physiologic data at higher rates depending on the monitor. Monitors with a high sampling rate such as the pulse oximeter are stored at much shorter time intervals (every 10 sec) in the MDI, as opposed to a 1-minute interval in the AIMS.

Case Description: A 21-month old child presented for surgery. During induction of anesthesia, the patient experienced acute airway obstruction consistent with laryngospasm, and the anesthesiologist immediately intervened with a jaw thrust, approximately 30cm H_2O of positive pressure ventilation, and succinylcholine. The obstruction resolved quickly and the remainder of the anesthetic was uneventful.

The AIMS and MDI data recorded during the obstruction event was later reviewed. The AIMS data with 1-minute intervals did not display sustained high inspiratory pressures, while the higher granularity MDI data showed the use of high pressures (Figure 1a). The MDI data showed the SpO2 dropped transiently below 60%; the AIMS data displayed only a brief SpO2 nadir that stayed above 85% (Figure 1b). In contrast, the end-tidal CO2 levels are more similar in the MDI and AIMS data, likely due to the slower MDI sampling time for that parameter (Figure 1c).

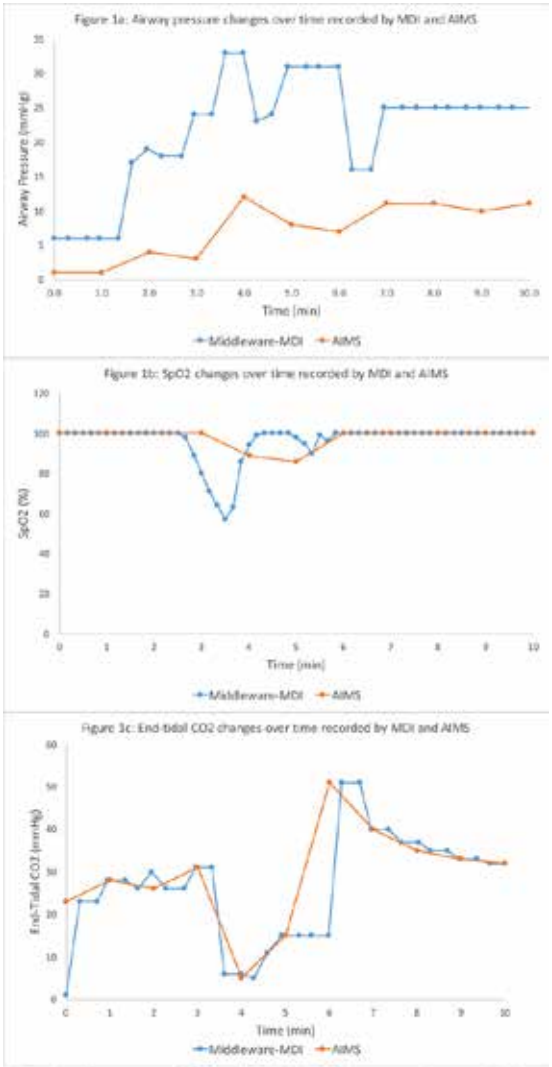

Figure 1: Airway pressure, SpO2, and End-tidal CO2 changes over time recorded by the medical device interface (MDI) and anesthesia information management system (AIMS).

Discussion: This case highlights the impact of data sampling rates and granularity on the post hoc interpretation of perioperative events based solely on physiological data. In pediatric anesthesia, events such as laryngospasm can be extremely brief and perioperative data that are sampled every 60 seconds may not accurately represent the actual physiologic

changes. Unfortunately, not all hospitals have the financial and technological resources to implement high fidelity MDI systems and store the large amounts of higher granularity data. However, if higher granularity MDI data is available, then such data should be examined alongside AIMS data and clinicians' annotations to obtain a more accurate view of perioperative events. While AIMS have come a long way as perioperative data recording systems, there still exist some potential pitfalls that should be kept in mind when relying on AIMS data for research and quality improvement efforts.

Medication Bar-Code Scanning in AIMS: An Impact Study of Education Efforts and a User-Interface Error on Anesthesia Provider Compliance

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Co-Author: Cynthia A. Wong MD, University of Iowa Hospitals & Clinics, Iowa City, IA

Introduction: The adoption of various technologies to improve patient care and safety has increased over the past few years with widespread use of Anesthesia Information Management Systems (AIMS).[1] Bar-code medication verification technology embedded in an Electronic Medical Record (EMR) has been shown to decrease administration errors and adverse reactions.[2] In this impact study, we assessed the association between education efforts on AIMS medication scanning, and the effect of an unintended systems error on provider performance.

Methods: Bar-code scanning for pharmacy-prepared medications (e.g., antibiotics, medication infusions) was introduced in the institutional AIMS (Epic ™, Madison, WI) in January 2016. Passive educational efforts to improve compliance began in May 2016. Compliance with scanning was introduced as a department patient safety metric, per the institution's guidelines, in July 2016. The goal was a 20% improvement from the baseline scanning rate (~40%). The extensive education effort included hands-on training in a simulation lab for all clinical providers was performed in June 2016. A planned AIMS upgrade occurred in August 2017. An error in the user-interface of scanning activity in AIMS appeared following the upgrade. The error could only be bypassed by opening the "medications activity" in AIMS and scanning again. The error was fixed with an update in October 2017. We examined the week-by-week rate of compliance of bar-code scanning by anesthesia provider type (attending anesthesiologist, resident, CRNA, SRNA) over this entire period of 2 years (January 2016 to December 2017).

Results: The week-by-week compliance percentage is shown in Figure 1. The compliance improved from approximately 2% in January 2016 to 10% by May 2016. Passive educational efforts resulted in improvement to 30% by June 2016. The introduction of medication scanning as a department metric, and hands-on training, resulted in a significant change from 40% to 75% by August 2016 (more than the expected 20% improvement). The rate gradually improved to more than 90% compliance by December 2016 and plateaued at this rate until August 2017. The error introduced by the AIMS upgrade resulted in a significant decrease in compliance to 75% in the first week after the upgrade, plateauing at 82% for the next 7 weeks. Fixing the system error resulted in compliance improvement to greater than 90%. Figure 2 shows the pattern of scanning compliance based on type of provider; all 4 types of providers followed a similar pattern.

Discussion: The initial roll out of scanning technology in AIMS resulted in only moderate compliance with the request to scan all pharmacy-prepared medications into the EMR. Hands-on training and making compliance a departmental quality metric resulted in significant improvement of the scanning rates. An unintentional error introduced by an AIMS system

upgrade resulted in a significant drop in scanning rates because additional steps were required to scan medications. Fixing this systems error resulted in provider compliance improving to baseline pre-upgrade rates.

User-interface issues of an EMR can result in a decrease in the *usability* of the system, an important component of human-computer interaction.[3] The error introduced by the system upgrade resulted in unintended *usability testing* of the AIMS and uncovered the implications of a task load and workflow burden on the compliance of an important quality metric for patient safety within EMR.

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Figure 1

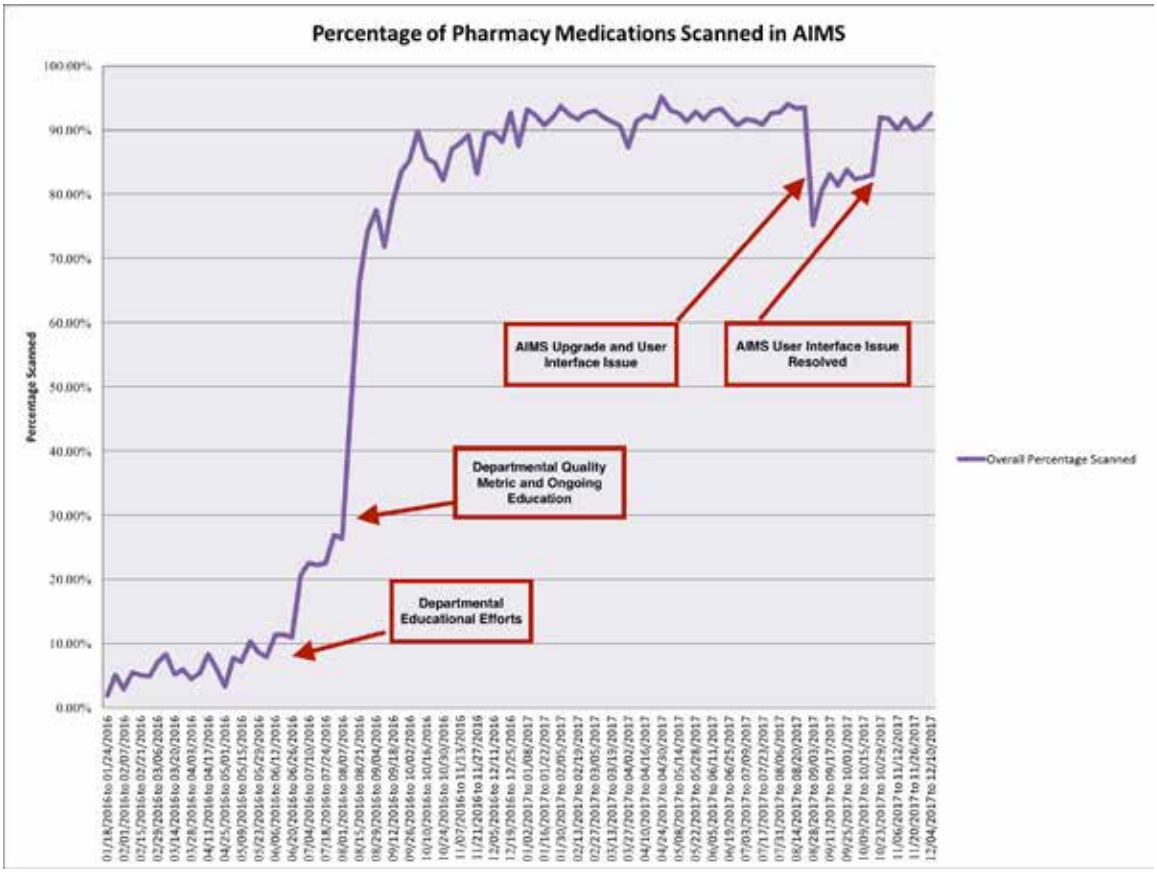
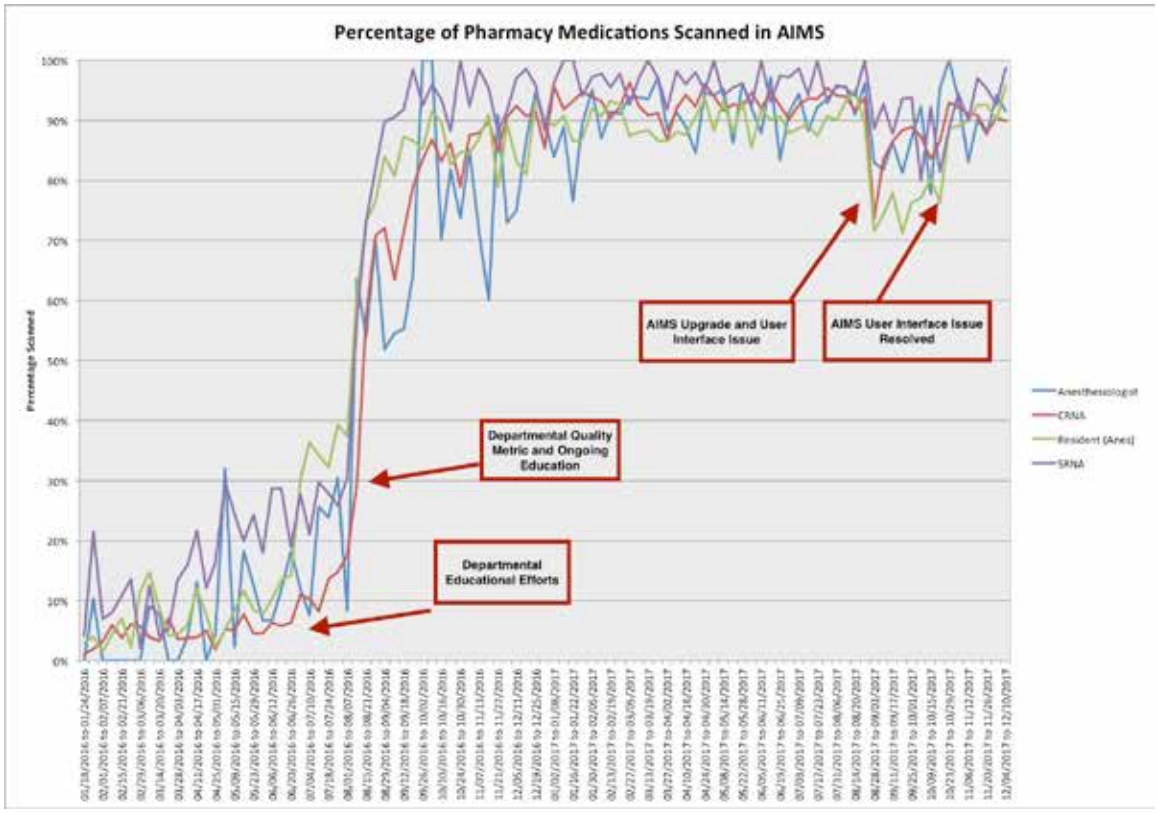


Figure 2



Targeting Blood Pressure by Monitoring Cerebral Autoregulation: Gradient Adjusted Flow-Pressure Curves

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Co-Authors: Paul S. Addison, PhD, Technical Fellow. Medtronic Respiratory & Monitoring Solutions, Edinburgh, Scotland, UK.
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Introduction: Cerebral blood flow is regulated over a range of systemic blood pressures through the Cerebral Autoregulation (CA) control mechanism [1]. The transcranial Doppler (TCD) based Mx measure has been proposed as a suitable proxy for blood flow in the analysis of CA [2]. Delineation of intact and impaired regions of autoregulation using Mx requires setting a minimum threshold above which the Mx measure is associated with impaired autoregulation [3]. This assumes that the gradient of the Flow-BP curve in the intact region is non-positive, which in practice is often not true. The method presented here allows for the enhancement of changes that occur between the intact and impaired regions of autoregulation, allowing a simple, automated algorithm to delineate the lower and upper limits of autoregulation (ULA/LLA).

Method: We used data from an in-house porcine study (N=9) that elicited blood pressure transitions to below the LLA. A linear regression between the TCD-based measure and MAP is calculated and used to subtract the values from the TCD-based signal. The gradient adjusted measure is calculated as

$$GA(x_i) = TCD(x_i) - y(x_i) \qquad [1]$$

where $GA(x_i)$ is the gradient-adjusted signal for the sample point x_i, $TCD(x_i)$ is the original TCD-based measure for the sample points x_i, and $y(x_i)$ is the value of the regression line for the same sample point. The method is fully explained in [4].

Results: Figure 1a shows the gradient adjustment technique applied to one of the animals in the study. It is very noticeable that in the top Mx plot there is not a clear-cut intact region, and traditional methods to segment the plot in intact/impaired regions would fail. The bottom plot depicts the same dataset after applying the GA method using a suitable Mx threshold. The transition zone between intact and impaired autoregulation is now obvious. Figure 1b shows box plots that includes the data for all the animals. The boxes for Mx above/below the LLA have a large overlap, and there is no large difference (0.149) between the median Mx values in both regions. In the boxes using the GA method, there is a clear difference (1.486) between the points above and below the LLA

Conclusions: The gradient adjustment method was successfully applied to a pig model to automatically evaluate the lower limit of autoregulation. There was a significant improvement in enhancing the transition zone between intact and impaired states. The gradient adjustment method appears to be a promising and simple to apply technique for evaluating the limits of autoregulation.

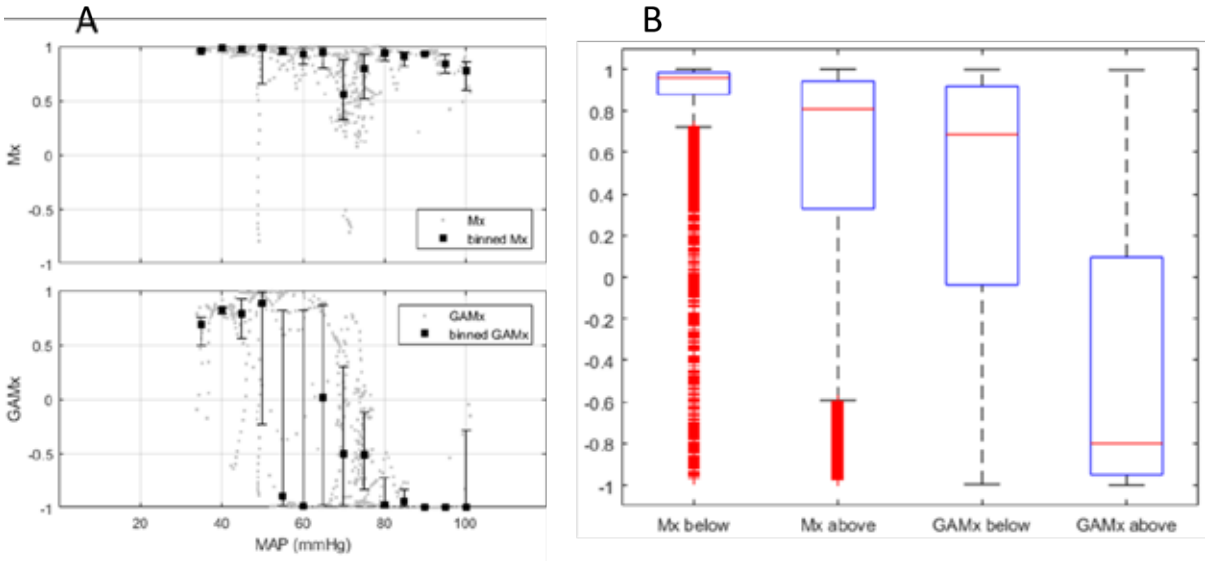

Figure 1. **A**: Mx and GA method applied on the Mx data for a single data set. **B**: box plots for all the animals for the Mx and GA method, separated in regions below the LLA and above the LLA. For the Mx data, median below LLA = 0.958, IQ: [0.880 0.985] and median above LLA = 0.809, IQ: [0.329 0.943]. For the Gradient-adjusted data, median below LLA = 0.686, IQ: [-0.037 0.917] and median above LLA = -0.800, IQ: [-0.950 -0.096].

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Monitoring at Home Before and After Tonsillectomy

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Introduction: Tonsillectomy and/or adenoidectomy (T/A) are commonly performed procedures. The most common indication for surgery is suspected or diagnosed Obstructive Sleep Apnea (OSA). Polysomnography (PSG) is the gold standard for diagnosing and assessing OSA [1]. While pulse oximetry is part of the standard monitoring used during PSG, its potential as a standalone tool to diagnose those patients most at risk of post-operative respiratory events has been investigated but is yet to be fully realized [2]. We aim to determine the feasibility of using the Phone Oximeter-OSA app to monitor children at home before and after T/A procedures.

Methods: Following Research Ethics Board approval and informed consent, children from 3 months to 17 years of age, undergoing T/A, were enrolled in this study. A Masimo pulse oximetry sensor (LNCS Inf-3TM) was attached to the participant's big toe and connected to the Phone Oximeter. Overnight pulse oximetry data was collected on the Phone Oximeter-OSA app for three nights at home before surgery, as well as three consecutive nights immediately post-surgery at home or in the hospital, if admitted. The app records heart rate, blood oxygen saturation (SpO_2), photoplethysmography and signal quality index (SQI). Pre and post-operative recordings lasting at least 5 hours, with a SQI exceeding 80 were considered successful. The best preoperative recording was chosen and the following features were characterized in 1-min signal segments: the average SpO_2 signal (SpO_{2ave}), the cumulative time spent below 94% (t94%), and the number of SpO_2 desaturations >3% below baseline (n3%). In order to evaluate overnight SpO_2 dynamics the mean of each feature were compared using the Mann-Whitney U test.

Results: Pre-operative recordings have been completed for 60 participants thus far; 97% had at least one successful recording. Participants were stratified into two groups based on their post-op disposition: admitted for overnight monitoring or discharged home. No significant differences in the means of SpO_{2ave} (mean difference = .101), n3% (mean difference = .011) or t94% (mean difference = .978) were found between groups. Additionally, no significant differences in the above mentioned parameters were found between participants diagnosed with SDB (n=47) versus those without SDB (n=10).

Conclusion: The initial phase of the study has shown that it is feasible to obtain recordings of sufficient quality at home; however SpO_2 characterization features are not well correlated with a clinical diagnosis of OSA. This finding is not surprising as clinical history alone may not be able

to diagnose and determine OSA severity. Hence determining the best post-op disposition for children undergoing T/A is rather arbitrary. Further research into the use of OSA risk scores to assist with minimizing post-operative risk and assisting clinicians in management of T/A cases warrants further investigation.

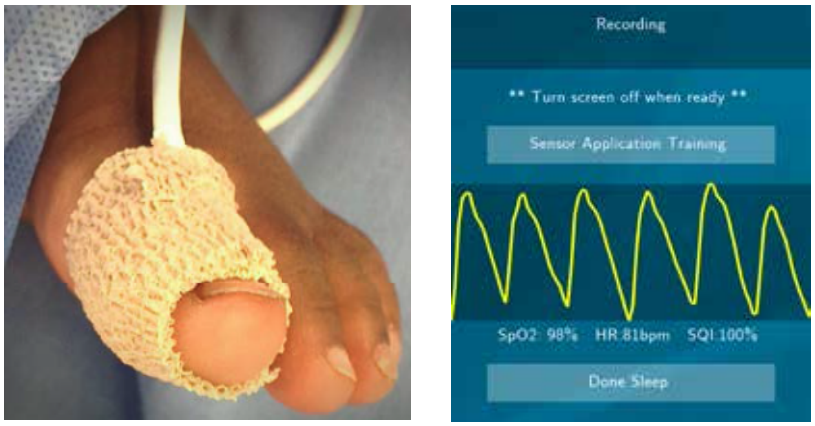

Figure 1: (a) Placement of the Masimo pulse oximetry sensor on the big toe. (b) Recording panel on the Phone Oximeter-OSA app including SpO_2, heart rate, photoplethysmography and SQI.

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Comparison of Electromyography Derived Train-Of-Four Ratios of the Adductor Pollicis and Abductor Digiti Minimi Muscles and Their Comparison to Acceleromyography Derived Train-Of-Four Ratios

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Background: This pilot study investigated a new electromyography (EMG)-based neuromuscular monitor, the TetraGraph™ (Senzime B.V., Uppsala, Sweden). The TG uses its own surface strip electrodes for ulnar nerve stimulation and compound muscle action potential recording from the adductor pollicis (mAP) or the abductor digiti minimi muscles (mADM).

Methods: Two TetraGraph™ devices were attached to the patient, one on each arm. One device was attached to the thenar eminence and the thumb to monitor the mAP. The other monitor was attached to the hypothenar eminence and 5th finger to monitor the mADM. This arm also served for acceleromyography (AMG) monitoring (IntelliVue NMT, Philips, Amsterdam, the Netherlands) of the thumb. After the induction of anesthesia, the three devices were calibrated to achieve supramaximal current intensities, then were started in train-of-mode (TOF) mode and ran automatically every 1 min in an alternating fashion. The EMG measurements on the two arms were performed at the same time and the AMG measurement was timed to be measured 30 sec later. We aimed to compare the correspondence of the two hand muscles' EMG TOF ratios (%), and to examine the agreement between the EMG and AMG measurements.

Results: After IRB approval and gaining informed consent, eleven patients {age: 58.1 ± 15 yr (mean ± SD); male: n=5, female: n=6; BMI: 30.3 ± 5.7)} were enrolled. The charge in µC (defined as the product of current intensity, in mA, and pulse width, in msec) required for supramaximal stimulation was lower for mADM than for mAP (11.3±4.3 vs. 13.6±3.7 µC, respectively), though this did not reach statistical significance ($p=0.27$). The onset of neuromuscular block was faster in 72.7% of cases at mADM than at mAP. The medians (interquartile range) of baseline TOF ratios were similar in the EMG measurements {mAP: 99.0 (97.3-100.0) vs. mADM: 98.0 (96.0-100.0), $p=0.075$}, yet both EMG derived mAP and mADM baseline TOF ratios were significantly lower than AMG mAP TOF ratios {112 (105-123), $p<0.001$}. The recovery EMG TOF ratios of the two muscles showed good correlation ($R = 0.716$, $p<0.001$, Fig. 1A) with a bias of -8.36 (95% CI = -28.59 to +11.88, Fig. 1B); however, the correlation was weaker with AMG derived mAP TOF ratios (for mAP EMG $R=0.659$, $p<0.001$; for mADM EMG $R=0.547$, $p<0.001$).

Conclusions: The TetraGraph™ measures the neuromuscular function of the mAP and mADM. Our preliminary results are consistent with a previous investigation [1-3] that found that these two muscles cannot be used interchangeably with EMG monitoring. The mADM has a faster onset and faster recovery of neuromuscular function than mAP.

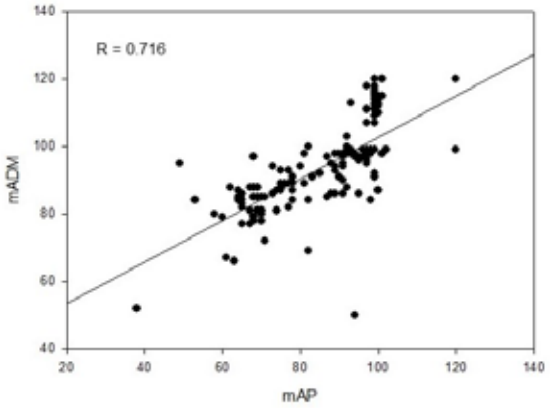

Fig. 1A – Linear regression of adductor pollicis (mAP) and abductor digiti minimi (mADM) derived recovery electromyography train-of-four ratios (%).

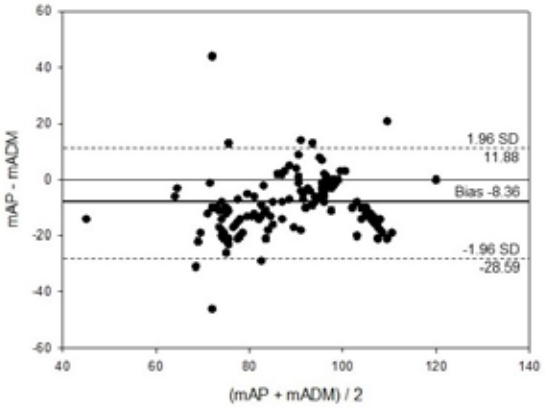

Fig. 1B – Bland-Altman plot of adductor pollicis (mAP) and abductor digiti minimi (mADM) derived recovery electromyography train-of-four ratios (%).

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Can You Turn It Down? Assessing Noise and Distractions from Music in the Operating Room

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Introduction: It has been noted that music has become a universal phenomenon in the operating room.[1] Music may serve as a distraction and pose a safety hazard by impairing alarm detection, communication and concentration.[1-3] This hazard has been acknowledged in a formal manner by statements on distraction and noise in the operating room by the American College of Surgeons (ACS), American Society of Anesthesiologists (ASA) and the Association of periOperative Registered Nurses (AORN). [4-6] More specifically, noise adversely affects patient safety by impairing alarm detection, communication, and cognitive processing. [3,7-11]

The acoustics in the operating room are generally poor *with* flat walls that cause sound reverberation. In addition, surgical masks preclude lip reading in acoustically suboptimal environments.[12] Noise levels in operating rooms frequently exceed Occupational Safety and Health Administration (OSHA) safe exposure standards of 45 dB.[13] A previous study found that noise levels in trauma operating rooms had average noise levels almost double the recommended EPA level.[14] Other rooms which are prone to high levels of noise include orthopedic and neurosurgery rooms, where peak sound levels intermittently exceed 100dB more than 40 percent of the time. As a reference, noise on a busy freeway is 110dB. 1 Studies focused on anesthesia have found that the noisiest periods during surgery are associated with induction and emergence of anesthesia.[15]

It is postulated that music levels may interfere with managing alarms. This is of additional importance given The Joint Commission in 2015 cited alarm management as a top priority and more recently included it in *Quick Safety* to raise awareness. To help address this potential safety issue, technology has been developed (CanaryBox™) that can automatically adjust intraoperative music at clinically appropriate times.

The goal of this study was to assesses anesthesiologists' perceptions to music in the operating room in order to determine the perceived clinical need for technology that automatically adjusts music volume.

Methods: A survey was electronically sent out to anesthesiologists at a large academic medical center. Surveys were completed anonymously and data was aggregated for analysis.

Results: 84% of respondents admitted to have experienced alarm fatigue. 64% of respondents felt that music can make it difficult to hear, discern information, or communicate effectively. 52% of respondents felt that music in the operating room can be distracting, increase the risk for error, or compromise safety. Approximately 1 out of 3 responded that they felt uncomfortable asking for the intraoperative music to be turned down. 48% responded that music reduces their ability to detect signals from patient monitors.

Conclusion: Approximately half of anesthesiologists surveyed felt that music reduced their ability to detect vital sign changes. This finding suggests that intraoperative music is a recognized patient safety concern. The data suggest that anesthesiologists recognize the clinical problem and are in need of solutions to overcome this safety issue. In light of these findings, solutions that could automatically adjust music levels when clinically appropriate may prove valuable.

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An Observational Study of Peripheral Muscle Oxygenation Using NIRS in a Cohort of Nourished and Malnourished Children with Pneumonia

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Introduction: Malnutrition is estimated to contribute to more than one third of all child deaths around the world especially in middle and low-income countries. Children affected by malnutrition are at 15-fold higher risk of mortality from pneumonia [1]. Pneumonia typical clinical signs may not be reliable in severe malnourished child due to an abnormal inflammatory response and severe muscle wasting and weakness [2]. Near Infrared Spectroscopy (NIRS) is a non-invasive optical technology used in clinical settings to measure changes in tissue oxygenation and hemodynamics that has demonstrated good prognostic capability in patients with sepsis [3]. The purpose of this study was to evaluate whether measurements of peripheral oxygen tissue saturation index (TSI) using a NIRS device could provide an objective measure of a child's systemic effects of pneumonia and allow identification of those who are at increased risk of dying from pneumonia.

Methods: With ethics approval and written informed consent from the parents or guardians, 185 children between 3 months and 5 years of age were recruited at two hospitals in Mbarara, Uganda. Children were stratified into four groups based on their nutritional status (a middle-upper arm circumference [MUAC], lower or higher than 12.5 cm) and the diagnosis of pneumonia (pneumonia and control group). Within six hours following admission, peripheral TSI was continuously recorded over the brachioradialis muscle using a portable NIRS device (PortaLite Mini, Artinis Medical Systems) before, during and following a vascular occlusion test (VOT). Demographic characteristics and clinical data including temperature, heart rate, respiratory rate and arterial oxygen saturation (SpO2) were measured. Multiple variables were calculated from the TSI (Fig.1 a). The diagnostic and outcome performance of the NIRS variables were assessed and compared to the other clinical variables using the Area Under the Receiver Operator Characteristic curve (AUROC).

Results: The baseline TSI was positively associated with the nutritional status of the child suggesting a higher oxidative stress of the muscle of malnourished children (Fig. 1 b). The most sensitive NIRS variables to identify children with systemic effects of pneumonia were the TSI Hyperemia Recovery Area which had an AUROC of 0.6799 (95% CI 0.6541 to 0.7452) in nourished children and the TSI Hyperemia Recovery Time which had an AUROC of 0.6966 (95% CI 0.5510 to 0.8036) in malnourished children. The respiratory rate performed best with an AUROC of 0.9609 (95% CI 0.9443 to 0.9833) and 0.9134 (95% CI 0.9107 to 0.9257) for nourished and malnourished children respectively, although confounded by the fact that respiratory rate is a component of pneumonia diagnosis. We also assessed the prediction of mortality among malnourished children with pneumonia, in which 23 children survived and 6 died. The best NIRS-related predictor was the TSI decline after 40s of vascular occlusion

(ΔTSI_{40s}), with an AUROC of 0.7681 (95% CI 0.7453 to 0.8880) while the best clinical predictor was the SpO_2 with an AUROC of 0.7043 (95% CI 0.5797 to 0.9091) (Fig. 1 c).

Conclusion: NIRS is an emerging technology that may allow clinicians to measure tissue level oxygenation and assess end-organ perfusion in a variety of tissues and for different clinical applications. However, it is still a young technology which requires further development and research. We found a weak association between NIRS features evaluated during a VOT on the brachioradialis muscle and the clinical diagnosis of pneumonia. Our results suggest that TSI baseline in a peripheral muscle is lower in a malnourished child but frequently preserved in the presence of pneumonia. The TSI decline after 40s of the arterial occlusion provided the best prediction of mortality from pneumonia but the small sample size precludes broader conclusions.

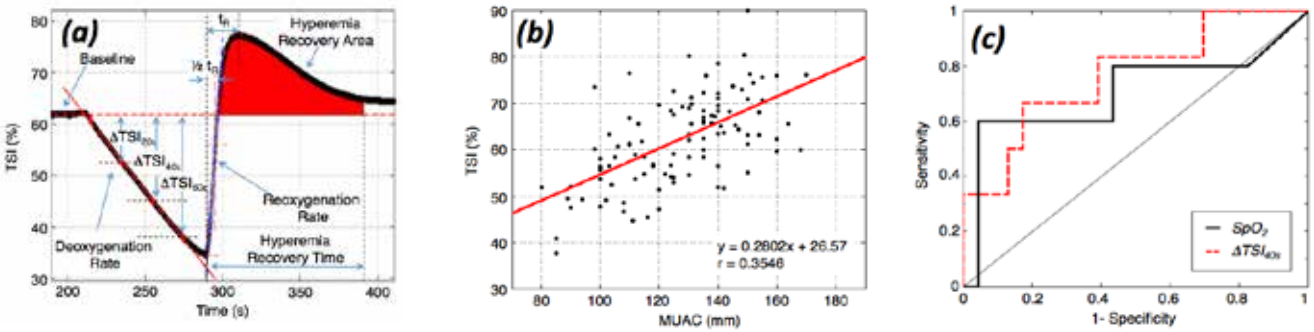

Figure1: (a) TSI before, during and after VOT and graphical representation of calculated variables (b) TSI baseline vs. MUAC (c) Receiver Operator Characteristic for mortality prediction in malnourished children with pneumonia.

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State of Validation Evidence for Computational Models Used for Design and Evaluation of Physiological Closed-Loop Mechanical Ventilation Devices

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Background: Mathematical models of physiological systems have potential to contribute to the design and evaluation of innovative and emerging safety-critical closed-loop mechanical ventilation systems. By leveraging such non-clinical test methods, it is possible to perform rigorous stress testing of controllers in a wide range of simulated challenging clinical scenarios. One of the biggest hurdles facing model-based design and evaluation of closed-loop mechanical ventilation is model validation and absence of a validation framework. In the fields of computational sciences, validation of the computational model of the system including assessing the uncertainty of the model form, parameter identifiability/sensitivity analysis, and uncertainty quantification is a critical component to enabling confidence in the testing results that rely on the model [1].

Methods: A literature review was performed to characterize state of validation evidence for models used in design and evaluation of closed-loop mechanical ventilation devices. The search was conducted based on articles found in Web of Science using the following criteria: 1) keywords such as closed-loop control, mechanical ventilation, and computational mathematical model/simulation. 2) The span of search was from 1980 to 2017. 3) The results were narrowed mathematical modeling studies specifically focused on the design and/or evaluation of closed-loop mechanical ventilation devices. Overall, 16 articles were reviewed.

Results: There have been some foundational modeling efforts [2-5] which have been referenced by authors in subsequent studies towards the design and evaluation of closed-loop mechanical ventilation systems. Robust objective validation evidence, such as information on and rationale for model form, selection/ identification of parameters, parameter sensitivity analysis, and uncertainty quantification were scarce, fragmented and in some cases [5] could not be found. Additionally, quantitative assessment of model performance on independent data either has not been conducted [3,5] or has been conducted under test inputs different than those in ICU, such as exercise and for a narrow range of model outputs [2]. Such foundational studies, while lacking basic validation evidence for their model use as a tool for design and evaluation automated mechanical ventilators, often were utilized in other studies (either by the same authors [6-8,18] or by other investigators [9,10], which invites additional modifications to the model, such as simplification of model structure [9,11], simplifying assumptions on model parameters (i.e. keeping them constant) [11-13], and addition of sub-models [14]. Such modifications are often done with minimal consideration to basic validity and

context of use of the original model and without justification that the previous validation results apply despite model modifications. This further complicates the validation of such models and hampers their utility for design and regulatory evaluation of automated mechanical ventilators. Recent data-driven modeling [15-17] are reported where models were directly developed from data to estimate parameters of underlying physiology. The models developed by [15, 16] were tuned using clinical data. However, a robust sensitivity analysis could not be found in [16] and for [15] the sensitivity analysis was not followed by a quantification of uncertainty in model parameters or inputs. The models were evaluated on calibration data but performance criteria were not established prior to the evaluation of the calibration procedure. Furthermore, it appears that the extent of validation stopped at the calibration level, and that the models were not evaluated on independent data to assess predictive capability of the model [15-17] before it was used in the context of design and/or evaluation of the controller.

Conclusion: Rigorous model validation has not been reported in the literature for design and evaluation of closed-loop mechanical ventilation. A framework for evaluation of such model to assist in evaluating the validity of the model with specific attention to concepts such as identifiability, parametric sensitivity, and uncertainty quantification [18] is needed.

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Feasibility and Utility of Continuous Noninvasive Hemoglobin Monitoring in the General Care Setting

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Noninvasive continuous monitoring of hemoglobin (Hb) may help identify patients with critically low Hb or detect changes over time (bleeding)[1-4], and may also reduce patient discomfort, expedite access to results, and make more efficient use of laboratory resources. Availability of Hb trends may assist clinicians in treatment planning and interventions, and allow for earlier recognition of patient deterioration[5]. The goal of the present study was to understand the practicality and impact of using noninvasive continuous Hb monitoring in a general care inpatient setting.

For the three month study duration (Jan-March 2016), 71 beds in two postsurgical units at Dartmouth-Hitchcock (D-H) Medical Center (5630 patient days), were equipped with specialized sensors (Rainbow^{TM}, Masimo Corporation, Irvine, California) allowing for direct monitoring of Hb (SpHb), in addition to blood oxygen saturation (SpO2), pulse rate (PR) and perfusion index (PI), which constitute the standard of care for inpatients at D-H. Established patient assessment procedures and alarm configurations for SpO2 and PR remained in use. SpHb alarms cannot be disabled per manufacturer design and therefore maximum thresholds were set for this parameter to reduce possible alarm fatigue. Workflow changed including allowing nurses to request a hemogram if the transcutaneous Hb value was 6 g/dl or less, without the presence of other symptoms. Patient data for each physiological measure, collected at the rate of 1 per second, were recorded and analyzed.

The SpHb data (n≈181.3 million) corresponding to the inpatient population presented a mean value of 11.08 ±0.0002 g/dl, a standard deviation of 1.34 g/dl and an interquartile range of 1.80 g/dl. Whereas the mean value was lower than the normal range cited for laboratory measurements[6], it is consistent with reported data for an inpatient population (~11.79 g/dl)[7].

A histogram of SpHb values versus PI distributions (Fig. 1), showed that 67.38% of the data correspond to SpHb values greater than 6 g/dl and PI values greater than 2.0. A PI value of less than 2.0 generally indicates low perfusion and could imply a low-quality signal for SpHb calculation. PI is subject specific and dependent on various factors including peripheral tissue perfusion, circulatory status, monitoring site, and sensor placement.

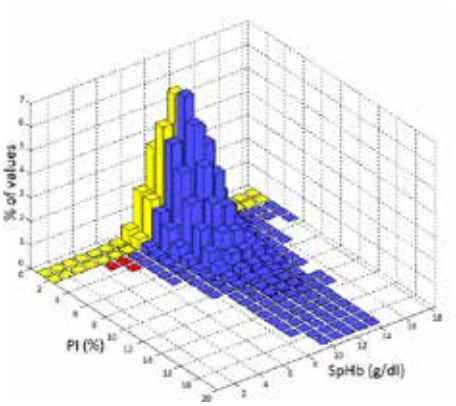

Figure 1. SpHb versus PI histogram. Blue designates *Hb > 6 g/dl and PI > 2%, yellow designates PI values <2%, and red: Hb below 6 g/dl and PI > 2%.*

There were 23.36% fewer valid SpHb data points collected versus the number of SpO2 (or PR, or PI) values. The disparity is likely due to signal confidence, and may be related to alignment of the multispectral sensor. The clinical staff acted upon SpHb values of less than 6 g/dl in a total of 9 instances (1.6 times per 1000 patient days), by requesting hemograms. There were no rescue events triggered as a result of the continuous SpHb measurements during the study period.

A survey of staff satisfaction and system performance was administered (n=32). Responses indicated that correct sensor placement, mainly due to its size, was somewhat challenging, and the weight of the connector cable resulted in patient discomfort (the manufacturer has since redesigned the connector). A lack of confidence in the continuous Hb values was also expressed by staff on occasion, although no evidence to support this was found in a comparison with laboratory data. Comments in the survey illustrate that this response could be due to suboptimal change management activities prior to and during the study. Survey results did show recognition of the necessity and utility of continuous Hb monitoring for patients at an increased risk of bleeding and after transfusions.

In summary, continuous monitoring of Hb in the general care setting is technically feasible with minimal impact on clinical workflow. The system provided fairly reliable continuous output, Hb values were consistent with other studies, and minor design issues encountered with implementation in a general care setting could likely be addressed in a full-scale implementation.

Funding: This project was supported by grant number P30HS024403 from the Agency for Healthcare Research and Quality (AHRQ). The content is solely the responsibility of the authors and does not necessarily represent the official views of the AHRQ.

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Development of a Method to Determine Geolocations for Anesthesia Specialty Coverage and Standby Call Allowing Return to the Hospital within a Specified Time Interval

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Background: Staffing requirements during non-regular hours can be determined using historical data form anesthesia or operating room information systems.[1] For emergent procedures, in-house teams are required to provide patient care. However, for many procedures, there is time to bring in a call team from home without increasing patient morbidity. Anesthesia providers taking call from home or on backup call are required to return to the hospital within a designated interval. Driving times to the hospital during the hours of such call need to be considered when deciding where one can be located when taking such call. Distance alone is an insufficient criterion because of varying traffic congestion and difference in access to highways.

Objective: Our goal was to develop a simple, inexpensive, method of determining the areas around the hospital in which people taking standby call could be located and meet the requirement for a timely return to the hospital.

Methods: Pessimistic travel times and driving distances using the Google Distance Matrix Application Programming Interface[3] (API) were calculated for postal codes[2] ≤60 great-circle ("straight line") miles of the University of Miami Hospital (Miami, Florida). A postal code was considered acceptable if the longest estimated driving time was ≤ 60 minutes (the anesthesia department's requirement) among all 108 weekly call hours. Linear regression (with a zero-intercept) minimizing the mean absolute percentage difference between the distances (great-circle and driving) and the maximum of the longest pessimistic driving times among all 108 hours of standby call per week was performed among all 136 postal codes. The software was written in Python.

Results: Postal codes allowing return to the studied hospital within the allowable interval were identified (Figure). Driving distances correlated poorly with the return driving times to the hospital (mean absolute percentage error = 25.1% ± 1.7% standard error [SE]; *N* = 136 postal codes). Great circle distances also correlated poorly (mean absolute percentage error = 28.3% ± 1.9%).

Conclusions: The described method allows identification of postal codes surrounding a hospital in which personnel taking standby call could be located and be able to return to the hospital within a specified interval during all call hours of the week. For areas at the perimeter of the acceptability, the Google Maps application can be used to check driving times during the hours of standby call.

Figure. Map of centroid locations (green balls) from the United States Census Bureau zip code tabulation areas surrounding the University of Miami Hospital (blue ball) where a return to the hospital during all non-regular hours would be possible within 60 minutes. Areas outside this zone are noted with red balls.

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Quality: Taking Action When It Matters

Presenting Author: Rocky Reston, MD, PhD, Chief Medical Information Officer, Cognitive Medical Systems

Co-Authors: Andrew Simms, PhD, Principal Informatics Scientist; Shannon O'Brien, CORA Product Manager

Background/Introduction:

Quality measures are used throughout the medical continuum to improve outcomes, prevent injuries, reduce costs, and optimize reimbursement. In anesthesia care, quality measures guide clinicians to perform actions that are known to positively impact safety, and patient outcomes. Typically these actions are easy to perform, but can be overlooked as the anesthesia team focuses on guiding the patient through a successful procedure. Unfortunately, an anesthesia provider's feedback from quality measures related to their anesthetic tends to occur long after the procedure is complete, when recognition of a missed intervention can no longer contribute to patient care delivery or affect reimbursement.

Recognizing the importance of closing this gap, we developed the Clinical Optimization Reasoning Architecture (CORA) application, which can provide intraoperative quality measure guidance. CORA is a standards based clinical decision support application, which collects and analyzes data during a procedure. The application can determine eligibility for a set of quality measures, and provide recommendations to perform corrective actions during the intraoperative period. This ability to provide intraoperative quality measure status can substantially improve provider compliance, patient care and reimbursement.

Methods:

Five high-value quality measures were chosen from the Anesthesia Quality Institute's NACOR registry [1], translated into production rules, and imported into CORA. We then extended CORA to communicate with the Draeger Innovian® [2] anesthesia information management system (AIMS). This enables the continuous evaluation of the measures, based on patient information and near real-time sensor data. Results in the form of alerts, and recommendations, are presented to the care team via a JavaScript flyout tab that runs alongside the AIMS system.
Figure 1 illustrates CORA's high-level architecture and data flow.

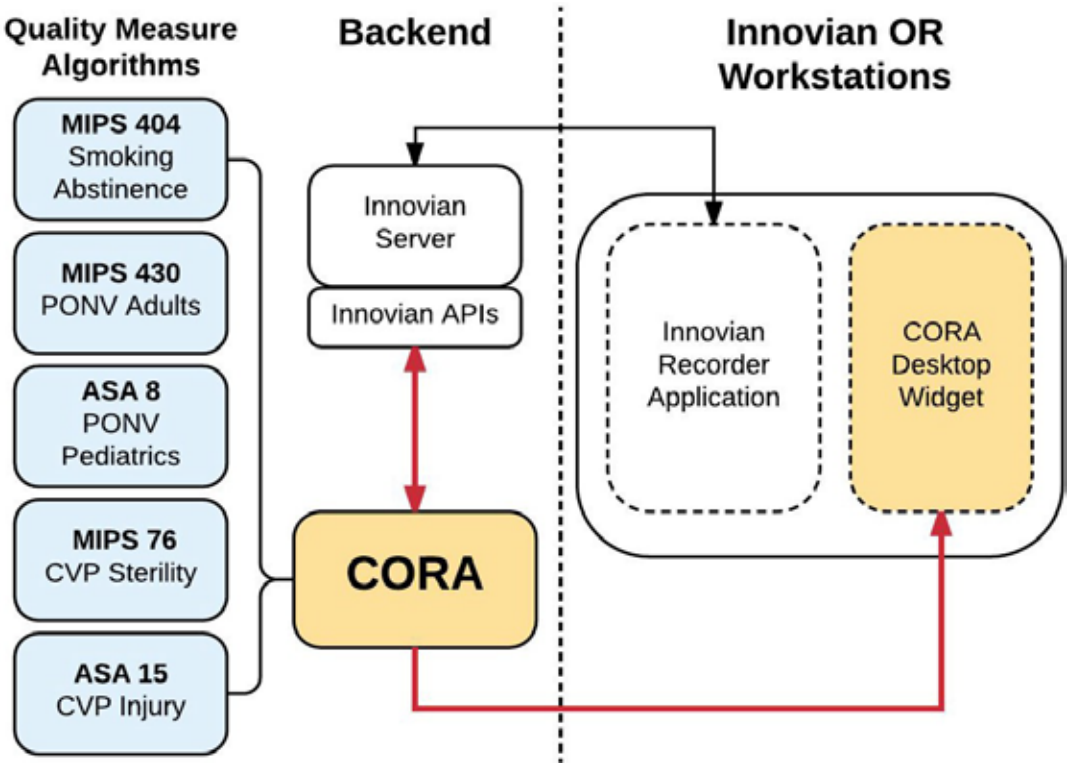

Figure 1. Continuous integration of quality measures with the Innovian® anesthesia platform through CORA. Five quality measures defined in NACOR were translated from narrative form into production rules. These rules are then executed in the CORA clinical decision support application, which continuously evaluates data in near real-time, and provides guidance to ensure measure goals are achieved.

Conclusions:

Working with the anesthesia staff at Magnolia Regional Health Center (12 ORs with an annual case load of 11,000) to identify and prioritize key quality measures, we implemented a system to continuously reason over data from individual anesthesia information management system instances, allowing up to 12 cases to be simultaneously active. The context-aware front-end was synchronized with the specific patient/case running on an Innovian® OR workstation to provide the anesthesia staff at Magnolia Regional Health Center with near real-time, intraoperative quality measure status, enabling impact *before* the patient leaves the OR.

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Closed-Loop Vasopressor Controller Robustness Against Variability in Pharmacokinetics, Pharmacodynamics, and Infusion Line Delay

Co-Authors: J. Rinehart[1], A. Joosten[2], M. Ma[1], M. Calderon[1], M. Cannesson[3]

University of California Irvine, Hôpital Erasme Brussels, University of California Los Angeles

Background: There is growing evidence that intraoperative hypotension, both cumulative time and degree, is associated with increased morbidity and mortality post-operatively. In the ICU, treatment of hypotension has long been a priority in patient management. In both settings, vasopressor drips are frequently used to maintain mean arterial pressure, but our own research has shown that titration of these drips is frequently suboptimal, with 30% of time spent > 20mm Hg above reasonable target MAP and 10% of time spend >10mm below reasonable target MAP. Automatic titration is a task easily managed by computer, and we have successfully demonstrated the feasibility of a novel closed-loop controller for this task. Individual patients may exhibit differences in both dose response and drug elimination, however, so safe performance of such a system must be demonstrated across a plausible range of possible pharmacokinetics and pharmacodynamics. We sought to establish whether the current controller would still operate safely given such variability.

Methods: Using a previously established and validated physiologic simulation model, we modified the response to a generic alpha-agonist agent modeled after phenylephrine to include randomization of: 1) Potency, with a range of 1/5x to 3x typical response. The drug was modeled with a convex response curve (decreasing impact with increasing dose) and a median-dose for 50% full potential effect (MD50) inflection point of 625 micrograms as baseline, with a range of 150 – 1500 in the randomization. 2) Drug clinical effect half-time. Baseline was set to 150 seconds, with randomization range set from 90 to 300 seconds. 3) Infusion delay: 0 to 60 seconds between 'infusion' of a dose and clinical effect. The closed-loop controller was run on a separate laptop using the network to communicate dose to the simulator and receive back vital signs data in return. 500 Monte Carlo runs per condition were used as a reasonable sample to assess overall performance. Performance across the runs was compared to no management and management in the "optimal" PK/PD patient (MD50=625, half-time of 150s, 10s infusion line delay). A 30-minute 3-stage sepsis/vasodilatory scenario was used as the testing condition. Controller target was set to 70mm Hg, with 'acceptable' performance permitted from 68-75 mmHg.

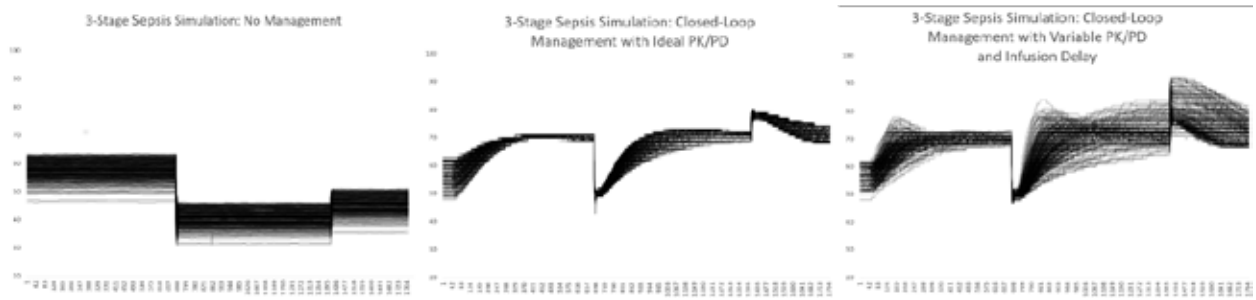
Results: Performance results for each condition are shown in Table 1. Spaghetti plots of mean arterial pressure over time are shown in Figure 1. Higher infusion line-lag was found to be the biggest contributor to overshoot, and low patient responsiveness the largest contributor to undershoot.

Discussion: The controller remained stable in all runs (convergent on target over time). Performance degradation was relatively minor in the Variable condition, with most error coming from being over-target.

Table 1: Results of Simulations

	Study Condition		
	No Treatment	Ideal	Variable PK/PD
Under Target	1770 ± 0	497 ± 108	488 ± 225
Over Target	0 ± 0	146 ± 46	234 ± 208
Under or Over	1770 ± 0	643 ± 148	682 ± 300
Major Err (> ±10)	1456 ± 337	157 ± 72	172 ± 95

Figure 1: Spaghetti Plots of MAP over 30-minute Simulation Scenarios



The Effect of Ketamine on Depth of Hypnosis Indices During Total Intravenous Anesthesia – a Comparative Study Using a Novel Case Replay System

Co-Authors: Stephanie Schueler, Christian L Petersen, J Mark Ansermino, Richard Merchant, Matthias Görges, Department of Anesthesiology, Pharmacology, & Therapeutics, University of British Columbia

Background: Processed electroencephalogram (EEG) monitors provide clinical information by deriving a single depth-of-hypnosis (DoH) index from a complex EEG signal comprising a multitude of frequency components. The reliability of DoH indices can be influenced by many factors, including the unanticipated EEG effects of co-administered drugs. Ketamine, frequently used to reduce postoperative pain [2], is known to affect high frequency EEG power [1]. We have previously reported the development of an EEG simulator for comparison of three common DoH monitors [3]. We recently completed a randomized study of total intravenous anesthesia with propofol and remifentanil in the presence of ketamine (Ketamine trial; NCT02908945). Patients were randomized to one of three groups: Group 0.5 received a 0.5 $mg \cdot kg^{-1}$ ketamine bolus, followed by a 10 $mcg \cdot kg^{-1} \cdot min^{-1}$ infusion [4]; Group 0.25 received a 0.25 $mg \cdot kg^{-1}$ ketamine bolus and a 5 $mcg \cdot kg^{-1} \cdot min^{-1}$ infusion; a control group received no ketamine. The purpose of this study is to compare three common DoH monitors in the presence and absence of ketamine by extending our EEG simulator to allow replay of previously recorded EEG.

Methods: A USB-based audio digital to analog converter (U-PHONO UFO202, Behringer, Willich, Germany) was modified by replacing the integrated 22 µF capacitors in the high-pass filter with 1000 µF capacitors, to improve low-frequency replay. Replay behavior was verified with sine waves over the clinically relevant frequency range (0.1-50.0 Hz) and by re-replaying both synthetic and previously recorded EEG. Signals were compared and analyzed in the time and frequency domain. Next, EEG data from the Ketamine trial were extracted at 900Hz, converted into audio files, scaled to adjust amplitude, and replayed to three monitors: NeuroSENSE (NeuroWave Systems, DoH index=WAV), BIS (Medtronic, DoH index=BIS) and Entropy (GE Healthcare, DoH index=RE). Differences in DoH indices during the surgical preparation phase (first 20 min of case), in which peak ketamine DoH effect was expected to be observed in the absence of surgical stimulation, were compared as violin plots, in 5 minute increments, for the three devices. DoH differences between the 2 ketamine groups and the control group were compared using Wilcoxon rank-sum tests for each monitor.

Results: Data from 29 cases were available for analysis. The presence of ketamine significantly increased the median DoH index for all three monitors: compared to the control group, median DoH difference (MD), calculated over a 1 minute window, for Group 0.5 were 14.0, 8.9, and 19.5 for BIS, RE, and WAV respectively; similarly, MD for Group 0.25 were 12.5, 17.2, and 8.2 for BIS, RE, and WAV respectively (Figure 1; all $p<0.025$). Comparing the three monitors at each time point, significant differences were found only when comparing BIS to RE, and WAV to RE for awake data (minute 1).

Conclusion: We observed a ketamine dose-dependent increase in the DoH index for all three monitors. Future work will include other processed EEG parameters such as Burst Suppression Ratio (BSR) and electromyography (EMG) in the monitor comparison. A limitation of this method is that replay of pre-recorded EEG is affected by the input filters applied during the original recording, and detailed filter characterization may be needed to fully reconstruct the raw EEG signal. Once perfected, replay technology can facilitate systematic evaluation of DoH monitors in the presence of adjunct drugs such as ketamine, and contribute to establishing a more widely accepted standard for quantitative measures of anesthetic effect.

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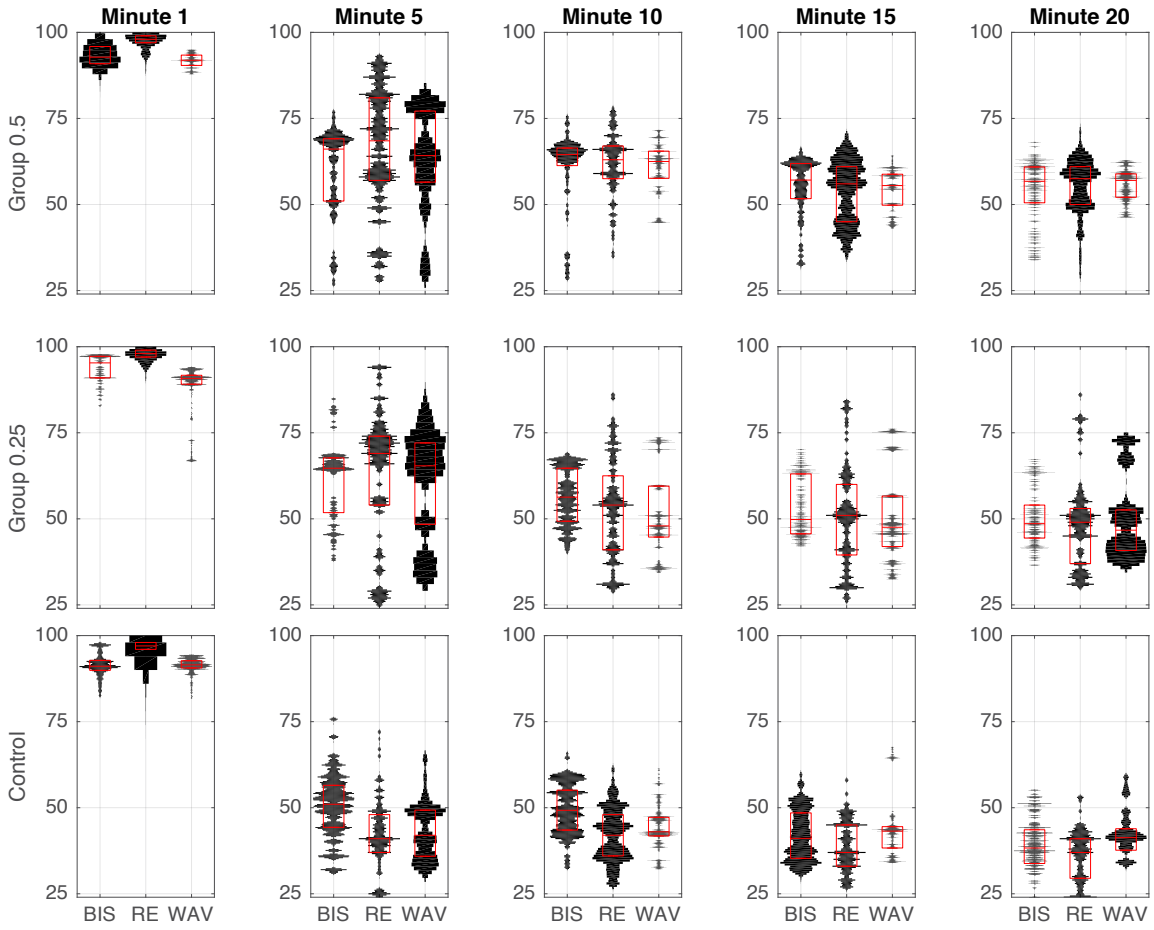

Figure 1: DoH index for Group 0.5, Group 0.25, and the control group, showing a combination of violin and boxplots for the first 20 min of each case, in 5 minute increments for 1 minute of values each, for each monitor-specific DoH index, grouped by ketamine dose.

There's An App For That: Smartphone App Use Among Anesthesia Providers

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Co Authors: Vendhan Ramanujam[1], Parmis Green[1], Farshad Rasidian[1], Johann Mathews [1], Michael Green[1].

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Background/Introduction: Health care related apps provide valuable facts in different hospital settings, including the perioperative and ICU surroundings. To date no study has reviewed the use of anesthesia apps and how they can help integrate technology into clinical practice.

Methods: The authors studied various mobile apps relevant to anesthesia providers in google play store, apple play store and Windows play store. These apps were organized into various categories (Figure-1). In the second part of the survey, we focused on the utilization of anesthesiology apps among practitioners, including anesthesiology residents, anesthesiology fellows, certified registered nurse anesthetists (CRNA), student CRNA's, and anesthesiology attending staff. A total of 416 anesthesia providers participated in the survey.

Results: Among the survey participants 99.27% (n=410) were using smartphones and 0.73% (n=03) of participants were not using the smartphones. Among smartphone users 18.09% were using Android OS, 81.66% were using iPhone OS, 0.24%(n=1) was using windows mobile OS, and none of the participants were using the mobile phones utilizing blackberry OS, Symbian or Palm OS.

Among the participants, 11.36% never used a smartphone apps related to anesthesiology,12.37% were using less than once per month, 6.06% were using once per month, 12.12% using 2-3 times per month, 13.64% were using once per week, 20.96% were using 2-3 times per week, and 23.48% were using daily.

Participants rated the usefulness of app in various categories on a scale of 0-100. Most of the participants consider dosage/pharmaceutical apps to be more useful and given a mean score of 78.73 on a scale of 0-100. In addition, the survey queried questions related to how much participants were willing to pay for an app if it saves 5-10 minutes per day or up to 30 minutes/week. 24.59% of participants were only willing to pay less than $2.00 , 25.14% were willing to pay up to $5.00, 30.33% were willing to pay $5-$10.00, 9.56% were willing to pay $10-$25.00 , 5.19% were willing to pay $25-$50.00, and 5.19% were willing to pay more than $50.00. Finally, 84.15% were interested in newer apps in anesthesiology and 15.85% were not interested in new anesthesia related apps.

Conclusion: There are more than 100 anesthesia apps available in the market today. In this age of smart phones, it was hardly surprising to see that more than 99% of the participants had access to anesthesia apps in our survey. This survey answered some of the important questions

about the utilization of mobile apps by anesthesia providers. This survey illustrates the convenience of apps for health care professionals at the point of care, due to portability and quicker access to information. The perturbing aspect to this new trend is the authenticity of some of these apps, with many of them not being reviewed and the absence of a regulatory body. Some of these apps, like opioid dosage conversion apps, was not reliable and accurate, lacked information on evidence-based content and no peer reviews in some cases, compromising patient safety. These issues could be some of the reasons why 16% in our survey felt they didn't need more apps in their practice, indicating an apparent lack of trust in mobile apps. Another interesting observation was that only 20% of participants were willing to pay for an app that was $10 or more. The data from this research could potentially be helpful In future development of mobile apps for anesthesia providers.

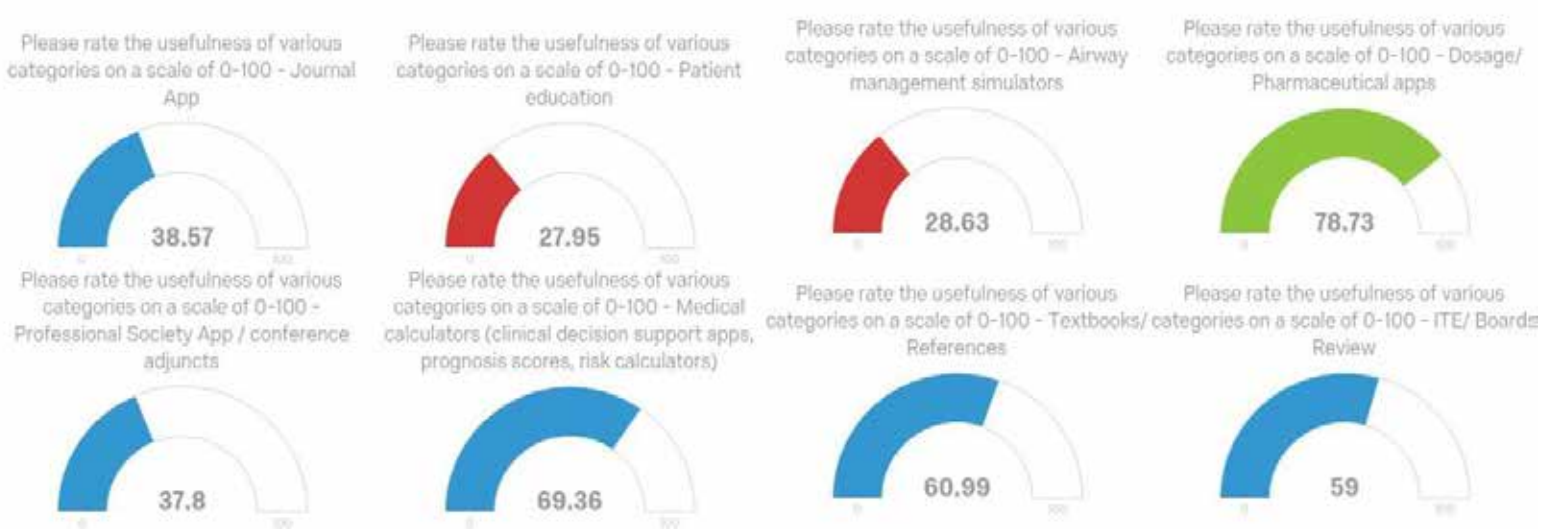

Figure 1- How the Anesthesia Providers rated the usefulness of various Anesthesiology Application.

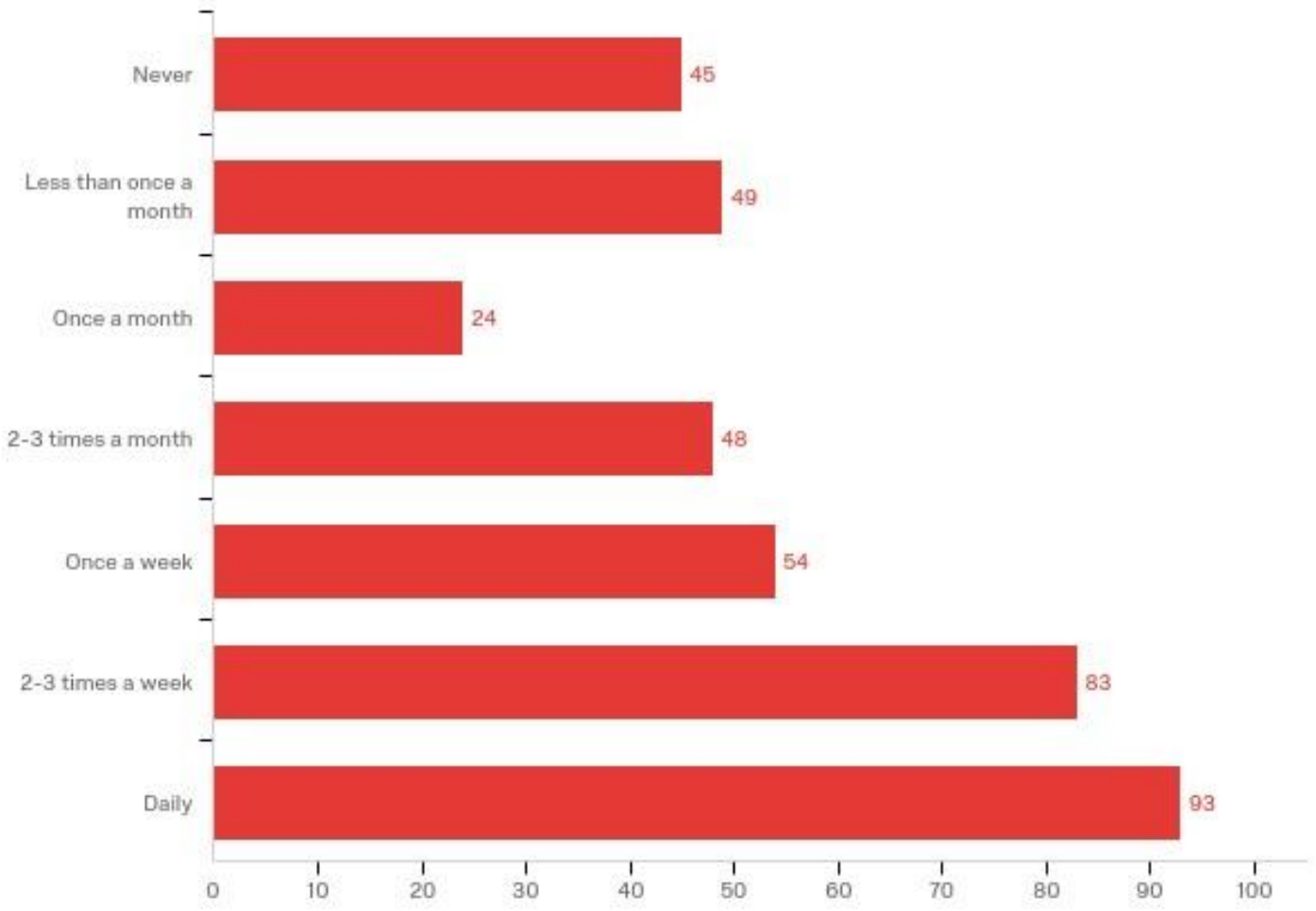

Figure 2. How Frequently Anesthesia Providers Used Smartphone Apps related to anesthesiology.

Automated Email Reminders Significantly Improve Faculty Compliance with Resident Evaluations

Presenting Author: Zachary A. Turnbull, MD, Weill Cornell Medicine Department of Anesthesiology

Co-Authors: Anna Nachamie, BS, Virginia Tangel, MA, Kane O. Pryor, MD, Weill Cornell Medicine Department of Anesthesiology

Introduction: Providing consistent and timely clinical and professional feedback to residents during their training is essential for growth into independent practice and is an Accreditation Council for Graduate Medical Education requirement of faculty members. This feedback allows for real-time improvements and potential positive impacts on the next patient interaction. At Weill Cornell Medicine's Department of Anesthesiology, an evaluation platform is used to provide structured feedback to trainees in areas such as competence, professionalism, resource utilization, and readiness for independent practice. In our department, we initiated global daily paging reminders but compliance did not improve substantially. Therefore, we hypothesized that a more direct, individualized email service for faculty members would have the biggest impact on compliance of completing resident evaluations.

Methods: We analyzed data from June 14, 2015 to October 28, 2017 to assess the impact of two technological interventions on the completion of resident evaluations. Daily global paging reminders were initially inconsistent and therefore stopped on June 29, 2016 and were reinstated on February 17, 2017. A shift to individualized email reminders with an embedded link to evaluations began on June 15, 2017. A custom application generated daily emails to faculty who paired with residents in our anesthesia information management system (AIMS). Duplicate faculty/resident pairings on the same day were removed from the analysis, as the department expectation is to submit one daily resident evaluation. We conducted an interrupted time series analysis of weekly data to assess the effect of the interventions. In addition, we analyzed a subset of weekly data from February 19, 2017 to October 28, 2017 to assess the percentage change in compliance by individual attending among a population who logged cases in AIMS both before and after the email intervention. All analyses were conducted in Stata SE 15 (College Station, TX, USA).

Results: In the first week after the reinstitution of paging reminders, there was an estimated 12 percentage point increase in the percentage of AIMS cases with a completed evaluation (compliance), 95% CI: 4-19%, $p < 0.01$. In the first week after the institution of e-mail reminders, there was an estimated 19 percentage point increase in compliance, 95% CI: 10-27%, $p < 0.01$. Among a pool of 73 attendings who had completed cases both before and after the email intervention, 86% (63) had completed evaluations before. The intervention brought participation to 100% as 10 attendings (14%) completed evaluations for the first time. In addition, compliance by attending grew to 53% after the email intervention, up from 31% (a 71% relative increase, $p < 0.01$).

Conclusions

Our individualized email service had a large impact on improving faculty completion of resident evaluations. As a result of the intervention, our department has a more accurate picture of resident performance because of the increased number of faculty participating in the evaluation process. One limitation of the study is the unclear expectation of evaluating a resident with whom a faculty member has worked with multiple times in one week. Further follow up on missed opportunities is needed to better understand the nuances of faculty thought process, time burden, and expectations. Similarly, technical improvements to the system as well as long term sustainability is essential.

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https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/040_anesthesiology_2017-07-01.pdf

Active Virtual Reality Improves Vascular Access Compliance in Anxious Children

Presenting Author: Justin C. Yuan, B.S.[1, 2]

Co-Authors: Alexandria Joseph, B.S.[2], Samuel Rodriguez, M.D.[2], Thomas J. Caruso, M.D.[2]

Affiliation: 1. Oakland University William Beaumont School of Medicine; 2. Department of Anesthesiology, Perioperative, and Pain Medicine, Lucile Packard Children's Hospital Stanford, Stanford University School of Medicine

Introduction: The fear of needles is commonly encountered by healthcare professionals when providing vascular access for pediatric patients. Virtual reality (VR) has been used in the healthcare setting for nearly two decades [1, 2], and it has recently demonstrated utility in vascular access settings [3]. The goal of this prospective, randomized study was to evaluate the efficacy of actively playing a VR game during vascular access compared to standard of care. Our primary outcome was compliance. Secondary outcomes were child self-reported fear, pain, and anxiety ratings.

Methods: 49 pediatric patients undergoing vascular access at the Lucile Packard Children's Hospital Stanford were enrolled. Vascular access included blood draw, IV placement, or port access. Participants were randomized to an active VR game (n = 24, mean age = 14.02, SD = 2.56) or control (n = 25, mean age = 13.44, SD = 3.55). For VR patients, the proprietary game Spaceburgers™ was played on a customized Samsung Gear VR headset and S8 smartphone during vascular access. For control patients, standard of care was provided. The primary outcome was measured by a modified Induction Compliance Checklist (mICC). The ICC is traditionally used to measure pediatric compliance during induction of anesthesia, but underwent minor modification of wording to apply it as a measure of compliance of vascular access. mICC scores of 0 indicate perfect access, while scores > 6 indicate poor compliance. Secondary outcomes were assessed via the Children's Fear Scale (CSF), pain scale, and Childhood Anxiety Meter (CAM).

Results: Percentage of perfect access were similar at 91.67% for the VR group and 88% for the control group (p = 0.68), demonstrating demographic homogeneity. For the population of interest, those in need of extra support during vascular access, there was a significant difference demonstrated between average mICC scores (p = 0.032). Patients in the control group who did not have perfect access exhibited a higher mICC average score of 3.67, indicating lower compliance. Patients in the VR group who did not have perfect access exhibited a lower mICC average score of 1.5, indicating higher compliance. For secondary outcomes, statistical significance was not found. The VR group had a smaller rise in fear (p = 0.060), larger rise in pain (0.91), and decrease in anxiety (p = 0.56) relative to the control group.

Conclusion: There was no statistical difference between groups in mICC scores for perfect vascular access. However, for those patients who did not have perfect access, the VR group performed at a lower mICC score with better compliance. The VR group also shows promise in

mitigating fear and anxiety, but not pain, amongst pediatric patients. Future studies should include larger sample sizes for greater power to examine covariates of interest.

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