



2019 Annual Meeting Syllabus

MIND and *Machine*

January 9-12, 2019
Four Seasons Resort
Scottsdale at Troon North
Scottsdale, Arizona

Annual Meeting
Program Co-Chairs
Charlene Blake, MD, PhD
Matthew Levin, MD

#STA19Scottsdale

THANK YOU CORPORATE MEMBERS



Welcome

A warm welcome to the Society for Technology in Anesthesia's (STA) 2019 Annual Meeting! We are looking forward to a superb program expertly organized by our program co-chairs, Drs. Charlene Blake and Matthew Levin, and abstract co-chairs, Drs. Robert Freundlich and Clyde Matava. Also, our meeting could not happen without our excellent staff, Marie Odden, Rachel Witte, and Jane Svinicki. Please make sure to express your thanks to all of them.

This year's meeting theme, "Mind and Machine," describes exactly what the STA is all about, especially, with the session subtopics of The Machine Makes the Mind, The Mind Makes the Machine, The Machine Has No Mind, The Machine Has a Mind, and Mind vs. Mind. We are going to hear from world class faculty about new technologies in education, closed-loop systems and new patient monitoring displays, next generation anesthesia IT systems, anesthesia applications of deep learning, and an entrepreneurial session of Anesthesiologist Idol. Add to that the scientific abstracts, the engineering challenge (quantum computing!), and our young researcher's workshop. Lots of opportunities to get together and network with like-minded anesthesia technologists from academia, industry, or government.

I have been attending STA meetings since the early 1990s and again and again this meeting is one of the highlights of my year. I just love to be able to learn about new technologies, about unsolved problems in the clinical real world, and find out about industry and regulatory perspectives on innovation. Our Society is very unique in the way it facilitates these interactions.

We would like to thank our Corporate Members for their continued and sustained support of our Society. Please make sure to interact with them, they appreciate our meetings for the opportunities to learn and discuss innovation with our non-industry members. STA would not be possible without our corporate friends!

Go out there, learn, discuss, mingle, enjoy!



Kai Kuck, PhD
President, Society for Technology in Anesthesia

Invited Faculty

Soodeh Ahani, PhD
University of British Columbia

Eric Bauman, PhD, FSSH
Adtalem Global Education

Charlene Blake, MD, PhD
2019 Annual Meeting Co-Chair
University of California, San Francisco

B. Randall Brenn, MD
Vanderbilt University Medical Center

Lara Brewer, PhD
University of Utah

Maxime Cannesson, MD, PhD
University of California, Los Angeles

Jesse Ehrenfeld, MD, MPH
Vanderbilt University Medical Center

Jan Ehrenwerth, MD
Yale University School of Medicine

David Feinstein, MD
Beth Israel Deaconess Medical Center

Jeffrey Feldman, MD
Children's Hospital of Philadelphia

Robert Freundlich, MD, MS
2019 Abstract Co-Chair
Vanderbilt University Medical Center

Eilon Gabel, MD
University of California, Los Angeles

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

Patrick Guffey, MD, MHA, FASA
University of Colorado

Thomas Hemmerling, MD,
MSc, DEAA
McGill University

Ira Hofer, MD
Ronald Reagan UCLA Medical Center

Craig Johnstone, MBChB, BSc,
MRCP, FRCA
Guy's & St. Thomas' NHS Trust

Thomas Joseph, MD, PhD
University of Pennsylvania,
Perelman School of Medicine

Daniel Katz, MD
Icahn School of Medicine at
Mount Sinai

Samir Kendale, MD
New York University Langone Health

Kai Kuck, PhD
President, STA
University of Utah

Christine Lee, MS
University of California, Irvine,
Edwards Lifesciences

Matthew Levin, MD
2019 Annual Meeting Co-Chair
Icahn School of Medicine at
Mount Sinai

Jeffrey Mandel, MD, MS
University of Pennsylvania,
Perelman School of Medicine

Clyde Matava, MD
2019 Abstract Co-Chair
Hospital for Sick Children
University of Toronto

Patrick McCormick, MD, MEng
Memorial Sloan Kettering Cancer
Center

Jack Neil, MD
MedStream Anesthesia

Olivia Nelson, MD
Children's Hospital of Philadelphia

Bahram Parvian
Lighthouse Regulatory Consulting Group

John Pawlowski, MD, PhD
Beth Israel Deaconess Medical Center

John Pearson, MD
Beth Israel Deaconess Medical Center

Christopher Quartararo, MD
Winchester Anesthesia Associates

Ben Ransford, PhD
Virta Labs

Cyrus Razavi, BMBCh, FRCA
NIAA Health Services Research Centre

Brian Rothman, MD
Vanderbilt University Medical Center

Cole Sandau, BS
Health Scholars

Norma Sandrock, MD
Beth Israel Deaconess Medical Center

Anjan Shah, MD
Icahn School of Medicine at
Mount Sinai

Joan Spiegel, MD
Beth Israel Deaconess Medical Center

Peter Szmuk, MD
UT Southwestern

Jonathan Wanderer, MD, MPhil
Vanderbilt University Medical Center

Meeting Accreditation Information

Activity Overview

The Society for Technology in Anesthesia (STA) 2019 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 the latest advances in automated drug delivery, innovations in education through use of technology, machine learning, anesthesia EHRs, the role of entrepreneurs in medical device technology 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 the current limitations of medical device cybersecurity and summarize the research being done in this area.
- Describe examples of innovations in resident education utilizing virtual reality and simulation.
- Summarize the latest advances in closed loop systems and automated drug delivery.
- Understand the strengths and limitations of next generation anesthesia EHRs.
- Describe the type of algorithms that are commonly used in machine learning in the healthcare space.
- Discuss the role that entrepreneurs can play in advancing medical device technology for clinicians and patients.
- Summarize current research being pursued by anesthesiologists and engineers in both industry and academic settings.

Barriers to change:

- Reduced ability to implement innovative or cutting-edge technologies in an era of increasing EHR consolidation and centralization.

Physicians

In support of improving patient care, this activity has been planned and implemented by Amedco LLC and the Society for Technology in Anesthesia. Amedco LLC is jointly accredited by the Accreditation Council for Continuing Medical Education (ACCME), the Accreditation Council for Pharmacy Education (ACPE), and the American Nurses Credentialing Center (ANCC), to provide continuing education for the healthcare team.

Credit Designation Statement

Amedco designates this live activity for a maximum of **17.25 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 8.5 LLSA credits towards ABPM MOC Part II requirements. Course ID#1544.

Satisfactory Completion

Learners must complete an evaluation form to receive a certificate of completion. If you need MOC credit through the American Board of Preventative Medicine (ABPM), you will also need to pass the post-test with a score of 80% or higher. Your chosen sessions must be attended in their entirety. Partial credit of individual sessions is not available. If you are seeking continuing education credit for a specialty not listed below, it is your responsibility to contact your licensing/certification board to determine course eligibility for your licensing/certification requirement.

Schedule of Events

Wednesday, January 9, 2019

0700-0800 Challenges & Opportunities Registration
Ironwood B Foyer (FOR INDUSTRY ONLY - Pre-Registration Required)

0800-1700 Exhibitor Registration & Setup
Ironwood A

0800-1200 Challenges & Opportunities in Developing Anesthesia Products
Ironwood B (FOR INDUSTRY ONLY - Pre-Registration Required)
David Feinstein, MD, Norma Sandrock, MD, John Paulowski, MD, PhD, Jesse Ehrenfeld, MD, MPH, Christopher Quartararo, MD, Jeffrey Feldman, MD

1800-2000 Registration & Welcome Cocktail Reception
Ironwood A

Thursday, January 10, 2019

0700-0800 Registration & Breakfast
Pinnacle Foyer

0800-0815 Welcome Address
Pinnacle AB Kai Kuck, PhD, Charlene Blake, MD, PhD & Matthew Levin, MD

Session 1: Keynote Address

Moderator: Charlene Blake, MD, PhD & Matthew Levin, MD

0815-0930 The Hidden Cybersecurity Risks of Hyperconnected Healthcare
Pinnacle AB Ben Ransford, PhD

0930-1000 Break with Exhibitors & Abstracts
Ironwood A & Ironwood Foyer

Session 2: Innovations in Technology in Medical Education (The Machine Makes the Mind)

Moderator: Daniel Katz, MD

1000-1030 Screen Based Simulation and Medical Education
Pinnacle AB Anjan Shah, MD

1030-1100 The Utility of the Virtual Environment in Medical Education
Pinnacle AB Cole Sandau, BS

1100-1130 Augmented Reality for Medical Education
Pinnacle AB Eric Bauman, PhD, FSSH

1130-1200 Panel Discussion
Pinnacle AB

1200-1315 Luncheon
Fountain Terrace

Session 3: Emerging Device Technologies (The Mind Makes the Machine)

Moderator: Jorge Galvez, MD, MBI

1315-1345 Developing Closed-Loop Systems and Machine Learning Algorithms for Clinical Use in Perioperative Care
Pinnacle AB Maxime Cannesson, MD, PhD

1345-1415 Redesigning Adult Monitors for Use in Pediatric Anesthesia
Pinnacle AB Peter Szumuk, MD

1415-1445 Closed-Loop Anesthesia Delivery Devices: Invention or Innovation?
Pinnacle AB Bahram Parvianian

1445-1515 Panel Discussion
Pinnacle AB

1515-1545 Break with Exhibitors & Abstracts
Ironwood A & Ironwood Foyer

1545-1615 Posters in a Minute: Moderated Poster Summaries Group A
Pinnacle AB Moderator: Robert Freundlich, MD, MS

Session 4: Abstract Awards & Presentations

Moderator: Thomas Hemmerling, MD, MSc, DEAA

1615-1640 Excellence in Technology Award Presentation
Pinnacle AB Lara Brewer, PhD

1640-1705 Best Clinical Application Award Presentation
Pinnacle AB Jorge Galvez, MD, MBI & Olivia Nelson, MD

1705-1730 Best of Show Award Presentation
Pinnacle AB B. Randall Brenn, MD

1800-2000 Resident Gathering
McDowell

Friday, January 11, 2019

0700-0800 Registration & Breakfast
Pinnacle Foyer

Session 5: Next-Gen Anesthesia AIMS/EHR (The Machine Has No Mind)

Moderator: Patrick McCormick, MD, MEng

0800-0830 Situational Awareness Pathways and Data Visualization
Pinnacle AB Patrick Guffey, MD, MHA, FASA

0830-0900 Integration Across Periop—Past, Current and Future
Pinnacle AB Jonathan Wanderer, MD, MPhil

0900-0930 Anesthesiologist Augmented Intelligence
Pinnacle AB Patrick McCormick, MD, MEng

0930-1000 Panel Discussion
Pinnacle AB

Schedule of Events

Friday, January 11, 2019 *continued*

1000-1030 Break with Exhibitors & Abstracts
Ironwood A & Ironwood Foyer

Session 6: Deep Learning/Machine Learning (The Machine Has a Mind)

Moderator: Ira Hofer, MD

1030-1100 What is Machine Learning and How Can It Be Leveraged in Anesthesiology?
Pinnacle AB
Christine Lee, MS

1100-1130 Use of Machine Learning to Predict Post-Induction Hypotension
Pinnacle AB
Samir Kendale, MD

1130-1200 Framework for Understanding Types of Artificial Intelligence Applications and Examples within Perioperative Care
Pinnacle AB
Ira Hofer, MD

1200-1230 Panel Discussion
Pinnacle AB

1230-1330 STA Business Luncheon & 2019 J.S. Gravenstein Award Presentation
Ironwood BC
Kai Kuck, PhD & Jan Ehrenwerth, MD

1330-1400 Posters in a Minute: Moderated Poster Summaries Group B
Pinnacle AB
Moderator: Clyde Matava, MD

Session 7: Research Grant Presentations

Moderator: Thomas Hemmerling, MD, MSc, DEAA

1400-1435 2017 Neurowave Research Grant Recipient Presentation
Pinnacle AB
Soodeh Ahani, PhD

1435-1510 2018 Neurowave Research Grant Recipient Presentation
Pinnacle AB
Clyde Matava, MD

1510-1530 Break with Abstracts
Ironwood Foyer

Session 8: Concurrent Sessions

1530-1730 Young Researchers Workshop
Ironwood B
Christine Lee, MS, Maxime Cannesson, MD, PhD, Thomas Joseph, MD, PhD

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

1530-1730 Technology in Education: Hands-on Session
Ironwood C
Daniel Katz, MD

In this hands-on session attendees will get the chance to try out the virtual reality ("Fire in the OR") and tablet based ("Liver Transplant") simulators presented in Session 2. In addition, there will be a development workstation set up, where attendees can play with the tools used to make the simulations.

1730-1930 Cocktail Reception
Fountain Terrace

Saturday, January 12, 2019

0730-0815 Registration (Only Coffee Provided)
Pinnacle Foyer

Session 9: STA Engineering Challenge

Moderator: Jeffrey Mandel, MD, MS

0815-0945 Engineering Challenge
Pinnacle AB
Jeffrey Mandel, MD, MS

0945-1015 Posters in a Minute: Moderated Poster Summaries Group C
Pinnacle AB
Moderator: John Pearson, MD

1015-1030 Break with Abstracts
Ironwood Foyer

Session 10: Entrepreneur Session: Anesthesiologist Idol (Mind vs. Mind)

Moderator: Brian Rothman, MD

Pinnacle AB Judges: Maxime Cannesson, MD, PhD; Thomas Hemmerling, MD, MSc, DEAA; Joan Spiegel, MD

1030-1055 Jack Neil, MD

1055-1120 Eilon Gabel, MD

1120-1145 Cyrus Razavi, MBChB, FRCA

1145-1210 Craig Johnstone, MBChB, BSc, MRCP, FRCA

1210-1230 Q&A/Voting

1230 Meeting Adjourned

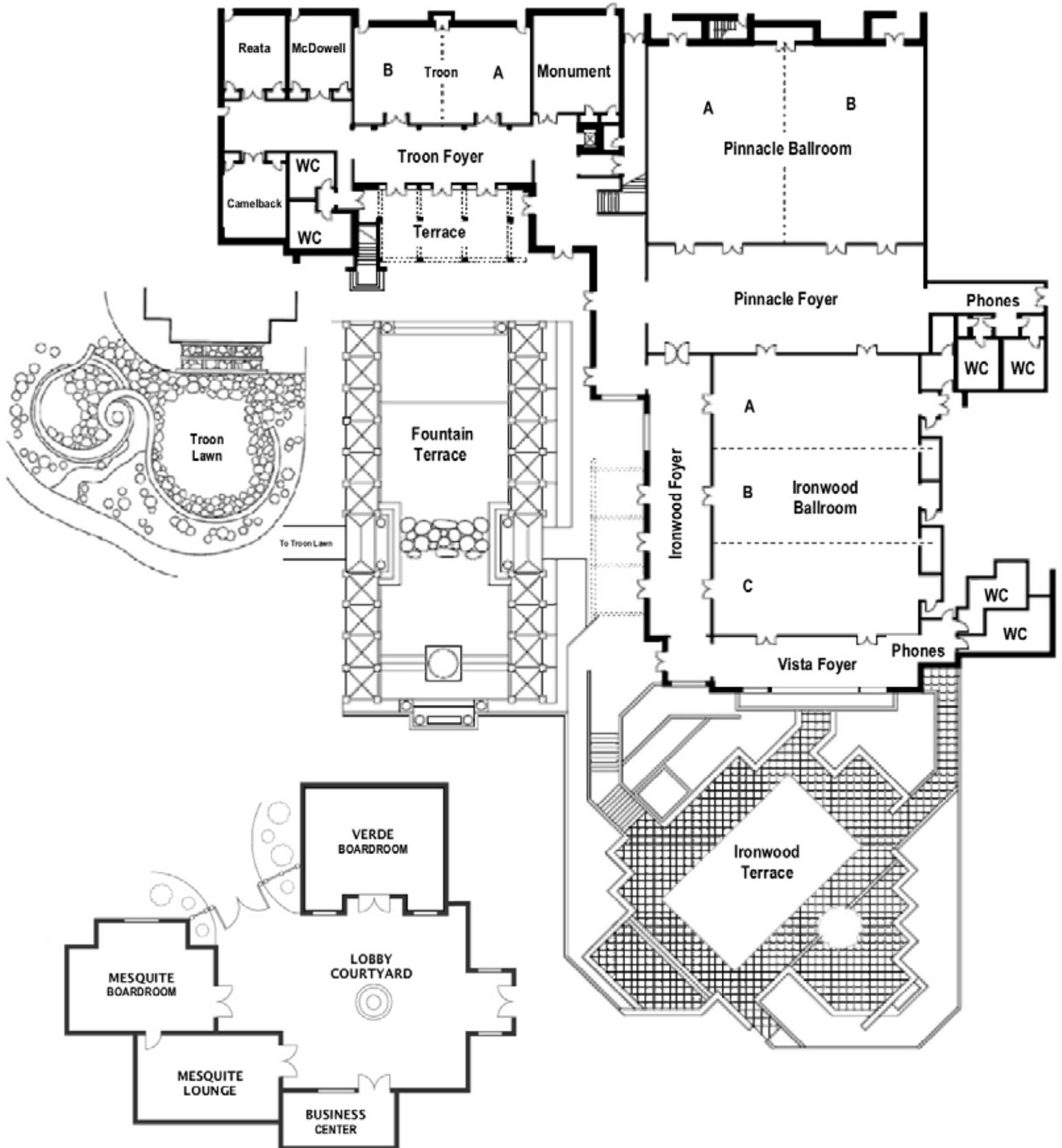
Save the Date



STA 2020 Annual Meeting
January 15-18, 2020
Four Seasons Resort • Austin, Texas

Four Seasons Resort Scottsdale at Troon North

WiFi Network: FourSeasons Meeting
Password: STA2019



Sustaining & Annual Corporate Members

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AlertWatch

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IER Innovations

MD Health Supplies

Micropore

NeuroWave Systems

Respiratory Motion

SKINLOGIC

Through the Cords

Vigilant Labels

Company Descriptions



AlertWatch • www.alertwatch.com

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. At the STA meeting, we will be demoing the following solutions:

AlertWatch®:OR

This application consolidates 250 real-time and historical data elements onto intuitive multi-patient and single-patient dashboards. With AlertWatch:OR, clinicians can track real-time patient status and case progress at a glance, including sophisticated alerts and clinical decision support built for the perioperative workflow.

AlertWatch®:OB

This application tracks each mother throughout the entire labor, delivery and post-delivery process, automatically assessing hemorrhage risk and alerting for emerging clinical issues. By providing a complete clinical picture for each patient, AlertWatch:OB will become a key piece of your maternal safety efforts.

AlertWatch®:ICU

This application, which is under development, helps clinicians oversee high-risk ICU patients, with clinical decision support built for high-risk ECMO and ventilated patients. This solution could also serve as a safety net for floor patients.

Sustaining & Annual Corporate Members cont.



Becton Dickinson • www.bd.com

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.



Codonics • www.codonics.com

Codonics Safe Label System (SLS), an FDA Class II device, is the standard of care for safety and TJC-compliance, helping to eliminate human error at preparation and administration while increasing workflow efficiency. Heralded as a 'best practice' and installed in over 6,000 ORs, SLS improves system interoperability to enhance clinical delivery, integrating with anesthesia dispensing carts to provide unparalleled safety and comprehensive barcode labeling at preparation. At administration, SLS labels integrate with Epic Anesthesia or any EHR that supports barcode scanning to improve documentation, providing a complete solution for barcode medication identification and verification of IV meds at the point-of-care.



Draeger Medical • www.draeger.com

For more than a century, Dräger has been providing anesthesia solutions clinicians can count on. From anesthesia machines to monitors to AIMS, no other company is more focused on anesthesia care than Dräger. Stop by our booth to experience the possibilities.



Edwards

Edwards Lifesciences • www.edwards.com

Edwards Lifesciences 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.

Edwards' Critical Care vision is to improve the quality of care for millions of patients per year with a focus on smart innovation. Through global leadership in hemodynamic monitoring and its comprehensive portfolio, Critical Care solutions enable clinicians to make proactive clinical decisions for their surgical and critical care patients. These monitoring and management solutions play an important role in enhancing surgical recovery enabling the improvement of patient outcomes and survival. Critical Care continues to lead by pioneering intelligent decision support through a new predictive monitoring category to improve the care of moderate to high risk patients.

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GE Healthcare • www.gehealthcare.com

GE Healthcare is a leading provider of medical imaging, monitoring, and Life Science technologies. GE Healthcare enables precision health in diagnostics, therapeutics and monitoring through intelligent devices, data analytics, applications and services to help providers, researchers and life sciences companies in their mission to improve outcomes for patients around the world.



IER Innovations • www.ierinnovations.com

IER Innovations is dedicated in providing high-intensity ultrasound devices for pain, trauma, mood disorders, alopecia, circulation and nocturnal sleep disorders. We provide LE, USE, LLLT and high-intensity FDA approved therapies and treatments worldwide.



IntelliGuard Inventory Solutions • www.ig.solutions

IntelliGuard offers the only enterprise-wide, RFID-enabled inventory management solution for hospitals, which frees up anesthesiologists to work at the top of their license. The IntelliGuard Anesthesia solution reduces diversion risk and provides precise management and tracking of controlled substances. The IntelliGuard Anesthesia solution combines secure medication access with automated data collection and predictive analytics to provide accurate inventory level visibility and control. With IntelliGuard, anesthesiologists have the right medications, at the right time, without any interruption to their workflows.



Masimo • www.masimo.com

Masimo is a global leader in innovative noninvasive monitoring technologies, including medical devices, a wide array of sensors, and connectivity solutions. Our mission is to improve patient outcomes and reduce the cost of care. In 1995, Masimo debuted SET® Measure-through Motion and Low Perfusion™ pulse oximetry, which has been shown in multiple studies to accurately monitor SpO₂ in challenging conditions. SET® is estimated to be used on more than 100 million patients in leading hospitals and other healthcare settings around the world each year, touching 3 patients every second. In 2005, Masimo introduced rainbow® Pulse CO-Oximetry technology, allowing noninvasive and continuous monitoring of blood constituents that previously could only be measured invasively, such as total hemoglobin (SpHb®). We continue to advance noninvasive monitoring through innovations like Root®, Radius-7®, and Rad-97™, while expanding into new markets with SedLine® brain monitoring, O3® regional oximetry, NomoLine™ capnography, and automation and connectivity solutions such as Patient SafetyNet™.

Sustaining & Annual Corporate Members cont.

MD Health Supplies • www.mdhealthcaresupplies.uk

These light therapy devices are used for pain relief, discoloration of the skin, and scarring from surgery,



Surgeons use our light therapy right after a procedure to speed up the healing process, as it helps with the pain and scarring of the tissue, this treatment is also effective against actinic keratose, which is rough patches of the skin that may develop into cancer, and can be used on any area in the body.

To achieve the best result it is recommended to use our light therapy devices in conjunction with our medical gels and creams.



Medtronic • www.medtronic.com

As a global leader in medical technology, we improve the lives and health of millions of people each year— with our innovative therapies, services, and solutions. Learn how we're taking healthcare Further, Together at Medtronic.com.



Micropore • www.spiralith.com

Micropore Inc. is a U.S.A. based company with exemplary experience in manufacturing CO2 Absorbents. We provide the U.S. Navy Seals with their CO2 Absorbent. Our Anesthesia product SpiraLithCa® is an innovative CO2 Absorbent that is a solid calcium cartridge. It is designed with pre-formed air passages that ensure uniform use and longer duration. Micropore is based in Elkton, MD and Newark, DE. Micropore is an ISO 9001 certified manufacturing company.



Mindray North America • www.mindraynorthamerica.com

Mindray is a leading global developer, manufacturer, and supplier of medical devices whose mission is to deliver high-quality, richly featured products making healthcare more accessible around the world. Mindray provides solutions in three core businesses: Patient Monitoring and Life Support, Medical Imaging, and In-Vitro Diagnostics. An industry leading investment of 10% annual revenue into R&D demonstrates Mindray's commitment to innovation and advancing technology. Mindray products and services can be found in healthcare facilities in over 190 countries and regions.

Brands: BeneVision, Passport Multi-parameter Monitors, eGateway EMR interface, Accutorr spot check monitors, A-Series anesthesia systems, Resona7 Cart based ultrasound and M-Series portable ultrasound systems.

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My Biomedical • www.mybiomedical.info

MY BIOMEDICAL is a national distributor for business solutions in various industries. Primarily involved with the Medical industry, we also invest in several industries in order to generate self-esteem, productivity, and the confidence to be successful in everyday life. We offer universal products for both men and women through the latest scientific advancements in medical technology. Our non-surgical alternatives to surgery offer a painless, effortless and convenient way to achieve the best results.



NeuroWave Systems • www.neurowavesystems.com

NeuroWave is dedicated to improving patient safety, outcome and quality of life in anesthesia, sedation, critical care and military medicine with innovative monitoring and drug delivery systems using advanced neurophysiological signal processing and control system engineering. The AutoTIVA™ will provide an intravenous anesthesia “autopilot” for military and civilian operating rooms, while the AutoSED™ is being developed as an intravenous sedation delivery system for ICUs and en-route care.



Respiratory Motion • www.respiratorymotion.com

The most dangerous adverse effect of opioid analgesics is respiratory depression but surgical pain can be intense and patient satisfaction is important. The Joint Commission guidelines now require monitoring ventilation and the depth of ventilation in non-intubated patients. Respiratory Motion, Inc. has developed the first and only minute ventilation monitor providing real-time, continuous, non-invasive monitoring for non-intubated adult and pediatric patients. ExSpiron™ provides Clinicians a superior solution for monitoring ventilation status, including life threatening hypoventilation. Whereas other technologies address the “Failure to Rescue”, meaning a patient is identified just-in-time before it is too late to rescue, the ExSpiron provides an earlier warning and the opportunity to, “Avoid the Need for Rescue.”



SenTec • www.sentec.com

Accurate and noninvasive ventilation monitoring independent from V/Q-mismatch, ventilation mode (HFJV, HFO, one-lung, HiFlow, BiPAP, ...), mucus or patient compliance issues, helping to identify opioid-induced respiratory events especially in high risk patients.

The SenTec Digital Monitoring System (SDMS) is supporting Anesthesiologists in clinical situations, such as:

- procedures involving special mechanical ventilation techniques (HFJV, HFO, One-Lung ventilation)
- monitored-anesthesia care / procedural sedation
- monitoring of adverse effects of pain medication
- and surveillance in the post anesthesia care unit

Comply with Joint Commission and APSF guidelines to monitor ventilation

Sustaining & Annual Corporate Members cont.



SKINOLOGIC • www.skinologic.com

SKINOLOGIC is a company that offers advanced led light therapy treatments for a variety of skin issues, we hand out information and a free demonstration of our device, The Device that we've manufactured is a handheld device that offers Red, Infrared & Blue Light Therapy.



Through the Cords • www.ttcmed.com

We design and manufacture airway introducers that help take the "difficult" out of difficult airways.



Vigilant Labels • www.vigilantlabels.com

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*

*** *Best Clinical Application Award*

** *Excellence in Technology Award*

**** *Honorable Mention*

Abstract #	Full Abstract Title	Presenting Author	Institution
1	Impact of Preload Changes on Peripheral Venous Pressure (PVP), Stroke Volume (SV) and Thoracic Fluid Content (TFC) in Healthy Volunteers	Kirk Shelley, MD, PhD	Anesthesia department, Yale University School of Medicine
2	Cerebral and Somatic Tissue Oximetry During Different Physiologic Challenges	Kirk Shelley, MD, PhD	Anesthesia department, Yale University School of Medicine
3	Closed-Loop Anesthesia: Invention or Innovation?	Bahram Parvinian, Principal Consultant	Bahram Parvinian
4	Potential for Data Systems Implementation to Prevent Medication Errors among Anesthesia Learners	Lauren Lobaugh, MD	Baylor College of Medicine
5	Review of the Medical and Environmental Implications of Additive Manufacturing (3D Printing) Filaments	Laura Banachek, BS, MSIV	Harvard Medical School
6	Virtual Reality as an Adjunct to Anesthesia in the Operating Room	Adeel Faruki, MD	Beth Israel Deaconess Medical Center- Harvard Medical School
7****	Assessing Pain Under General Anesthesia with Functional Near Infrared Spectroscopy	Andrea Gomez Morad, MD	Boston Children's Hospital
8	A Portable, Tablet-Based PK/PD Simulator for Volatile and Intravenous Anesthetics in Combination	Christopher Connor, MD, PhD	Brigham and Women's Hospital

Abstract Table of Contents *cont.*

Abstract #	Full Abstract Title	Presenting Author	Institution
9	A Proof-of-Concept Framework for Testing and Validating Networked Medical Device Applications and Closed-Loop Physiology Management Systems for Critical and Perioperative Care	Dikendra Karki	Bucknell University
10	The Development of the AAMI Standard for a “Forensic Data Logger for an Integrated Clinical Environment (ICE)”	Julian Goldman, MD	Massachusetts General Hospital
11	Patient Experience of Anesthesia and Surgery from Twitter Data	Jack Wasey, BM, BCh, MA, MSci, Msc	Children's Hospital of Philadelphia
12	Video Assisted Oro-tracheal Intubation Device	Sam Nour, MD	CHLA
13	A Novel Approach to Systematically Translate Anesthesia Quality Measures into Computable Representations for Clinical Decision Support Systems	Rocky Reston, MD, PhD	Cognitive Medical Systems
14	Feasibility of Computer-Assisted Vasopressor Titration using Non-Invasive Blood Pressure Monitoring (Clearsight) During Renal Transplant Surgery: A Case Series	Sean Coeckelenbergh, MD	CUB Erasme, Université Libre de Bruxelles
15	Low, Minimal and Metabolic Anesthesia Using a Novel Membrane Technology Instead of Chemical Absorbents for Carbon Dioxide Removal - Clinical Data	Michael Schmidt, Dr. med.	Dalhousie University
16	Automated Titration of Vasopressor Infusion Using a Novel Closed-Loop Controller: In Vivo Feasibility Study Using a Swine Model	Alexandre Joosten, MD	ERASME
17	NMBM Accel – A Novel Programmable Prototype Neuromuscular Block Monitor	S. Mark Poler, MD	Geisinger
18	Agreement Between Depth of Anesthesia Monitors Depends on the Patient and Procedure	Marcus Badgeley, MEng, MS4	Icahn School of Medicine at Mount Sinai
19	Analysis of Twitter Content and Sources on Nitrous Oxide for Labor Analgesia	Ryan Wang, MD	Icahn School of Medicine at Mount Sinai
20	Identifying Unnecessary Blood Transfusions in Patients Undergoing Craniofacial Surgery Using National Craniosynostosis Registry Dataset	Allison Fernandez, MD, MBS	Johns Hopkins All Children's Hospital
21	Automated Notifications Improve Time to Anesthesia Induction: Integrating Health Information Technology Systems to Enhance Perioperative Efficiency	Luis Tollinche, MD	Memorial Sloan Kettering Cancer Center
22	Staff Tracking and Perioperative Efficiency of Anesthesiologists	Cindy Yeoh, MD	Memorial Sloan Kettering Cancer Center
23	Scraping of Intraoperative Textual Report for Acquisition and Storage of Clinical Data from the Epic Electronic Medical Record (EMR)	David Kramer, MD	Montefiore Medical Center
24	Surface Scraping of Intraoperative Hemodynamic Data for the Acquisition and Storage from Epic Electronic Medical Records (EMR)	David Kramer, MD	Montefiore Medical Center
25	In Vivo Performance of a Membrane CO2 Filter during Target-Controlled Closed-Circuit Anesthesia	Rik Carette, MD	OLV Hospital Aalst Belgium
26	Sodalime Absorber versus Membrane CO2 Filter Performance during Automated Closed-Circuit Anesthesia: A Case-Report	Rik Carette, MD	OLV hospital Aalst
27	Comparison of Tidal Breathing Flow-Volume Loops Generated by a Respiratory Volume Monitor and Spirometry	Jenny Freeman, MD	Respiratory Motion Inc
28	Tracking Dynamic Arterial Pressure Waveform on Vasoactive Medication via Manifold Learning Method	Yu-Ting Lin, Dr.	Taipei Veterans General Hospital
29***	A Visual Analytics Dashboard to Summarize Serial Anesthesia Records in Pediatric Radiation Therapy	Olivia Nelson, MD	The Children's Hospital of Philadelphia
30	Assessing Depth of Hypnosis with the NeuroSENSE Monitor During Desflurane General Anesthesia – A Randomized Trial	Matthias Gorges, PhD	The University of British Columbia

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Abstract #	Full Abstract Title	Presenting Author	Institution
31	Creation of Arterial Blood Pressure Nomograms for Children Undergoing General Anesthesia – Results From a Pilot Feasibility Study	Matthias Görge, PhD	The University of British Columbia
32	Comparison of a High-Fidelity Peripheral Venous Access Phantom to a Commercial Phantom	Preetham Suresh, MD	UC San Diego School of Medicine
33	Deep Learning to Predict Postoperative Acute Kidney Injury	Nadav Rakocz, BSc	UCLA
34**	Rating the Severity of Opioid-induced Ataxic Breathing in Healthy Humans	Lara Brewer, PhD	University Health
35	Prediction of Postinduction Hypotension with Deep Learning	Christine Lee, MS	University of California, Irvine
36	An Automated Machine Learning-Based Model Predicts Postoperative Mortality Using Readily-Extractable Preoperative Electronic Health Record Data	Brian Hill, BS	University of California, Los Angeles
37	Carbon Dioxide Absorption Capacities of Amsorb® and Soda Lime During Simulated Clinical Conditions	Jacob Ludin, BS	University of Florida College of Medicine
38	Cluster Randomized Trials and Case-Control Studies of Surgical Site Infections with Group Assignments Being the Operating Rooms	Franklin Dexter, MD, PhD, FASA	University of Iowa
39	ProcedureView (ProView): Analyzing and Presenting Anesthesiology Case Data for Providers using Machine Learning	Michael Burns, PhD, MD	University of Michigan
40	A Novel Digital 3D Printed Cricoid Pressure Device	Michael Dinsmore, BSc, PhD, MD, FRCPC	University of Toronto
41	Investigating Environmental Carbon Dioxide Sensors as Proxy for Capnometry in Austere Surgical Settings	Patrick Kolbay, BS	University of Utah
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43	Catheter Depth Control During Endotracheal Tube Exchanges in an Airway Manikin; A Comparison of a Novel Color-Zoned Qualitative System vs Traditional Quantitative System.	Sean Runnels, MD	University Of Utah Dept of Anesthesiology
44	Risk Factors for Loss of Voice and Hoarseness after General Anesthesia at Post-Operative Day 1 in Out Patient Surgery.	Smitha Warriar, MD	University of Utah Dept of anesthesiology
45	Smoothed I0 (SL0) Based Burst Suppression Detection Method	Soodeh Ahani, Dr.	University of British Columbia
46*	Endotracheal Tube Intracuff Pressure is Not Equal to Tracheal Wall Pressure on a Simulated Trachea	B. Randall Brenn, MD	Vanderbilt University Medical Center
47	Multiple Pathways of EEG Spectral Pattern Progression with Anesthetic Agent Reduction	Christopher Scheib, MD	LOG2
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51	Use of Continuous Noninvasive Arterial Pressure Cycle Duration to Predict Hypovolemia in Low Body Negative Pressure	Kirk Shelley, MD, PhD	Yale University School of Medicine
52	Study of Nasal Pulse oximeter amplitude during LBNP induced hypovolemia	Mohamed Elgamal, MB, BCh	Yale University School of Medicine
53	Nasal Pulse Oximeter: New Site for Monitoring Central Blood Volume During LBNP Induced Hypovolemia	Mohamed Elgamal, MB, BCh	Yale University School of Medicine
54	Data Driven Investigation of Bispectral Index Algorithm	Hyun-Kyu Yoon	Seoul National University Hospital

Impact of Preload Changes on Peripheral Venous Pressure (PVP), Stroke Volume (SV) and Thoracic Fluid Content (TFC) in Healthy Volunteers

Presenting Author: Kirk Shelley, MD, PhD

Co-Authors: Abdullah Yassin Elsayed MD¹, Mona Ganash MD¹, Mai khairy Elshafey MD¹, Samar Seleem MD¹, Somaia Mohamed MD¹, Aymen Alian MD², Kirk Shelley, MD. PhD²

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Background: Accurate assessment of blood volume status and the response to fluid challenge remains an important clinical goal. Leg raise test (LRT) is associated with an increase in venous return (300 cc) to the heart,^{1,2} while Valsalva maneuver is associated with increased intrathoracic pressures and a reduction in preload and stroke volume (SV). Peripheral venous catheter is the most commonly used method of vascular access and peripheral venous pressures (PVP) reflects 'downstream' pressure to the right atrium.

Methods: With IRB approval 28 healthy volunteers underwent two physiologic challenges: 1) LRT: period of baseline (2 min) followed by LRT (2 min) and 2) Valsalva maneuver: baseline period for (3 min) followed by Valsalva maneuvers for 20 seconds. Each subject was monitored with EKG, blood pressure and PVP waveform were recorded at 100 Hz with a data acquisition system (Collect S5). PVP waveforms generated from a transduced upper extremity 20-gauge intravenous catheter. SV as well as an index of thoracic fluid content (TFC) derived from the measured impedance to an electrical current applied to the chest was measured non-invasively using (Cheetah Medical, MA, USA)³. Data analyzed with commercially available software (LabChart 7 Pro, v 7.3.8). Values during LRT and Valsalva maneuver were compared to their corresponding baseline with paired t-tests, data is expressed as mean (SD). P value <0.05 is considered significant.

Results: LRT was associated with an increase in PVP, SV and TFC (28%, 13% and 1%) respectively, while Valsalva maneuvers showed an increased in PVP by 130% with reduction in SV and TFC by 15% and 6% respectively. All variables were found to be statistically significant. Raw data of PVP is shown in figure 1-(A), while figure 1-(B,C,D) and (E,F,G) showed changes in PVP, SV and TFC during LRT and Valsalva respectively. Table-1 shows the percent change for complete data set.

Discussion: Transient LRT resulted in an increase in preload which lead to an increase in SV and TFC and reflected as an increased in PVP at the periphery. On the other hand, Valsalva (increased intrathoracic pressure) was associated with reduction in preload, SV and TFC and an increased in PVP (shock wave down the arm). This is an example of the importance of understanding the context of an increase in PVP and its relation to the preload and SV.

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		Leg raise test (LRT)			
		Baseline	LRT	1 min after LRT	% change from baseline
PVP	Mean	11	14	10	28
	SD	3	5	3	
SV	Mean	93	103	94	13
	SD	29	35	23	
TFC	Mean	65.50	66.17	65.18	1.05
	SD	13.51	13.57	13.32	
		Valsalva			
		Baseline	Valsava	1 min after Valsalva	% change from baseline
PVP	Mean	10	25	11	133
	SD	3	12	3	
SV	Mean	91	76	94	-15
	SD	21	18	28	
TFC	Mean	65.13	60.97	64.88	-6
	SD	13.64	11.57	13.57	

Table 1: Summary of the data with percent change from baseline during each challenge

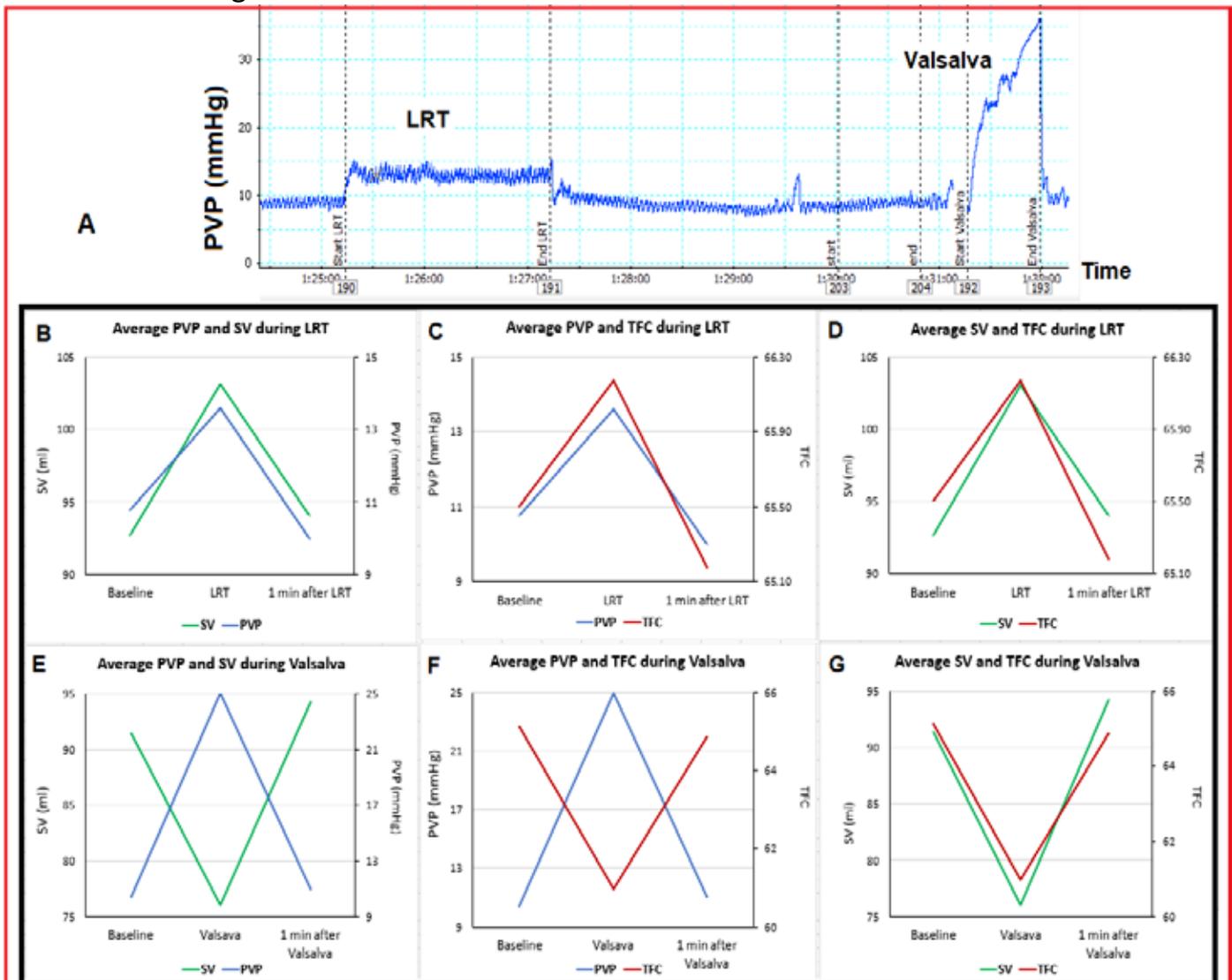


Figure 1. Changes in PVP, SV and TFC during LRT and Valsalva

Cerebral and Somatic Tissue Oximetry During Different Physiologic Challenges

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Co-Authors: Mona Ganash MD¹, Abdullah Yassin Elsayed MD¹, Mai khairy Elshafey MD¹, Somaia Mohamed MD¹, Samar Seleem MD¹, Aymen Alian MD², Kirk Shelley, MD. PhD²

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Background: Measuring tissue oxygen saturation based upon near infrared spectroscopy (NIRS) allow reliable measurements of cerebral and regional circulations. We hypothesized that continuous tissue oximetry can detect changes in preload during leg raise test and Valsalva maneuvers.¹

Methods: With IRB approval 28 healthy volunteers underwent two tests: 1) Leg rise Test (LRT)²: period of baseline monitoring (2 min) followed LRT (2 min) and 2) Valsalva maneuver: baseline period for (3 min) followed by Valsalva maneuvers for 20 seconds. Each subject was monitored with EKG, blood pressure. Stroke volume derived from the measured impedance to an electrical current applied to the chest was measured non-invasively (Starling, Cheetah Medical, MA, USA)³. Data analyzed with commercially available software (LabChart 7 Pro, v 7.3.8). Summary values are expressed as mean (SD). Values during LRT and Valsalva maneuver were compared to their corresponding baseline with paired t-tests, P value <0.05 is considered significant.

Results: Valsalva maneuvers was associated with reduction in SV, cerebral and forearm regional oxygen saturation by 18.2, 2.2 and 1.4 % respectively. LRT was associated with an increase in SV and forearm regional oxygen saturation by (15.7% and 1.0%) respectively. Summary of the data with percent change from baseline during each challenge is shown in table 1

Discussion: Valsalva resulted in an increase in intrathoracic pressure which impede venous return and reduce preload associated with reduction of SV resulting in reduction on oxygen saturation to brain and forearm. While in transient LRT there is increase in preload which is resulted in an increase in SV which is reflected by mild increase in the forearm rSO₂

	Valsalva		
	Baseline	during Valsalva	% change
Cerebral rSO ₂	76.2 (6.7)	74.4 (7.8) **	-2.2
Forearm rSO ₂	75.9 (6.8)	74.8 (6.4) **	-1.4
SV	91 (20)	75(18) **	-18.2
	Leg raise test (LRT)		
	Baseline	during LRT	% change
Cerebral rSO ₂	76.8 (6.8)	76.9 (6.8)	0.1
Forearm rSO ₂	75.4 (7.7)	76.1 (6.9) **	1.0
SV	90 (24)	105 (26) **	15.7
** P value < 0.05			

Table 1: Summary of the data with percent change from baseline during each challenge

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Closed-Loop Anesthesia: Invention or Innovation?

Presenting Author: Bahram Parvinian, M.Sc. Principal Consultant, Lighthouse Regulatory Consulting Group LLC

Abstract Content: Transportation and energy industries have leveraged automation extensively in the past decades [1]. The quest for automation has also penetrated medical device industry, particularly in critical care settings where there is an abundance of physiological monitors combined with an ever-increasing clinician cognitive overload and burnout [1-4]. In recent years there has been a surge of medical devices in field of anesthesia and critical care that not only automate routine tasks but have evolved to take on more diagnostic and therapeutic responsibilities to care for patients. Such devices may be referred to as Physiological Closed-Loop Controlled (PCLC) medical devices [1]. FDA defines PCLCs as system of devices that incorporate physiological sensor(s) to manipulation physiological variable(s) through actuation of therapy that is conventionally made by clinician [1]. Automated anesthesia, mechanical ventilation and fluid resuscitation are examples of PCLCs. This technology has the potential to provide timely, consistent, and distraction-free therapy to the patient [2] potentially leading to efficient maintenance of physiological variables within a prescribed range, reduction of human errors, alarm fatigue, clinician burnout, and ultimately improved patient outcomes. PCLCs are *en route* towards becoming an innovative technology with potential for positive impact on the safety and effectiveness of care delivery in anesthesia and critical care settings. The major hurdles for the process of taking PCLCs from invention to innovation can be combination of factors including lack of or slow clinician adoption [5] and absence of a standardized regulatory approach due to PCLC complexity. Opportunities to overcome these challenges include careful benchmarking of advanced PCLC systems such as Artificial Pancreas System in which adoption of automation is more mature [1,6]. Furthermore, new and novel regulatory tools such as the Early Feasibility Studies Program [7] and Parallel Review Program [8] can be leveraged to generate evidence needed for regulatory as well as reimbursement approval.

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Potential for Data Systems Implementation to Prevent Medication Errors among Anesthesia Learners

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Background/Introduction: Robust evidence exists supporting the utilization of clinical decision support (CDS) in reducing medication errors and improving safety and quality for patients undergoing anesthesia¹. However, many healthcare environments lack the implementation of such systems. We hypothesized that a substantial medication calculation error rate exists amongst pediatric anesthesia learners when relying upon electronic medical records without CDS.

Methods: We sampled 8 learners during their first pediatric anesthesiology clinical rotation at a large tertiary children's hospital. Learners included 3rd year anesthesiology residents and 2nd year student nurse anesthetists. Participants were given an anesthesia medication survey that elicited unassisted dose calculations for eight commonly used drugs in pediatric anesthesia. A maximum of fifteen minutes was allowed to complete the survey.

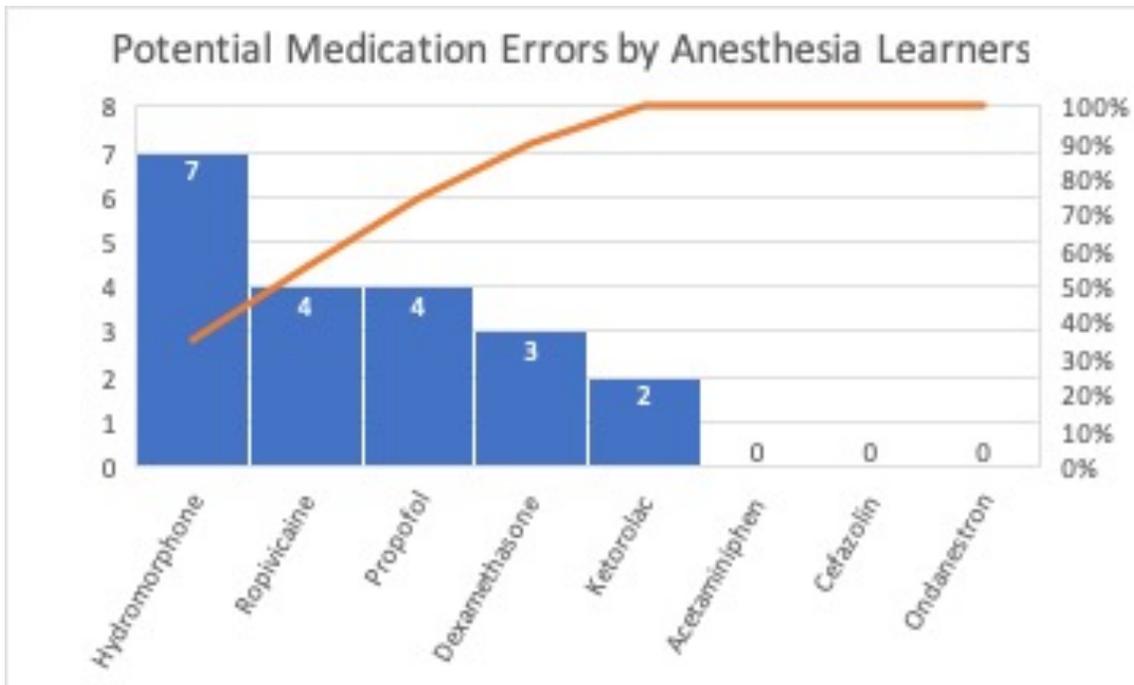
Results: All 8 participants made at least one prescribing error in the survey responses. Roughly 88% of the learners made a dosing error with a high-risk medication. High-risk medications, such as narcotic, local anesthetic, or intravenous anesthetic, comprised 75% of potential medication errors.

Conclusion: The complex, dynamic perioperative environment makes anesthesiologists uniquely predisposed to commit medication errors without direct supervision or safety checks that occur in other areas of the hospital.² The potential for medication error is heightened in the pediatric environment secondary to recognizing the appropriate dose and calculating the correct amount to administer. A recent study from Boston Children's Hospital found that the majority of medication errors were made by trainees, which contrasts the 2017 Wake-Up Safe report that identified attending anesthesiologists as the most common responsible provider.^{2,3} Balancing the priorities of patient safety and education demand better safety measures to prevent medication errors in this vulnerable patient population. Most current anesthesia information management systems (AIMS) lack CDS or at best provide passive and post hoc systems.⁴ The sizeable potential medication error rate demonstrated by our small sample of learners further demonstrates the need for real-time CDS that mitigates risk to patients while supporting a learning environment.

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Review of the Medical and Environmental Implications of Additive Manufacturing (3D Printing) Filaments

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Introduction: Since the advent of additive manufacturing (AM) in the mid-1980's, the use of 3D printing has expanded and diversified at an exponential rate.¹⁻⁴ Largely driven by innovation in science and technology and bolstered by the increasing availability and affordability of printers, materials, and design software, AM continues to create new opportunities for novel and unique printed products. Early medical applications focused predominantly on individualized surgical and dental implants, but over the last two decades, this has expanded to include perioperative planning, pharmaceutical drug delivery, bioprinting, prosthetics, simulation models, and more.²⁻⁶ Fused deposition modeling (FDM), a type of material extrusion, is the most common 3D printing method and is used for many of these applications. It utilizes filaments of varying size, color, and chemical composition to produce objects of differing strength, durability, flexibility, and function.⁶ As this variety increases, however, so must the medical and environmental considerations used in choosing a particular filament. In our review, we sought to evaluate the medical and environmental implications of three of the most common filaments used in FDM: PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), and PETG (polyethylene terephthalate glycol-modified).

Methods: A literature review was performed using PubMed, Web of Science, and IEEE Xplore Digital Library. Where available, material safety data sheets (MSDS) were also reviewed from various manufacturers. Particular attention was paid to the following stages of filament use: production, heating/deposition, degradation, and disposal.

Results: Despite an increasing rate of publications related to 3D printing, there remains a paucity of evidence regarding the health, safety, and environmental implications of various filaments used in FDM.^{2-4,7-10} For example, while PLA is generally regarded as the most eco-friendly and sustainable option of the three due to its natural composition, limited research suggests that the resources necessary to produce its source crops may actually offset this advantage.¹¹ By contrast, the health and environmental effects of the heating and deposition process have been far better studied. All three filaments produce volatile organic compounds (VOC) and ultrafine particles (UFP) that may lead to skin, pulmonary, and mucosal irritation.¹²⁻¹⁵ ABS off gasses the most VOCs, including styrene (a possible carcinogen), while PLA off gasses the least.^{13,15} This can change if additives are incorporated into the base material to change its properties, but because this information is frequently proprietary, it is difficult to evaluate.⁴ In addition, the MSDS for each filament varies by manufacturer and often does not include information on said additives or melting/decomposition temperatures, product stability, cleaning/sterilization instructions/limitations, specific health effects, or disposal options.⁴ There

is also scarce evidence regarding the stability of these products once the final product is handled, cleaned, or otherwise used for its intended purpose.⁵

Conclusion: The limitations of such specific health and safety data make it difficult to gauge whether one material is superior to another. Given the rapid expanse of this technology for medical use, this creates the potential for both short- and long-term harm to patients, practitioners, and the environment. For this reason, we recommend that further research be conducted that focuses on how the precise chemical composition of these materials affects the health and safety of those in contact with the materials during heating/deposition and use, as well as the environmental implications of its production, degradation, and disposal. Furthermore, we advocate for regulatory clarification and increased transparency regarding these materials to help guide the choosing of safe and appropriate materials based on the intended use of the final product.

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Virtual Reality as an Adjunct to Anesthesia in the Operating Room

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Introduction: Advancements in virtual reality (VR) technology have resulted in the expansion of the technology from the personal entertainment industry into the medical field. Preliminary studies have found VR to be a safe and effective adjunct to standard sedative and analgesic protocols for reducing pain and anxiety for patients undergoing upper gastrointestinal endoscopy, dental procedures, dressing changes for burns and joint arthroplasty¹⁻⁴. Given these findings, it is possible that VR technology has the potential to serve as a useful adjunct to standard anesthesia practice in surgeries where patients’ intraoperative anxiety is the primary concern for the anesthesiologist because regional anesthesia has prevented majority of the surgical stimulation.

Objective: To investigate the potential for VR to reduce intraoperative sedative requirements during surgical procedures of the hand and wrist, as compared to usual care.

Methods: In this randomized controlled trial, 40 adult patients undergoing hand and/or wrist surgery at a single academic institution will be randomly assigned to either intraoperative VR immersion or usual care (Figure 1). All patients receive a peripheral nerve block prior to surgery. The intervention, VR immersion, is designed to provide patients with a relaxing virtual environment to alleviate intraoperative anxiety. The software to be used in this trial was created in collaboration with VRHealth. Patients in the intervention group will select a playlist of videos and immersive environments to create a customized intraoperative experience. A VR headset paired with sound canceling headphones will be used to reduce the effect of potentially disturbing operating room stimuli. The patient interface is designed to enable the user to change videos or environments using just their eyes, to prevent impacting the operative environment through patient movement. The tablet interface was designed to allow the anesthesiologist to communicate with the patient via text without requiring the patient to remove their headphones, thus maintaining the immersive experience. Since virtual reality is a 360-degree environment, a feature is integrated into the tablet to reposition the visual content into the line of sight if a patient changes position. Patients in the intervention group can receive propofol and sedatives if needed during the procedure at the discretion of the anesthesiologist. Patients in the control arm will receive usual care, consisting of a propofol infusion with supplemental analgesia at provider discretion. The primary outcome is total propofol dose administered intraoperatively and will be assessed between study groups. Additionally, perioperative opioid requirements, intraoperative airway interventions, postoperative pain scores and patient satisfaction will be assessed.

Discussion: VR immersion can potentially allow for a reduction in the dose of anesthesia needed for patient relaxation and comfort, and may be a promising option for patients undergoing hand or wrist surgery. A positive result from this study could lead to a change in anesthesia practice through the introduction of a technology based, non-pharmacologic, patient-led intervention which can potentially reduce the burden of over-sedation while providing a satisfactory perioperative experience.

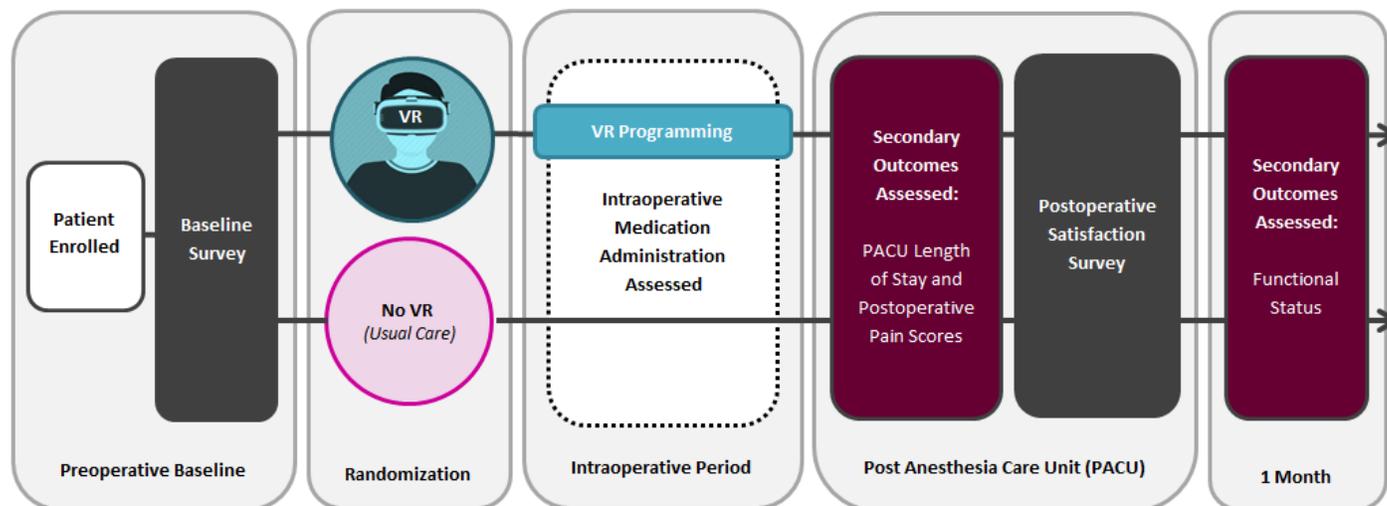


Figure 1. Study Schema

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Assessing Pain Under General Anesthesia with Functional Near Infrared Spectroscopy

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Abstract content: Establishing an objective evaluation of pain perception with a low-cost, portable device will dramatically improve current medical care for pain patients, including those undergoing surgical procedures. Functional near infrared spectroscopy (fNIRS) is a robust neuroimaging technique that is able to provide non-invasive, long-term measure of cortical hemodynamic changes. In this study, we applied fNIRS in both healthy, awake volunteers and anesthetized surgical patients to monitor the brain activities during induced ongoing pain (awake case) and during surgical procedures (anesthetized case).

Methods: Eleven healthy, male volunteers and ten pediatric patients undergoing knee surgery participated in this study. We recorded fNIRS signals mainly from the medial prefrontal cortex (mPFC), an area that has recently been highlighted to play an important role in the processing of pain. Each healthy volunteer had two scanning sessions: an ongoing heat pain session in which the subject received a continuous heat pain for 5 minutes and a warm session in which the subject received a 5-min nonpainful warm stimulus. For surgical patients, their mPFC signals were recorded during the entire surgery. The timings of major invasive surgical events, such as incisions, injections, soft tissue removal and suture were marked in the data. Support for this work was provided by NIH R01GM122405.

Results: With fNIRS, we observed significant alterations in the low frequency component of the mPFC signal during induced pain (in healthy volunteers) and major surgical procedures (in anesthetized surgical patient, see **Fig.1**).

Conclusion: These results suggest that nociceptive/pain pathways may not be fully blocked by general anesthesia. This work also reveals the potential of using fNIRS as a useful tool to evaluate pain in surgical conditions.

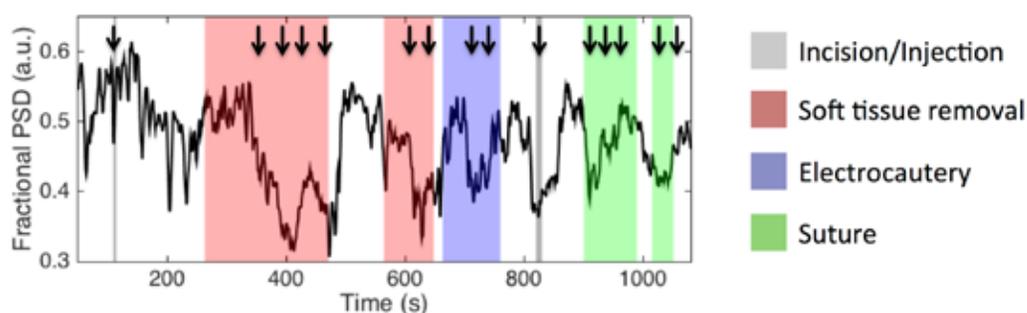


Figure 1. Case study: fractional power spectral density timecourse of mPFC low frequency (0.02-0.08Hz) hemodynamic signals during a knee arthroscopic surgery of a 14-year old female under general anesthesia. Significant power shifts were observed during or shortly after major surgical events, which potentially indicate ongoing pain processing in the brain.

A Portable, Tablet-Based PK/PD Simulator for Volatile and Intravenous Anesthetics in Combination

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Pharmacokinetic/pharmacodynamic (PK/PD) simulators have been available as tools for education in anesthesia¹ since the late 1980s, notable examples being GasMan² for volatile anesthetic agents and StanPump³ (and later related works, such as StanGraf) for intravenous agents. However, these tools have two evident weaknesses. Firstly, they are bound to the desktop computing environment rather than being available in a readily portable form. Secondly, these existing tools provide no cross-over between simulation of volatiles and intravenous agents and hence no simulation of their interactions, despite the commonality of inducing and maintaining anesthesia with some combination of a volatile agent and several intravenous agents. In order to address this deficit, a tablet-based, portable, combined volatile and intravenous PK/PD simulator was developed. The project was provisionally titled "*Brigham Anesthesia Simulator*" with the aim of deploying the project to the iOS platform⁴ and making it available for free, worldwide from the Apple iPad App Store for the educational benefit of residents, student nurse anesthetists and medical students.

While most pharmacology simulators only handle one agent at a time, Brigham Anesthesia Simulator can handle any simultaneous combination of any of the medications that it knows. The volatile anesthetic agents available are desflurane, enflurane, ether, halothane, isoflurane, sevoflurane and xenon. The available intravenous agents are alfentanil, atracurium, bupivacaine, cisatracurium, diazepam, d-tubocurarine, etidocaine, fentanyl, fospropofol, hydromorphone, lidocaine, lorazepam, meperidine, mepivacaine, methadone, midazolam, morphine, pancuronium, propofol, remifentanil, rocuronium, ropivacaine, succinylcholine, sufentanil, thiopental and vecuronium. These medications collectively span a range of agents in common and current practice, agents of historical interest, and agents whose activity is expected to be known to residents but whose current availability is limited by manufacturing shortages such that practical experience of their activity is difficult to obtain. For any combination of these intravenous and volatile agents, pharmacodynamics are simulated and forecasted, showing the anesthetic state in terms of a predicted processed-EEG sedation monitor, equipotent analgesia, neuromuscular blockade, local anesthetic serum levels and volatile agent MAC. The administration of a combination of sevoflurane and remifentanil is shown in Figure 1.

Simulations of intravenous agents are performed using an implementation of the standard three-compartment model with effect site. Volatile anesthetics are simulated with the classic three-compartment VRG, muscle and fat compartments, as well as simulation of fresh gas flow

and ventilation into the anesthesia circuit and patient lungs. All simulated medications can be administered either manually with boluses and infusions, or automatically with effect-site targeting. The simulator therefore effectively runs two simulation cores in parallel and in real time; one core handling IV agents, the other handling volatile agents. The combined outputs of these cores are used for pharmacodynamic calculations, based upon equipotency models, and subsequently in the calculation of a response surface model that predicts and projects the output of a bispectral-index-type processed-EEG sedation monitor based on clinical studies by Bouillon (2004)⁵ and Schumacher (2009)⁶. The correctness of the implementation of the pharmacokinetic models was tested by validating the simulator against results obtained for equivalent medication administration schedules when evaluated on the reference simulator tools of GasMan² and StanPump³. The concentrations of sevoflurane³ in all compartments was matched to within an accuracy of 0.01%, and concentrations of fentanyl were matched to within an accuracy of 0.01 ng/ml. These tests were found to adequately validate the software for release as an educational tool.

Brigham Anesthesia Simulator was released worldwide to the iPad App Store on July 6th 2018 for download at no cost. It is the most downloaded app released under the Brigham and Women's marque this year, and also the first such app to be programmed and developed solely by clinicians.

Image (1 figure of 1 allowed, 300dpi JPEG)



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A Proof-of-Concept Framework for Testing and Validating Networked Medical Device Applications and Closed-Loop Physiology Management Systems for Critical and Perioperative Care

Presenting Author: Dikendra Karki, Bucknell University

Co-Authors: Farooq Gessa, BS, Bucknell University, Aaron Bray, BS, Kitware, Inc., Rachel Clipp, PhD, Kitware, Inc., Philip Asare, PhD, Bucknell University, S. Mark Poler, MD, Geisinger

Managing physiology in critical and perioperative settings could benefit from closed-loop control of interventional systems driven by data from patient monitors. While in the United States clinicians manually operate medical devices, augmented clinician performance through TCI (Target Controlled Infusion) and closed-loop control are widely adopted in other countries¹. While the FDA has interest in potential benefits, difficulties and expenses likely will continue encumber approvals in the US^{1,2}. We are addressing acquisition of data and costs hoping to facilitate system approvals.

Thorough verification and validation of closed-loop control systems are critical to improving and ensuring safe, robust operation before and during clinical testing. During early control system development, being able to test ideas reproducibly with realistic simulation over wide ranges of individual parameters and multivariate combinations is desirable. In later development, unplanned combinations of control systems could be tested for maladaptive behavior and graceful moderation in potentially dangerous situations.

Extensive, repeatable evaluation of many variations in biological animal or human physiology experiments is not achievable at any price. However, the use of *in silico* patients (computer models of patient physiology) is gaining credibility^{3,4}. We have developed and validated an open-source proof-of-concept system that leverages the open-source Pulse Physiology Engine⁵, developing a hardware-software system that allows *in silico* patients to interact with automatic closed-loop control systems (which includes standard, non-modified patient monitor and infusion pump) in real-time.

Our current physiology models are limited in their ability to produce simulation over a wide and realistic range of observed physiological variation. Passive recording of physiological parameters from clinical situations can augment simulator model development, producing higher fidelity and more sophisticated simulations for testing. In addition, during testing, robust logging of digital activity at every control and response node would provide the necessary data for debugging undesirable behavior. The same devices used to implement recording for enhancement of simulation could provide these testing functions. Our system includes components useful for both recording to augment high fidelity physiological simulation, and data logging for robust understanding of control system behavior.

We hope to engage others in expanding the range of these open source tools.

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The Development of the AAMI Standard for a “Forensic Data Logger for an Integrated Clinical Environment (ICE)”

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Need/Genesis: Between the 19th and 20th century, it has been noted that the view of transportation accidents changed from the accidents being an impediment, to that of a catalyst for technological progress (Siegel, 2005) as a result of the availability of comprehensive system-based data logging (i.e. “black box recorders” or flight data recorders). Microprocessor-based medical devices typically have had some level of internal data logging capabilities for decades. The logs usually contain device performance metrics for technical troubleshooting and maintenance. Device data logs are downloaded when needed for forensic purposes, for example to assess device failures. But even if a single device log is fairly “complete” for that single device, a time-coordinated log of the entire clinical picture, which requires data from all devices in use, is not available. Forensic data logging is necessary for quality improvement and to address responsibility and liability concerns when a heterogeneous (multi-vendor) interoperable system is used for clinical care. The need for reliable data logging from all devices in-use is becoming increasingly important as the reliance on clinical decision support increases, and autonomous and closed loop system become more prevalent. Currently, device data logs are not standardized as to content or format which makes analysis of the individual logs difficult and complicates aggregation of individual logs into a single system-wide database of time-aligned events. In addition, device logs are often stored in proprietary formats that can only be accessed with the assistance of the device manufacturer.

Developing the Standard: Over the last two years the Interoperability Working Group (IOWG, SM-WG03) of the Association for the Advancement of Medical Instrumentation (AAMI) has been convening manufacturers, regulators and clinicians in order to promulgate a novel standard that will help enable the development of reliable and safe heterogeneous interoperable systems. The standard for a forensic data logger titled “Forensic Data Logger for an Integrated Clinical Environment (ICE)” (part of the “ICE” family of standards) is intended to address essential needs for achieving safe and secure device interoperability. A forensic data logger was identified in the Integrated Clinical Environment (ICE) standard (ASTM F2761-09) to provide essential data to address liability concerns and support safety in an ICE. (This rationale is documented in the data logger draft standard.) Patient waveform and parameter data, images and video, configuration, settings and the capabilities of each connected monitoring and therapeutic device and all interactions with each device by the patient and clinicians (e.g. button presses) and between devices could be logged and time-synchronized. The data store can be retrieved, replayed, and reconstructed. The drafting committee have sought to develop this standard to meet high-level requirements initially outlined in ICE (ASTM F2761), in

alignment with related requirements under development in AAMI-UL 2800 standards. The content of the draft standard is based in part on research performed by the program on Medical Device “Plug-and-Play” Interoperability & Cybersecurity (MD PnP) at the Massachusetts General Hospital, supported in part by the Department of Defense*.

The Standard: The writing and organizing of the new ICE forensic data logging standard required an extended period of investigating (a) existing data loggers used in clinical practice and research, (b) data loggers and their associated standards in other fields, (c) the state of computing, memory, and networking technologies and (d) applicable use cases that the standard was seeking to address. Many companies offer data logging capabilities for their product or platform but have not yet addressed comprehensively capturing the entire patient care system of devices. This will require additional data and meta-data from each connected device to be made available to allow forensic analysis. In view of the standardization of data loggers that has occurred in the transportation field in the past few decades, standards for aircraft flight data recorders (EuroCAE), automobile event recorders (IEEE) and other transportation mode recorders were consulted for relevant requirements related to data acquisition, storage and reliability. The availability of low-cost memory, increased availability of cloud storage, and high-speed wireless networks has allowed the focus to be on identifying the “right data”, rather than on technical or cost constraints. The airplane “black box” recorder model and needs for capturing the clinical environment before and during adverse events or near misses was the initial primary driver for the work. It quickly became clear that several additional categories of use cases – including assessment of connectivity, performance, quality improvement, and safety needed to be addressed and such are discussed at length as well.

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Patient Experience of Anesthesia and Surgery From Twitter Data

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Background: Patient feedback is necessary to improve care guidelines, patient education and the patient experience. Traditional methods of interviews, focus groups and questionnaires are known to give an incomplete and biased picture, whereas social media is often frank and contemporaneous, offering insights into patients’ experiences undergoing anesthesia and surgery. Our study aims to characterize public Twitter messages to find peri-operative reports,

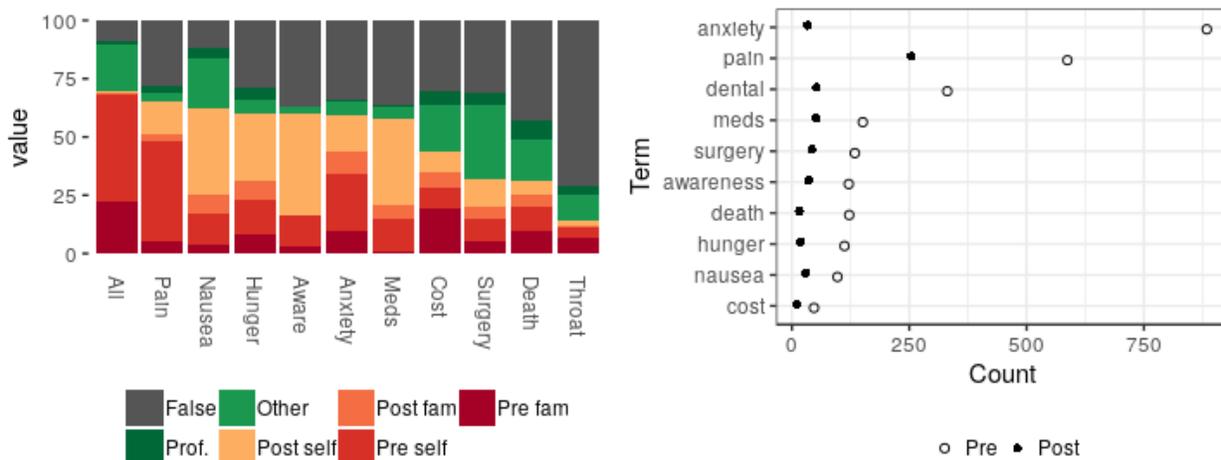
Methods: We retrieved tweets from a database comprised of a random subset of approximately 10% of all ‘tweets’ from October, 2011 to March, 2018. We first searched for tweets related to anesthesia and surgery (sub-strings ‘surgery’, ‘anesth’ or ‘anaesth’), and used this filtered subset for all analysis. We excluded ‘re-tweets’ and messages with hyperlinks. Next we classified tweets by theme, e.g., pain. Each theme was defined by a set of word stems, e.g. for pain, pain, agony, hurt, ache. These were honed by reading many tweets. We manually reviewed 100 tweets for each theme to calculate specificity.

Results: The database contained a total of 5,173,115,347 tweets, of which 2,584,474,720 were in English. Of these, 180,838 tweets mentioned surgery or anesthesia and were neither retweets nor contained hyperlinks. See Figure 1a for specificity. The most common themes regardless of temporal relation to surgery were, in order of prevalence: family (n=26,057), pain (n=7,346), and anxiety (n=3,817). Hunger/thirst (n=964) and PONV (n=1,024) were similar. Figure 1b presents numbers also filtered for pre- vs. post-op.

Conclusion: We demonstrate a new use of social media as a rich source of information on patients’ peri-operative experiences. Compared to well-known peri-operative concerns, tweets related to hunger and fasting were more prominent than expected. Patient experiences seen on social media may help with targeted education, shared-decision making, and better choices for patients before surgery and anesthesia.

Figure 1

Figure 1a : Red, orange are personal or family; green shows general observations about surgery or anesthesia; grey represents false positives. Figure 1b: Counts of tweets by group



Video Assisted Oro-tracheal Intubation Device

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Video laryngoscopes have created a lot of attention in recent years in the anesthesia community as a valuable tool in managing airway intubations, especially in difficult airway cases. This has resulted in wider adoption of video laryngoscopes and also increased usage.¹ There is a need for a device that combines both fibro-optic and video-assisted airway images in one screen.

Video laryngoscopes play a significant role in the management of routine and difficult airway intubations. The same design requires the use of a stylet and introduces blind spots in the oropharynx during intubation. As a result, cases of airway trauma have been reported. Fibro-optic intubation (FOI) scope is the "gold standard" tool in difficult intubations, but not free of limitations including: Difficulties keeping the upper airway open, shortsighted, narrow-angle views, complete view obstruction caused by the presence of blood or heavy secretions.² In order to limit the disadvantages of both the video laryngoscope and the FOI scope, a combination of both methods is ideal. We have developed a video assisted oral airway mouthpiece with an adjustable angle that can combine both technologies and provide a laryngeal view of the patient's airway while allowing the endotracheal tube to be loaded on a flexible stylet/optic scope and guided to the wind pipe under direct vision of a single operator.

The Value: Limit the square footage of room space needed and reduce the number of operators (from 2 to 1), easy to use so the operator can focus on the procedure. Overcomes the limitations of both video laryngoscopy and fiber optic devices used alone, improves visualization, improves management of difficult intubations, allows inexperienced operators to perform difficult intubations and limits potential for complications and improved outcome for the patient.



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A Novel Approach to Systematically Translate Anesthesia Quality Measures into Computable Representations for Clinical Decision Support Systems

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Object of Study: The impact of quality measures on clinical care delivery and reimbursement within the anesthesia community is undeniable. In order to maximize the positive impact of these measures, it is desirable to create computable representations of them so that they can be used efficiently at the point of care--ideally in a clinical decision support (CDS) system. Unfortunately, translating the human-readable narratives present in quality measure guidelines into an executable version that reflects the original clinical intent is not straightforward. We propose the application of a knowledge representation framework in conjunction with a quality measure semantic model to provide the foundation for a reproducible process for this translation.

Methods: To create these knowledge bases, we developed a systematic approach to translate clinical intent into computable artifacts using a multi-layered framework for representing knowledge [1, 2]. Beginning with a human-readable quality measure narrative (Level 1), we created a semi-structured representation with appropriate data bindings (Level 2) using a semantic model that captured quality measure intent. An example of a semantic model that was used for postoperative nausea and vomiting is depicted in Figure 1.

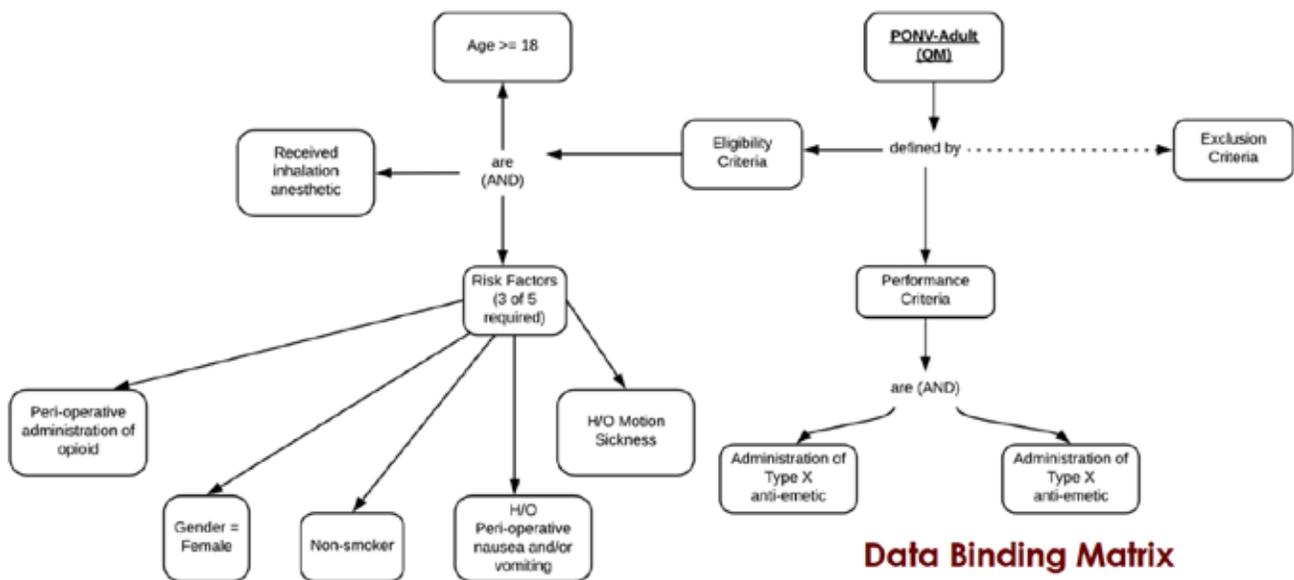


Figure 1: A representative Level 2 semantic model for quality measure MIPS #430 [3].

From this Level 2 representation, we created a standardized structured document reflecting the clinical context, intent, and logic to make the measure computable at the machine level (Level 3). In addition, where possible, this was aligned with standard terminologies including SNOMED CT, LOINC, and Rx NORM to facilitate broad use of existing coded data elements. Finally, the Level 3 representation was converted to computable code using Drools and implemented within a clinical decision support system as a knowledge base.

For the purposes of validating the run-time representations, we used our CDS platform, CORA, integrated with the Draeger Innovian[®] anesthesia information management system (AIMS) [4]. CORA is a standards-based, extensible CDS platform that collects and analyzes data from an AIMS as it is generated, using algorithms and logic encoded in knowledge bases. Following the process described above, we implemented and validated the following core anesthesia quality measures:

- MIPS #44: CABG: Preoperative Beta-Blocker in Patients with Isolated CABG Surgery
- MIPS #76: Prevention of CVC-Related Bloodstream Infections
- MIPS #404: Anesthesiology Smoking Abstinence
- MIPS #424: Perioperative Temperature Management
- MIPS #426: Post-Anesthetic Transfer of Care Measure: Procedure Room to PACU
- MIPS #427: Post-Anesthetic Transfer of Care Measure: Procedure Room to ICU
- MIPS #430: Prevention of Postoperative Nausea and Vomiting
- MIPS #463: Prevention of Postoperative Vomiting (Pediatrics)

Conclusions: We successfully demonstrated a repeatable process to translate core anesthesia quality measure guidelines into computable representations. These representations were then implemented and validated within CORA and Innovian[®] to ensure that the executable version of the quality measure reflected the original clinical intent from the human-readable narrative. Furthermore, this work demonstrates a capability which will facilitate the rapid deployment of clinical knowledge and support the governance and refinement of deployed clinical knowledge to reflect current evidence.

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Feasibility of Computer-Assisted Vasopressor Titration Using Non-Invasive Blood Pressure Monitoring (Clearsight) During Renal Transplant Surgery: A Case Series

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Background: Both magnitude and duration of hypotension are associated with cardiovascular¹, renal² and neurological³ adverse events. Anesthesiologists and intensivists frequently use vasopressors, which are either given in sporadic boluses or adjustable infusions with the goal of maintaining adequate arterial pressure for organ perfusion (e.g. mean arterial pressure of >70mmHg). These manual approaches are time-consuming and limited by distractions. This can ultimately lead to poor compliance to the initial goal-directed strategy and consequently hypotension⁴. Using lessons learned in the development and testing of a closed-loop fluid resuscitation algorithm, we developed a mixed proportional-integrative and rule-based closed-loop system that allows automatic titration of norepinephrine infusion to optimize MAP. This system, linked to a minimally invasive hemodynamic monitoring device, has been tested extensively *in silico*⁵ and in animal^(under review) studies.

In this case series, we sought to determine the feasibility of using our novel controller linked to a non-invasive blood pressure monitor. We aimed to maintain normotension in a series of patients undergoing renal transplant surgery.

Methods: Three high-risk renal transplant surgery patients were recruited for this case series. All three were monitored with non-invasive continuous blood pressure monitoring (Clearsight, Edwards Lifesciences, Irvine, USA), which was linked to the closed-loop controller. The controller automatically titrated norepinephrine doses to achieve a predetermined MAP of 70 mmHg in two patients and of 80 mmHg in one patient (target chosen based on patient's baseline MAP). The primary objective was case time spent in hypotension, which was defined as a MAP below 5 mmHg of the target MAP. Secondary objectives were the percentage time spent above the target value with norepinephrine still running (i.e., overtreatment) and the amount of norepinephrine administered to the patients.

Results: The controller maintained MAP within ± 5 mmHg of the predefined target MAP for 91.4% [86.6 -94.7]% (median [25-75] percentiles) of the case time. Patients spent 5.7% [3.7-

8.2]% of case time in hypotension and 2.9% [1.7-5.3]% above target with norepinephrine still running. Median case duration was 2.57 hours and norepinephrine was running during 97.3% of the case time (min: 81.4% ; max: 98.1%). The median dose of norepinephrine was 3.74 $\mu\text{g}/\text{min}$ and the controller did 189 changes per hour. The target for one patient was increased to 90mmHg following surgical assessment of poor renal graft perfusion. Patients stayed hospitalized 7 to 9 days and no major postoperative complication occurred. One patient was treated for urinary tract infection.

Discussion: Managing blood pressure using a closed-loop vasopressor administration system guided by continuous non-invasive blood pressure monitoring is feasible. Patients maintained MAP within a ± 5 mmHg target range for more than 90% of the case time with 5.7% of case time under target and 2.9% above target. This system may become a powerful new tool for preventing hypotension in surgical patients.

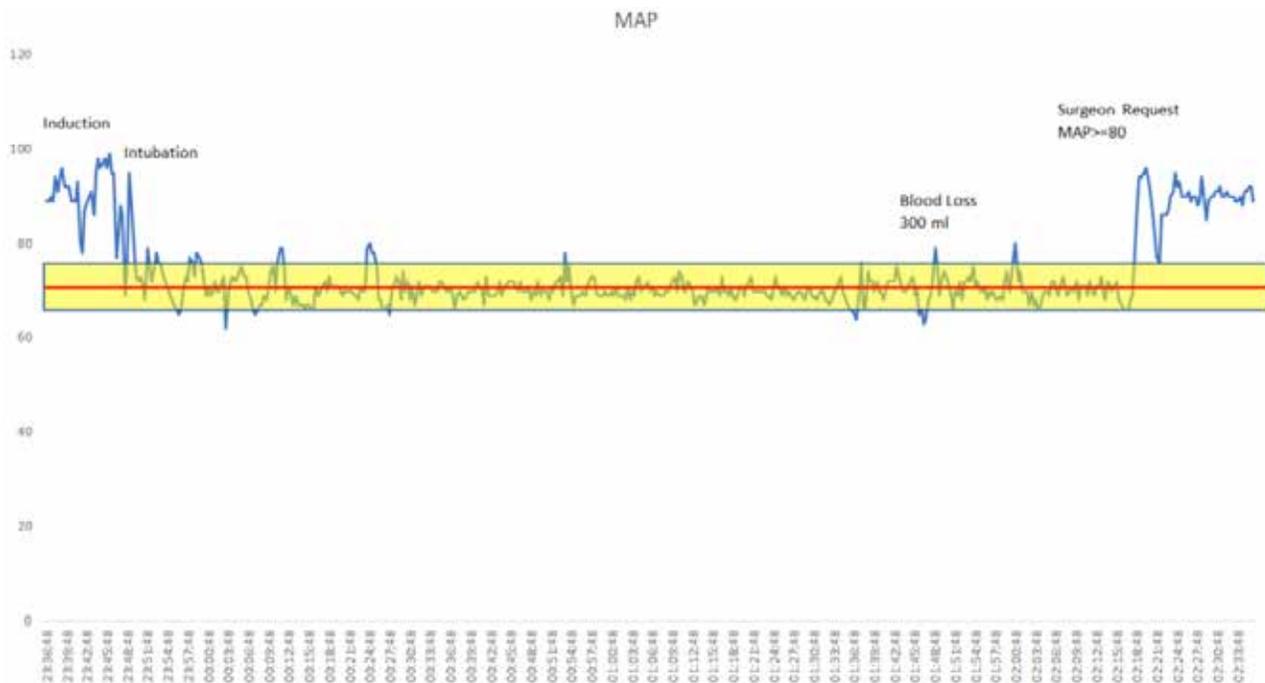


Figure: Intraoperative mean blood pressure (MAP) throughout the intraoperative period in a patient undergoing renal transplantation. The controller automatically titrated norepinephrine to achieve a predetermined MAP of 70 mmHg.

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Low, Minimal and Metabolic Anesthesia Using a Novel Membrane Technology Instead of Chemical Absorbents for Carbon Dioxide Removal – Clinical Data

Co-Authors: Michael K Schmidt, MD, PhD; Florentin M Wilfart, Dipl-Ing (FH), PhD; R Zachary Ford; David C Roach, PEng, PhD; Orlando Hung, MD, PhD; Dalhousie University, Halifax, Nova Scotia, Canada

Background: Lowering fresh gas flow (FGF) rates in anesthesia circuits reduces the gas volumes vented to the environment.¹ This effort is rapidly gaining importance due to increasing pressure to (a) save cost and (b) decrease the environmental footprint of anesthesia practice, both achievable by lowering FGFs.¹

While *low-flow* (≤ 1.0 Lpm), *minimal-flow* (≤ 0.5 Lpm), and *metabolic-flow* (≤ 0.35 Lpm) anesthesia practices have long been technically feasible using chemical absorbents, membrane technology promises a host of advantages including improved simplicity, reliability, safety, environmental stewardship and cost.^{2,3} In addition, membrane technology eliminates the concerns that have resulted in vapor manufacturers' recommended minimum FGF rates of 1-2 Lpm (country dependent).^{4,5} Last but not least, membrane technology has the ability to automatically satisfy the metabolic oxygen need of any patient simply based on concentration gradient-mediated transmembrane gas transport, eliminating the need for a FGF to maintain a target FiO_2 .

Objective: This study aims to investigate the safety and feasibility of using a membrane technology-based product, (memsorb™, DMF Medical Inc., Halifax, NS, Canada) instead of chemical absorbers under *low-flow*, *minimal-flow*, and *metabolic-flow* conditions for carbon dioxide removal. Memsorb™ is designed to function continuously over 10-12 months, significantly reducing (i) absorber waste (ca. 300 absorbers/ year), (ii) carbon footprint from absorber transportation, (iii) cost of storage and disposal, and (iv) safety concerns associated with eliminating dust and other chemical reactions with absorber use and disposal.

Methods: After REB approval, memsorb™ was tested in 129 patients replacing the chemical absorber on Fabius® machines (Dräger, Lübeck, Germany) while standard general anesthesia was practiced using vapors. The flush gas for memsorb™ was set to 15 Lpm and its Air:O₂ ratio was adapted to match the target oxygen concentration of the anaesthesia system. Cases with FGF ≤ 1.0 Lpm were selected and divided into low, minimal, and metabolic FGF groups. Vapor consumption was determined using photo-volumetric analysis of the fill degree on the vaporizer.

Results: As main result the EtCO₂ value for each FGF group divided into sevoflurane and desflurane cases are shown in Table 1. The consumption of vapor was investigated under different fresh gas flows.

Table 1. Study results.

FGF Group	FGF [median (SD)]	Agent	N	EtCO ₂ [median (SD)]
Low ≤ 1.0 Lpm	0.78 (0.14) Lpm	Sevo	23	4.89 (0.46)
		Des	9	4.96 (0.47)
Minimal ≤ 0.5 Lpm	0.43 (0.05) Lpm	Sevo	4	5.13 (0.46)
		Des	5	5.44 (0.32)
Metabolic ≤ 0.35 Lpm	0.21 (0.05) Lpm	Sevo	6	5.83 (0.18)
		Des	4	5.12 (0.52)

Conclusions: memsorb™ showed physiologically safe EtCO₂ data under all studied conditions. This confirms that memsorb™ provides a safe and valid alternative to chemical-based absorbents, while also reducing the environmental impact of CO₂ removal.

Conflict of Interest: Dr. Schmidt is the Founder, Chief Medical Officer and major shareholder for DMF Medical without remuneration. Dr. Roach is the President and major shareholder of DMF Medical. Dr. Wilfart is a Director and shareholder of DMF Medical. Mr. Ford reports personal fees from DMF Medical. Dr. Orlando Hung has independently run this study and recorded the data as principal investigator and reports no conflict of interest.

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Automated Titration of Vasopressor Infusion Using a Novel Closed-Loop Controller: In Vivo Feasibility Study Using a Swine Model

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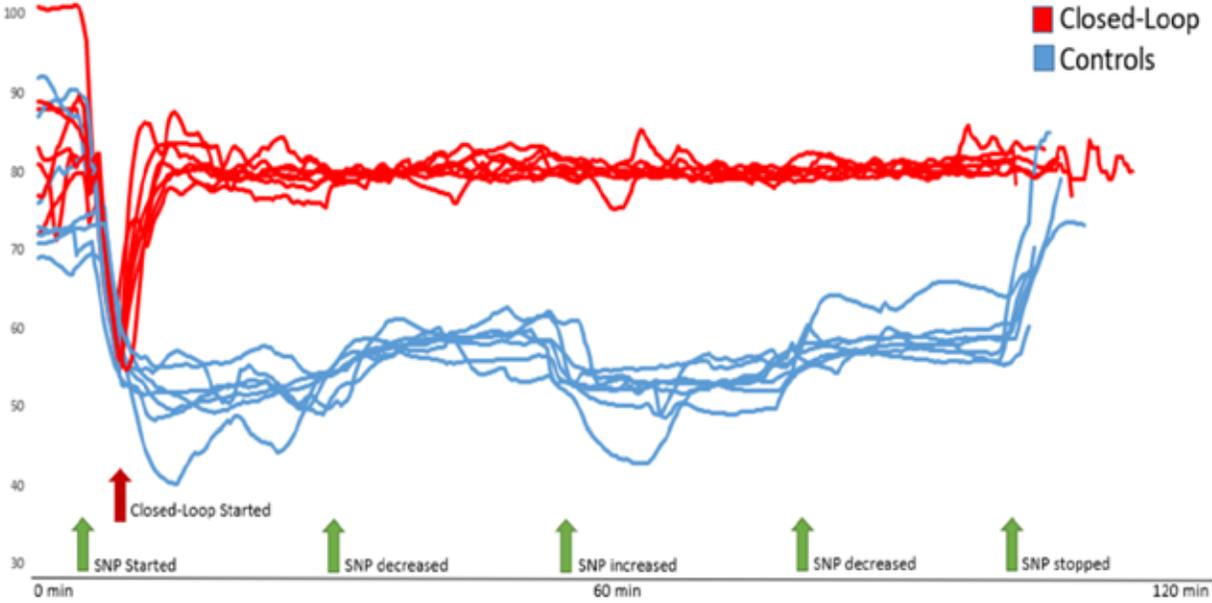
Background: Multiple large retrospective studies have reported associations between intraoperative hypotension and adverse postoperative complications. One of the most common interventions in the management of hypotension is vasopressor administration. Unfortunately, this approach requires careful and frequent vasopressor boluses and/or multiple adjustments of an infusion. We recently developed a closed-loop controller that titrates vasopressors to maintain mean arterial pressure (MAP) within set limits. Here we assessed the safety, feasibility and overall performance of this system in a swine model. We hypothesized that the closed-loop controller would be able to maintain MAP at a steady, predefined target level of 80 mmHg for more than 85% of the time.

Methods: We randomized 14 healthy anesthetized pigs (42 ± 6 kg) either to a control group or a closed-loop group (7 per group). Using infusions of sodium nitroprusside at doses between 65 and 130 $\mu\text{g}/\text{min}$ we induced four normovolemic hypotensive challenges of 30 minutes each. In the control group, nothing was done to correct hypotension. In the closed-loop group, the system automatically titrated norepinephrine doses to achieve a predetermined MAP of 80 mmHg. The primary objective was study time spent within ± 5 mmHg of the MAP target. Secondary objectives were the Varvel criteria (performance error (PE), median PE, median absolute PE, wobble and divergence).

Results: The closed-loop controller maintained MAP within ± 5 mmHg of the target for $98 \pm 1\%$ (mean \pm SD) of the time. In the control group, the MAP was 80 ± 5 mmHg for $14.0 \pm 2.8\%$ of the time ($p < 0.0001$). The MAP in the closed-loop group was above the target range for $1.2 \pm 1.2\%$ and below it for $0.5 \pm 0.9\%$ of the time (**FIGURE 1**). The Varvel performance criteria were all optimal.

Conclusion: In this experimental model of induced normovolemic hypotensive episodes in healthy pigs, an automated closed-loop system accurately titrated norepinephrine infusion to correct hypotension.

MEAN ARTERIAL PRESSURE IN ALL ANIMALS



NMBM Accel – A Novel Programmable Prototype Neuromuscular Block Monitor

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Co-Authors: Elizabeth Fischman BS, Joshua Leighton BS, Dylan Matteson BS, Quinn McCarthy BS, Eric Kennedy PhD (Bucknell University, Lewisburg, PA)

Assessment of neuromuscular transmission is essential for competent management of balanced anesthetic technique. Available devices and methods for clinical monitoring range from very simple to sophisticated, with proportional prices. Despite evolution of hardware implementations, conceptually little has changed since Viby-Mogensen introduced the double-burst stimulus pattern [1]. We have produced a programmable prototype neuromuscular block monitor designed to address clinical and research issues.

Clinical difficulty monitoring very small muscle responses during profound block, or completeness of reversal, are persistent blind spots using current technology and stimulus patterns. Advances in pharmacology increase demand for profound muscle relaxation to facilitate challenging surgical procedures, while production pressure for rapid turnover between procedures encourages inadequate attention to complete reversal to neuromuscular block -- hazards for patient safety and opportunities for improvement [2].

The historical standard of measuring force of adductor pollicis contraction to ulnar nerve stimulation is too difficult and impractical for routine clinical application. Many sensing alternatives attempt to provide easily usable alternatives for routine clinical practice. Likewise, numerous neuromuscular transmission stimulus patterns have been employed clinically, each with advantages and disadvantages for interpretation.

As a capstone project, a team of four undergraduate senior Biomedical Engineering students at Bucknell University designed and implemented an Arduino-based neuromuscular stimulator with a faculty advisor and a clinical mentor. Three-axis accelerometry was employed in this prototype as the most accessible response parameter [3]. Design and programming included a logic board supporting an Arduino processor, pulse trigger and output current pulse generator, accelerometer data capture and display, 3D printed case and accelerometer finger clip, and clinician stimulus selector control (single twitch, train-of-four, double-burst, tetanus, post-tetanic count). Measured response was displayed graphically on an LCD display in the prototype. A USB port provided for programmability and could output acquired data.

Thus far this prototype has produced a novel neuromuscular block monitor. Control of hardware design and programmability provide opportunities to exploit capabilities of modern electronics and microsensors to expand the dynamic range for monitoring from profound block to complete recovery of neuromuscular transmission.

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Agreement Between Depth of Anesthesia Monitors Depends on the Patient and Procedure

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Introduction: Anesthesiologists can assess the Depth of Anesthesia (DoA) with gestalt or by monitoring surrogates of DoA. Surrogates include the end-tidal anesthetic concentration (ETAC) and a summary of EEG response, the bispectral index (BIS). ETAC and BIS have different analytes, but similar effectiveness for avoiding intra-operative awareness in the largest randomized clinical trial, B-Unaware [1]. In the B-Unaware trial the median intra-individual ETAC-BIS correlation was -0.16 (interquartile range -0.50, -0.03) [2]. The variable relationship between ETAC and BIS response has been used to suggest the susceptibility to anesthesia. Here we identify patient and procedural determinants of BIS-ETAC concordance.

Methods: Adult (age > 18) patients undergoing general anesthesia between 2010 and 2015 in which BIS monitoring was used were included. Exclusion criteria were cardiac surgery, spinal fusions and laminectomies, and cases lacking documented gender and BMI. After removing outlier BIS and ETAC measures, we included only cases with at least 5 minutes of concurrent BIS and ETAC measurements. ETAC was age and equivalent adjusted. BIS and ETAC were sampled q15 seconds.

The concordance of BIS and ETAC was measured with the cross-correlation for each case. We then trained multiple linear regression models to predict a case's BIS-ETAC concordance based on patient and procedural factors that were known prior to the operation (age, gender, BMI, race, ASA physical status, attending anesthesiologist, and procedure CPT code). Predictors were assessed for significance with type II ANOVA tests.

Results: 31,505 cases met inclusion criteria, with mean anesthesia durations of 214 min (s.d. 126 min) and mean concurrent BIS and ETAC measures for 145 min (s.d. 107 min). The DoA concordance had a wide spread (median -0.48, interquartile range -0.67, -0.22). Multiple linear regression explained 10% of the observed variance in DoA concordance. Patient age and ASA status were the strongest predictors of DoA concordance ($p=4e-93$ and $6e-93$), and additional significant factors were CPT code ($p=5e-132$), anesthesiologist ($p=8e-89$), patient race ($p=2e-9$), and emergency status ($p=4e-3$).

Conclusions: BIS and ETAC monitors provide alternative assessments of DoA. We found a stronger overall BIS-ETAC concordance than prior work, but weaker associations in high risk and emergency cases, and older and lower BMI patients. It is still unclear which monitor is superior for DoA, but knowing when these monitors are redundant or incongruous can guide monitor selection in clinical practice and case selection in clinical trials.

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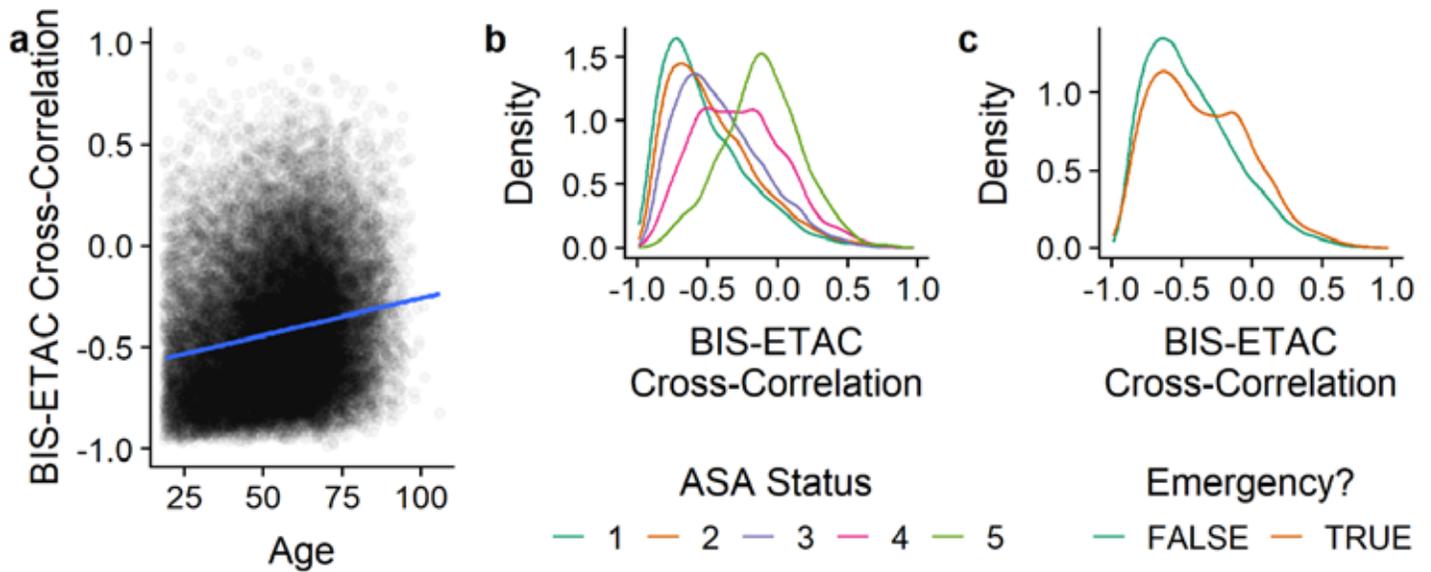


Figure 1: a) Association between BIS-ETAC concordance and patient age. Each point represents one case, and the blue line is a linear regression. b&c) Density of BIS-ETAC cross-correlation grouped by (b) ASA physical status level and (c) emergency status.

Analysis of Twitter Content and Sources on Nitrous Oxide for Labor Analgesia

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Societal expectations have a significant influence on patient labor preferences.¹ Providers caring for obstetric patients can better educate patients by understanding and contributing to the broader conversation on nitrous oxide in pregnancy.² The goal of this pilot study was to analyze publically available Tweets related to the use of nitrous oxide for labor analgesia in order to characterize their content, sentiment, and user demographics.

We used twitterscraper, a script that accesses Twitter's search functionality, to retrieve Tweets using the search terms "(nitrous) AND (pregnancy OR labor OR obstetric OR birth)" on October 30, 2018.³ Data fields collected included Tweet text, uniform resource locator (URL), user handle, and date and time posted. Tweets were scored on text content and sentiment toward nitrous oxide use in pregnancy. The Twitter user posting the Tweet was also categorized.

For the initial analysis, 200 of the 764 returned Tweets (26%) were randomly selected and manually categorized. Of these, the earliest was posted April 2, 2009 and the latest October 15, 2018. 78 Tweets (39%) related to news media coverage of nitrous oxide use for labor. 48 (24%) were personal anecdotes or opinions. 9 (5%) Tweets were irrelevant and not included in further analysis. The sentiment of 93 Tweets (49%) were predominantly positive toward nitrous use for labor analgesia, 75 (39%) were neutral, 12 (6%) were negative, and 12 (6%) were primarily humorous. 81 (42%) of the Twitter users discussing nitrous oxide in pregnancy were laypeople, while 15 (8%) were peripartum healthcare providers.

Non-healthcare providers made up a large proportion of Twitter activity on nitrous oxide for labor. Studies have indicated there is physician concern that media and internet sources of medical information may contain inaccuracies or be difficult for patients to interpret.⁴⁻⁵ Obstetric patients may benefit from greater healthcare provider contribution to the online discussion of nitrous oxide use in pregnancy.

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Identifying Unnecessary Blood Transfusions in Patients Undergoing Craniofacial Surgery Using National Craniosynostosis Registry Dataset

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Background: Craniosynostosis is the premature fusion of one or more cranial sutures that often requires surgical intervention. Surgery often involves extensive osteotomies which can lead to substantial blood loss. The aim of this study is to use a national craniosynostosis dataset to compare blood transfusion use for patients undergoing a wide range of craniosynostosis repairs in order to identify patients that were potentially inappropriately transfused and compare the risk factors for postoperative events (ASA 3 or 4, weight ≤ 10 kg, tranexamic acid use (TXA), and syndromic patients) established by Goobie et al.². The broader aim is to decrease the amount of inappropriate transfusions.

Methods: The national Pediatric Craniofacial Collaborative dataset contains data from 2390 patients in the pre-, intra-, and post-operative phases of perioperative care¹. Patients with comorbidities such as congenital heart disease as defined in the dataset were excluded from our study. To identify patients who received inappropriate or unnecessary transfusions, we made two assumptions: 1) the lowest acceptable intraoperative hematocrit is either 24% or 30% and 2) the estimated allowable blood loss (EABL) was calculated using the following equation:

$$EABL = \frac{H_1 - H_2}{H_1} \times EBV \quad (1)$$

where, H_1 is the starting hematocrit level, H_2 is the acceptable hematocrit (i.e. 24% or 30%), and EBV is estimated blood volume.

From the EABL we subtracted the total blood transfused during the surgery to estimate the blood transfusion difference (BTD). Finally, we compared the BTD during surgery to the EABL and established thresholds to separate the patients into 3 distinct categories: no transfusion, inappropriate transfusion (transfusion (ml/kg) less than EABL), appropriate transfusions (transfusion >60 ml/kg).

To identify patients as having received an inappropriate transfusion we based our criteria as follows: (i) pre-operative hemoglobin (Hb) >10 , (ii) BTD ≤ 0 and (iii) total intraoperative crystalloid administration > 3 times EABL. Using this criteria we removed patients that were anemic and patients that were potentially hemodiluted.

Results: Among the 2390 patients, 2157 patients had all the required fields for calculation of EABL and BTD. None of these patients had preoperative anemia. Table 1 represents the number of patients in each group based on the defined criteria for acceptable hematocrit levels. In Table 2 we compared the percentage of patients with ASA 3-4, body weight < 10 Kg, use of tranexamic acid (TXA) and presence of a craniosynostosis syndrome as previously published studies show these features are associated with an increased risk of major post-operative complications².

Conclusion: We found based on our calculation assumptions of a hematocrit of 24% and 30%, 271 and 616 cases respectively of inappropriate transfusion. These numbers account for 13% and 29% of the craniosynostosis population respectively which is relatively high numbers especially for hematocrit levels of 30%. We also found 370 cases did not require blood product transfusion. The data demonstrated that patient’s weight less than ten kilograms were more likely to receive an inappropriate transfusion. Many clinical factors require consideration when deciding to transfuse any patient during the intraoperative period. However, a patient weighing less than 10 kg are likely to loose a significant amount of circulating blood volume quickly during cranial vault reconstruction surgery. It is possible that many providers are transfusing blood product in anticipation of large blood loss. Although our blood product transfusion threshold calculations are subjective, the findings of this study present an opportunity to support consensus guidelines and protocols to reduce inappropriate transfusions and hence reducing the morbidity associated with transfusions in patients undergoing surgery for craniosynostosis.

Table1: Number of patients in each category.

Group	H_2 = Hematocrit 24	H_2 = Hematocrit 30
No Transfusion	370	370
Inappropriate Transfusion	271	616
Appropriate Transfusion	1516	1171

Table 2: Percentage of patients with risk factors for postoperative events.

Group	ASA 3-4	Weight < 10kg	No TXA	Syndromic Patients
All	31%	55%	55%	14%
No Transfusion	26%	41%	54%	13%
Inappropriate Transfusion	28%	92%	46%	10%
Appropriate Transfusion	32%	48%	55%	15%

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Automated Notifications Improve Time to Anesthesia Induction: Integrating Health Information Technology Systems to Enhance Perioperative Efficiency

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Objective: To evaluate the effects of health information technology systems integration on perioperative efficiency of anesthesiologists. Investigate if automatic notifications that patients have arrived in the operating room leads to decreased time to induction.

Methods: We performed a retrospective chart review of all outpatient and short-stay patients who received General Anesthesia at Josie Robertson Surgery Center between July 1, 2017 and June 30, 2018.

Time was used as a measure of efficiency between the two comparison groups. The two comparison groups were as follows:

Group 1: Pre-event notification implementation (July 1, 2017-Dec 31, 2017)

Group 2: Post-event notification implementation (Jan 1, 2018 – June 30, 2018)

Event is defined as the launch date of the automatic text page notifications to anesthesia attendings that patient has arrived in the operating suite. This text page is driven by the real time locating system (RTLS) badge that all patients now wear throughout the hospital stay. In this study, our primary outcome measure duration (DUR) was collected from patient electronic medical records:

DUR: Time (duration in minutes) between anesthesia start and induction of anesthesia, exclusively for first case of the day.

Results: Duration of induction was significantly shorter post-event notification implementation compared to pre-event implementation (median duration, 6 min vs 7 min; $p=0.001$).

Conclusion: We demonstrate that health information technology systems integration improves perioperative efficiency of anesthesiologists at our institution. Further investigation is warranted to provide data to support provider buy-in and greater uptake and implementation of these systems to enhance patient care and coordination in the healthcare setting.

Staff Tracking and Perioperative Efficiency of Anesthesiologists

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Objective: Improving our assessment of the effect of Real Time Locating System (RTLS) technology on the perioperative efficiency of anesthesiologists.

Methods: A retrospective chart review was performed for all outpatient and short-stay patients who received General Anesthesia care at our institution between January 2016 and October 2017. Patients included were over 18 years and had ASA classification scores of 1, 2, and 3. Only first cases of the day for individual anesthesiologists were included. Time was used as a measure of efficiency between two groups of anesthesiologists.

Group 1: Anesthesiologists at Main Campus who do not use RTLS

Group 2: Anesthesiologists at Josie Robertson Surgery Center who use RTLS

The outcome measure collected from patient electronic medical records was DUR: Duration between when patient is admitted to the operating room and initiation of induction only for first case of the day by attending anesthesiologist.

Results: We found that anesthesiologists who had access to RTLS technology at JRSC took less time to induction of first case of the day compared with anesthesiologists who did not use RTLS at Main Campus. The difference in time taken was 1 minute and this was statistically significant to $p < 0.001$.

Conclusion: In the study preceding this, we found that anesthesiologists who had access to RTLS at JRSC performed more efficiently in their preoperative evaluation of patients as well as time to induction for general anesthesia cases. Because of various confounding factors that potentially influenced the increase in efficiency of anesthesiologists with access to RTLS, this follow-up study eliminates these confounding factors by assessing only time to induction of general anesthesia for all first cases of the day by anesthesiologists. We continue to find a small but statistically significant difference in time to induction of anesthesiologists with access to RTLS. This translates directly into increased efficiency in perioperative workflow. Additional investigation and application can help elucidate the value of RTLS on workflow efficiency in the healthcare setting.

Scraping if Intraoperative Textual Report for Acquisition and Storage of Clinical Data from the Epic Electronic Medical Record (EMR)

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Introduction: Since enactment of The American Recovery and Reinvestment Act of 2009, Electronic Medical Records (EMR's) have been broadly instituted in hospitals. Many anesthesia departments have implemented these systems, and others continue to do so. While automated and procedural-driven capture of intraoperative clinical information has expanded, much of this data is not archived for research and Quality Improvement (QI) efforts. Some institutions have excelled at this endeavor; however, many Anesthesia departments find the process of data retrieval and archiving into research and QI-friendly formats to be resource intensive and financially prohibitive. With these constraints in mind, our group has endeavored to access and digitize textual information from native clinical reports into a spreadsheet format that can then be easily imported into statistical programs.

Methods: After IRB approval, the charts of 1,066 patients, who underwent spine surgery at our Hospital, from January 1, 2016 to June 30, 2018, were reviewed. APACHE, MySQL server, and phpMyAdmin (PHP) computer programs were installed on a personal computer running Microsoft Windows 10. A set of clinical data to be extracted from these anesthesia records was enumerated by our team. In total, 54 parameters were identified for extraction. Each clinical report was hand copied using two sets of two keystroke commands and pasted into Microsoft Word 2010. A sample of 60 charts was chosen and examined for characters that demarcate the boundaries (loci) of clinical data to be extracted. A program was developed in PHP to identify these loci and to extract the clinical data between them. When the loci failed to identify the demarcation of data, the clinical report was re-examined, and conditional statements were added to the original PHP function. For each group of clinical datasets, a SQL statement was written in PHP to import these data points into 14 related tables in MySQL server, using SQL procedural language.

Results: Once a stable version of the PHP scraping program was finalized, the native clinical anesthesia reports of 1,066 patients were analyzed. The program proved to be very accurate in extracting data and placing it into the MySQL tables. In total, over 58,000 data points were analyzed with 97.1% accuracy. The inaccuracies were related to parsing of textural information without loss of data.

Conclusion: Our data scraping program has proven to be successful in extracting clinical information from a pre-existing EPIC report form and placing it in a retrievable database system, with greater than 97% accuracy. The advantages of this approach to data acquisition are that: 1) it is extremely inexpensive; 2) has low resource utilization; 3) data acquisition and storage are rapid; (4) it requires no utilization of hospital or departmental-based IT resources; 5) the data output can be readily accessed with simple SQL commands, or through a project driven dashboard;6) it can be completely isolated from the Internet or hospital networks to prevent breach of Health Care Information and; 7) the spreadsheet format can be easy importing into statistical packages for analysis . To improve on the 2.9% parsing oversight, we will in future versions of this application import a dictionary of terms to enhance the accuracy of the program. This technique of surface scraping pre-existing reports could be used to facilitate research and Quality Improvement efforts at small to medium-sized anesthesia departments that do not have resources of continuous IT support

Images:

The image shows a database interface with a tree view on the left and a table of data on the right. The tree view includes tables like 'anestdrugs', 'anestevent', 'anesthypv', 'landos', 'last_id', 'main', 'medicaltr', 'physexam', 'preopmeds', 'probiolist', 'procedure_info', 'quicknotes', 'substanceuse', and 'vari_stats'. The table on the right has columns 'Record_ID', 'AnestEvt_Incd', and 'AnestEvt_Txt'. Below it, another table has columns 'Record_ID', 'QuickNotes_Incd', and 'QuickNotes_Txt'.

Record_ID	AnestEvt_Incd	AnestEvt_Txt
979	1	0721 Equipment Check
979	2	0721 Anesthesia Start
979	3	0723 Start Data Collection
979	4	0732 Induction
979	5	0739 Intubation
979	6	0749 Anesthesia Ready
979	7	1046 Extubation
979	8	1053 Stop Data Collection
979	9	1053 Out of room
979	10	1103 Post-Op Handoff
979	11	1103 Anesthesia Stop

Record_ID	QuickNotes_Incd	QuickNotes_Txt
979	1	0822 Quick Note Temp probe inconsistent with readings. Requested for new cable

Figure 1 Image of database structure, sample capture of Anesthesia Events and QuickNote entries from one patient.

Surface Scraping of Intraoperative Hemodynamic Data for the Acquisition and Storage From Epic Electronic Medical Records (EMR)

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Introduction: Since the enactment of The American Recovery and Reinvestment Act of 2009, Electronic Medical Records (EMR) have been broadly implemented in hospitals. It is often difficult to acquire and download hemodynamic data into database, spreadsheet and statistical software packages without the allocation of IT resources and financial expenditures. With these constraints in mind, our group has endeavored to access and digitize hemodynamic information from native clinical reports and save it in a spreadsheet format that can then be easily imported into statistical software packages. Such data could then be used to support research and Quality Improvement (QI) endeavors.

Methods: After IRB approval, the charts of 1,066 patients, who underwent spine surgery at our Hospital, from January 1, 2016 to June 30, 2018, were reviewed. A version of APACHE, MySQL server, and phpMyAdmin (PHP) were installed on a personal computer running Microsoft Windows 10. A set of hemodynamic criteria were enumerated by our team to be extracted from these anesthesia records. In total, 6 parameters were identified for extraction (heart rate, systolic blood pressure, mean arterial pressure, diastolic blood pressure, end-tidal carbon dioxide and temperature). When applicable, arterial-line blood pressure readings (systolic arterial-line blood pressure, mean arterial-line blood pressure, diastolic arterial-line blood pressure) were also extracted. Each clinical report was copied using two sets of two keystroke commands and pasted into Microsoft Word 2010. A small sample of 100 charts were chosen and examined for characters that demarcate the boundaries (loci) of hemodynamic data to be extracted. A program was developed in PHP to identify these loci and to extract the hemodynamic data between them. When the loci failed to identify the demarcation of data, the clinical report was re-examined and conditional statements were added to the original PHP function. Conditional statements were added to identify hand-entered hemodynamic parameters, and these were marked with an asterisk. For each group of clinical datasets, SQL statements were written in PHP to import these data points into five related tables in MySQL server using SQL procedural language.

Results: Once a stable version of the PHP scraping program was finalized, the native clinical anesthesia reports of 1,066 patients were analyzed. The program proved to be very accurate in extracting data and placing it into the MySQL tables. 1,066 patient records were analyzed with accuracy of 100%.

Conclusion: Our data scraping program has proven to be extremely successful in extracting hemodynamic data from a preexisting report form and placing it in a retrievable database system. The advantages of this frontend approach to data acquisition are, it: 1) is extremely inexpensive; 2) uses minimal resources; 3) data acquisition and storage is rapid; 4) it does not require hospital or departmental-based IT support; 5) the data output can be readily accessed with simple SQL commands or through a project driven dashboard; 6) can be completely isolated from the Internet or hospital networks to prevent breach of Health Care Information; and 7) it can be easily imported into spreadsheet and statistical packages. We feel that this technique of surface scraping of preexisting reports for hemodynamic data is a model which will facilitate research and QI endeavors in small to medium-sized anesthesia departments.

In Vivo Performance of a Membrane CO₂ Filter during Target-Controlled Closed-Circuit Anesthesia

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Introduction: Currently used soda lime based CO₂ absorbents are safe [1] but not ideal for reasons of ecology (production and disposal), ergonomics (need to refill or replace), economy (discarded before used to full potential), and dust accumulation in sensitive machine parts. These issues are absent with the Memsorb™ (DMF Medical, Halifax, NS, Canada), a new device for gas-to-gas exchange and separation that uses technology similar to oxygenator membranes for cardiopulmonary bypass machines. A sweep gas flows through the lumen of semipermeable hollow fibers and adds or removes gases from the circle breathing system (whose gases pass in between the fibers) according to the prevailing partial pressure gradients across the fiber wall and the relative permeability of the gases. Because the permeability of CO₂ is higher than that of inhaled agents, the CO₂ transport rate and thus washout should be relatively higher than that of inhaled anesthetics. We tested the performance of the device during target-controlled closed-circuit anesthesia (TCCCA) with desflurane in O₂/air with the Zeus IE (Dräger, Lübeck, Germany).

Materials and Methods: After obtaining IRB approval and written informed consent, 8 ASA PS I-III patients undergoing robotic prostatectomy were enrolled. After induction of anesthesia and intubation of the trachea, TCCCA with the Zeus IE was used with the following settings: target inspired O₂ (F_IO₂) 39% in O₂/air; target end-expired (F_A) desflurane 5.0%; controlled mechanical ventilation, adjusted to F_ACO₂ 4.5-6.0%; and 5 cmH₂O PEEP. An O₂/air blender (Scanatron Technics, Affoltern-am-Albis, Switzerland) delivered the sweep gas (40% O₂) to the inlet of the Memsorb™ canister. Sweep O₂% was set 1% above target F_IO₂. The sweep flow was titrated to keep F_ICO₂ ≤ 0.8%. RUGloop (DEMED, Temse, Belgium) collected the following data: F_IO₂, F_Adesflurane, F_ICO₂, F_ACO₂, minute ventilation; O₂ and air FGF; sweep flow; and cumulative desflurane usage (V_{des}). Only data of the first 2h are reported. Data are displayed as average (standard deviation) unless indicated otherwise. V_{des} was compared (for F_Adesflurane = 5.0%) with historical data of the Zeus IE used with soda lime (Dräger 800+) [2] and during conventional CCA [3].

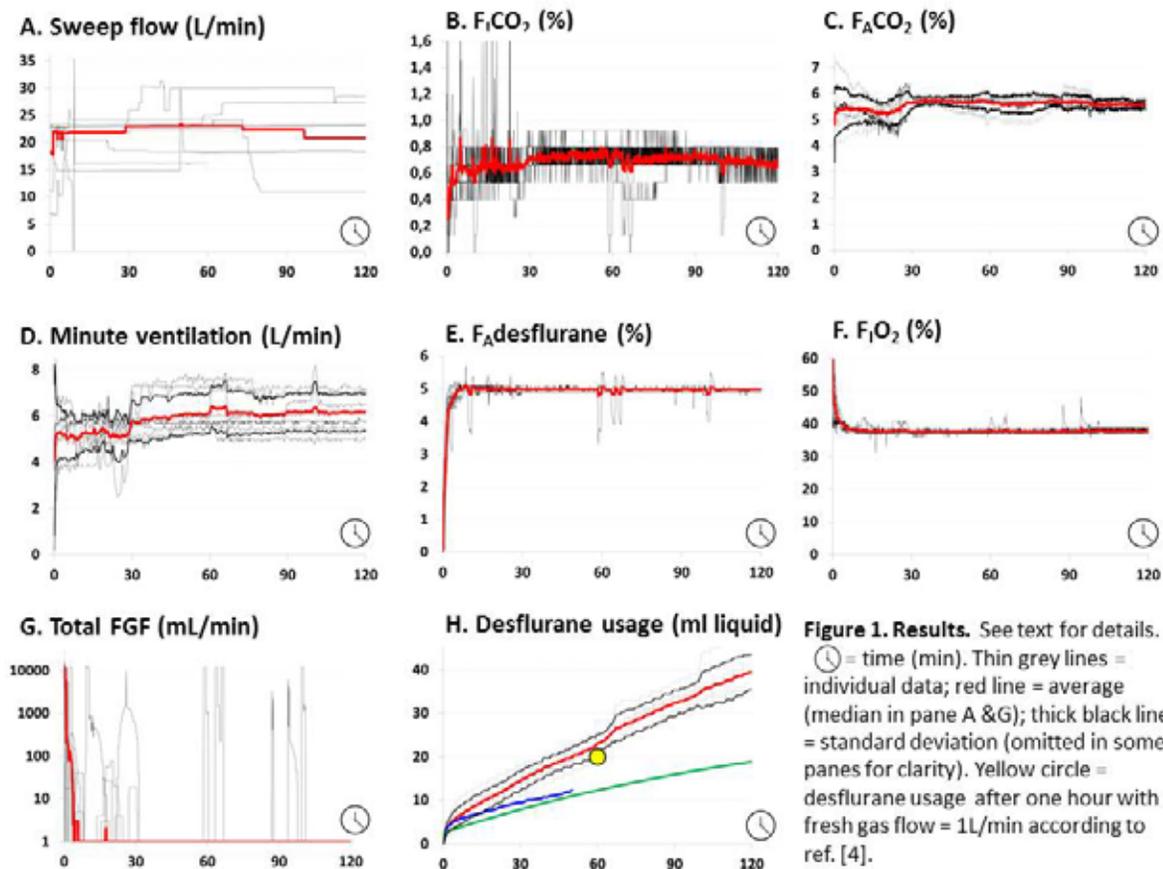
Results: see **Figure 1**

Age (years), height (cm) and weight (kg) were 67(8), 173(5) and 78(10), respectively. A 14-25 L/min sweep flow maintained F_ICO₂ ≤ 0.8% and F_ACO₂ ≤ 6.0% combined with a minute

ventilation of 5-7.6 L/min while a CO₂ pneumoperitoneum (CO₂PP) was applied. F_Adesflurane and F_IO₂ targets were maintained within a very narrow range. Total FGF dropped to zero within 1.5-6 min, occasionally briefly increasing upon initially applying the CO₂PP, only to remain zero thereafter most of the time. V_{des} was higher than during identical conditions with a soda lime absorbent with the Zeus IE during TCCCA [2] and during conventional CCA [3].

Discussion: During TCCCA, Memsorb™ removes CO₂ well under conditions of high CO₂ elimination (adult patient with prolonged CO₂PP). The small increase in F_ICO₂ is inconsequential because its effect on F_ACO₂ can easily be overcome by a small increase of minute ventilation. The amount of O₂ transferred from the Memsorb™ to the circle breathing system sufficed to cover patient O₂ consumption. In order to keep FGF low during TCCCA, the target F_IO₂ and the F_IO₂ in the sweep gas should be very similar in the target F_IO₂ mode. Liquid V_{des} in the Memsorb™ group was 2.05 mL/h per 1% F_Adesflurane higher than during historical CCA data, making V_{des} with Memsorb™ during TCCCA after 1h equivalent to V_{des} with a FGF slightly above 1L/min when a soda lime absorber is used [4]. The exact routes of carrier gas and agent losses need to be further defined.

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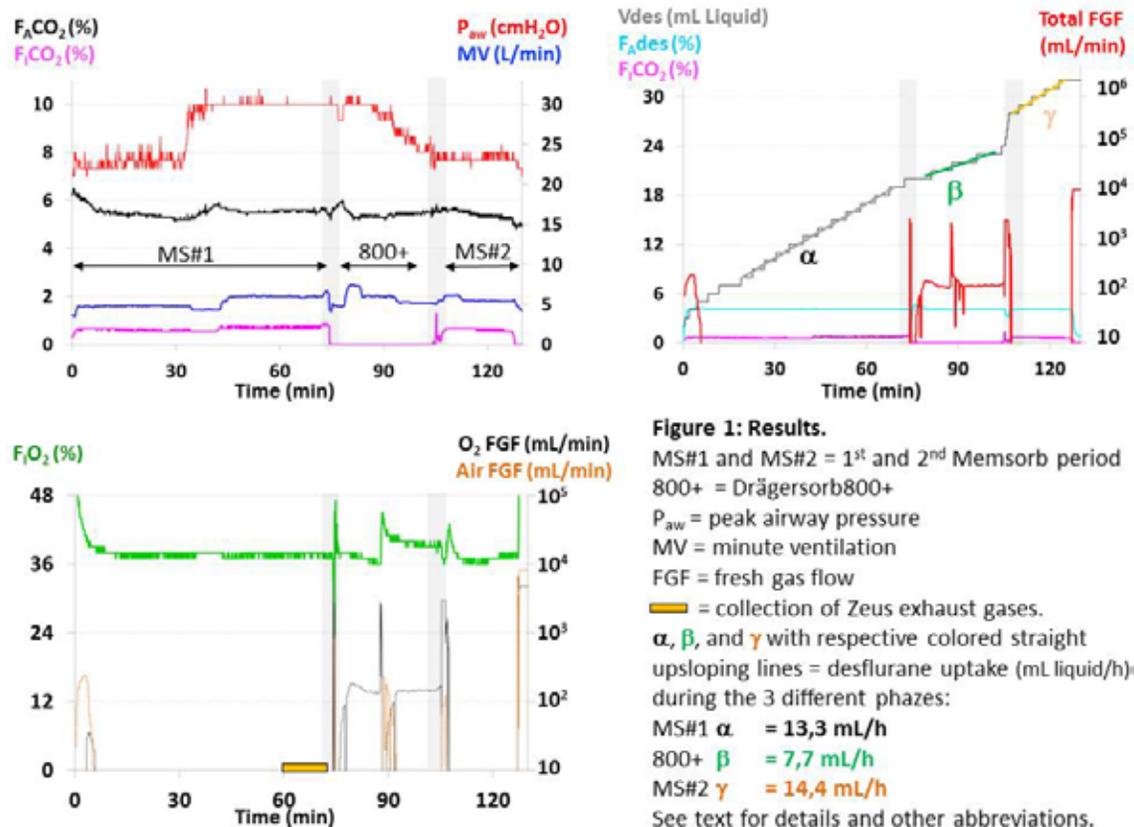
Sodalime Absorber versus Membrane CO₂ Filter Performance during Automated Closed-Circuit Anesthesia: A Case-Report

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Introduction: Sodalime CO₂ absorbents are safe but not ideal for reasons of ecology (production and disposal), ergonomics (need to refill or replace), economy (discarded before used to full potential), and dust accumulation in sensitive machine parts. These issues are absent with the Memsorb™ (DMF Medical, Halifax, NS, Canada), a new device for gas-to-gas exchange and separation that uses technology similar to oxygenator membranes for cardiopulmonary bypass machines: the sweep flow determines CO₂ removal, and the sweep gas O₂ concentration the O₂ transfer across the fiber wall (which depends on the prevailing O₂ gradient across the fiber wall.) We present a case report in which we alternated the Memsorb™ with sodalime absorbent (Drägersorb 800+) during target-controlled closed-circuit anesthesia (TCCCA) with desflurane in O₂/air with the Zeus IE (Dräger, Lübeck, Germany).

Materials and Methods: IRB approval and written informed consent were obtained in a 75 year old ASA PS III patient (73 kg, 164 cm) undergoing robotic abdominal wall hernia repair. After induction of anesthesia and intubation of the trachea, TCCCA with the Zeus IE was used with the following settings: target inspired O₂ (F_IO₂) 39% in O₂/air; target end-expired (F_A) desflurane 4.2%; controlled mechanical ventilation, adjusted to F_ACO₂ 5.2-5.8%; and 5 cmH₂O PEEP. An O₂/air blender (Scanatron Technics, Affoltern-am-Albis, Switzerland) delivered the sweep gas (40% O₂) to the inlet of the Memsorb™ canister. Sweep O₂% was set 1% above target F_IO₂. The sweep flow was titrated to keep F_ICO₂ ≤ 0.8%. Forty minutes after applying the CO₂ pneumoperitoneum (CO₂PP), a Drägersorb800+ canister was inserted for 30 min, after which the Memsorb™ was inserted for the remainder of the procedure (see Figure 1). RUGloop (DEMED, Temse, Belgium) collected the following data: F_IO₂, F_Adesflurane, F_ICO₂, F_ACO₂, minute ventilation (MV); O₂ and air FGF; sweep flow; and cumulative desflurane usage (V_{des}). A linear curve fit to the cumulative V_{des} data during the last 50 min of the first Memsorb™ period, the 30 min Drägersorb800+ period, and the second (and final) Memsorb™ period. The initial maintenance phase (0-25min) and the first few min after changing the CO₂ scrubbers were excluded from analysis. Losses of O₂, CO₂, desflurane and N₂ (calculated as balance gas) from the Zeus' exhaust prior to switching to the Drägersorb800+ gases were calculated by measuring the amount of exhausted gases collected for 15 min into a 6 L breathing bag (volumetrically with 250 mL glass syringes) and by analyzing the gas content (M-CAiOV, GE, Madison, WI, USA).



Results: See Figure 1.

$F_{A\text{desflurane}}$ and $F_{I\text{O}_2}$ targets were maintained within a very narrow range. Liquid V_{des} during TCCCA was higher with Memsorb™ (13.3 and 14.1 mL/h during the first and second run, respectively) than with Drägersorb800+ (7.7 mL/h). FGF was zero with Memsorb™ and 156 mL/min O_2 with the Drägersorb800+. Using the Memsorb™, a total of 162 mL/min gas lost via the Zeus' exhaust consisted of 52 mL/min O_2 , 1.6 mL/min CO_2 , 4.9 mL/min desflurane vapor (= 1.4 mL liquid/h) and 104 mL/min N_2 . This suggests $156+52 = 208$ mL/min O_2 is transferred from the Memsorb™ to the breathing system (under the prevailing study conditions and assuming minimal leaks). Of the extra amount liquid desflurane used during Memsorb™ use ($13.3-7.7=5.6$, and $14.1-7.7=6.4$ mL/h during run 1 and 2, respectively), 4.2 (= $5.6-1.4$) to 5.0 (= $6.4-1.4$) mL/h were lost via the Memsorb™ exhaust (approximately 1 mL/h liquid per 1% $F_{A\text{desflurane}}$). $F_{I\text{CO}_2}$ was 0 with Drägersorb800+ and ranged between 0.5-0.8% with Memsorb™ with the use of sweep flows ranging from 15 to 23 L/min.

Discussion: During TCCCA, Memsorb™ removes CO_2 well under conditions of high CO_2 elimination (adult patient with prolonged CO_2PP). The small increase in $F_{I\text{CO}_2}$ is inconsequential because its effect on $F_{A\text{CO}_2}$ can easily be overcome by a small increase of minute ventilation. The amount of O_2 transferred from the Memsorb™ to the circle breathing system sufficed to cover patient O_2 consumption. Approximately 1 mL/h liquid per 1% $F_{A\text{desflurane}}$ is lost via the Memsorb™, with an additional small amount lost via the Zeus exhaust due to O_2 and N_2 transfer in excess of patient uptake from the Memsorb™ into the breathing circle.

Comparison of Tidal Breathing Flow-Volume Loops Generated by a Respiratory Volume Monitor and Spirometry

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Introduction: Flow-volume loops (FVLs) are used to diagnose and monitor the progression and treatment of lung disorders such as COPD and asthma. The gold standard for generating FVLs is a spirometry-based forced vital capacity test, which requires the use of a mouthpiece or facemask and patient cooperation to generate maximum effort breaths. These tests cannot be performed by young children and adults unable to follow instructions. For these patients, the use of tidal breathing flow-volume loops (TBFVLs) has been proposed but has not been widely adopted due to lack of a reliable, non-invasive, technological solution. An impedance-based respiratory volume monitor (RVM) non-invasively measures minute ventilation and can be used to generate TBFVLs. The objectives of this study were: 1) to use a spirometer to evaluate TBFVLs measured by the RVM in healthy volunteers and 2) to monitor TBFVLs in post-operative patients using only the RVM over an extended period of time.

Methods: As part of an IRB approved study, 20 healthy adult volunteers were simultaneously monitored with a RVM (ExSpirom 1Xi, Respiratory Motion Inc, Waltham, MA) and a pneumotachometer (SpiroAir-LT, Morgan Scientific, Haverhill, MA) while breathing at rest for 10 minutes. Another 20 patients recovering from abdominal surgery were monitored with only the RVM for up to 48 hours on a hospital floor. TBFVLs and metrics were recorded for both devices including: respiratory rate (RR), tidal volume (TV), inspiratory time (tI), expiratory time (tE), inspiratory and expiratory ratio (tI/tE), duty cycle (tI/tTot) and inspiratory and expiratory flow ratio at 50% tidal volume (IE50). Bland Altman accuracy of TBFVL metrics were calculated for volunteers using the pneumotachometer as the gold standard. TBFVLs were visualized over time for post-operative patients.

Results: Bland Altman analysis showed that the differences between the RVM and pneumotachometer was small and clinically irrelevant for TV and RR, with a root mean square error (RMSE) of 9.9% and 1.5%, respectively. The RMSE for tI and tE measured for each breath were 11.8% and 10.9%, respectively. The RMSE for ratios tI/tE, tI/tTot and IE50 were 15.3%, 10.8% and 17.0% respectively. In order to visually detect changes in TBFVLs over extended monitoring periods from post-operative patients, breath by breath TBFVLs (Figure 1A) were also visualized as 3D plots over time (Figure 1B). Sample traces of breath by breath volume, flow, peak tidal expiratory flow, and volume at peak tidal expiratory flow were also plotted against time (Figure 1C).

Conclusions: The RVM can generate TBFVLs that are similar in morphology compared to spirometry without the need for patient cooperation or inconvenient instrumentation. Therefore, the RVM can be used to non-invasively monitor TBFVLs and provide clinically relevant pulmonary metrics for extended durations. The FVLs and metrics generated by the

RVM can potentially be used to detect anomalies in breathing and diagnose patients, either at the bedside or in the pulmonary function test laboratory.

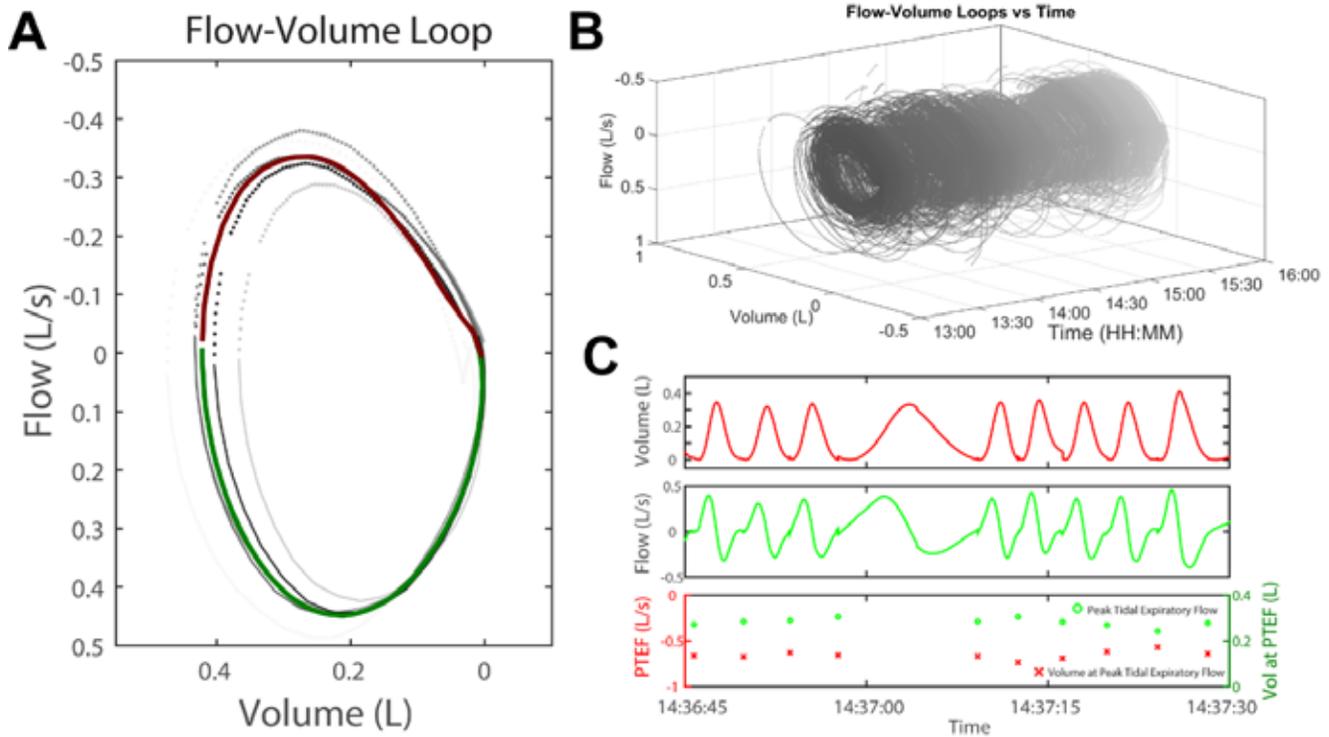


Figure 1: **A)** Sample flow-volume loop for four consecutive tidal breaths (grey), averaged together for inspiration (green) and expiration (red). **B)** Flow-volume loops plotted vs time in 3D. **C)** Sample volume, flow, peak tidal expiratory flow (PTEF), and volume at PTEF plotted vs time.

Tracking Dynamic Arterial Pressure Waveform on Vasoactive Medication Via Manifold Learning Method

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Introduction: Vasoactive medication is an indispensable part of armament in daily anesthetic management. Besides anesthetics, anesthesiologists administer vasoactive medication to preserve brain perfusion, to protect myocardium, to control surgical bleeding, or to treat life-threatening shock. We assess their clinical effects on cardiovascular system, either vasodilation or vasoconstriction, by the blood pressure readings shown in the patient monitor. At the same time, the vasoactive medication also exerts effects on the morphology of the blood pressure pulse wave, which is more difficult to be perceived with the waveform displayed in the patient monitor. It is possible that the extra information carried in the morphology of blood pressure waveform may provide further understanding in cardiovascular physiology. That is, the same blood pressure value with different shape of the pulse wave may indicate different state of the cardiovascular system. It is also possible that the pulse waveform may provide further understanding to the pharmacological effect in physiology.

In this study, we use an unsupervised manifold learning method, diffusion map (DM), to analyze the blood pressure waveform signal recorded from patient monitor to analyze the dynamic waveform. The goal is to investigate the vasoactive effect on blood pressure waveform in high dimension space.

Methods: From physiological database collected for observational study, we analyzed the arterial blood pressure waveform during bolus dosage of vasoactive agents, which includes 12 epochs of data of nicardipine (1mg) as vasodilatory agents, 12 bolus doses of norepinephrine (10 μ g) as vasoconstrictive agents, and 6 bolus doses of ephedrine (8mg) as indirect pressor agents. These data segments are from patients undergoing major surgery and general anesthesia. DM is a new data analysis approach that treats every oscillatory cycle as a high dimensional data point; in other words, the pulse waveform during the surgery is converged into a large collection of high dimensional variables. DM works by finding a geometric structure in high dimensional space representing the collection of the pulse waveform to be observed. Being unaware of the medication, the temporal relationship, or any knowledge of the data except the waveform, this unsupervised method extracts dynamical information from the pulse waveform objectively.

Results: The three-dimensional embedding of the pulses from nicardipine, norepinephrine and ephedrine shows common direction and path, representing the pharmacological feature of vasodilatory, vasoconstrictive and the mixed pressor effects respectively. The 3-D

embeddings of nicardipine and norepinephrine demonstrate the contrarily directional movement of the common path, featuring the reciprocal effect between vasodilation and vasoconstriction. This phenomenon preserves after we remove the effect of blood pressure.

Conclusions:

Machine learning method can provide additional information regarding the pharmacological effects of vasoactive agents.

Images:

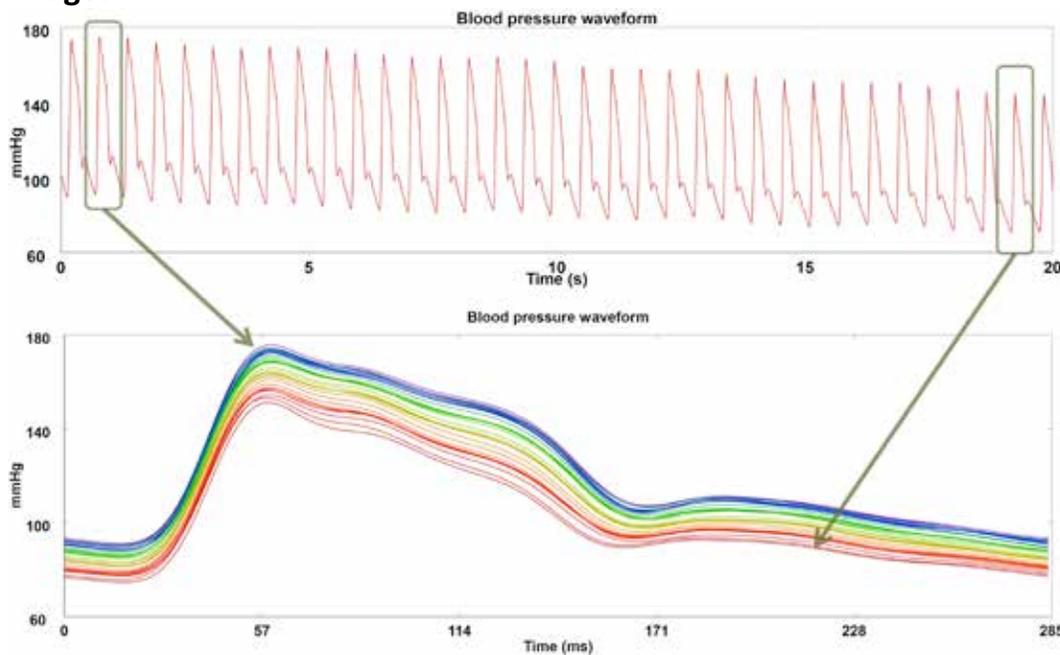


Figure1. Pulse waveforms from one epoch of blood pressure waveform on the bolus of nicardipine. Each pulse represents one data point in high dimensional space.

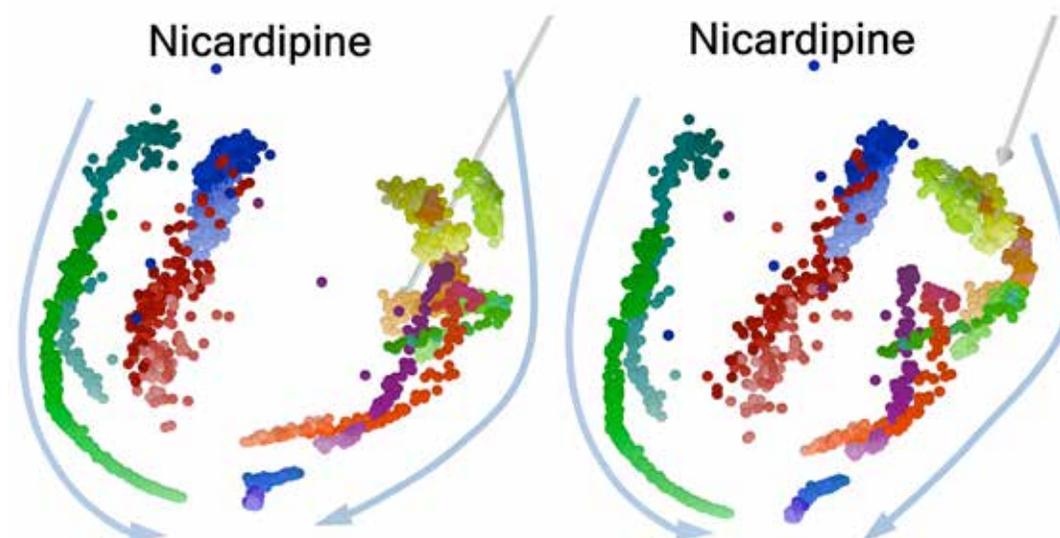


Figure 2. The 12 epochs of data show the common effect of nicardipine as the downward trend. Both graphs are the same 3-D embedding with merely a slight rotation. Blue arrows indicate the common downward direction. Different color represents different epoch of data, and the transition of darker to lighter color represents the evolving with time.

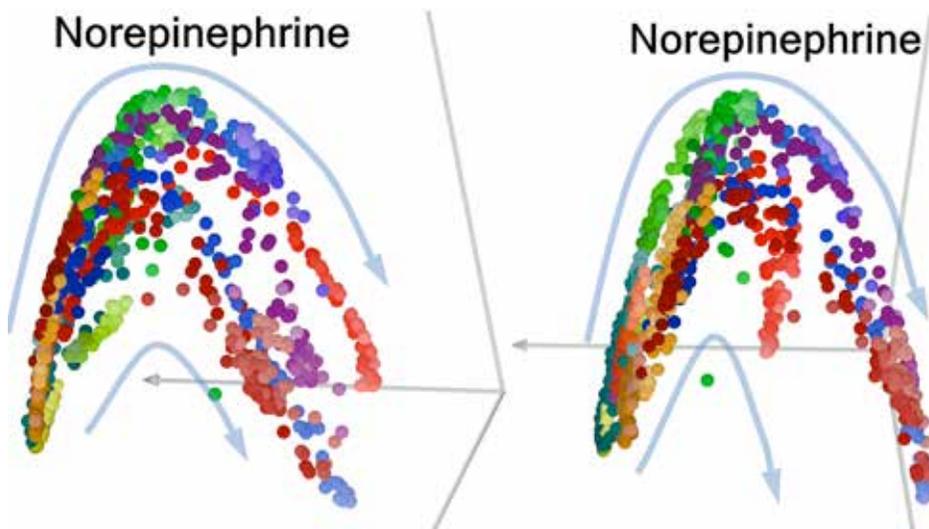


Figure 3. As the same representation of Fig.2, the 3-D embedding graphs show the common movement trend of norepinephrine. Both graphs are the same 3-D embedding with merely a slight rotation.

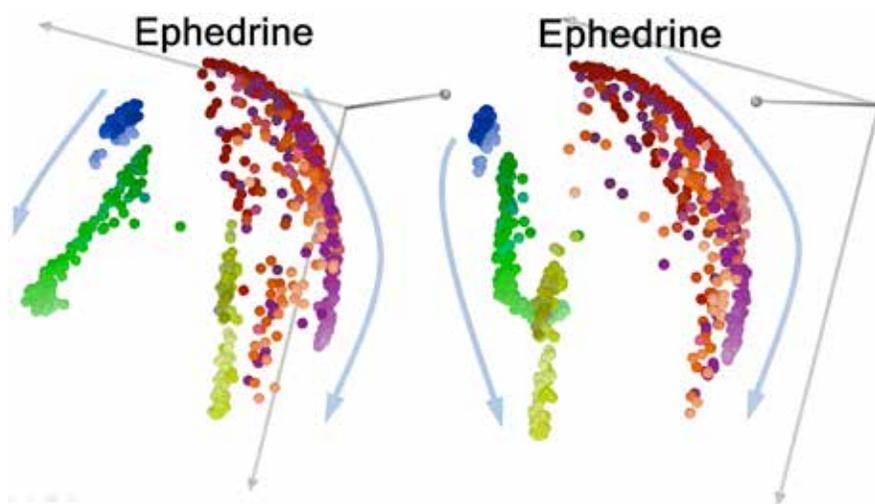


Figure 4. As the same representation of Fig.2, the 3-D embedding graphs show the common movement trend of ephedrine. Both graphs are the same 3-D embedding with merely a slight rotation.

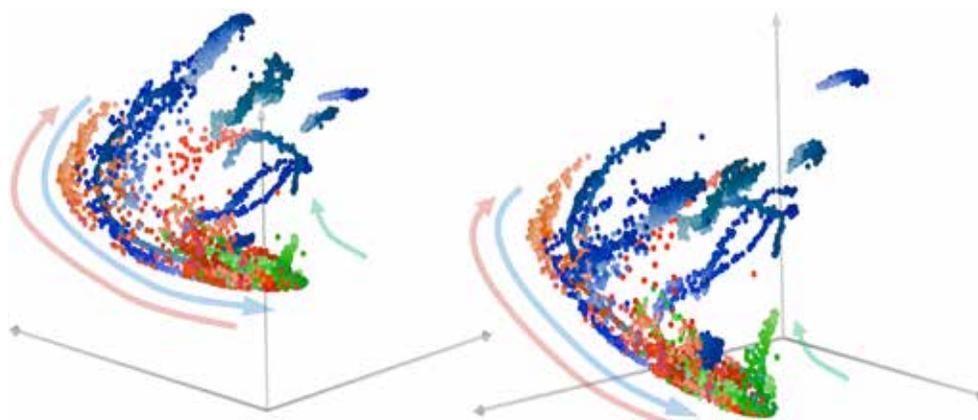


Figure 5. As the same representation of Fig.2, the 3-D embedding graphs show the combination of nicardipine (blue), ephedrine (green) and norepinephrine (red). Both graphs are the same 3-D embedding with merely a slight rotation. Blue arrow indicates common trend of nicardipine, which is contrary to red arrow indicating common trend of norepinephrine. Green arrow indicates the slightly different direction of ephedrine.

A Visual Analytics Dashboard to Summarize Serial Anesthesia Records in Pediatric Radiation Therapy

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Introduction: Children undergoing radiation therapy require daily sedation or general anesthesia for the duration of their treatments.[1] Patient position is paramount to allow precise targeting of the radiation beam which is then replicated during subsequent treatments. The user interface of the electronic health record can hinder reviewing serial anesthesia records. We designed a visual analytics interface that simultaneously displays data from multiple anesthesia encounters.

Methods Documentation in the electronic health record (EHR, Epic Systems, Verona, WI) is backed up in a clinical data warehouse on a daily basis. A visual analytics interface (Qlikview, QlikTech, Radnor, Pennsylvania) was built to aggregate data from all anesthesia encounters in pediatric radiation oncology at The Children's Hospital of Philadelphia. The display includes the patient schedule, medications administered, airway device used, radiation procedure completed, recovery room time and agitation scale. The application was embedded in the EHR's anesthesia module and automatically updated daily.

Results: The dashboard was divided into four sections with icon legends: medications, airways, procedures, and recovery score and time. Each anesthesia encounter is represented by a vertical line with the date at the bottom of the screen. The medication icons display dosing information when the mouse cursor hovers over an icon. The airway section shows icons for endotracheal tube (ETT) or laryngeal mask airway (LMA) and a number to denote the size of the

device (e.g. a green circle with 1.5 represents a size 1.5 LMA). The procedures section shows the various procedure types including CT simulation (CT-SIM), conventional radiation therapy (XRT) and proton radiation therapy (PROTON). The “days between” represents the number of days between the current and previous anesthetic.

The patient displayed underwent one course of radiation therapy finishing in 2017, and then began another course of radiation therapy 352 days later. The recovery score and time section includes “Time to Phase 2” representing the duration of the initial recovery phase from anesthesia in minutes. The delirium scale shows the patient’s maximum recovery score based on the Watcha scale (1- calm, asleep, 2- calm, can be consoled, 3- crying, cannot be consoled, 4- thrashing and inconsolable).[2] The dashboard was incorporated into the pediatric radiation therapy team’s daily morning huddle.

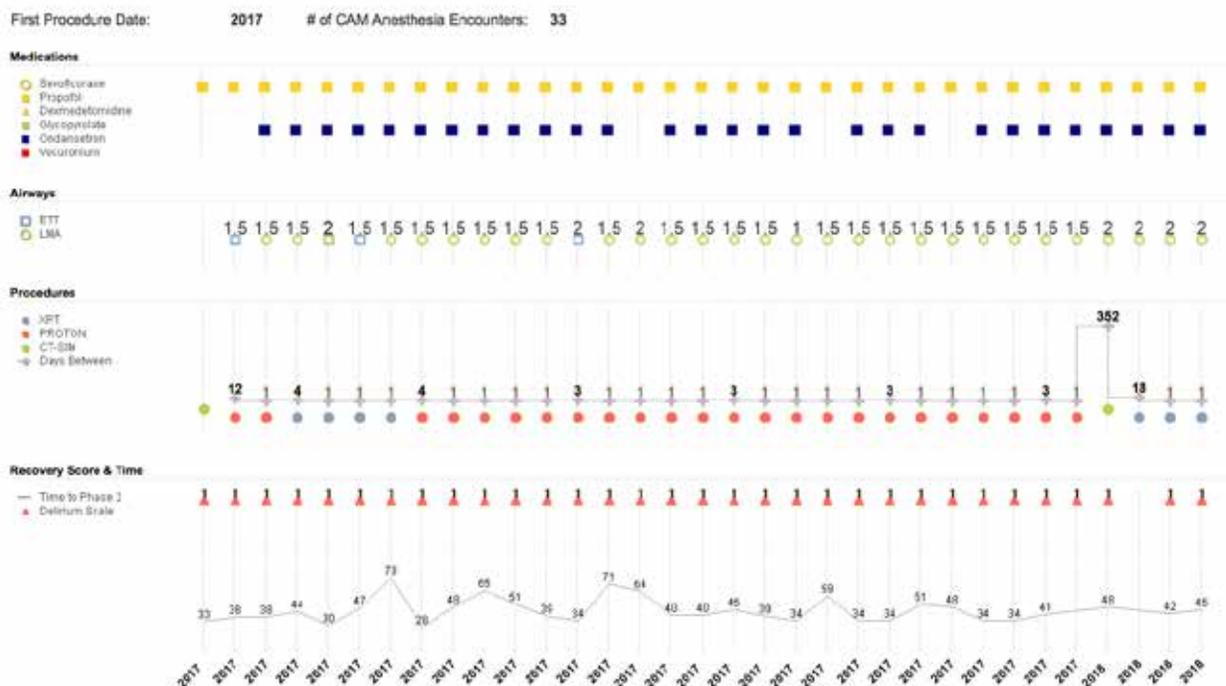
Users can identify patterns and changes more readily in a summary view. For example, in the case displayed, both ETTs and LMAs were used. The ETT sizes correspond to LMA sizes (LMA 2 instead of size 2.0 ETT) representing user data-entry error. This type of error led us to re-design the user interface for airway device documentation in order to minimize user data-entry errors.

Discussion: The dashboard provides a high-level summary of all radiation therapy anesthesia records for children receiving recurrent treatments. In this clinical scenario, it is desirable to replicate an optimal anesthetic approach each day or to adjust the anesthetic based on observed patterns. In the future, we will continue to develop this dashboard to summarize multiple anesthesia records for other patient populations.

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Figure 1



Assessing Depth of Hypnosis with the NeuroSENSE monitor during Desflurane General Anesthesia – a Randomized Trial

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Background: Processed electroencephalography (EEG) monitors support depth of hypnosis assessment during anesthesia [1,2]. This randomized study investigated the performance of the NeuroSENSE EEG monitor (NeuroWave Systems Inc., Cleveland Heights, OH) to determine how well its WAV_{CNS} index [3] distinguishes consciousness from unconsciousness during induction and emergence from anesthesia, and whether it correlates with changes in desflurane minimum alveolar concentration (MAC) during maintenance of anesthesia.

Methods: In a prospective clinical trial, following ethics approval and informed consent, EEG was collected from patients using a fronto-temporal bilateral montage. WAV_{CNS} was continuously recorded by the NeuroSENSE monitor, to which the anesthesiologist was blinded. Anesthesia was induced with propofol/remifentanyl and maintained with desflurane; randomized changes of -0.4/0/+0.4 MAC target were performed every 7.5 minutes within the 0.8–1.6 MAC range, if clinically acceptable to the anesthesiologist. During emergence from anesthesia, desflurane was stepped down by 0.2 MAC every 5 minutes.

Results: Data from 75 patients aged median (range) 41 years (18-71) were obtained. The WAV_{CNS} distinguished consciousness from unconsciousness, with area under the receiver operating characteristic curve (95% confidence interval) of 99.5% (98.5-100.0) at loss of consciousness and 99.4% (98.5-100.0) at return of consciousness. Bilateral WAV_{CNS} changes correlated with desflurane concentrations, with -8.0/-8.6 WAV_{CNS} units per 1 MAC change in the 0.8-1.6 MAC range during maintenance of anesthesia, and with -10.0/-10.5 WAV_{CNS} units in the 0.4-1.6 MAC range including emergence from anesthesia (Fig 1).

Conclusions: The NeuroSENSE monitor can reliably determine loss and return of consciousness. The WAV_{CNS} correlates with desflurane dosing. At higher doses, the response plateaus as with other EEG monitors [4,5], which suggests limited utility to titrate higher concentrations of anesthetic vapor.

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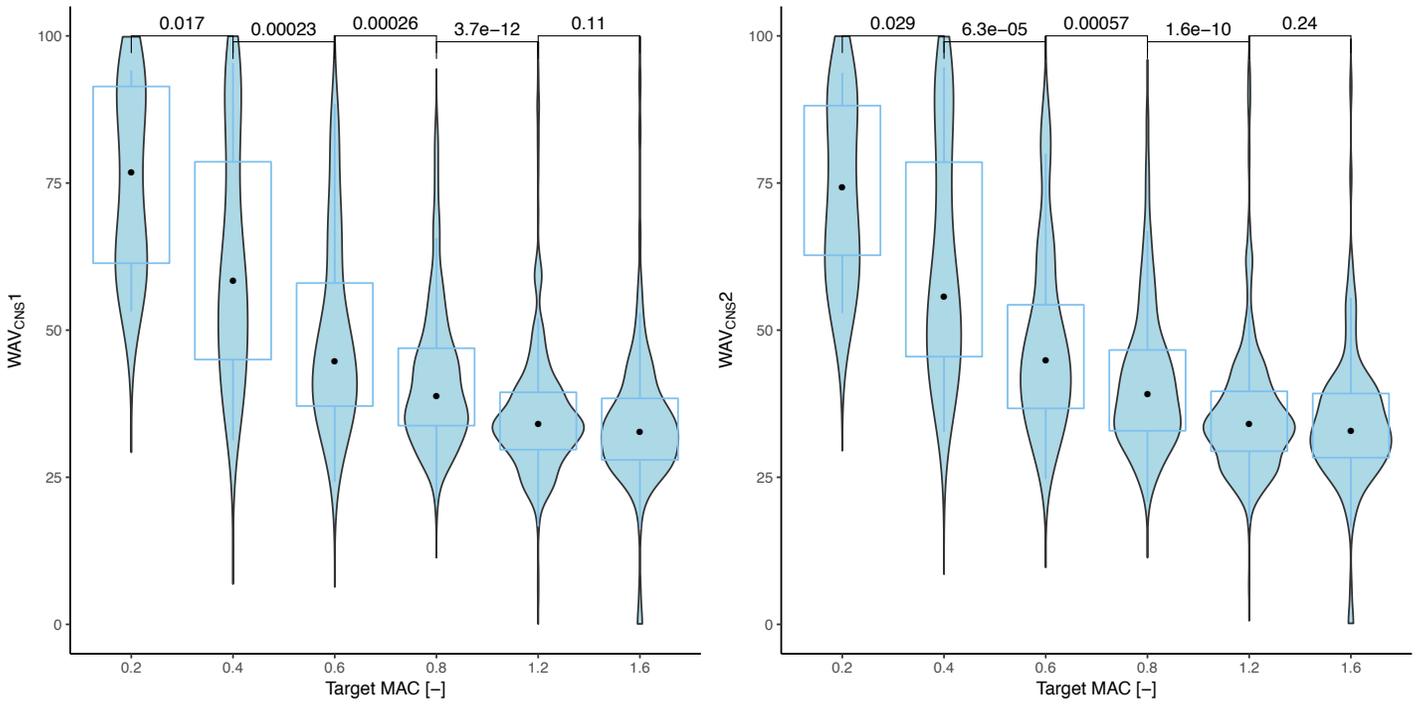


Figure 1: Observed WAV_{CNS} range for each MAC target. Data are shown as hybrid of violin plots, overlaid by boxplots, with statistical comparisons to their next neighbor indicated above; all comparisons, except for the MAC 1.2 vs. 1.6, were statistically significant, due to the large amount of samples included in the analysis.

Creation of Arterial Blood Pressure Nomograms for Children Undergoing General Anesthesia – Results From a Pilot Feasibility Study

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Background: Intraoperative vital signs monitoring is an integral aspect of anesthetic care. Reference values for non-invasive blood pressure (BP) are available in healthy, non-anesthetized children [1], and in children undergoing inhalational anesthesia (IHA) [2]. However, BP reference values are not currently available for children undergoing total intravenous anesthesia (TIVA), a technique which is known to reduce some undesired side effects of anesthesia [3]. The aim of this study was to identify age-specific mean arterial BP reference values for children undergoing general anesthesia at BC Children’s Hospital, and subsequently to compare BP between three different anesthetic regimes: a) TIVA, b) IHA, and c) mostly intravenous anesthesia (MIVA), allowing for an inhalational induction followed by intravenous maintenance of anesthesia.

Methods: With Research Ethics Board approval and waiver of informed consent, non-invasive BP data were extracted from a de-identified vital signs database. For this pilot evaluation, we included data from children <19 years undergoing anesthesia for procedures in the main operating rooms, excluding cardiac surgery, performed between Jan - Sep 2016; we will use Jan 2013 - Dec 2016 for the full cohort. Data artifacts were removed by excluding physiologically impossible values, a moving median filter was applied, and representative values were obtained by randomly sampling 20 BP values per case. The children’s ages were obtained by probabilistic matching of cases against an export from the operating room booking system, and were divided into the following groups: <1 month, 1-3, 3-6, and 6-12 months, and continuing in one year increments up to 18 years of age. Anesthetic type was determined using minimum alveolar concentration (MAC) thresholds as follows: a) TIVA: cumulative MAC of 0, b) IHA: MAC ≥ 0.3 for >70% of case, c) MIVA: MAC >0.2 for first 20% of case and MAC of 0 for the remainder. Data were plotted using MATLAB and compared between anesthetic types using Wilcoxon rank-sum test for each age group (with Bonferroni correction for 3 comparisons).

Results: In this pilot cohort, data were available from 4,850 children, with median (interquartile range [IQR]) age of 6 (3-12) years. Of these, 3,913/4,850 (81%) cases had valid BP data and could be assigned to one anesthetic type: TIVA 2,334 [60%], IHA 847 [21%], and MIVA 732 [19%]. Figure 1 shows the BP nomograms generated. Mean BP values ranged from median (IQR) 46 (41-50) mmHg for TIVA, 44 (37-49) mmHg for IHA and 43 (34-44) mmHg for MIVA in newborns to 72 (64-80) mmHg for TIVA, 71 (64-82) mmHg for IHA and 74 (67-79) mmHg for MIVA in 18 year old’s. Children in groups under 5 years of age had significantly higher BP with TIVA than patients with IHA ($p < 0.001$), as did some of the older groups. Data from 25,949 children have been matched for the planned analysis of the full cohort.

Conclusions: Creating BP nomograms has been shown to be feasible with the data available in our databank. As expected, BP increases with age, but interestingly, younger patients with IHA had a lower BP than patients with TIVA. These data have the potential to guide the setting of alarm limits based on age and anesthetic type, and will support future investigations into the effects of anesthetic technique on BP. Results from the full analysis, with additional subgroup analyses are pending.

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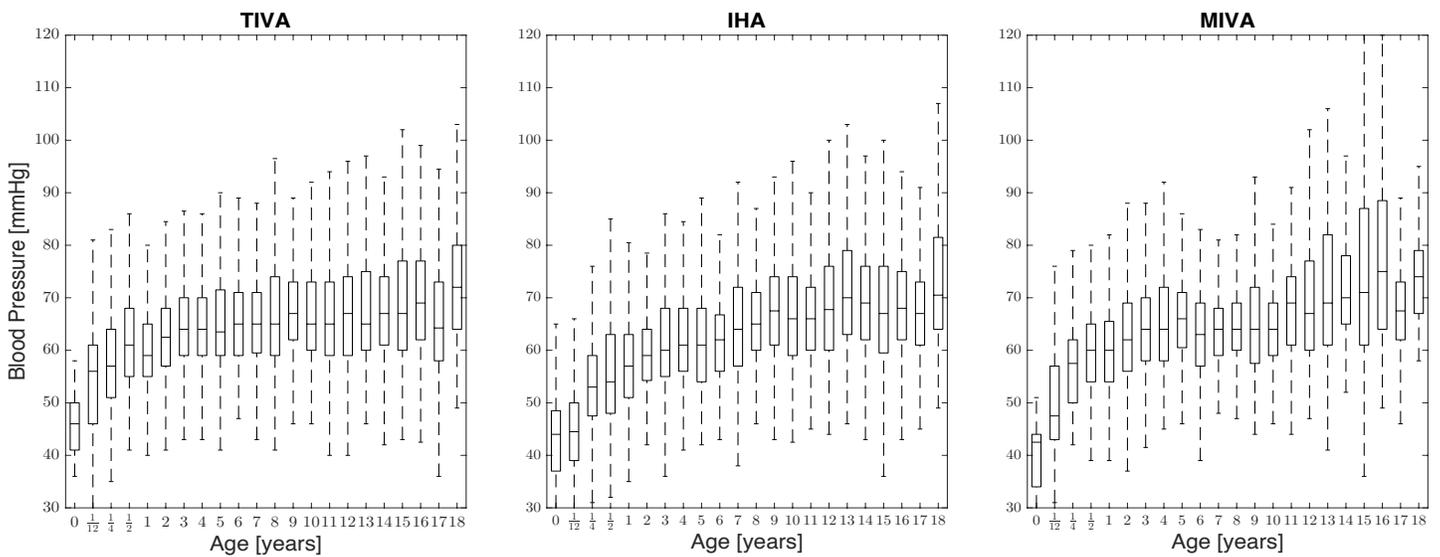


Figure 1: Nomograms for NIBP split by anesthetic type (left TIVA, middle IHA, right MIVA). Boxplot shows median and interquartile range (IQR); whiskers reach to last datum within 1.5 IQR.

Comparison of a High-Fidelity Peripheral Venous Access Phantom to a Commercial Phantom

Presenting Authors: Shiv Patel, B.S., UC San Diego, Preetham Suresh, MD, UC San Diego Department of Anesthesiology

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Introduction: Ultrasound (US) guided peripheral venous access is an increasingly common procedure that reduces the use of central lines and their complications such as pneumothorax, arterial puncture, and Central Line-Associated Bloodstream Infection [1]. One barrier to wider adoption is provider comfort with this technique. Despite the commercial availability of procedural training phantoms, their widespread availability is limited due to their cost [2]. As a result, many institutions have described methods of developing low-cost phantoms for peripheral venous access training [2]. Unfortunately, many of these models lack fidelity and have suboptimal US image quality/echogenicity [3]. There is also a lack of objective comparisons of these do-it-yourself solutions and commercially available phantoms. This study seeks to provide an approach for comparison and uses said approach to assess our low-cost solution.

Methods: Ballistics gel (Clear Ballistics - Smith, Arkansas), dye, and flour were heated and mixed in a metal container for 2 hours and poured into a 3D printed nylon mold with steel rods placed to simulate blood vessels. Then the mold was placed in an oven for 30 minutes at 300°F to allow time for bubbles to clear. After cooling, the metal rods were removed from the phantom leaving the simulated blood vessels behind which were melted shut at both ends and injected with water. Five experts who perform/teach ultrasound guided peripheral access were asked to target two veins in Block A (our model) and Block B (commercial model) and then fill out an assessment form. Five categories were used for comparison: US image realism, US needle visualization, vein compression, haptic feedback, vein depth. The small sample size in this case is validated by a mathematical model that shows 5 experts in a field will capture 80% of the data that is available about a model [4].

Results: The data suggests that experts find no difference between the Block A and Block B in all five categories since the average rating for US needle visualization, vein compression, haptic feedback we're not statistically different (3.6, 3.2, 3.0) and a two-tailed t-test yielded p-value=0.374 and 0.704($\alpha=0.05$) for US image realism and vein depth respectively. Furthermore, the data also suggests that 80% of the experts prefer Block A over Block B for training. In terms of cost, Block A is \$7.90, with negligible cost to re-melt the phantom over many years, and the commercial model is \$628.

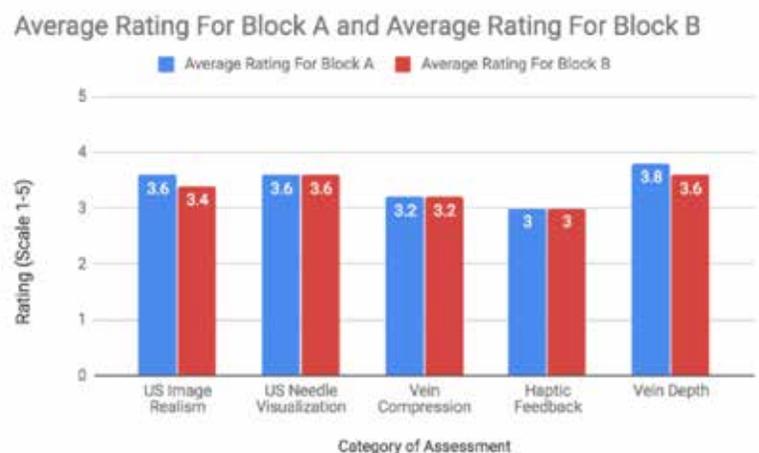


Figure 1. In each category, the data suggests that there is no difference between Block A and Block B when compared to a patient.

Discussion: This model offers a similar experience to commercially available vascular trainers for a fraction of the cost. Additionally, the trainer can be re-melted to refurbish the phantom back to new and eliminate any prior needle tracks. Furthermore, 3D printing allows for precision and customization in the model, but silicone molds and metal trays are also viable options for institutions that do not have access to 3D printers. To quantify the impact of increased phantom availability, we plan to outfit all ultrasounds across our facility with a vascular access phantom to allow for Just-in-Time(JIT) practice (practicing a procedure before performing it on a patient) which has been shown to increase procedural confidence, skills, and decreases supervisor intervention [5].

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Deep Learning to Predict Postoperative Acute Kidney Injury

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Background: Rapid, preoperative identification of those patients at highest risk for medical complications is necessary to ensure that limited infrastructure and human resources are directed towards those most likely to benefit. Existing risk scores often lack specificity at the patient level, utilize the American Society of Anesthesiologists (ASA) physical status classification which requires a clinician to review the chart, or are focused on a broad array of outcomes and this inaccurate for specific outcomes. Recently machine learning has been used as a technique to make more focused risk scores that can be targeted at specific outcomes. In this abstract we describe the creation of a score to predict postoperative acute kidney injury (AKI) based on data that can be readily abstracted from the electronic medical record before surgery.

Methods: We use deep learning to create a fully automated score that predicts postoperative severe (AKIN stage 2, stage 3) Acute Kidney Injury (AKI), based solely on structured data available before the time of surgery. We use an embedding layer that transforms our categorical features (sex, type of surgery, self-reported ethnicity, etc.) to numerical ones as part of our deep learning model. Then, combined with the numerical feature we train a 4 layers (2 hidden) fully connected neural network to generate our prediction score. The total number of trainable parameters in our model is 68,864. Our model was trained on a total of 63411 unique patient admissions when out of those 5.29% suffered from AKI post-surgery. We use dropout to prevent over fitting and train our model with batch stochastic gradient descent. We've chosen our hyper-parameters (number of layers, dropout rate, etc.) using cross validation.

Results: We found that the deep learning model we use achieves an AUC of 0.939 [0.934-0.943], outperforming existing methods (e.g., koyner et al 2018¹, AUC of 0.90 [0.90-0.90], ASA score, AUC 0.784 [0.779-0.789], Charlson comorbidity scores, AUC 0.77 [0.755-0.785]).

Conclusions: Our automated model can help predict acute kidney injury prior to surgery and changes in serum creatinine. Our model shows superior accuracy compared to existing methods and can potentially help clinicians make real-time decision that can help prioritize the treatment of patients that are at higher risk for acute kidney injuries and allow more efficient allocation of resources.

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Rating the Severity of Opioid-Induced Ataxic Breathing in Healthy Humans

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Abstract: Opioid induced respiratory depression is traditionally recognized by assessment of respiratory rate, arterial oxygen saturation, end-tidal CO₂, and mental status. Although an irregular or ataxic breathing pattern is widely recognized as a manifestation of opioid effects, the presence of ataxic breathing is not routinely monitored. A major obstacle to widespread monitoring for ataxic breathing is the lack of a reproducible metric for it and the necessity for manual offline analysis. We explored the feasibility of using an automated machine learning algorithm to quantify the severity in ataxic breathing pattern for healthy volunteers experiencing opioid induced respiratory depression. The primary aim was to assess the agreement among all raters, including the machine learning algorithm and the domain experts. The secondary aim was to compare the scores from the machine learning algorithm to those from the domain experts.

After IRB approval, informed written consent was obtained from 26 volunteers (13 male, 13 female) who were given target controlled infusions of propofol and remifentanyl with the goal of modeling light sleep together with opioid induced ventilatory depression. Respiration data were collected from chest and abdomen Respiratory Inductance Plethysmography (RIP) bands and a nasal pressure transducer sampled from a nasal cannula during steady state periods. Three domain experts scored the severity of ataxic breathing in accordance with predefined scoring guidelines. Krippendorff's alpha and Vanbelle's Kappa were used to assess the level of agreement in ataxic breathing severity scores from the machine learning algorithm and the domain experts.

Krippendorff's alpha was 0.912 (CI 0.852- 0.949) for the RIP-based algorithm and 0.899 (CI 0.819- 0.941) for the intranasal pressure-based algorithm. Vanbelle's Kappa was 0.976 (0.951- 0.983) for RIP and 0.893 (0.813-0.936) for intranasal pressure.

We concluded it may be feasible for a machine learning algorithm to quantify ataxic breathing severity in a manner consistent with a panel of domain experts. This measure may be helpful in conjunction with measures of respiratory rate and SpO₂ to identify patients at risk for opioid induced respiratory depression.

Prediction of Postinduction Hypotension with Deep Learning

Presenting Author: Christine Lee, MS, UC Irvine Department of Biomedical Engineering

Co-Authors: Maxime Cannesson, MD PhD, UCLA Department of Anesthesiology; Pierre Baldi, PhD, UC Irvine Department of Computer Science

Introduction: Surgical patients with hypotension 0 to 10 minutes postinduction have been shown to have higher prevalence poor outcomes.¹ However, there are few tools available to help predict who is at risk for such hypotension. Recently, Kendale et al. compared machine learning methods to predict hypotension utilizing 56 EMR features and demonstrated an AUC of 0.74 for a stochastic gradient boosting machine.² This model utilized only static EMR features, and so we hypothesize that convolutional neural network models (CNNs) can leverage the complexity of arterial pressure waveforms (AP) as a dynamic feature to predict postinduction hypotension.

Methods: Data used in these experiments came from UCI Medical Center with IRB approval. The data includes all surgical procedures performed from November 2015 to August 2017 (n=19,545). Patients with no induction time, no MAP 10 minutes after induction, negative time difference between surgical start and induction, and < 18 years of age were excluded, resulting in 16,495 patients. Postinduction hypotension was defined as any MAP \leq 55 mmHg 10 minutes post induction, taken from the EMR. Induction time was defined as first recorded induction event, etomidate or propofol administration time. For comparison, we extracted the same EMR features as described in Kendale et al., except for those related to medical comorbidities and preoperative medications due to data availability, to develop a logistic regression and deep neural network model (DNN). This resulted in 15 EMR features related to demographics such as age and ASA; and intraoperative features such as first MAP and fentanyl amount. Values for medications greater than a clinically normal maximum (M.C) were assumed as annotation error and set to the maximum. Missing values for other features were filled with the mean, and all features were rescaled to mean 0 and standard deviation 1. These features were utilized in a logistic regression and deep neural network model (DNN). For the CNN model, we extracted all available AP (100 Hz) prior to 1 minute before induction. This resulted in 237 patients (1.4%). All waveforms were processed for noise removal and then parsed into 20 second samples. Each sample was rescaled to have mean 0 and standard deviation 1 across time. The label of each sample was assigned as the label of the respective patient. All models were trained to classify hypotension and were trained on 80% of the data (n=13,196; n=204 with AP) with five-fold cross validation. 20% of the data was held out as a future test set. Performance was assessed using mean and standard deviation of AUROC from cross validation.

Results: The occurrence of postinduction hypotension is 9.6%, and 32.6% in the train patients with AP. The parsing of the waveform data available in the 204 patients with AP resulted in n=5683 waveform interval samples for training. The reported DNN with EMR features has 5 dense layers with 200 neurons each with ReLu activations. The CNN with AP had 2 convolutional layers with 8 filters of size 5 and a stride 1 with ReLu activations, followed by 5 dense layers, 100 neurons each with ReLu activations.

Table 1. 5 fold cross validated AUC results (mean \pm std) on training data

Model	5 Fold Cross Validated AUC	
	All Patients	Patients with Arterial Waveforms
Logistic Regression w/ 15 EMR features	0.73 \pm 0.01	0.74 \pm 0.07
DNN w/ 15 EMR Features	0.75 \pm 0.01	0.76 \pm 0.08
CNN w/ Arterial Waveform		0.73 \pm 0.06

Conclusion: CNNs with AP inputs exhibit potential for being able to not only classify patients at risk for postinduction hypotension but also predict hypotension 1 minute prior to induction start. In addition, while all other features are available prior to induction, the intraoperative medication features from Kendale et al.² are extracted from entry into the procedure area to 10 minutes post induction and were chosen as most common medications relevant to general anesthesia. Thus, the CNN is not only predictive prior to induction but is also independent of clinician decision. Future work is needed to further clean the AP for noise as well as to continue to assess different model architectures.

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An Automated Machine Learning-Based Model Predicts Postoperative Mortality Using Readily-Extractable Preoperative Electronic Health Record Data

Presenting Author: Brian L. Hill, UCLA

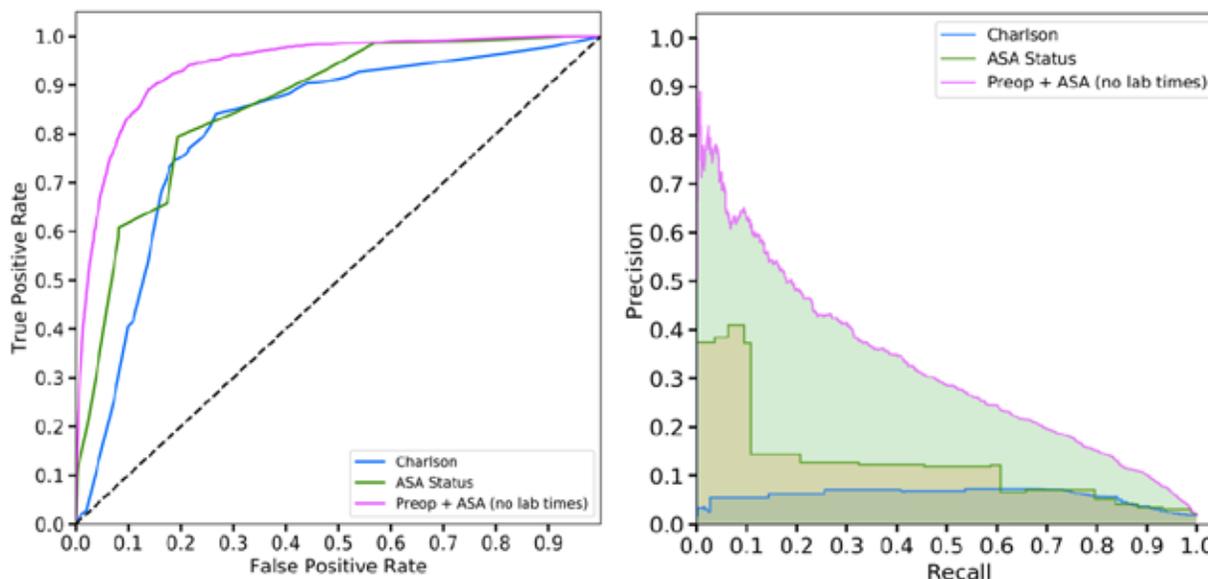
Co-Authors: Robert Brown, Ph.D., UCLA; Eilon Gabel, M.D., UCLA; Nadav Rakocz, UCLA; Christine Lee, M.S., UCI; Maxime Cannesson, M.D., Ph.D., UCLA; Pierre Baldi, Ph.D., UCI; Loes Olde Loohuis, Ph.D., UCLA; Ruth Johnson, UCLA; Brandon Jew, UCLA; Uri Maoz, Ph.D., UCLA; Aman Mahajan, M.D., Ph.D., University of Pittsburgh; Sriram Sankararaman, Ph.D., UCLA; Ira Hofer, M.D., UCLA; Eran Halperin, Ph.D., UCLA

Background: Rapid, preoperative identification of patients with the highest risk for medical complications is necessary to ensure that limited infrastructure and human resources are directed towards those most likely to benefit. Existing risk scores either lack specificity at the patient level or utilize the American Society of Anaesthesiologists (ASA) physical status classification, which requires a clinician to review the chart.

Methods: We report on using machine learning algorithms, specifically random forests, to create a fully automated score that predicts postoperative in-hospital mortality based solely on structured data available at the time of surgery. The model was created using a set of 59 features including basic patient information such as age, sex, BMI, blood pressure, and pulse rate; lab tests frequently obtained prior to surgery such as sodium, potassium, creatinine, and blood cell counts; and surgery specific information such as the surgical procedure codes.

Results: Using a random forest classifier we found that automatically obtained preoperative features (AUC of 0.931, 95% CI 0.918-0.944) outperforms Charlson comorbidity scores (AUC of 0.828, 95% CI 0.801-0.856) and ASA status (AUC of 0.873, 95% CI 0.853-0.892). Including the ASA status with the preoperative features achieves an AUC of 0.938 (95% CI 0.927-0.949).

Conclusions: This automated score outperforms both the ASA physical status score and the Charlson comorbidity score for predicting in-hospital mortality. Additionally, we integrate this score with a previously published postoperative score to demonstrate the extent to which patient risk changes during the perioperative period.



Carbon Dioxide Absorption Capacities of Amsorb[®] and Soda Lime During Simulated Clinical Conditions

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Co-Authors: Nikolaus Gravenstein, M.D., University of Florida Health Department of Anesthesiology, Robert Loeb, M.D., University of Florida Health Department of Anesthesiology

Amsorb[®] is a carbon dioxide absorbent designed for low flow anesthesia that does not produce harmful byproducts such as formaldehyde, compound A, or carbon monoxide because it does not contain sodium hydroxide. Prior research has shown that Amsorb[®] absorbent is exhausted faster than soda lime, which contains sodium hydroxide.¹ The aim of this study was to examine longevity and color changes of pre-packed soda lime (Sodasorb[®] or Medisorb[®]) and Amsorb[®] canisters in Aestiva and Avance anesthesia machines during simulated clinical conditions.

Three of each canister type (Sodasorb[®]/Aestiva, Amsorb[®]/Aestiva, Medisorb[®]/Avance, Amsorb[®]/Avance) was studied after the starting weight of contained absorbent was measured. Aestiva anesthesia machines hold two absorbent canisters; to speed the study, only the upper canister contained absorbent and the lower canister was filled with fish tank gravel. During each trial, CO₂ was metered at a rate of 250 ml/min into a 2 L breathing bag attached to the Y-piece of a circle breathing system. The breathing bag was ventilated using pressure control at a rate of 10/min and an inspiratory to expiratory ratio of 1:2 to achieve tidal volumes of roughly 500 ml. Low fresh gas flow of 1 L/min oxygen was maintained. Lines on each canister marked 20%, 40%, 60%, and 80% of the distance from top to bottom. Photographs of the canisters were taken at 30-minute intervals. Inspired and expired CO₂ concentrations were continuously recorded from the breathing circuit elbow sampling site. Endpoints included times until inspired partial pressure CO₂ reached 4, 6, and 8 mmHg. Absorbent capacity was calculated as total amount of CO₂ added to the breathing circuit per 100 grams of absorbent at the time when the inspired partial pressure of CO₂ equaled 4 mmHg.

Results are shown in the table. There was no difference (P=0.085) in absorbent capacity between soda lime and Amsorb[®]. Serial photographs of the canisters during each trial revealed variable visible color changes due to channeling, but that when 60% of the canister had changed color the inspired CO₂ was usually 4 mmHg.

These absorbent CO₂ capacity comparisons can be used to estimate the cost of absorbent use or change from one absorbent to another.

Table. Amount (in L) of CO₂ absorbed per 100 g of absorbent at time when partial pressure of CO₂ in the circuit equaled 4 mmHg

CO₂ absorbent	Aestiva Trial 1	Aestiva Trial 2	Aestiva Trial 3	Avance Trial 1	Avance Trial 2	Avance Trial 3	Average
Amsorb[®]	18.4	16.7	16.5	17.3	17.0	14.9	16.8
Medisorb[®]/Sodasorb[®]	18.7	19.3	16.0	19.1	16.9	19.2	18.2

T test: P value = 0.085

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Cluster Randomized Trials and Case-Control Studies of Surgical Site Infections with Group Assignments Being the Operating Rooms

Presenting Author: Franklin Dexter, MD PhD FASA, Anesthesia, University of Iowa

Co-Authors: Johannes Ledolter, PhD, and Randy W. Loftus, MD, University of Iowa, and Richard H. Epstein, MD, University of Miami

Introduction: We consider designs of observational studies and clinical trials of interventions to mitigate surgical site infections (SSI) in patients receiving care with or without interventions that are 1:1 with operating room (ORs). Our use case is a large teaching hospital buying 5 anesthesia machines (e.g., with modified surfaces) or renovating 5 ORs (e.g., bactericidal OR lighting), and aiming to compare SSI within 1-year between intervention ORs and 5 or 15 control ORs.

Methods: To model heterogeneity of risk factors for SSI among ORs, we used 10 years of accurate OR information system data from a teaching hospital, 221,796 cases.

To model heterogeneity of SSI among 24 procedure categories (e.g., colorectal surgery), we used 2015 California Department of Public Health data, SSI or not, for 676,530 surgical cases performed at 338 hospitals.

Results: Mean OR times of cases were 3.01 hr (standard error SE 0.01) for the hospital surgical suites versus 1.10 hr (0.01) in the outpatient departments. The percentages of cases where the patient was American Society of Anesthesiologists' Physical Status (ASA PS) ≥ 3 were 50.6% versus 19.9%, respectively. Thus, limiting a study of new equipment to inpatient ORs is warranted. For such ORs, and obtaining consent from patients Monday-Friday, expect $\cong 600$ patients per OR during 1-year study.

Patients' baseline risks of SSI depend on case duration, urgency, and ASA PS. Six specialties each had $\geq 10,000$ cases: orthopedics, general surgery, otolaryngology, urology, neurosurgery, and gynecology, not distributed randomly among ORs ($P < 0.00001$). For each specialty, the Bonferroni adjusted Kruskal-Wallis test for equality of case durations among the 32 inpatient ORs were $P < 0.00001$. For each of the specialties, the proportion of cases added to the schedule after 7 PM the day before surgery differed in distribution among ORs, all 6 Bonferroni adjusted chi-square $P < 0.00001$. Finally, ASA PS ≥ 3 versus 1-2 varied among ORs, all 6 $P \leq 0.00034$. Thus, expect SSI risk to differ among ORs, even if ORs are paired by specialty.

Selection of ORs for the intervention should not be simply the ORs with patients of the greatest risk of SSI or ORs with the most patients exposed to the OR, because the criteria result in different ORs selected. Those ORs with fewer cases per year were those with longer mean OR times (Spearman correlation -0.84 SE 0.10 , $P < 0.00001$). Those ORs with fewer cases per year also had larger ASA PS ($P < 0.00001$).

Sample sizes for case-control studies depend on the probabilities of patients listed as receiving the intervention but not receiving it, and vice-versa. This occurs due to error in the listed OR where the patient had surgery. With OR identification based on the machine recording most of the patients' pulse oximeter saturations, error $\cong 0.016\%$. Applying this, with 5 intervention ORs and 5 or 1 control patients for each intervention patient, and $\alpha=0.05$, $\cong 94\%$ or 78% statistical power, respectively, would be obtained in a 1-year study to detect a reduction in the SSI incidence from 3.6% to 2.4%.

Cluster randomized trials depend on the estimated coefficient of variation of the count of cases among ORs, 24.1% (3.4%). They depend also on the intracluster correlation, $\cong 0.03$ estimated from the State of California hospitals. Applying these values, with either 25 or 5 control ORs, the statistical power is only $\cong 7\%$. Matched paired cluster randomization designs have no greater estimated power.

Discussion: Retrospective analysis by pivot table of raw % incidence of SSI among patients having surgery in each OR results in a cluster design. Such tables and/or graphs will inevitably falsely fail to detect benefit even if present, resulting in poor hospital decision-making for OR capital equipment. Instead, when the intervention is the OR itself, evaluate SSI using case-control matching of patients.

ProcedureView (ProView): Analyzing and Presenting Anesthesiology Case Data for Providers using Machine Learning

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Co-Authors: Anik Sinha, MS¹, Yuwei Bao¹, Sean Meyer, BS², John Vandervest, MS¹, Sachin Kheterpal, MD MBA¹

University of Michigan: ¹Department of Anesthesiology ²Department of Integrated Systems and Design

Introduction: As an anesthesiologist you realize there is tremendous variation in executed anesthetic techniques. Practicing anesthesia providers can rely on personal experience, institution guidelines, training, and continuing education – but pertinent case examples may be lacking for specific cases of interest in published case series and review articles. Through wide spread adoption of electronic medical record systems, we now have access to vast amounts of electronic anesthesiology clinical data. **The objective of our study** is to create an organized system to identify and understand anesthesiology practice variation and potentially associated outcomes with the intent of improving anesthesiology education and clinical practice.

Methods: We used unsupervised machine learning (ML) techniques to develop key path anesthetic decision points. Using data from the Multicenter Perioperative Group (MPOG) registry, we identified over 10 million unique cases across 18 states and over 50 hospitals. We developed clusters of case/patient combinations in an attempt to organize data. Patient-specific data included age, sex, American Society of Anesthesiologists physical status (ASA), and emergent status. Intraoperative data included administered medications, venous access, perioperative nerve blocks, airway management, case-specific physiologic observations, and existing MPOG phenotypes. Cases were grouped by institution and displayed in a web-interface (Figure 1) in which a “user” can login and interact with the data. Data is organized by institution (with de-identified comparison between institutions) and displayed with analysis of patient demographics, executed anesthetic treatment plans separated into unique treatment “paths”, and associated outcomes defined by institution and anesthetic path. Outcomes currently include 30-day in-hospital mortality, intraoperative complications (including myocardial infarction, respiratory failure, pulmonary embolism, AKI), estimated blood loss, urine output, fluid and blood product administration, intraoperative medication use (including oral morphine equivalency (OME) and vasopressors), and provider-specific information including staffing ratios and provider quality assessments.

Results and Conclusions: In grouping procedure data with institutions we were able to gain valuable understanding of clinical practice variation. As an example, there were 137 unique anesthetic paths across all institutions for knee arthroplasty with the frequency of the top path ranging from 14.5 - 72.6% by institution. Among 50 distinct hospitals there were 15 distinct top paths. Using OME as an example outcome for this procedure, OME ranged from 21.5 to 146.5, with an average OME per institution of 55.1 (+/- 23.3). A procedure with considerably less variability is liver transplant where the top path was chosen 77% of the time across all MPOG sites. The ProView tool we have created illustrates the considerable

variation in anesthesiology practice both between and within institutions for given procedures. We envision we have created an analytical tool for understanding and analyzing variation in anesthesia practice. With this tool, we have begun to investigate clinical practice variation including opioid use and billing applications. This information could be useful for providers at various levels of training and continuing medical education. Additionally, we are currently utilizing supervised machine learning models to identify potentially optimal or detrimental paths in anesthetic care. As several decisions within the anesthetic paths are chronological, and the real-time anesthesiology decision making relies heavily upon chronological physiologic data, we believe reinforcement learning techniques can also be applied and offer insight to anesthesiology decision making. Overall, the results of medical treatment path clustering and ML implementation can be utilized within any field of medicine and/or across complete patient care paths encompassing multiple medical fields.

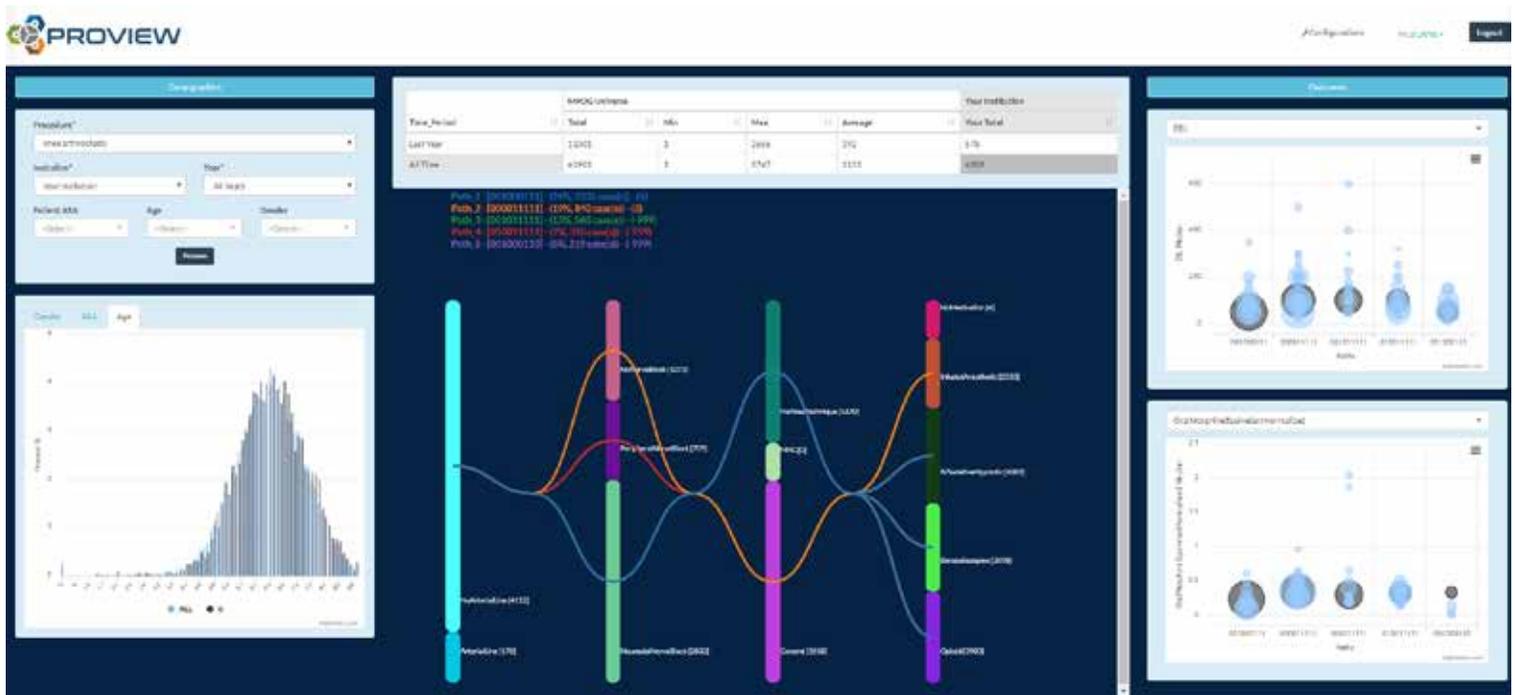


Figure 1: Web version of ProcedureView (ProView), a practice variation tool for anesthesia providers. Paths are shown as lines through specified anesthetic decisions (bars). Demographic (age) histogram is shown on the left, while estimated blood loss (EBL) and oral morphine equivalent (OME) are shown on the right.

A Novel Digital 3D Printed Cricoid Pressure Device

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Co-Authors: Sachin Doshi, Medical Student, University of Toronto, Mandeep Singh, Assistant Professor, Department of Anesthesia, University of Toronto

Introduction: The application of cricoid pressure is a widely adopted, yet controversial component of RSI^{1,2}. One major component of the controversy is the inability to apply and maintain the correct force. Too little force is ineffective at preventing gastric regurgitation and too much force may restrict ventilation and worsen views during laryngoscopy². Therefore, the objective was to develop a customizable, 3D printed device capable of applying an accurate and reproducible force.

Materials and Methods: The device contains a compression/tension micro load cell (model: TAS520-5kg HT Sensor Technology Co. Ltd.) that is incorporated into a 3D printed cricoid pressure application system (Figure 1). It is designed for testing forces in the range of 0-5 kg (~50 N). The load cell system is calibrated using scientific grade calibration weights. The load cell system is then attached to an Arduino circuit board, HX711 load cell amplification circuit and LCD digital display that are all encased in a 3D printed enclosure. The system can either be directly attached to a computer via USB in order to capture and analyze all of the data or conversely with a 9V battery to give improved portability. In either case, the Force (N) is displayed on the LCD screen to give the user the exact force being applied in real time.

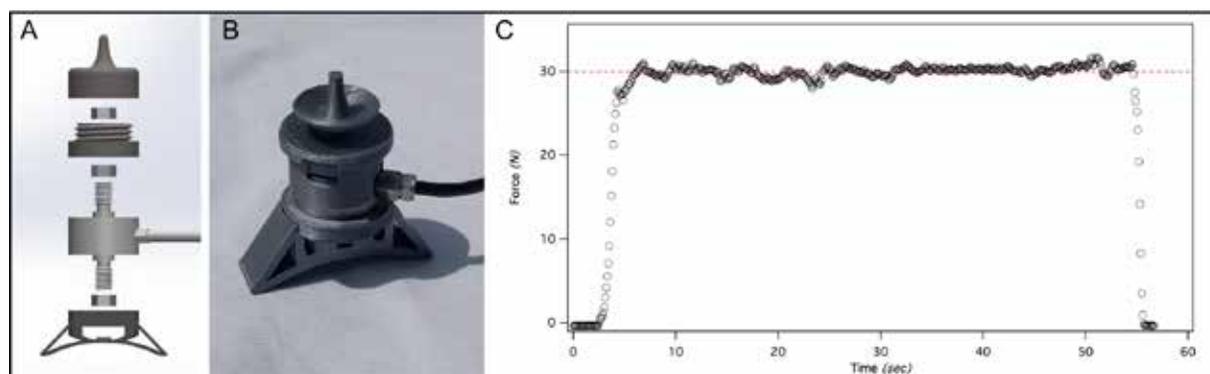


Figure 1. A) Schematic representation of tension/compression load cell embedded in a 3D printed system B) Prototype Version 1 C) A single experiment showing cricoid pressure on a model maintained at 30 N over 1 min duration using the 3D printed cricoid pressure device.

Conclusion: We have developed an ideal cricoid pressure device that is capable of reliably producing accurate forces. In addition, it has detachable custom blades that are both disposable and can be printed to fit a variety of patients of various ages and anatomical differences.

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Investigating Environmental Carbon Dioxide Sensors as Proxy for Capnometry in Austere Surgical Settings

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

Co-Authors: Maziar Nourian, B.S., University of Utah; Kai Kück, Ph.D. University of Utah

Introduction: Several medical devices have been introduced to address, in part, the discrepancy in surgical and anesthesia access between high-income regions and their lower-income counterparts. The ‘Glostavent’ is an anesthetic machine designed specifically for use in difficult environments, emphasizing portability, durability, and independence from electrical grids [1]. ‘Lifebox’ is a charity project aimed at providing pulse oximeters for use in low- and middle-income countries with a similar emphasis on durability [2]. However, there are no continuous respiratory monitoring devices intended for austere conditions despite the American Society of Anesthesiologists (ASA), World Health Organization (WHO), and the World Federation of Societies of Anaesthesiologists (WFSA) all designating capnography as an essential instrument in anesthesia monitoring [3]–[5].

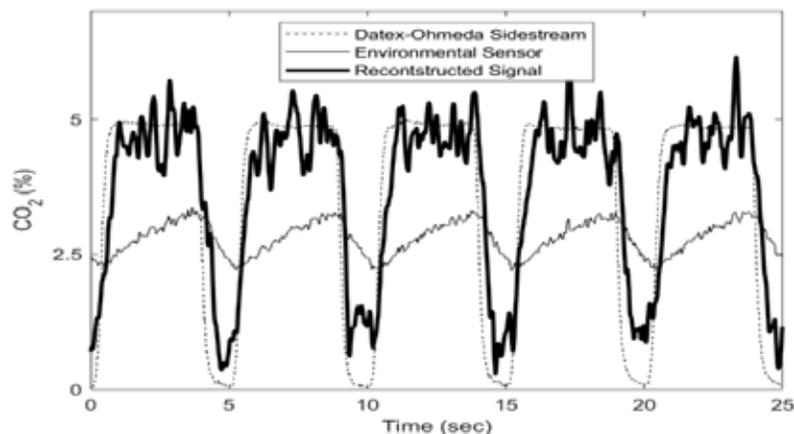
Utilizing a low-cost environmental CO₂ sensor typically used for emissions testing, the primary aim of this work was to develop a capnography device and then compare to other capnometry devices. Additionally, a deconvolution filter was applied to accelerate the system response to recreate the raw waveform for improved estimations in respiratory pathology detection (esophageal intubation, bronchospasm, cuff leak, etc.).

Methods: A sampling pump (Diaphragm Pump 2002 VD LC, CO₂Meter, Inc., Ormond Beach, FL) was used to draw sample gas at 500mL/min through a 3 ft. long sampling tube to the environmental sensor (SprintIR 20%, CO₂Meter, Inc. Ormond Beach, FL). A microcontroller (Arduino Uno, Arduino, Italy) both sampled the sensor at 40 Hz and displayed the waveform and respiratory rate on a 3.2” LCD display (Nextion NX4024T032, ITEAD Intelligent Systems Co. Ltd, China). A lung simulation model was created using a Servo Ventilator 900C (Siemens-Eléma, Sweden) and a test lung (TTL Training Test Lung, Michigan Instruments, Grand Rapids, MI). A mass flow controller (Alicat Scientific, Tucson, AZ) was used to delivery carbon dioxide to the test lung. For comparison, reference waveforms were simultaneously measured using a sidestream capnography unit ((Datex-Ohmeda, Helsinki, Finland) and a mainstream capnography unit (Respironics NM3, Philips, Amsterdam Netherlands). To test the accuracy of the implemented deconvolution filter, in silico waveforms were created the simulated normal breathing, pediatric breath, obstructive disease, spontaneous breath, cardiac oscillation, and apnea.

Results and Discussion: Our proof-of-concept device was successful in determining respiratory rates and showed no discrepancy between modern capnometry and capnography devices. The reconstruction of the carbon dioxide waveform yielded mixed results, however was generally capable of revealing the underlying the waveform at the cost of noise amplification (Figure 1). Future iterations will emphasize addressing these high-frequency artifacts to recreate a more realistic waveform.

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Fusion of Basic Spirometers for Anesthetic Gas Concentration Sensing

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: Volatile anesthetic gas monitoring confirms both a functioning anesthesia machine as well as aids clinicians in identifying and titrating anesthetic depth of the patient. Operating rooms capable of volatile anesthetic gas monitoring accomplish this with infrared spectroscopy units. However, the high capital and maintenance costs make these devices ill-suited and quickly obsolete in low-resource settings. Infrared absorption represents only one of several physical and chemical property differences between volatile anesthetic agents and carrier gases. Density, viscosity, thermal conductivity, and acoustic resonance are all features that differ between volatile anesthetic agents and carrier gases and are also features that are used to measure respiratory flow already. We hypothesize that through smart fusion of these sensors and studying their measurement changes as a function of volatile anesthetic gas changes could yield a combination capable of determining both respiratory flows and anesthetic gas concentration.

Methods: Several spirometers were placed in series in a recirculating system driven by a radial turbine. Included were a custom orifice-plate differential pressure anemometer, hot-wire anemometer, and rotary vane anemometer. Flow rates were also measured via a VT-Plus Gas Flow Analyzer (Fluke Corp., Everett, WA), a commercial thermal flow sensor (AwM700, Honeywell International Inc., Morris Plains, NJ), as well as the internal tachometer existing in the driving radial turbine (U51DL-012KK-4 Miniature Radial Blower with Integrated Electronics, Micronel, Tagelswangen, Switzerland). All sensors were sampled at a rate of 20 Hz with flow rates ranging from 10-60 liters/minute. During steady-state flow, isoflurane was introduced into the system at concentrations ranging from 0-3.5% by volume, and the reported changes in flow from all sensors monitored. Multiple linear regressions were developed across all sensors in a scatter plot matrix to determine which sensors were independent or dependent on the presence of isoflurane.

Results and Discussion: Several of the standard spirometers exhibited significant variability in reported flow with the presence of isoflurane, indicative of an underlying sensitivity. Two linear regressions of note were between the rotary vane and hot-wire anemometer as well as the orifice-plate anemometer and commercial Honeywell thermal sensor, with both exemplifying clear patterns of difference to determine isoflurane concentration and flow rate simultaneously (Figure 1 and 2).

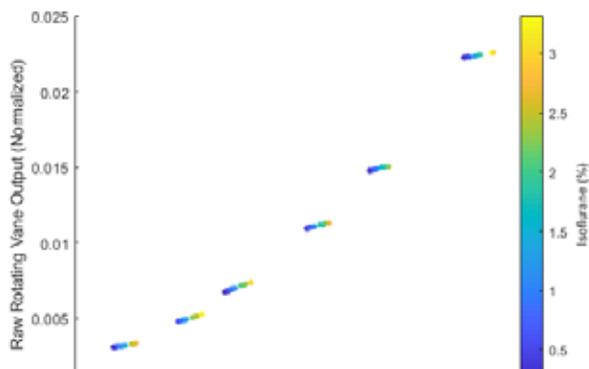


Figure 1 - Relationship between the hot-wire anemometer and rotating vane spirometer at 10, 15, 20, 30, 40, and 60 liters per minute with changes in isoflurane concentration from 0-3.5%.



Figure 2 - Relationship between the orifice-plate spirometer and commercial Honeywell sensor at 10, 15, 20, 30, 40, and 60 liters per minute with changes in isoflurane concentration from 0-3.5%.

Catheter Depth Control During Endotracheal Tube Exchanges in an Airway Manikin; A Comparison of a Novel Color-Zoned Qualitative System vs Traditional Quantitative System

Presenting Author: Sean T Runnels, MD

Co-Authors: Benjamin Fogg MD, Samer Merchant, ME, Jonathan Rich, MS 4

Problem: Lack of depth control of airway introducers and exchange catheters is the prime cause of airway injuries and failed intubations when these devices are used.^{1,2,3}

Hypothesis: Catheters with a qualitative color zoned depth control system, designed to be visually monitored with a video laryngoscope, at the level of the vocal cords, can improve catheter depth control during airway procedures.

Study design: 22 faculty anesthesiologists or senior residents performed 3 endotracheal tube exchanges in an airway manikin each with differing visual feedback and either qualitative or quantitative depth control markings.

Exchange 1: Exchange catheter with standard numeric depth markings (quantitative). The exchange was performed without a laryngoscope.

Exchange 2: Exchange catheter with standard numeric depth markings (quantitative) and a video laryngoscope to monitor exchange at the glottis.

Exchange 3: Exchange catheter with novel, qualitative color-zone depth control markings on the catheter tip and a video laryngoscope to monitor the exchange at the glottis.

Data Gathering

All exchanges were monitored in two ways:

1. All airway exchange catheters were fitted with a magnet in the tip and a magnetometer was used to monitor tip depth in the trachea throughout all exchanges;
2. A video, at the level of the glottis, was taken of all exchanges.

End points for catheter tip depth in the trachea:

- 1) Shallowest point during procedure
- 2) Deepest point on initial insertion of exchange catheter
- 3) Deepest point during entire procedure
- 4) Number of incursions into the bronchus
- 5) Total tip excursion

Results: Results are presented in Figure 1.

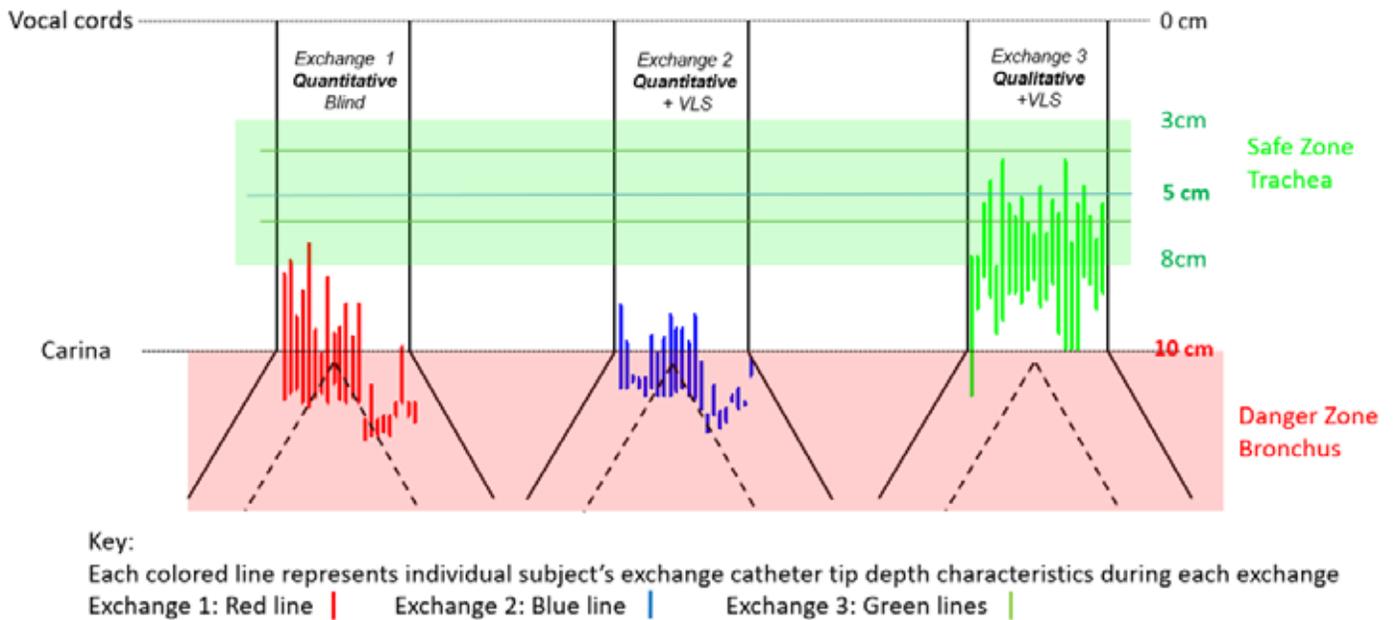


Figure 1: CATHETER TIP DEPTH IN TRACHEA AND BRONCHUS DURING AN ENDOTRACHEAL EXCHANGE WITH 3 DIFFERENT DEPTH MONITORING TECHNIQUES

Conclusion: Airway exchange catheters with qualitative color zoned depth markings the decreases tip travel below the carina when used with a video laryngoscope during endotracheal exchanges in an airway manikin. Improved catheter depth control could lead to safer endotracheal exchanges in humans.

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Risk Factors for Loss of Voice and Hoarseness after General Anesthesia at Post-Operative Day 1 in Out Patient Surgery

Presenting Author: Smitha Warriar, MD

Co-Authors: Sean Runnels, MD; Rebecca Freeland, MD

Background: Sore throat is common source of patient pain affecting patient satisfaction after surgery. Less is known about the incidence or impact of vocal changes after surgery. The incident of sore throats after general anesthesia are well described with rates of up to 50%.^{1,2} Several studies have described hoarseness after endotracheal intubation,^{3,4} however little is known about hoarseness with other airway techniques. Little is known about loss of voice. We retrospectively analyzed an outpatient surgery dataset to explore vocal changes after general anesthetics.

Methods: The study is approved by the University of Utah IRB. Design; Retrospective EMR review.

Outpatient surgical cases at the University of Utah routinely receive a follow up call on POD 1. The questions; 1) Do you have hoarseness? 2) Did you have a loss of voice? Were asked at that time. We performed a retrospective data including all outpatient surgery call back notes and corresponding airway note from our EMR. These cases was analyzed for reported hoarseness and loss of voice for different airway management techniques. Any patient who received a regional anesthetic or a MAC was excluded. All patients in the data set who received a general anesthetic and an airway note documenting In total 4861 cases met our inclusion criteria.

Results: 6547 cases were analyzed. results are given in tables 1 and 2.

Table 1. Number of airways managed by technique.

	Number
ETT	4731
LMA	1816
Direct laryngoscopy	4102
Video Laryngoscopy	514
Light Wand	23
Fiberoptic Scope	24
Bougie	75

Table 2. Hoarseness and loss of voice for different airway techniques.

	% Hoarseness	% Loss of voice
LMA	8.7%	2.6%
Direct Laryngoscopy	15.4%	3.6%
Video Laryngoscopy	16.1%	3.1%

Light Wand	34.7%	17%
FOS	20.8%	4.16%

Conclusion: Patient reported hoarseness and loss of voice are common after general anesthetics for outpatient surgeries across a wide variety of airway management techniques. Hoarseness occurs at a higher rate than loss of voice for all forms of airway management studied. Further studies are needed to understand the incidence and mechanisms of vocal changes, We find evidence of vocal changes with LMA interesting as it is described as a ‘supraglottic airway’ technique which in theory, has little contact with the vocal cords themselves. The high rates of hoarseness and loss of voice with the use of a light wand warrants further study.

Caution should be used in drawing conclusions from this data as it is retrospective from a single institution.

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Smoothed ℓ^0 (SLO) Based Burst Suppression Detection Method

Presenting Author: Soodeh Ahani^{1,2} PhD

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Introduction: Accurate automatic detection of burst suppression electroencephalographic (EEG) patterns (BSP) is important as its presence is an indicator of deep unconsciousness [1]. Accurate automatic BSP detection can reduce the risk of over-sedation during surgery by giving early warning to the attending anesthesiologist.

Based on our experience, the commercially available NeuroSENSE monitor [2] tends to overestimate suppressions as it is shown in Fig. 1. We aim to address the overestimation of detected suppression by EEG monitors as it can result in alarm fatigue leading the anesthesiologist to ignore real BSP episodes due to repeated false alarms.

Method: We use machine learning to develop a real-time algorithm to detect BSPs in the EEG signals of patients under general anesthesia during surgery. The RUSBoost technique [3] is used to train an ensemble classifier to address the problem of class imbalance in our application, as the non-suppression class instances greatly outnumber suppression class instances.

The smoothed ℓ^0 (SLO) norm of a vector [4] is utilized to introduce novel appropriate features for the BSP classification. We propose SLO-based features in order to track the time-evolution of spatial properties of the EEG signal. We refer to the proposed algorithm as the SLO-based BSP detection method, emphasizing that the proposed BSP detection method successfully uses the SLO norm of a vector for the BSP detection.

For the time-varying EEG signal denoted, we consider the SLO norm [4] of EEG epochs, as a good candidate for suppression detection. We also used several spectral features in addition to the SLO-based features to design our classifier.

Results: We use an EEG database collected from adult patients of age 19 and older [6]. We employed a large and diverse amount of training data of 192 hours of EEG recordings over 90 subjects under surgery.

Our results show that the proposed automatic BSP detection method greatly outperforms the method in [1] as well as the method in [5] which is currently under use by the NeuroSENSE monitor, NeuroWave Systems Inc. [2] in terms of reducing false alarms and the overall classification accuracy. Our proposed method results in 38.74 minutes of false detections over 45.86 hours of test data, i.e. a substantial improvement compared to 60.64 [5] and 353.21 [1] minutes of false detections. In terms of true suppression detection, the proposed SLO-based algorithms performs similarly to the existing methods in [5] and [1]. Our method correctly

detects 33.38 minutes of suppressions comparing to 34.74 and 33.64 minutes of suppression correctly detected by the methods in [5] and [1].

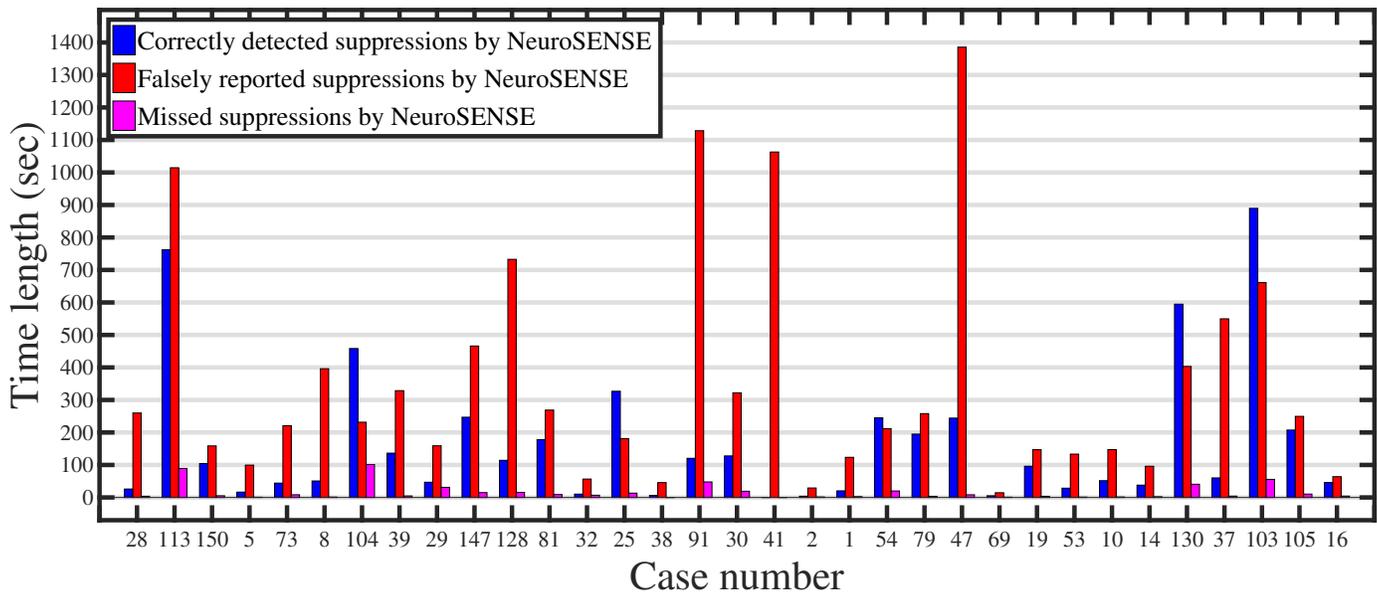


Fig. 1 The false alarm time length reported by NeuroSENSE monitors compared to the time length of accurately detected and missed suppressions for several selected cases.

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Endotracheal Tube Intracuff Pressure is Not Equal to Tracheal Wall Pressure on a Simulated Trachea

Presenting Author: B. Randall Brenn MD, Vanderbilt University Medical Center, Nashville TN;
Co-Authors: Dinesh K. Choudhry MD, FRCA, Alfred I. duPont Hospital for Children, Wilmington DE; Nicholas A. Brenn BSEE, MSEE, Nespresso: Industrial Engineering, Lausanne CH

Introduction: It has been known for decades that pressure exerted by the inflated endotracheal tube cuff on the tracheal wall (TWP), if excessive, can cause tracheal mucosal ischemia leading to necrosis, scarring and tracheal stenosis.(1) It is generally accepted that if the TWP does not exceed 30 mm Hg that there will be little chance of mucosal damage in long term intubation. (2) Also, it is accepted that high-volume low-pressure cuffs if not stretched, the intra-cuff pressure, as measured by the attached pilot balloon, should closely correlate with TWP. (3) The objective of this study was to test the correlation between intra-cuff pressures and TWP using 3 different cuffed tubes in a simulated trachea.

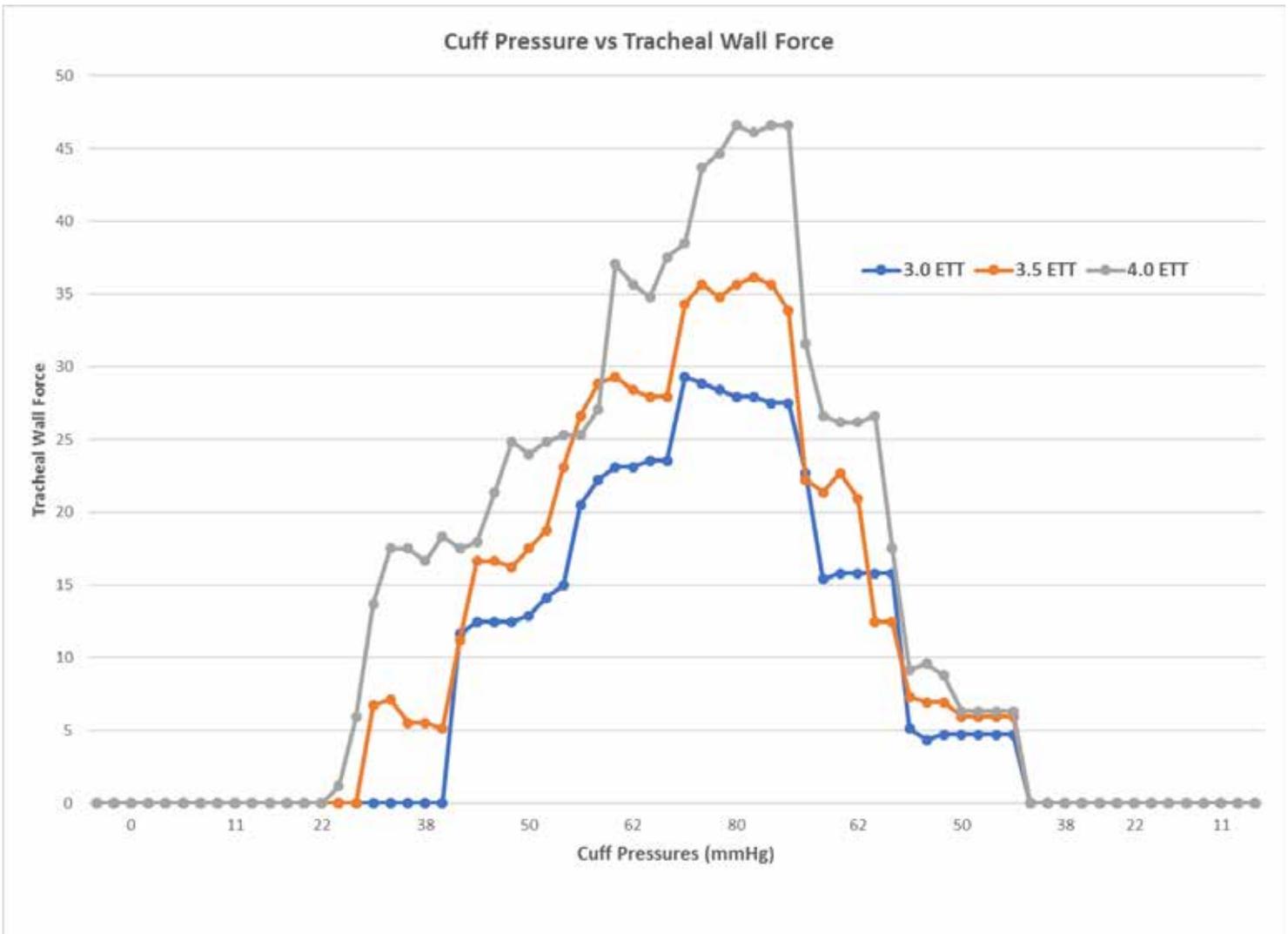
Methods: A 4mm force sensitive resistor (SEN-09673, Sparkfun.com) was transposed between the outside of ETT cuff positioned inside an 8 mm ID ETT serving as an in-vitro trachea (faux trachea). Three different sizes of ETT (3.0, 3.5, and 4.0 mm ID) were placed in the faux trachea for the study purpose. A voltage divider circuit was created with the sensor and a current limiting resistor. The pressure applied to the sensor generates a variable voltage output which is read by the Analog-to-Digital Converter (ADC) on an Arduino (Arduino Uno-R3) microcontroller (Software version: Arduino 1.8.5). The ETTs pilot balloon was attached to a three-way stopcock attached to tubing to a manometer in an airtight closed system. Each ETTs pilot balloon was inflated in 0.5cc increments. The pressures inside the cuff were measured with the connected manometer and force exerted by the inflated pilot balloon on the inside of the faux trachea were measured by the transposed sensor. Recordings of the serial pressures were transferred to a spreadsheet for graphical interpretation.

Results: The intracuff pressures and the transmural forces exerted between the ETT cuff and the faux trachea are recorded with an interposed sensor for each ETT are shown in figure 1. As the volume and pressure in the pilot balloon is increased, there are clear differences in the resultant recorded tracheal force exerted by the cuffs of different sized ETT tubes.

Conclusions: This apparatus revealed that the same intracuff pressure exerts different tracheal wall pressures depending on the size of the endotracheal tubes. The concept that the pilot balloon measured cuff pressure is a good measure of tracheal wall pressure exerted by the ETT cuff is not true.

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Figure 1.



Multiple Pathways of EEG Spectral Pattern Progression with Anesthetic Agent Reduction

Presenting Author: Christopher M. Scheib MD

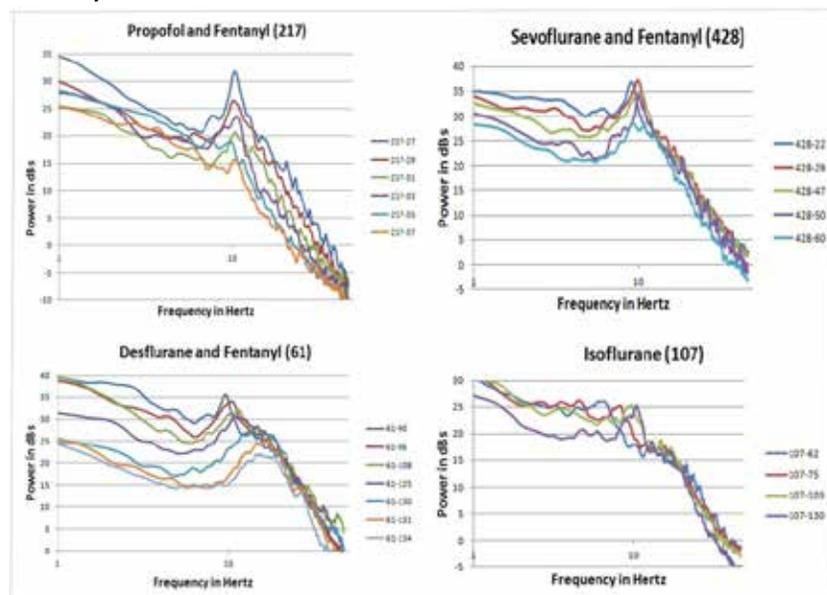
Co-Author: William Hefner VAMC

Introduction: It has been suggested that EEG derived algorithms such as the Bispectral Index™ can be used to monitor the “depth of anesthesia” or the “hypnotic effect” of an anesthetic for several purposes. The underlying assumption is that anesthesia is a depression or inhibition of neural activity which leads to consistent changes in the amplitudes of the different frequencies in the EEG signal. If this were true, a series of EEG spectra over a wide range of anesthetic agent concentrations would vary consistently in some manner for all subjects.

Method: Log-log presentations were used to examine the series of EEG spectra over the course of surgery and emergence from more than one hundred patients. They were examined visually to determine if there was more than one pattern (or “pathway”) to the changes.

Results: Evaluating the series of EEG spectra discovered several pathways. Case 217 had a loss of amplitude at all frequencies and no shift in the frequency of the peak at 10 Hertz. Case 428 had a loss of amplitude at frequencies below the peak. Case 61 had a shift of the frequency of the 10 hertz peak to higher frequencies and a loss of amplitude at frequencies less than the peak. Case 107 had a shift of the peak from 7 to 10 Hertz with no loss of amplitude until the last spectrum and always had a “plateau” out to 20 Hertz. In some other cases (not shown) the 20 Hertz plateau developed into a peak distinct from the 10 Hertz peak.

Conclusion: A universal quantitative EEG algorithm based on spectral analysis as used in several commercial EEG “depth of anesthesia” monitors would likely be inaccurate for many individuals. Accuracy for an individual would require a method that identifies both the pathway and the location on the pathway. Patient factors and choice of anesthesia technique appear to determine which pathway occurs.



The figure above shows four different progressions of spectra as the hypnotic agent component of the anesthetic is reduced.

Details of an EEG Spectra Pathway with Propofol and Opioid TIVA

Presenting Author: Christopher M. Scheib MD

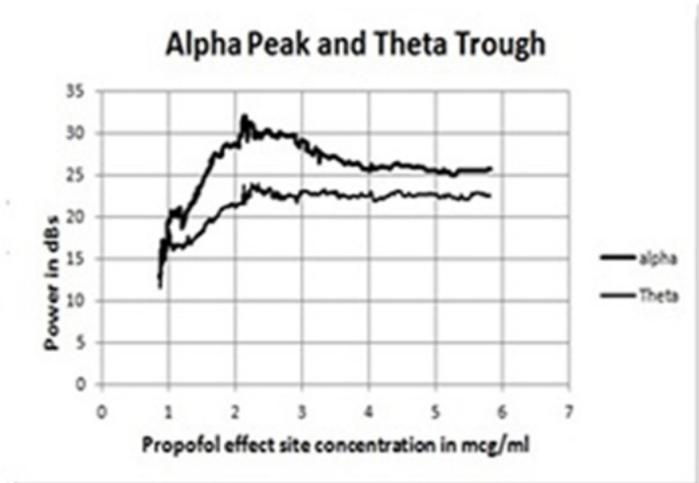
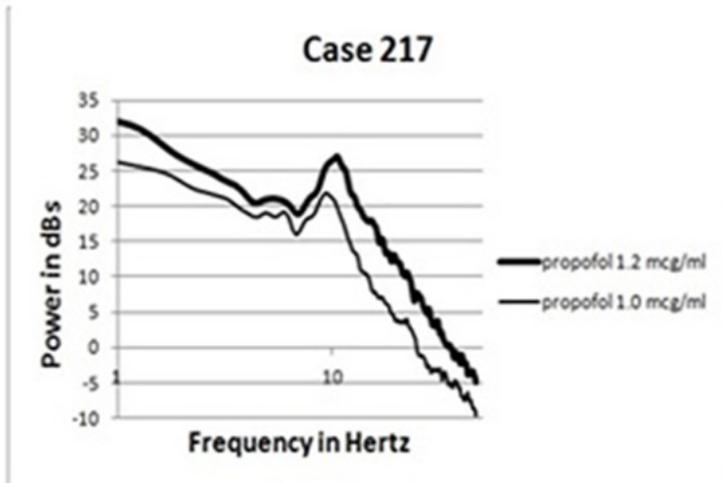
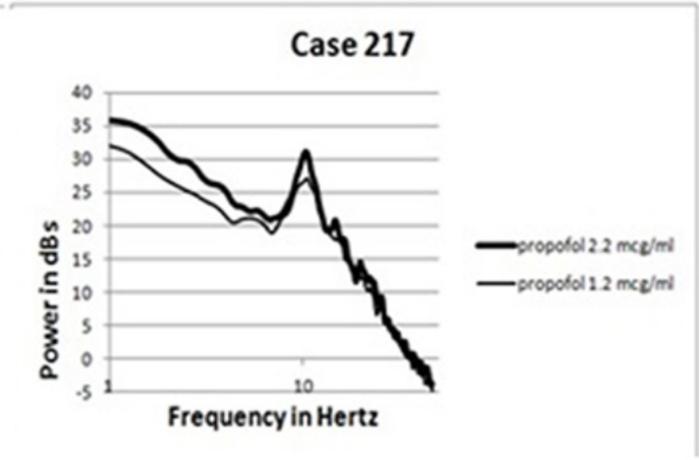
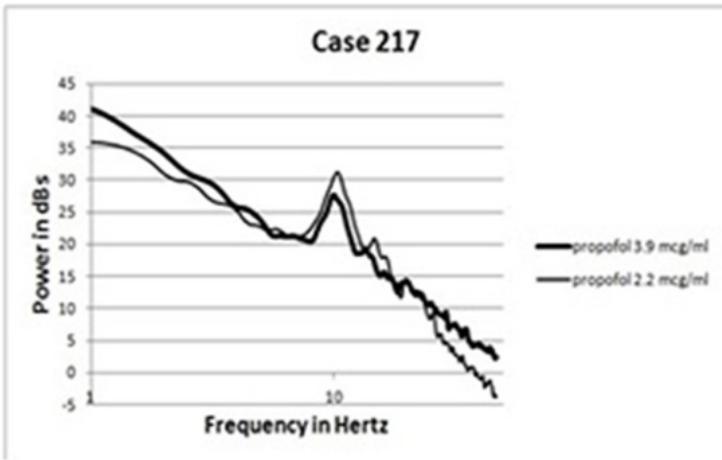
Co-Author: William Hefner VAMC

Introduction: Propofol plus an opioid such as fentanyl is one example of a category of anesthesia protocols known as “total IV anesthesia” (TIVA). A common progression of EEG spectra from high to low concentration of propofol (“pathway”) is illustrated with one case below.

Method: The EEG signal was previously recorded with a BIS™ monitor. A custom program based on LabView™ was used to generate the spectra and the alpha peak and theta trough parameters. A pharmacokinetic model was used to calculate the effect site concentrations.

Results: The change in EEG spectra shape and amplitude from high to low propofol concentration is biphasic. The initial change in the alpha peak is an increase in power as the propofol concentration declines. Further reduction in the concentration results in the power of the alpha peak declining. This implies that a spectrum with the maximum alpha peak power can be used as a reference point. There are other changes in the shape of the EEG spectra during this process. The sections of the spectra above and below the alpha peak frequency often form a straight line on a log-log presentation. These two segments can be referred to as the “high frequency segment” and the “low frequency segment”. EEG spectra from an anesthetic agent concentration above the maximum alpha peak power reference spectrum have a low frequency segment that is steeper than the low frequency segment of the reference spectrum and a high frequency segment that is less steep than the corresponding segment of the reference spectrum. This is illustrated in the top left section of the figure. As the concentration of propofol is reduced below the level of the maximum alpha peak, the power at every frequency point from below and including the alpha peak is reduced. This is illustrated in the upper right section of the figure. Further reduction of propofol results in a loss of power at all frequencies. The apparently straight lines in the log-log spectra, the peak at 10 Hertz (alpha peak) and the trough at 7 Hertz (theta trough) are shape features and can be tracked to help locate an individual spectrum on the pathway. The values for the peak and trough parameters relative to the calculated effect site propofol concentration for case 217 are shown in the bottom right section of the figure.

Conclusions: The EEG spectrum in the sequence with the maximum alpha peak power can be used for a reference spectrum in the pathway. The EEG spectra were most affected by the estimated effect site propofol concentration. As long as the estimated effect site fentanyl concentration met a minimum value it did not appear to affect the pathway.



Opioid Requirement at Different Levels of Hypnotic Anesthetic Agent

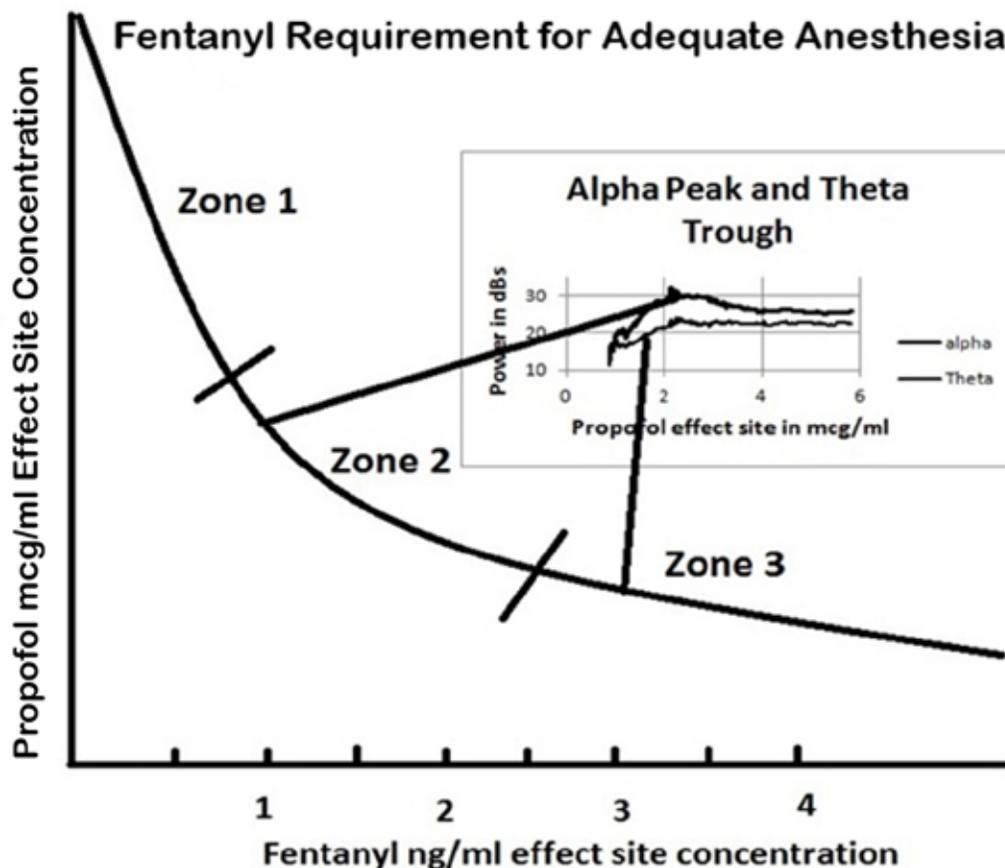
Presenting Author: Christopher M. Scheib MD

Co-Author: William Hefner VAMC

Introduction: Over the years many papers have been published which reviewed EEG and neuroscience topics and suggested that they may be important to understanding anesthesia. But so far, few clinicians have used this information to change the way they practice. EEG based monitors were developed empirically and are alleged to measure the “depth” of anesthesia which is a clinical rather than a neuroscience based concept. It is debatable whether or not these monitors have changed anesthesia practice.

A potential clinical advantage of a neuroscience based monitor would be to enable a reduction of the level of the hypnotic anesthetic agent (halogenated inhalational agent or propofol) below the levels commonly used without the benefit of such a monitor. This can only be done routinely if the clinician knows how much analgesia is needed to prevent response to surgical stimulation as the inhaled agent or propofol is reduced.

Proposed theory: Tracking the alpha peak and theta trough of the EEG spectrum could be used to divide the well known relationship between the hypnotic and analgesic agents into three zone. Zone 2 is the most efficient section of the curve and is at the level of maximum alpha peak. Zone 3 requires high levels of analgesic agent and is when both the alpha peak and theta trough lose power rapidly with small changes in the primary anesthetic agent. The clinician would try to achieve zone 2 and maintain a constant and moderate level of opiate.



A New Time Domain Display Method to Monitor an EEG Signal During Anesthesia

Presenting Author: Christopher M. Scheib MD

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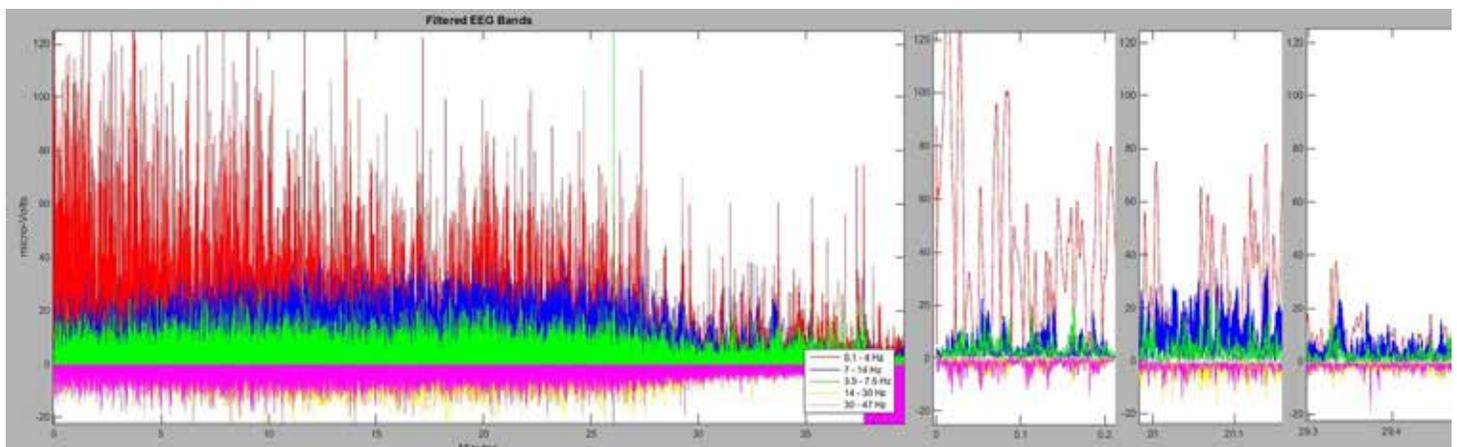
Introduction: Propofol plus an opioid such as fentanyl is one example of a category of anesthesia protocol known as “total IV anesthesia” (TIVA). A common progression of EEG signals from high to low concentration of propofol (“pathway”) is illustrated with one case below. A time domain method based on digital filters which can be used to monitor the anesthetic is used in the illustration below.

Methods: The EEG signal was previously recorded with a BIS™ monitor. A Custom program using LabView™ was used to generate the illustration. Superimposed rectified filtered frequency bands were used to display the peak to peak amplitude of each of the five standard EEG frequency bands. Delta is red, theta is green, and alpha is blue. All three signals are rectified and displayed on the upper half illustration on the same scale. Beta is yellow and gamma is purple. Both are rectified and displayed on the lower half of the illustration. Beta is on the same scale as delta, theta, and alpha but gamma is on a scale that makes it appear five times larger than it would if on the same scale as the other bands.

The left of the illustration is the entire procedure which lasted almost 40 minutes. The three panes in the left of the illustration are from 0, 20, and 29 minutes at a much more expanded time scale.

Results: The illustrated method shows the changes in the five frequency bands from 3.9 mcg/ml to 0.7 mcg/ml propofol in a manner that is easy to follow. The Increase and then decrease in the power of the alpha band (blue) is easy to appreciate.

Conclusions: The illustrated time domain method provided an alternative to frequency domain methods for the monitoring of an EEG signal during an anesthetic. This method may be easier for clinicians to interpret and respond to changes more quickly than traditional frequency domain methods and offers more complexity than an index such as BIS™.



Use of Continuous Noninvasive Arterial Pressure Cycle Duration to Predict Hypovolemia in Low Body Negative Pressure

Presenting Author: Anna-Maria Eid, MD, Yale New Haven Health

Co-Authors: Mohamed Elgamal, Mohamed Eid, Aymen Alian, MD, Kirk Shelley, MD, PhD, Yale New Haven Health

Introduction: Clinical signs of hypotension are considered late indicators of hypovolemic shock. Low Body Negative Pressure (LBNP) is an experimental model that mimics hypovolemia by pooling blood in the lower extremities. Continuous Noninvasive Arterial Pressure (CNAP, CNSystems, Austria) is currently being used as a blood pressure monitor. In this study, the duration of ejection time (EJ), an estimate of systole, and non-ejection time (NEJ), an estimate of diastole, were measured together with the ratio of these values to the Total Cycle Duration (TCD = EJ + NEJ). This study aims to see if the variations in cardiac cycle length provides a tool for early prediction of hypovolemia.

Methods: The data of 18 healthy volunteers subjected to a readily reversible LBNP protocol were used. This entailed 3-minute phases during which the pressure was progressively decreased by 15 mmHg. The study continued until the subject reached either 3 minutes at -75 mmHg or any phase in which symptoms consistent with significant hypovolemia occurred- light headedness, nausea, diaphoresis, blurred vision, tingling in extremities, or a measured systolic blood pressure less than 80 mmHg. Once an end-point was reached, pressure in the chamber was increased to -30 mmHg for 1 minute then to 0 for 3 minutes before concluding the study. Blood pressure tracings were recorded utilizing the CNAP double finger sensor. Subjects able to tolerate the entire negative pressure protocol without symptoms were designated as high tolerance (HT), while those with symptoms were designated low tolerance (LT). In the first part of the analysis, EJ and NEJ durations and ratios of the CNAP waveforms were identified using LabChart Pro 7. Data were then reported as average and SD, p-value <0.05 was considered significant.

Results: In the LT group, there was 23% and 32% reduction in the NEJ duration and ratio (NEJ/TCD) respectively between baseline and LBNP -45, while there was a 3.4% and 1.9% reduction respectively in the HT group. There was no significant difference when comparing the NEJ/TCD ratio between the LT and HT groups at baseline, LBNP -15 and -30, which correspond to no blood loss, 330 ml of blood loss, and 660 ml of blood loss, respectively. However, at LBNP -45, which corresponds to 1 liter of blood loss, there was a significant difference between HT and LT groups in the NEJ/TCD ratio (p-value=0.015). LT participants had an intercept of the EJ and NEJ duration curves (Graph 1.1) which is at least 4 minutes before the development of symptoms (nausea, lightheadedness...) were noted. In comparison, the percent change in Mean Arterial Pressure (MAP) amongst the HT group was 1.5% (\bar{X}_{BL} = 86.2 mmHg, \bar{X}_{-45} = 87.5 mmHg) and 3.9% in LT group (\bar{X}_{BL} = 91.2 mmHg, \bar{X}_{-45} =87.6 mmHg), respectively.

Conclusion: In progressive hypovolemia, heart rate is expected to increase commensurate to shortening of the diastolic phase, which corresponds to the NEJ duration. LT subjects had a significant change in their NEJ/TCD ratio at LBNP -45, approximately 3 minutes before becoming symptomatic. Conversely, the HT group did not have any significant changes in

their NEJ/TCD ratios. In face of stable MAP, changes in the NEJ/TCD ratio were more significant indicating that it may be a useful noninvasive measure of impending hypovolemia.

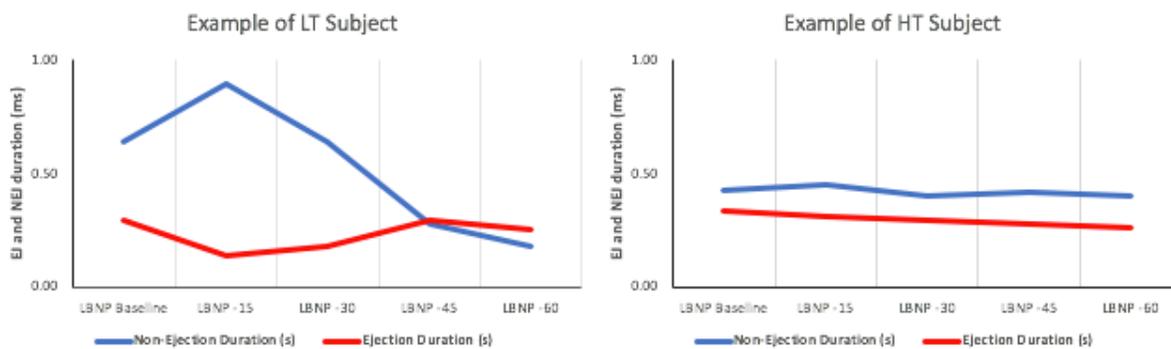
References: *Journal of clinical monitoring and computing*, 25(6), 377-385.

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Journal of trauma and acute care surgery, 61(3), 629-634.

The American journal of surgery, 192(6), 727-731.

Graph 1.1-Non-ejection and Ejection Durations of LT and HT Groups at Progressive LBNP



Study of Nasal Pulse Oximeter Amplitude During LBNP Induced Hypovolemia

Presenting Author: Mohamed Elgamal. Yale Medical school.

Co-Authors: Alex Yang, Mohamed Eid, Anna Eid, Aymen Awad. Alian, M.D., Kirk Shelley, M.D., Ph.D. Yale Medical school.

Background/Introduction:

- In trauma patients, hypotension and tachycardia are late clinical indicators of hypovolemia that are masked by compensatory changes in vascular tone until the point of cardiovascular collapse.¹
- Early detection of hypovolemia is therefore crucial to increasing survival outcomes in trauma patients.
- The photo plethysmograph (PPG) waveform, while widely used today as a monitor for arterial oxygen saturation, has the potential to be used as a non-invasive clinical tool for monitoring changes in blood volume.²
- Using lower body negative pressure (LBNP) simulated hypovolemia, we examined morphological changes in the PPG waveform at the nose and finger sites with changes in stroke volume (SV) and mean arterial pressure (MAP).

Methods:

- With IRB approval, 36 healthy subjects ages 18-40 underwent progressive LBNP (baseline, -15, -30, -45, and -60 mmHg or until the subject became symptomatic).
- Subjects that completed the LBNP protocol without symptoms were designated as high-tolerance (HT) and symptomatic subjects were designated as low-tolerance (LT).
- Subjects were monitored with a 5-lead EKG and continuous non-invasive blood pressure (CNAP). PPG waveforms were monitored using nasal (Xhale) and finger (Nellcor) pulse oximeter probes. Stroke volume (SV) was measured non-invasively using NICOM (Cheetah). All data was digitized and continuously recorded to a laptop using LabChart (ADInstruments).
- LabChart peak analysis was used to measure the average PPG amplitude during each stage of the LBNP protocol.
- Friedman ANOVA and Wilcoxon tests were used to identify changes in hemodynamic and PPG variables, $P < 0.05$ was considered statistically significant.

Results:

- Changes in nasal PPG amplitude demonstrate a strong correlation with changes in stroke volume (SV) in both HT subjects ($r = 0.94$) and LT subjects ($r = 0.91$) while changes in finger PPG amplitude show a lower correlation ($r = 0.73$) and ($r = 0.70$) in HT and LT subjects respectively.
- With progressive LBNP, stroke volume was significantly reduced (i.e. reduction in SV $> 10\%$) in both HT and LT subjects with no significant changes in MAP.
- PPG amplitude declined precipitously only at the finger site in both HT and LT subjects at an estimated blood loss of 350cc

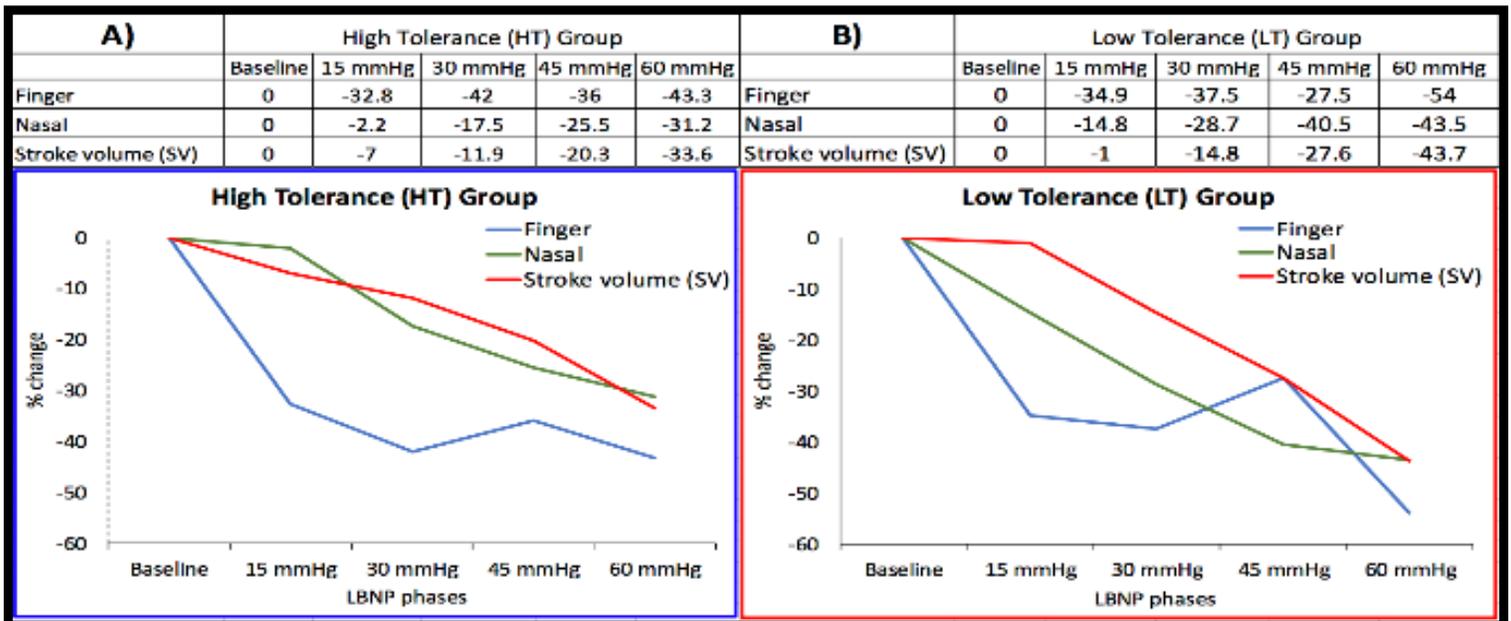
- PPG amplitude at both nasal and finger sites declined significantly at an estimated blood loss of 700cc with changes of -17.5% and -42.0% in HT subjects and -28.7% and -37.5% in LT subjects respectively.

Discussion:

- Stroke volume declined with progressive hypovolemia while MAP remained relatively constant demonstrating compensatory changes in vascular tone
- BP and cardiac output were maintained with progressive hypovolemia
- Finger PPG declined before a level of significant hypovolemia was achieved suggesting that changes in finger PPG amplitude are sensitive to early changes in vascular tone but not to central volume loss.⁴
- No significant change in Nasal PPG amplitude was observed in HT subjects until central volume loss was significant
- Changes in nasal PPG amplitude were strongly correlated with changes in stroke volume suggesting that the nasal site is relatively immune to vasoconstriction and more representative of central volume loss.

Conclusion:

- The Nasal PPG waveform may be a more sensitive clinical tool for monitoring early changes in central hypovolemia than the finger PPG waveform



Nasal Pulse Oximeter: New Site for Monitoring Central Blood Volume During LBNP Induced Hypovolemia

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Co-Authors: Mohamed Elgamal, Anna Eid, Aymen Awad. Alian, M.D., Kirk Shelley, M.D., Ph.D. Yale Medical school.

Background/Introduction:

- The photo plethysmograph (PPG) waveform, while widely used today as a monitor for arterial oxygen saturation, has the potential to be used as a non-invasive clinical tool for monitoring changes in blood volume.¹
- Clinical indicators of hypovolemia (namely Hypotension and tachycardia) are late signs and usually masked by compensatory changes in vascular tone until the point of cardiovascular collapse.² Early detection of hypovolemia is therefore crucial to increasing survival outcomes in trauma patients.
- Using lower body negative pressure (LBNP) simulated hypovolemia, we examined morphological changes in the PPG waveform (amplitude and area) at the nose with changes in stroke volume (SV) and mean arterial pressure (MAP).
- Nose supplied by internal carotid artery branches which we think is more immune to sympathetic changes compared to more commonly used sites for pulse oximeter (finger). was used to monitor amplitude and area of waves in LBNP.

Methods:

- With IRB approval, 18 healthy subjects ages 18-40 underwent progressive LBNP (baseline, -15, -30, -45, and -60 mmHg or until the subject became symptomatic).
- Subjects that completed the LBNP protocol without symptoms were designated as high-tolerance (HT) and symptomatic subjects were designated as low-tolerance (LT).
- Subjects were monitored with a 5-lead EKG and continuous non-invasive blood pressure (CNAP). PPG waveforms were monitored using nasal (Xhale) and finger (Nellcor) pulse oximeter probes. Stroke volume (SV) was measured non-invasively using NICOM (Cheetah). All data was digitized and continuously recorded to a laptop using LabChart (ADInstruments).
- LabChart peak analysis was used to measure the average nasal PPG amplitude, area during each stage of the LBNP protocol together with SV and MAP.
- Correlation was used to identify changes in hemodynamic, stroke volume and PPG variables.

Results:

- In HT subjects, there was a strong correlation between nasal PPG amplitude and area with stroke volume (SV) ($r = 0.99$), while the LT subjects demonstrated strong correlation ($r = 0.97$ and $r = 0.98$) respectively.
- With progressive LBNP, stroke volume was significantly reduced (i.e. reduction in SV >10%) in both HT and LT subjects with no significant changes in MAP.

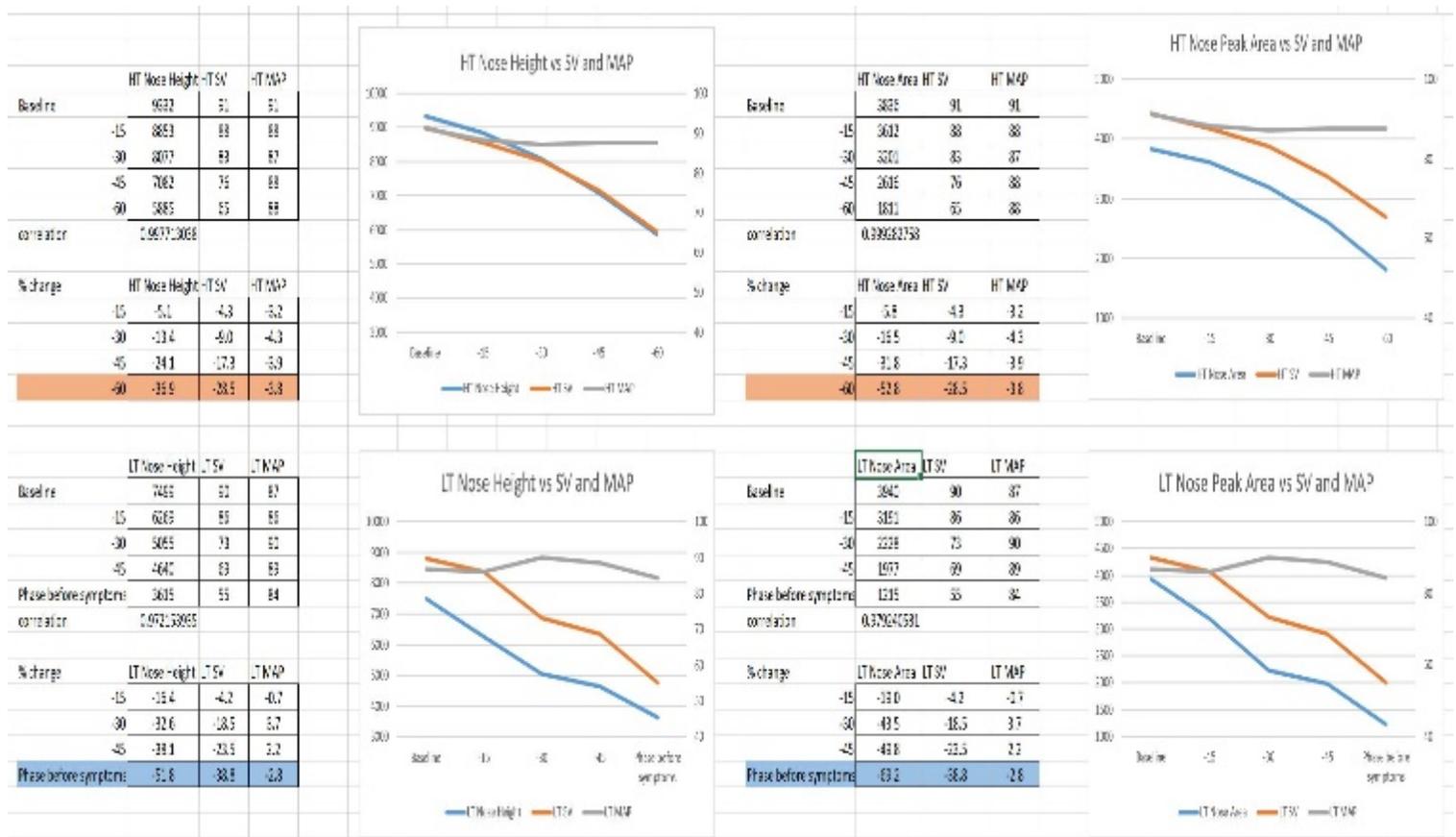
- Nasal PPG amplitude and area declined >50% and 69% in LT subjects, while in HT nasal PPG amplitude and area declined to 37% and > 52% respectively

Discussion:

- Stroke volume declined with progressive hypovolemia while MAP remained relatively constant demonstrating compensatory changes in vascular tone.
- Changes in nasal PPG amplitude and area were strongly correlated with changes in stroke volume suggesting that the nasal site is relatively immune to vasoconstriction and more representative of central blood volume.

Conclusion:

- Nasal pulse oximeter is an important site to track changes in central blood volume and stroke volume during LBNP induced hypovolemia.



Data Driven Investigation of Bispectral Index Algorithm

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Co-Authors: Hyung-Chul Lee, M.D., Ph.D.; Yoonsang Park, M.D.; Soobin Yoon, M.D.; Chul-Woo Jung, M.D., Ph.D.

Background/Introduction: Bispectral index (BIS), a useful marker of anesthetic depth, is calculated by a statistical multivariate model using nonlinear electroencephalography (EEG)-based subparameters. However, only a part of proprietary algorithm has been identified. We investigated the BIS algorithm using clinical big data and machine learning techniques.

Methods: Retrospective data from 5,427 patients who underwent general anesthesia with BIS monitoring were used. Burst suppression ratio (BSR), 95% spectral edge frequency (SEF), and power of electromyogram (EMG) were received from the BIS Vista. SynchFastSlow (SFS) and relative beta ratio (RBR) were calculated from raw EEG waveform. Decision tree analysis (Figure 1) was performed to determine the criteria for EEG subparameters to classify five anesthetic states. For each anesthetic states, random sample consensus regression analysis was performed to derive a multiple linear BIS calculation model. The performance of decision tree and regression models were externally validated with predictive accuracy and mean absolute error, respectively.

Results: A total of 31,372,258 data points were used. A decision tree was built with subparameters. The accuracy of each binary branch of decision tree was 98%, 93%, 80%, and 88% for splitting BIS at 22, 61, 41, and 78 respectively. The median absolute errors of regression models was BIS value of 4.1.

Conclusions: A data driven algorithm of BIS calculation using multiple EEG subparameters of different criteria depending on anesthetic states has been proposed. The results will help the anesthesiologists interpret the BIS values observed during clinical practice.

Figure 1. Decision tree analysis

