Society for Technology in Anesthesia

#STA21Meeting

STA Virtual Annual Meeting Syllabus

The One That Was Different

January 15, 2021
7:00am - 4:30pm PST
9:00am - 6:30pm CST
10:00am - 7:30pm EST

Program Co-Chairs:
Matthias Görges, PhD
Ira Hofer, MD

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Society for Technology in Anesthesia
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Welcome

Welcome to the Society for Technology in Anesthesia's (STA) 2021 Virtual Annual Meeting, the meeting the pandemic couldn't stop. When we last met, none of us could have predicted the events of the past year. I want to thank our Program Chairs, Drs. Matthias Görges and Ira Hofer for marshalling on through uncertainty to put together a program that we hope exceeds everyone's expectations, and for our loyal support staff. Marie Odden is to be commended for not only dealing with life during COVID, but also becoming a new mother. Aubrey Trecek was tireless in doing double duty on behalf of the Society. For anyone contemplating taking on the role of President, I can assure you that having the assistance of the Board of Directors and the support staff make this job feasible even in the worst of times. I'm optimistic that some of the innovations that were necessitated by the virtual format will enhance our future Annual Meetings.

The meeting will be condensed from the usual two and a half days to a single day. Many of the sessions will draw on lessons learned from the pandemic: building your own ventilator, regulation during times of crisis, virtual care, and wellness, but we have also included sessions that could fit into any Annual Meeting. We hope it strikes a fair balance. We continue to honor those who have made significant contributions to the goals of the Society, and will confer the J.S. Gravenstein Award to Jeffrey Feldman, MD, PhD.

We could not survive as a Society without our Corporate Members, and I hope everyone takes time to interact with them in our industry sessions. As a Society committed to bringing innovation to the anesthesia community, we play a unique role in the lifecycle of technology.

So, put on some casual Zoom attire, clean the lenses on those webcams, and settle into a comfortable chair for *The One That Was Different*!

Don't forget to tag the STA in your Annual Meeting social media posts: @STAhq and #STA21Meeting

Jeff E. Mandel, MD, MS
President, Society for Technology in Anesthesia

Invited Faculty

Justin Adams, MBA, BSc
AlertWatch, Inc

Fahad Alam, MD, MHSc
Sunnybrook Health Sciences Centre
University of Toronto

Alia Busuttil, MD
University of Toronto

Shelly Dev, MD, FRCPC
University of Toronto

Nicholas Douville, MD, PhD
Michigan Medicine

Robert Freundlich, MD, MS, MSCI
Vanderbilt University

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

Matthias Görges, PhD
2021 Annual Meeting Co-Chair
British Columbia Children's Hospital

Ira Hofer, MD
2021 Annual Meeting Co-Chair
Ronald Reagan UCLA Medical Center

Laleh Jalilian, MD
University of California, Los Angeles

Nirav Kamdar, MD, MBA
University of California, Los Angeles

Minjae Kim, MD
Columbia University
Irving Medical Center

Kai Kück, PhD
University of Utah

Amy Lu, MD
Stanford School of Medicine

Jeff E. Mandel, MD, MS
Jersey Shore University Medical Center

Clyde Matava, MD
Hospital for Sick Children/
University of Toronto

Dorothee Mueller, MD
Vanderbilt University Medical Center

John Pearson, MD
2021 Abstract Co-Chair
True Health Technologies

Manu Prakash, PhD
Stanford University

Hans Ulrich Schüler
Drägerwerk AG & Co. KGaA

Terri Sun, MD
University of British Columbia

Jack Wasey, BMBCh, MA, MSci, MSc
2021 Abstract Co-Chair
Children's Hospital of Philadelphia

Theodora Wingert, MD
University of California, Los Angeles

Meeting Accreditation Information

Activity Overview

The Society for Technology in Anesthesia (STA) 2021 Annual Meeting will provide a forum for discussion of emerging innovations and technology in anesthesia, with a particular emphasis on the value of innovation in data science and medical devices. Topics covered throughout the program include the latest advances in automated drug delivery, innovations in education through the use of technology, machine learning, electronic anesthesia records, teleHealth applications, and the role of entrepreneurs in medical device technology.

Educational Objectives

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

1. Better understand how to leverage technology in a rapidly changing environment
2. Gain knowledge on best practices for the integration of technology into clinical practice
3. Know about the barriers and opportunities for implementing technology into perioperative care

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.

CME Accreditation Statement

In support of improving patient care, this activity has been planned and implemented by Amedco LLC and the Society for Technology in Anesthesia (STA). 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.

Amedco LLC designates this live activity for a maximum of **5.75** ***AMA PRA Category 1 Credits***™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

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Schedule of Events (Time Zone Specific)

Friday, January 15, 2020 (Time Zones Listed)

Pacific Standard Time	Central Standard Time	Eastern Standard Time

7:00am – 7:10am PST	9:00am – 9:10am CST	10:00am – 10:10am EST

Introduction & Welcome

7:10am – 8:10am PST	9:10am – 10:10am CST	10:10am – 11:10am EST

Panel: Rapid Innovation: Build Your Own Ventilator, Repurposed Anesthesia Machines and Other Gadgets
Moderator: Kai Kück, PhD

- The Rocky Road from Additive Manufacturing to Commercialization: Lessons Learned During the COVID-19 Pandemic
  John Pearson, MD
- Pufferfish: Developing a Rapidly Scalable Full-Feature Ventilator for COVID-19 Patients with ARDS
  Manu Prakash, PhD
- Making the Impossible Possible
  Hans Ulrich Schüler
- Q&A Panel Discussion

8:10am – 9:10am PST	10:10am – 11:10am CST	11:10am – 12:10pm EST

Panel: Virtual Care: Did You Zoom Your Patient Yet?
Moderator: Nirav Kamdar, MD, MBA

- Telehealth: A Digital Portal to Perioperative Care
  Nirav Kamdar, MD, MBA
- Designing High-Quality Telehealth for Anesthesiology
  Amy Lu, MD
- Virtual Care in the Health System of the Future: Digital Technologies for a Remote Future
  Laleh Jalilian, MD
- Q&A Panel Discussion

9:10am – 9:40am PST	11:10am – 11:40am CST	12:10pm – 12:40pm EST

Poster Discussion Breakouts

9:40am – 9:55am PST	11:40am – 11:55am CST	12:40pm – 12:55pm EST

Break

9:55am – 10:25am PST	11:55am – 12:25pm CST	12:55pm – 1:25pm EST

Medtronic Corporate Member Session

- NOL: The Missing Link in Perioperative Pain Monitoring
  Frank Overdyk, MSEE, MD

10:25am – 10:55am PST	12:25pm – 12:55pm CST	1:25pm – 1:55pm EST

Break

10:55am – 11:55am PST	12:55pm – 1:55pm CST	1:55pm – 2:55pm EST

Panel: Wellness/Staffing: Staying Sane (and Working in Teams) When Someone Pulled the Rug Out Under You
Moderator: Clyde Matava, MD

- Nothing Soft About These Skills: Why Emotional Intelligence May Save Us All
  Shelly Dev, MD, FRCPC
- Living with Uncertainty: What Being a Parent in the NICU Taught Me About Living Through a Pandemic
  Alia Busuttil, MD
- Trials, Tribulations & Lessons Learned from Starting a Resident Wellness Curriculum
  Fahad Alam, MD, MHSc
- Q&A Panel Discussion

11:55am – 12:10pm PST	1:55pm – 2:10pm CST	2:55pm – 3:10pm EST

STA Annual Business Meeting

12:10pm – 1:10pm PST	2:10pm – 3:10pm CST	3:10pm – 4:10pm EST

Corporate Member Networking Lunch
Moderator: Justin Adams, *STA At Large Industry Director*

- **AlertWatch**
- **Codonics**
- **Draeger Medical**
- **Expanesthetics, Inc**
- **Medtronic**
- **GE Healthcare**
- **Getinge**
- **Micropore, Inc**
- **Mindray North America**

1:10pm – 2:10pm PST	3:10pm – 4:10pm CST	4:10pm – 5:10pm EST

Pediatrics: It's Not Just Small Adults..
Moderator: Theodora Wingert, MD

- Pediatric Medical Device Innovation - Call to Action!
  Jorge Galvez, MD, MBI
- Development of Panda: A Smartphone App to Support Post-Operative Pain Management in Kids
  Terri Sun, MD
- Big Data, Little People: Challenges and Opportunities in Pediatric Database Research
  Theodora Wingert, MD
- Q&A Panel Discussion

2:10pm – 2:40pm PST	4:10pm – 4:40pm CST	5:10pm – 5:40pm EST

Poster Discussion Breakouts

2:40pm – 3:00pm PST	4:40pm – 5:00pm CST	5:40pm – 6:00pm EST

Break

3:00pm – 3:20pm PST	5:00pm – 5:20pm CST	6:00pm – 6:20pm EST

Mindray North America Corporate Member Session

- Top of Mind Customer Concerns During COVID-19 Pandemic: Cleaning/ Disinfection of Equipment & Remote Customer Training

3:20pm – 4:20pm PST	5:20pm – 6:20pm CST	6:20pm – 7:20pm EST

Retrospective Data Analytics: Why Did You Open Pandora's Box and How Do We Fix It?
Moderator: Robert Freundlich, MD, MS, MSCI

- How Can We Identify Decompensating Patients Faster?
  Dorothee Mueller, MD
- Using Intraoperative Data to Improve Identification (and Management) of Postoperative Acute Kidney Injury Risk
  Minjae Kim, MD, MS
- Incorporating Predictive Algorithms into Clinical Support Systems for the Operating Room and Intensive Care Unit
  Nicholas Douville, MD, PhD
- Q&A Panel Discussion

4:20pm – 4:35pm PST	6:20pm – 6:35pm CST	7:20pm – 7:35pm EST

Closing Remarks

Sustaining & Annual Corporate Members

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Entrepreneur Silver
AlertWatch
Codonics
Expanesthetics, Inc.
Micropore

Company Descriptions

AlertWatch • www.alertwatch.com

AlertWatch develops integrated decision support software to help anesthesiologists improve quality, safety, and efficiency 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 hundreds of 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. The solution is now being used, under IRB, to monitor hundreds of rooms from a Tele-OR facility. Reach out to learn more about this innovative use case.

AlertWatch®:OB - This application tracks each mother throughout the entire labor, delivery and post-delivery process, automatically assessing hemorrhage risk and related clinical issues 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. Research has shown that our proprietary alerting algorithms are more effective at identifying hemorrhages than the existing national guidelines.

AlertWatch®:AC - This application, pending FDA clearance, helps clinicians oversee all types of acute care patients in the ICU and lower acuity settings in the hospital. The solution has powerful clinical decision support built for ECMO and ventilated patients, and also helps clinicians improve their response to sepsis. AlertWatch:AC will be the foundation to your future telehealth initiatives.

AlertWatch®:PACU - This application, pending FDA clearance, helps anesthesiologists remotely monitor and discharge PACU patients. The solution passes on useful analysis from intraoperative data and helps the entire care team provide more consistent care. This solution is now being used, under IRB, to remotely sign out PACU patients. Reach out to learn more about this innovative use case.

Company Descriptions *continued*

Codonics • www.codonics.com

Codonics Safe Label System (SLS) helps to greatly improve medication safety, compliancy and efficiency in the operating room. An award-winning FDA Class II medical device, SLS integrates with anesthesia dispensing carts to help identify and label medications during preparation. A quick scan of a vial or ampoule provides visual and audible verification of the drug in hand, acting as a second set of eyes. A full-color, easy-to-read, TJC-compliant label is presented as the medication is drawn up. Ready to apply to the prepared syringe, the label also includes a barcode for integration at preparation with Epic and Cerner. Using Codonics SLS-WAVE, a highly optimized scanner, enables prepared syringes to be electronically verified while eliminating clicks and improving workflow, simultaneously documenting the drug, concentration and time-stamp 'hands-free' in the patient record. Advanced integration with Epic enables interoperable syringe pump interoperability to significantly improve the anesthesia workflow through automated programming and documentation that significantly reduces provider interaction with the EMR. Let us help you modernize your anesthesia workflow for improved safety, compliancy and documentation.

Draeger Medical • https://www.draeger.com/en-us_us/home

Drager is an international lead in the fields of medical and safety technology. Our products protect, support and save lives. This is what drives: Improving Critical Care in the Operating Room. We optimize OR workplaces for efficient anesthesia delivery and surgical procedures using innovation equipment with intuitive user interfaces. Our proven anesthesia machines are uniquely designed to protectively ventilate surgical patients and thus help reduce the risk for postoperative pulmonary complications. Our perioperative care portfolio supports your surgical teams because it is technically sophisticated without being complicated. "Your specialist in Critical Care".

Edwards Lifesciences • www.gehealthcare.com/products/anesthesia-delivery

Our company is driven by a passion to help patients. We partner with clinicians to develop innovative technologies in the areas of structural heart disease and critical care monitoring to help patients live longer, healthier and more productive lives.

Expanesthetics. Inc • www.expanesthetics.com

Expanesthetics is the global leader in developing new inhaled general anesthetics with fewer side effects. The company aims to revolutionize anesthesia care and accelerate surgical access for the 5 billion people who lack it by developing new agents with more specific mechanisms of action. At the heart of the company's technology is a scientific discovery related to a 175-year-old mystery: how the inhaled general anesthetics work at a molecular level. This technology, licensed on a globally exclusive basis from a major research university, powers the company's work to increase the choice of agents available to anesthesia clinicians around the world.

GE Healthcare • www.gehealthcare.com

GE Healthcare is a leading provider of anesthesia delivery and patient monitoring. GE Healthcare enables precision health through intelligent devices, data analytics, and applications to help providers and researchers in their mission to improve outcomes for patients around the world. With the Aisys CS2 anesthesia machine and cloud-based analytics platform, Carestation Insights, we are building an intelligent ecosystem of connected machines the reveal patterns and actionable insights that may help clinicians improve patient outcomes.

Company Descriptions *continued*

Getinge • www.getinge.com

With a firm belief that every person and community should have access to the best possible care, Getinge provides hospitals and life science institutions with products and solutions aiming to improve clinical results and optimize workflows. The offering includes products and solutions for intensive care, cardiovascular procedures, operating rooms, sterile reprocessing and life science. Getinge employs over 10,000 people worldwide and the products are sold in more than 135 countries.

Masimo • www.masimo.com

Masimo is a global medical technology company that develops and produces a wide array of industry-leading monitoring technologies, including innovative measurements, sensors, patient monitors, and automation solutions. The rainbow SET™ Pulse CO-Oximetry family includes such measurements as SET® pulse oximetry, noninvasive and continuous hemoglobin (SpHb®), and acoustic respiration rate (RRa®).

Medtronic • https://www.medtronic.com/us-en/healthcare-professionals/products/patient-monitoring.html

Medtronic plc (www.medtronic.com), headquartered in Dublin, Ireland, is among the world's largest medical technology, services and solutions companies – alleviating pain, restoring health and extending life for millions of people around the world. Medtronic employs more than 90,000 people worldwide, serving physicians, hospitals and patients in more than 150 countries. The company is focused on collaborating with stakeholders around the world to take healthcare Further, Together.

Micropore • www.microporeusa.com

Micropore, Inc. located in Elkton, Maryland, packages fine powder chemistries into solid absorbent cartridges that are used to absorb carbon dioxide in rebreathing and life support systems. Founded in March of 1997, Micropore's solid cartridge technology out performs traditional granular CO_2 absorbents. The patented technology is the first major advance in CO_2 absorbent technology in over 100 years, providing superior performance advantages over existing granular absorbents.

The CO_2 absorbent cartridges are marketed under the ExtendAir® and SpiraLith®Ca™ brand names and are used for life support in the fire-fighting, medical, dive, submarine, and military markets.

Mindray North America • www.mindray.com

At Mindray, we believe we can change lives by making the most advanced healthcare technology attainable for all. We are a leading developer, manufacturer and supplier of medical device solutions and technologies used in healthcare facilities around the globe. We empower healthcare professionals through innovative, high-value solutions that help create the next generation of life-saving tools across patient monitoring, anesthesia delivery, and ultrasound imaging.

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*** Best Clinical Application Award ** Excellence in Technology Award *** Best in Show Award**

	Abstract #	Full Abstract Title	Presenting Author	Institution
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	2	Design and Implementation of a Voice-Based Controller for the Solar 8000 Monitor	Christopher Connor, MD, PhD	Brigham and Women's Hospital
	3	Pre-Deployment Assessment of NETCCN COVID-19 Tele Critical Care Technologies in a Laboratory Environment	David Arney, PhD	Massachusetts General Hospital
	4	Intraoperative Arterial Pressure Waveforms Shows Temporal Structure Complexity Correlated with Acuity of Liver Transplant by Pulse Wave Manifold Learning Analysis	Shen-Chih Wang, MD, PhD	Taipei Veterans General Hospital
	5	Resurrecting a 'Shocking' Dinosaur: Updating the Original Mechanomyography Gold Standard for 2020	Kelly Michaelsen, MD, PhD	University of Washington
	6*	Analgesic Monitoring Indices in Response to Noxious Stimuli of Laparoscopic Cystectomy Surgery and Their Time Optimization	Yu-Ting Lin, MD, PhD	Taipei Veterans General Hospital
	7	Approximating the Inter- and Intra-Patient PK/PD of Propofol-Induced Burst Suppression	Jason Huang, BS	University of Utah
	8	Comparison of Near-Infrared Spectroscopy-Derived Cerebral and Somatic Oxygenation Indices During Pediatric Scoliosis Surgery	Michael Wood, PhD	University of British Columbia
ADVANCEMENTS IN TECHNOLOGY	9**	Measuring the Performance of Multi-Pump Infusion Systems with Spectrophotometry	David Arney, PhD	Massachusetts General Hospital/Harvard University
	10	Preliminary Experience With a New High-Speed Flow Sensor for Investigating and Improving Syringe Pump Flow Performance	Robert Butterfield, BSE	RDB Consulting
	11	Detecting Abnormalities on Displays of Patient Information	Sydney Fleishman	Vanderbilt University
	12	A Framework for Evaluating Healthcare Machine Learning Models: Application and Analysis Using Hospital Readmission	Eilon Gabel, MD	University of California, Los Angeles
	13	Improved Sedation Capnography And Enhanced Patient Safety For Sedation Anesthesia	Michael Jach, MD	
	14***	Reduction of Preoperative Anxiety Using Virtual Reality vs Midazolam: A Randomized Controlled Trial	Anthony Koo, MD Sanjana Khanna, BS	Phoenix Children's Hospital
	15	Leveraging the Human Digital Twin for Perioperative Monitoring of Pediatric Patients- An Early Case Study	Hannah Yates, BS	Johns Hopkins
BIG DATA & DATABASE RESEARCH	16	Modeling the Cost Savings of Continuous Pulse Oximetry and Capnography Monitoring of United States Hospital Ward Patients Receiving Opioids	Ashish Khanna, MD, FCCP, FCCM	Wake Forest School of Medicine
	17	Defining Gender and Race/Ethnicity-Specific Laboratory Reference Ranges and its Impact on Predicting Post-Operative Acute Kidney Injury and Mortality Outcomes	Andrew Lee, MS	University of California, Los Angeles
	18	Machine Learning Approaches to Predict Intraoperative Transfusion	Matthew Zapf, MD	Vanderbilt University
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A Novel Device That May Lower the Incidence of Injectable Medication Errors

Presenting Author: Tariq Chaudhry MD, Associate Professor, Tufts Medical Center, Boston
Co-Author: Kevin Small, BSPS, Medical Engineering, Tufts Medical Center, Boston

Background: Medication errors injure at least 1.5 million patients per year, increase hospital costs of approximately $4700 per admission and result in excess costs of over 2 billion dollars every year in the US.[1, 2]

As many as 81% of medication errors occur in the operating rooms and the post-anesthesia care units as these are the most medication intensive areas with high-potency medications.[3] Anesthesia providers select, calculate and administer medications, monitor patients and equipment while dealing with distractions, fatigue and productivity pressures.[4]

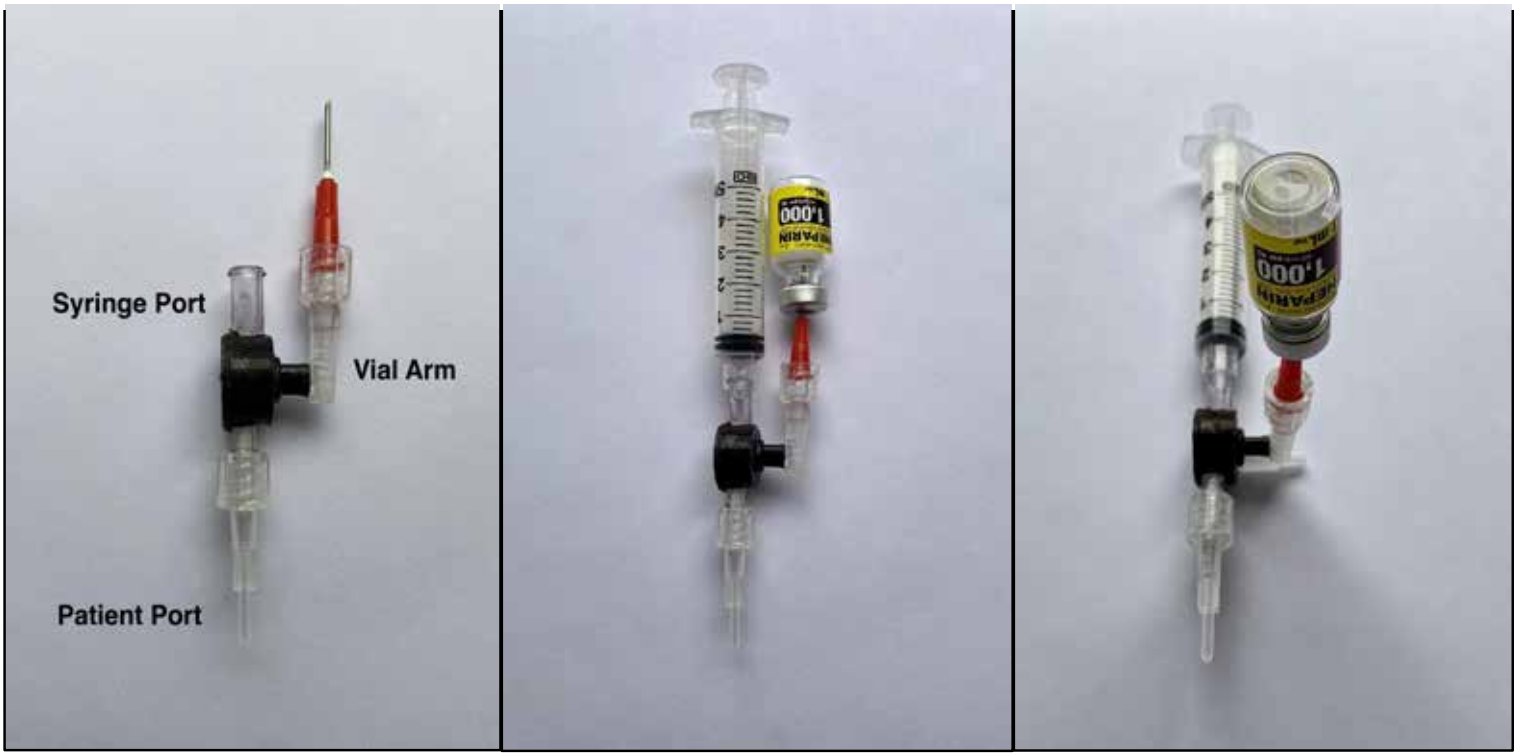
In 2004 the FDA mandated the use of barcodes on all medications however, the goal of a 50% error reduction has not been achieved.[5] A recently published prospective study found 1 in 20 perioperative medication administration resulted in a medication error even though the hospital in the study often used a barcode-assisted syringe labeling system.[6]

The most common errors are associated with absent or incorrect labeling, wrong doses and wrong medications.[7] Common causes leading to these errors are unlabeled syringes, similar looking drug vials, vials sitting in wrong drawers, drug shortages leading to unfamiliar vials by a different provider, manually creating a label or picking up the wrong syringe.

Methods: Following the concept and a working prototype, a functioning device was manufactured at the medical engineering lab at Tufts Medical Center. Drug vial is loaded on the vial-arm and medication is drawn in a syringe. Injecting the medication will flush it back into the drug vial. In order to inject into the patient, the vial-arm is rotated 90 degrees which closes the vial-channel and opens the patient-channel.

The device reliably creates a system where the medication is interacted with twice - initially when a medication vial is picked up and finally, prior to injecting into the patient. A final verification is performed before surgeries and invasive procedures to prevent patient injuries. While it is common to discard medication vials once the medication is drawn up, this device allows the final verification against the used-vial addressing wrong medication or wrong dose errors associated with mislabeled or unlabeled syringes.

Discussion: The device is relatively inexpensive to manufacture and once a vial is loaded, the second verification cannot be bypassed, ensuring improved safety-compliance and could play a role in lowering the incidence of the injectable medication errors.



Left, device components explained. Center, drug vial is connected using the vial-arm needle and medication is drawn up in the syringe. Injecting the medication flushes it back into the vial. Right, the vial-arm must be rotated 90-degrees to open the patient-channel before the patient can receive the medication.

References:

1. Mike Stabile; Craig Webster; Alan Merry: *Medication Administration in Anesthesia:* Anesthesia Patient Safety Foundation, Fall 2007
2. Institute of Medicine.*To Err is Human: Building a Safer Health System*. Washington, DC: National Academies Press; 2000
3. Steve Frandzel, *Bar-Code Scanning Can Fix Black Hole of OR Drug Safety,* Anesthesiology News, Jan 2012
4. Institute of Safe Medication Practices: *Key Medication Errors in the Surgical Environment April 2016*
5. Mike Stabile; Craig Webster; Alan Merry: *Medication Administration in Anesthesia:* Anesthesia Patient Safety Foundation, Fall 2007
6. Nanji, M.D, Amit Patel, M.D: *Evaluation of Perioperative Medication Errors and Adverse Drug Events,* Anesthesiology, V 124, No 1, Jan 2016
7. Matthew Grissinger: *Key Vulnerabilities in the Surgical Environment-Container Mix-ups and Syringe Swaps,* Pharmacy and Therapeutics, Mar 2018

Design and Implementation of a Voice-Based Controller for the Solar 8000 Monitor

Presenting Author: Christopher W Connor, MD, PhD, Brigham and Women's Hospital

Background/Introduction: Recently, in response to the STA Engineering Challenge for 2020, we demonstrated and published that a standard Solar 8000 anesthesia monitor (General Electric, Madison, WI) could be controlled by touchless gestures by electronically modifying an external controller [1]. In the course of this work, we found that there was considerable enthusiasm among surveyed clinicians for also implementing a method for obtaining voice control of this near-ubiquitous anesthesia device.

Methods: A Solar 8000 controller was purchased on the secondary market and re-wired to a Raspberry Pi (Raspberry Pi Foundation, Cambridge, UK) and a custom daughter board containing an MT8808 8x8 Analog Switch Array (Microsemi, Ottawa, Canada). The controller was modified so that all possible keypresses or dial movements on the controller could be generated electronically through programmatic manipulation of the switch array gates. An external microphone/speaker was attached, as shown in Figure 1. Detection of wake-words was accomplished using Snowboy (https://snowboy.kitt.ai) locally on the device, and received speech was parsed into intentions using Google Voice (https://voice.google.com) in the cloud. Intentions were effected by creating the relevant sequence of simulated keypresses or dial movements on the controller through the intermediary hardware interface.

Results: A range of spoken word commands, such as to cycle the blood pressure or to silence an alarm or to zero an arterial line, were successfully detected, parsed, and effected through the modified controller interface. Response times were satisfactory for plausible clinical application even when relying upon cloud-based remote services for speech interpretation.

Conclusion: Voice-based operation of the GE Solar 8000 monitor is technically viable by modification and retrofitting of an existing controller, and a combination of local and cloud-based software. Surveyed anesthesiologists appear to be enthusiastic about the potential for novel, hands-free user interaction.

References:

1. Owens GE, Connor CW, "Controlling Anesthesia Hardware with Simple Hand Gestures: Thumbs Up or Thumbs Down?". Anesthesia & Analgesia 2020, online ahead of print. PMID: 32701544

Figure:

Pre-Deployment Assessment of NETCCN COVID-19 Tele Critical Care Technologies in a Laboratory Environment

Presenting Author: Julian M. Goldman, MD
Co-Authors: David Arney, PhD, Yi Zhang, PhD, David Guffrey, MS, MSM, and team leads of The Geneva Foundation NETCCN DISTRESS team: Tracy Rausch, Steven Dain, MD (DocBox), Sanjay Subramanian, MD (Omnicure), Christopher Colombo, MD (Geneva Team P.I.)

The COVID-19 pandemic has led to an increased interest in using telemedicine and tele-critical care (TCC). Solutions typically comprise multiple components, such as patient monitoring and reporting, clinician communication, and administrative coordination. This complexity and urgency necessitate testing prior to clinical deployment. The Medical Device Plug-and-Play Interoperability and Cybersecurity lab at Massachusetts General Hospital (MD PnP) contains an environment to facilitate the rapid evaluation of new medical devices and systems, including engineering development of prototypes and improvised setups that may have not yet been cleared for clinical use. We used the MD PnP lab to evaluate a novel combination of technologies, developed by the DISTRESS team, intended for tele critical care of COVID-19 patients in the TATRC National Emergency Tele Critical Care Network* [https://www.tatrc.org/www/resources/covid-19.html].

Our approach included configuration of the system to reflect simultaneous care of 3 patients by local and remote providers. Connected medical devices included three patient monitors and two ventilators. Two of the patient monitors were physical devices (Philips MX800 and MP70) and one was virtual - simulated in software. One ventilator was a physical device (PB 980 or GE Engstrom) and one was virtual. The mix of physical and virtual devices permits testing of data connectivity from real medical devices while enabling scalability with virtual devices to simulate numerous patients. Patients were represented by 2 Fluke ProSim 8 patient simulators, a Michigan Instruments test lung, and pre-recorded time series of vital signs, integrated into a test harness which included modifications to the ProSim8 to allow for long-term remote operation through the OpenICE platform (openice.info). Additional patients were simulated by custom software. The medical devices were connected to three DocBox systems (docboxmed.com), which captured data from the bedside medical devices, translated communications into a standards-based nomenclature and time-base, provided an interface for bedside visualization and notation, and transmitted data to cloud servers.

Medical device data and other patient information was retrieved from these servers and presented to remote clinicians using the Omnicure app (omnicuremd.com). Omnicure provided the ability for clinicians to manage multiple patients and create alerts and notifications based on the medical device data. Omnicure also integrates with text, voice, and video chat capabilities to allow remote clinicians to assist the local providers.

The aim of the project was to demonstrate, test, and evaluate this end-to-end system to assess its suitability to support remote consultation and care of COVID-19 patients, as well as develop generalizable test methods. We tested the ability of Omnicure to receive data from medical devices accurately and in a timely manner. This was done by creating clinical scenarios, modeling typical COVID-19 progression, and using these to drive patient simulators. Then the data could be observed as it was recorded in the server database and the Omnicure app to evaluate performance. These tests were done repeatedly while introducing network perturbations through varying available bandwidth and overall latency between the lab) and servers. These parameter adjustments represented varying qualities of network connection at

care facilities as well as enabled characterizing minimum network quality needed to support reliable system communications.

System issues were identified by iterative functional and usability testing which enabled resolution prior to clinical deployment. The approach to creating test scenarios, scripts, and developing patient simulators to create realistic vital sign progressions, and evaluation of system performance under varying network conditions is broadly applicable to telemedicine applications and especially to the development of Smart and Autonomous Medical Systems (SaAMS).

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Intraoperative Arterial Pressure Waveforms Shows Temporal Structure Complexity Correlated with Acuity of Liver Transplant by Pulse Wave Manifold Learning Analysis

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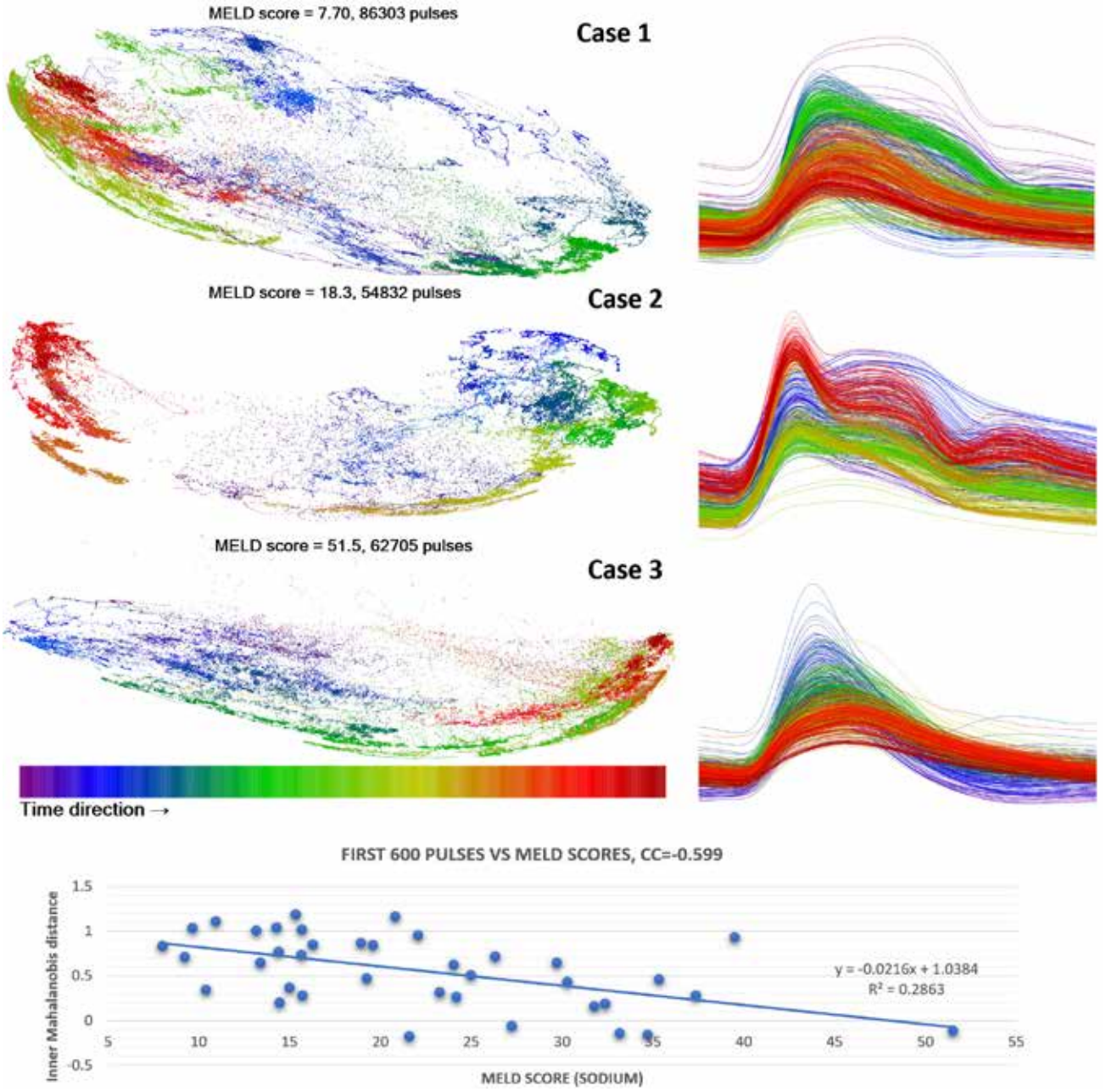
Introduction: Arterial blood pressure (ABP) waveform reflects numerous aspects of the human circulation system. The waveform morphology has been exploited in clinical scenarios to predict hypotension, to assess arterial stiffness, or to derive the profiles of the cardiovascular system. As the intrinsic physiological mechanisms are continuously regulating to maintain homeosis, the temporal evolution information may reveal this dynamic process, which is not addressed by the above ABP waveform applications.
Recipients of the liver transplantation range from relatively stable chronic liver disease to critically fulminant hepatic failure. Careful preoperative evaluation and preparation is paramount to this life-saving surgery. To assess the outcome preoperatively, the Model for End-Stage Liver Disease (MELD) score was developed from lab tests including creatinine, bilirubin, INR, and sodium data. As the disease acuity may also compromise numerous physiological mechanisms for homeosis, we propose that the ABP waveforms evolving with time reflect the severity of the patient's condition.
We hypothesize that favorable condition of liver transplant recipient possesses more intricacy in the pulse waveform time evolution structure. We evaluate ABP pulse waveforms immediately after anesthetic induction as this period representing the initial status.

Methods: We conducted a prospective observational study for liver transplant after institutional ethic review board approval and the informed consent obtained from every case. We collected intraoperative physiological signal data of 39 liver transplant recipients from the standard patient monitor (GE CARESCAPE B850, GE Healthcare, Chicago, IL). To effectively measure the "inner structure" of ABP waveform, we use an unsupervised manifold learning method, diffusion map (DMap), to "condense" the temporal information into a "relatively" low dimensional structure. DMap treats every oscillatory cycle as a high dimensional data point and finds a geometric structure in high dimensional space representing the trajectory of the waveforms evolving with time. Using only the successive pulse-to-pulse waveform morphology, this unsupervised method was performed objectively without the input of medical history, lab test data, or the surgical procedure.
Quantitative measurement of the intricacy of the manifold structure was performed by the Mahalanobis distance, which is the multi-dimensional version of the famous standard deviations. The more intricacy of the structure leads to the larger inner Mahalanobis distances measured. We use information of top 10 dimensions to calculate the Mahalanobis distance, which was measured from the first 600 ABP pulses of each case to assess their "initial condition" just after the anesthetic induction. Spearman rank correlation between the distance and MLED score is evaluated.

Results: Visually presented by DMap, the ABP pulse waveform evolving with time exhibits a trajectory. The trajectory structure from the case of favorable condition (suggested by MELD score) exhibits a more intricate structure and vice versa (Fig. 1). The Spearman rank correlation to MELD score is –0.60 as high MELD score represents unfavorable outcome.

Conclusions: Intraoperative ABP pulse waveform contains the acuity information of liver transplant.

Figure 1:



Three liver transplant cases of different MELD scores (upper panel) and the Spearman rank correlation of 39 liver transplant recipients (lower panel). Their whole intra-operative ABP pulse waveforms (right column) and the different intricacy of the time evolution trajectory extracted by manifold learning (left column).

Resurrecting a 'Shocking' Dinosaur: Updating the Original Mechanomyography Gold Standard for 2020

Presenting Author: Kelly Michaelsen, MD, PhD, University of Washington

Co-Authors: Srdjan Jelacic, T. Andrew Bowdle, MD, PhD, University of Washington

The gold standard assessment tool for measuring neuromuscular blockade (NMB) has traditionally been mechanomyography[1], despite the lack of commercially available testing systems. Recent advances in pharmacologic reversal as well as new commercialized electromyographic measurement tools have been hampered by a lack of access to this gold standard. Previously, at this conference, we demonstrated a novel mechanomyography device for assessment of quantitative train of four (TOF) ratio[2,3]. However, this device has never been externally validated through comparison with one of the original mechanomyography systems due to a lack of access[4]. Having recently obtained an original mechanomyography system modifications to the hardware and software have been made to allow the device to work with modern computers for comparison testing our new compact, inexpensive mechanomyography device.

Original studies used a Grass Instruments FT 10 force (Grass Instruments, Quincy, MA) transducer which we obtained in addition to a Grass Model 7400 physiological recorder (Astro-Med, Inc, Warwick, RI) as shown in the figure (A, B). The recorder has a small electronic display. Data results could be written in real time on a roll of graph paper (broken on our instrument) or saved to a 3.5” hard disk, neither of which are in use today. An analog output channel was available, which was functional after wire splicing, shielding and digitization via an analog to digital converter, NI DAQ USB 6009 (National Instruments, Austin, TX). A LABView (National Instruments, Austin, TX) program was written to control the data collection process and calculate the train of four measurements in real time.
After updating the data collection process, a complex arm holder was needed to suspend the force transducer above the hand of the patient as shown in the figure (C). Design considerations for this phase included minimizing force dispersions during high loads and keeping a precise parallel relative to the thumb to maximize the output signal. Using an old research arm holder device as a starting point, a mechanism for suspending the force transducer was built into it. The design allowed for multiple degrees of adjustment through set screws and a beaker clamp to adapt precisely for a given patient. The thumb is held in place by a disposable commercial finger brace suspended by Kevlar thread (Superior Threads, St. George, UT).

The system was calibrated using a series of weights up to 2kg (Ohaus, Florem Park, NJ) in order to calculate the system accuracy, precision, sensitivity and resolution, shown in figure (D). Data analysis was performed using MATLAB (Mathworks, Natick, MA). Measurement ranges were -3 to 3V for the original MMG and 0 to 5V for the new MMG. Both were highly linear, with original and new calibration R squared values of 0.999 and 1.000 respectively. Measurements were remarkably stable with mean standard deviation of 1.5 and 0.5 mV respectively for 1000 sequential samples at eighteen weights. Resolution of 0.36 and 0.31 mV and measurement precision to 56mV and 16mV respectively. This original system was less accurate than the new prototype mechanomyography system likely due to degradation of mechanical parts with time and the advent of more stable electronics over the past fifty years, other drawbacks include significantly longer set up time and larger size. The IRB approved patient trial of original mechanomyography compared with our new mechanomyography has been delayed by the pandemic but results will be presented at the conference if available.

Force transducer (A) and physiological recorder (B), hand setup (C) and device calibration (D)

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Analgesic Monitoring Indices in Response to Noxious Stimuli of Laparoscopic Cystectomy Surgery and Their Time Optimization

Presenting Author: Shen-Chih Wang, MD, Taipei Veteran General Hospital

Co-Author: Yu-Ting Lin MD, Shen-Chih Wang, MD, Chien-Kun Ting, MD, Shin-E Wang, MD, Yi-Ming Shyr, MD, Taipei Veteran General Hospital

Introduction: Adequate pain relief is a sophisticated work for perioperative patient management. Parameters, based on different physiological data, including heart rate, autonomic nervous system and electroencephalographic (EEG) activity are developed to reflect dynamic changes of noxious stimuli in surgery. However, the duration from the painful stimulus to the peak index of these parameters are not elucidated. Several factors are involved, such as the physiologic response time and the time window of data processing in the instrument. The knowledge of such time profiles of parameters for pain may help the anesthesiologist to assess the analgesia-nociception balance more accurately.
In this study, we investigate the time profile of indices from several analgesic monitoring instruments in response to uniform noxious stimuli. The precise time points facilitate the subsequent probing of the best time duration of index responses in terms of the group receiver operating characteristic (ROC) area.

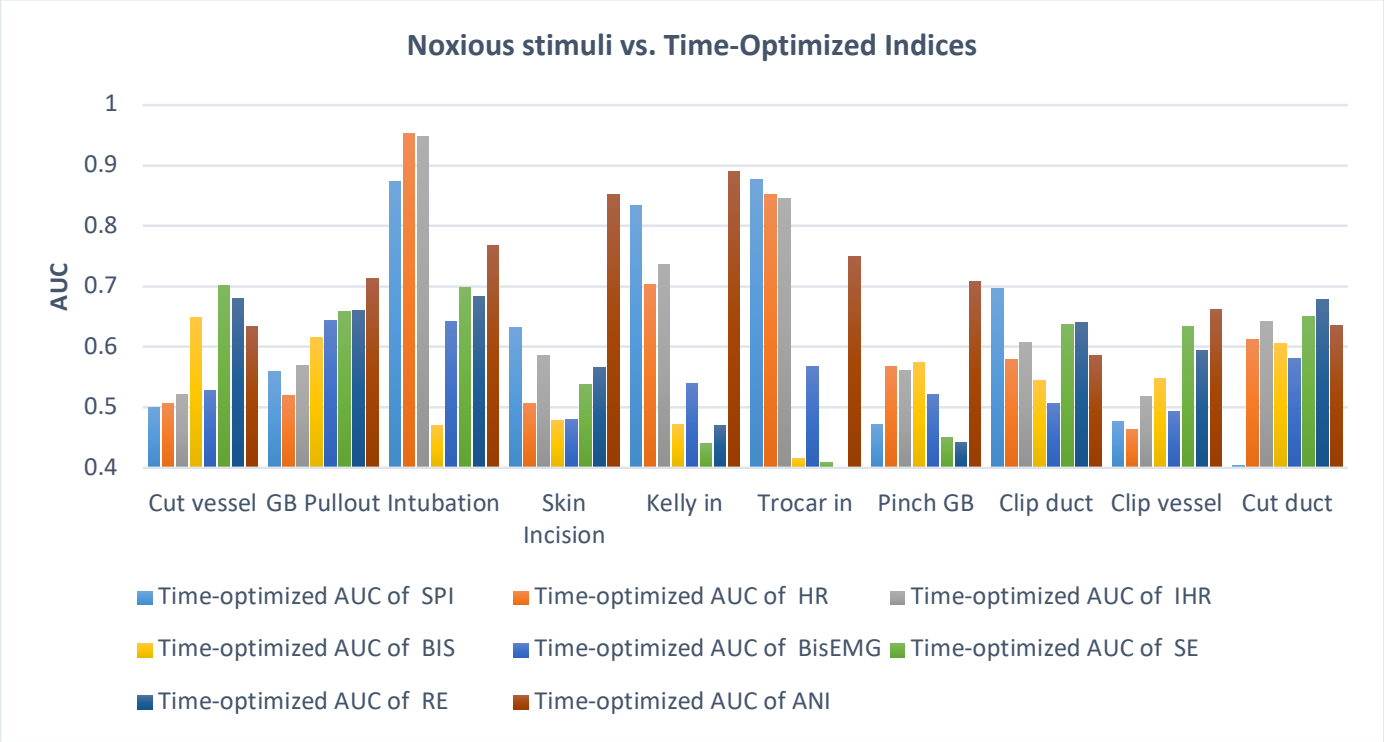
Methods: After obtaining institutional ethic committee approval, we conducted the prospective observation study to collect intraoperative data from the monitoring instrument from patient undergoing laparoscopic cholecystectomy surgery with each informed consent. EEG monitoring instruments including Bispectral Index (BIS), Entropy module (Spectral Entropy and Response Entropy), Analgesia Nociception Index (ANI), and Surgical Pleth Index (SPI) as well as the standard patient monitor (GE CARESCAPE B850, GE Healthcare, Chicago, IL) were attached with corresponding sensors per clinical standard and manufacturers' instructions. The data were recording for offline analysis. We recorded the exact time stamps of sequential noxious stimuli, including endotracheal intubation, skin incision, peritoneal penetration via Kelly hemostatic forceps, laparoscopic trocar tube insertion, ballbladder pinch, cystic duct clamping, cystic duct cutting, cystic vessel clamping, cystic vessel cutting.

The data analysis is performed with respect to the stimulus time to find the "best" time interval after. With respect to each stimulus, we use the one minute before as the "pre-stimulus" period and the subsequent two minutes as the interval to search for the "optimal" post-stimulus period. After normalizing data of "potential" post-stimulus period by the mean value of pre-stimulus period with respect to each case and index, we use the group area under the ROC curve (AUC) as the fitness function to obtain the optimal post-stimulus period. Data between 10% and 90% percentile were considered for calculation. The analysis was performed by R language (ver. 4.0.3) and the R package *pROC* (ver. 1.16.2).

Results: SPI and ANI are the best two noxious indices across all noxious stimuli except the endotracheal intubation. The time optimization shows stronger responses in somatic area than visceral area, while the pinch of gallbladder and the cystic duct clipping are the most two visceral stimuli according to SPI and ANI index. The maximum response time of SPI (73.5s) is earlier than that of ANI (100.0s). EEG derived indices are relatively obtuse.

Conclusions: The strengths and time profiles of indices are distinct and probably valuable for Intraoperative analgesics administration.

Figure:


Noxious stimuli vs. Time-Optimized Indices
AUC
1
0.9
0.8
0.7
0.6
0.5
0.4
Cut vessel
GB Pullout
Intubation
Skin Incision
Kelly in
Trocar in
Pinch GB
Clip duct
Clip vessel
Cut duct
Time-optimized AUC of SPI
Time-optimized AUC of HR
Time-optimized AUC of IHR
Time-optimized AUC of BIS
Time-optimized AUC of BisEMG
Time-optimized AUC of SE
Time-optimized AUC of RE
Time-optimized AUC of ANI

Approximating the Inter- and Intra-Patient PK/PD of Propofol-Induced Burst Suppression

Presenting Author: Jason C Huang BS; University of Utah

Co-Authors: Scott Tadler MD, Brian Mickey MD PhD, Keith Jones BS, Kai Kuck PhD; University of Utah

Introduction: Our group is investigating the antidepressant effects of high-dose propofol[1] over repeated treatments. Propofol is titrated to induce a standardized depth and duration of burst suppression. Accurately controlling propofol-induced burst suppression (PIBS) is challenging due to limited knowledge of each patient's pharmacokinetics (PK) and pharmacodynamics (PD). Approximating a PK-PD model for PIBS, and optimizing the model over repeated treatments, could support individualized propofol dosing. In this exploratory study, we fitted model parameters to characterize the relationship between propofol administered, predicted effect-site concentration (pCe), and BSR. In particular, we sought to study the intra-patient (inter-treatment) and inter-patient distribution of model parameters.

Methods: Following IRB approval and informed consent, each of six patients (5:1 female:male, 33-51 yo, BMI 18.3-36.7 kg/m^2) underwent 4 to 8 treatments within 3 weeks, targeting a burst suppression ratio (BSR) of 80% ± 10% for 15 min. We recorded the administered boluses and infusion rates, along with the BSR(t) from a BIS™ Vista Monitor (Medtronic, Dublin, Ireland). The patients' demographics (sex, height, age, weight) were used to approximate PK parameters via the Eleveld Model[2], then used Euler's numeric approximation to calculate pCe(t). The ke0 parameter was iteratively determined for each treatment by maximizing the least squares fit (R^2) to the Hill Equation[3] between pCe(t) and the observed BSR(t). The regression also identified the corresponding Hill and EC50 parameters for each treatment. For each patient, we determined the inter-treatment mean and geometric coefficient of variation[4] (CV) for all three parameters. We also determined the overall mean and CV for all three parameters across all treatments in all patients.

Results:

	ke0 (min^{-1})		Hill		EC50 (mcg/mL)		Treatments	Demographics		
Patient	Mean	CV	Mean	CV	Mean	CV		Sex	Age (yr)	BMI (kg/m^2)
A	0.124	24%	5.50	15%	5.49	5%	**6**	M	33	27.6
B	0.189	23%	8.54	80%	7.63	10%	**4**	F	48	36.7
C	0.124	39%	9.13	94%	6.27	28%	**6**	F	49	18.3
D	0.128	35%	4.64	79%	6.81	24%	**6**	F	39	27
E	0.101	67%	7.85	39%	5.75	46%	**6**	F	51	20
F	0.121	22%	7.76	48%	4.40	13%	**8**	F	51	23.2
Overall	0.126	60%	7.39	90%	5.88	48%				

Discussion: Our study approximated the PK/PD characteristics of PIBS and offers preliminary insight into intra-patient PK/PD variability. Results provide an initial indication that PK/PD parameters might have less intra-patient variability than inter-patient variability. Our study is limited by its small sample size and by the experimental design, which did not primarily pursue a pharmacological characterization. The inter-patient variability of model parameters could also be confounded by demographic differences. If confirmed in a larger study, these results indicate PK/PD-inspired models could be optimized over repeated treatments, then further used to individualize high-dose propofol dosing and improve control of PIBS.

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Comparison of Near-Infrared Spectroscopy-Derived Cerebral and Somatic Oxygenation Indices During Pediatric Scoliosis Surgery

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Background: Posterior spinal instrumentation and fusion (PSIF) for scoliosis surgery is a long surgical procedure, commonly performed in pediatrics. As such, patients are exposed to significant physiologic insult, including significant blood loss,[1] and thus inadequate end-organ perfusion. Near-infrared spectroscopy (NIRS) is a non-invasive technique to continuously quantify tissue oxygenation and may allow anesthesiologists to better understand individual patient physiology. However, NIRS monitoring has not been established as a measure of systemic tissue perfusion in many elective surgical procedures and the relationship between NIRS-derived regional cerebral oxygenation (ScO_2) and tissue oxygen saturation (StO_2) is currently unclear.

Objective: To evaluate the association and agreement between ScO2 and StO_2 during scoliosis correction surgery.

Methods: A prospective observational pilot study of children undergoing single-stage PSIF was undertaken. After induction of general anesthesia, Fore-Sight Elite (Edwards Lifesciences, USA) NIRS sensors were applied to the forehead and forearm to measure ScO_2 and StO_2, respectively. Anesthetic management was left to the discretion of the attending anesthesiologist, who was blinded to the NIRS recordings for both sensors. We conducted repeated measures correlations to assess the within-subject associations across sensors (i.e. separate parallel regression lines are fit to each participant's data using the same slope but with varying intercepts)[2]. To quantify the mean bias and level of agreement between the two NIRS sensors, repeated measures Bland Altman analysis was implemented[3].

Results: Data from 48 children (39 female), with a median [IQR] age of 16.3 [14.8-18.0] years, and a BMI of 20.5 [18.6-23.2] kg/m^2, were available for analysis. All 48 children underwent successful dual-sensor placement; sensors recorded similar levels of NIRS-derived oxygen saturation throughout the period of recording with a median [IQR] ScO_2 of 79.1 [74.6-84.8] and StO_2 of 79.3 [75.6-82.4]. The repeated measures correlation between the cerebral and somatic sensors (Figure 1A) indicated a significant positive association ($r = 0.42$, 95% CI 0.39-0.45, $p < 0.001$). Bland Altman analysis indicated that the mean difference (i.e., bias) between the sensors was 0.77, which indicates that the somatic sensor on average records 0.77% lower than the cerebral sensor. However, the lower and upper limits of agreement (-17.1% and 18.6%, respectively) were wide, indicating that the 2 sensors display low agreement (Figure 1B).

Conclusions: Although ScO_2 and StO_2 signals were positively correlated, Bland Altman analysis indicated that ScO_2 and StO_2 had wide and unacceptable limits of agreement. These results indicate that further research is needed in a larger cohort to validate our current findings and to characterize the physiologic determinants of the two NIRS signals. As regional tissue perfusion might be an earlier indicator of perfusion deficits, further elucidation of these signals may provide anesthesiologists with physiologic information to help guide therapy during scoliosis correction surgery.

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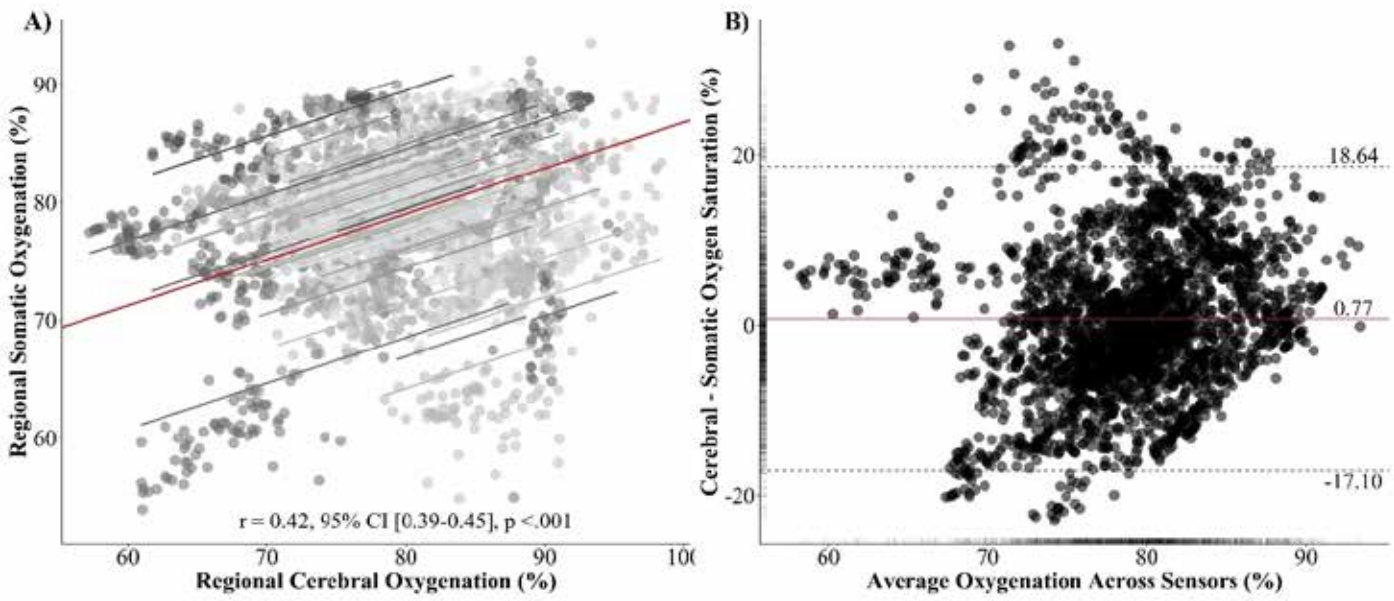

Figure 1: A) Scatterplot indicating the association between near-infrared spectroscopy derived regional cerebral and somatic oxygenation. The corresponding repeated measures correlation coefficient and 95% confidence intervals are mapped onto a gray scale indicating different patients and their individual line of fit. The red line indicates the linear model fit to the entire sample. **B)** Bland Altman plot indicating that the pooled data across the cerebral and somatic sensors display a wide range of agreement. The dotted black lines indicate the 95% limits of agreement (i.e., the two sensors mean minus 1.96 SD and plus 1.96 SD). The red line represents the mean (i.e., bias) of recordings across sensors. Black dots represent repeated recordings of regional cerebral and somatic oxygenation across 48 participants.

Measuring the Performance of Multi-Pump Infusion Systems with Spectrophotometry

Presenting Author: David Arney, PhD
Co-Authors: Nathaniel M. Sims, MD; Lauren E. Gibson, MD; Anders S. Knudsen; Robert A. Peterfreund, MD, PhD

Background: Infused drugs are often delivered to a patient via an infusion system consisting of a pump, tubing, and the intravascular catheter. For some patients receiving multiple infusions, the output of 2 or more pumps merge at a junction point or manifold, often with a carrier, then flow together through one catheter lumen. The rate at which a pump delivers fluid, even at a static setting, changes over time with cycles ranging in length from seconds to minutes because of the way the pumps are designed and manufactured. The composition of the combined pump output at the point where it meets the patient's bloodstream is affected by the changing rates of the multiple pumps and by fluid dynamics, particularly mixing that occurs in the infusion system dead volume. For many drugs, the rate variations are small enough to not be clinically relevant. However, short term variations in drug concentration may be clinically relevant when fast-acting drugs with a short half-life are given at high concentrations and low flow rates. These conditions are encountered when treating patients limited in the total amount of fluids they can receive, such as in pediatric populations. To understand the performance of multi-drug infusion systems, we need to determine the overall system flow rate and the composition of the combined infusion.

Methods: We have developed a technique to continuously measure the composition of a fluid containing multiple drugs flowing together. We combine this composition measurement with gravimetric measurement of total fluid flow to determine the overall rate of delivery. This is an improvement over previous methods which used a mechanical fraction collector to integrate the delivered fluid over one-minute intervals and required manual processing before measurement. This approach is similar to (Snijder et al, 2016) which used continuous spectrophotometry to measure the composition of fluid flowing through a flow cell. Flow cells add considerable dead volume, increasing mixing of the fluids being measured. Our approach is to use a multi-lumen catheter inserted into a piece of clear tubing. The tubing is inserted into a carrier plate which holds it in the light path immediately distal to the end of the catheter. This allows measuring the fluid composition precisely where it would reach a patient's bloodstream. In previous work, we use dyes such as methylene blue and tartrazine yellow as model drugs (Tsao 2013, Parker 2017). We use a narrow band light sources selected to be at the spectral absorbance peaks of the model drugs (e.g., ThorLabs M660L4 for methylene blue) and measure the amount of transmitted light at each band simultaneously using a spectrophotometer (Ocean Optic USB2000). We calibrate the system using known concentrations of the model drug across the concentration range of interest, producing a series of light measurements at various concentrations, and build a linear regression model to interpolate measurements between these points. By using narrow band light sources that are chosen to match non-overlapping absorbance peaks of the model drugs, we can independently measure the concentration of several model drugs without interaction.

Results: We have collected preliminary data comparing the new measurement system to the previous techniques. We are finding that we get data more often (10 to 300 measurements/second vs 1 measurement/minute), with minimal manual intervention, and with comparable spectral and amplitude resolution.

Conclusion: Precise measurement of the performance of multi-drug infusion systems is necessary to better understand the limitations of these systems, particularly when high

concentration, fast-acting drugs with short half-lives are given at low flow rates. Understanding the system's current performance is essential for devising improvements, both to individual infusion pumps and to the whole multi-pump system.

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Preliminary Experience With a New High-Speed Flow Sensor for Investigating and Improving Syringe Pump Flow Performance

Presenting Author: Robert Butterfield, BSE, Becton-Dickinson Fellow (Ret), AAMI and IEC Standards, RDB Consulting
Co-Authors: Jingzhi An, PhD. and Nathaniel M. Sims, MD, Department of Anesthesia, Critical Care, and Pain Medicine; Massachusetts General Hospital, Boston, MA and Harvard Medical School

Background: Much like the flight of an aircraft, intravenous (IV) pump flow may transition from take-off through descent and landing operating over a wide dynamic range of flow rates during patient care. The interaction of pump mechanical design with syringe and fluid path properties can give rise to undesirable flow behaviors requiring more complete characterization than has heretofore been possible, to permit mitigation. Present day methods and metrics[1,2] for measurement of pump performance are complex, costly and limited in ability to measure many aspects of flow behavior, such as those that adversely impact the onset and titration of vasoactive and anesthetic/sedative drugs. This is important to present-day practice, and vital to future target-control and closed loop infusion systems[3]

Methods: We investigated use of a new, low cost, miniaturized high speed thermodilution flow sensor[4] to characterize syringe pump flow behavior across a range of clinically relevant flow rates and rate changes. We then applied low-pass digital filtering inspired by a simple one compartment pharmacokinetic model, to visualize potential in vivo responses of different medications ranging from e.g. short half-life vasoactives, to e.g. long half-life antiarrythmics - see Figure 1. Flow data was acquired with the inline sensor according to a 'staircase' test protocol which, when plotted as in Figure 1 (right), provided an integrated view of pump performance across the selected range of rates, and included flow data across the entire travel of the stopper through the barrel. Quantitative indices of mean error, continuity, and uniformity were calculated at each step (not shown).

Results: Our experiments revealed previously unknown flow errors associated with time- and speed-dependent stopper-to-barrel friction forces. Our staircase plot intuitively revealed a basis for justifying the alerts that modern syringe pumps issue when flow rates for a specific syringe size/brand fall below a manufacturer's predefined minimum recommended rate.

Conclusion: The use of new, low cost, miniaturized flow sensors together with 'staircase' test protocols and a graphical presentation format, combined with calculated indices, enriches our understanding of challenging/undesirable aspects of syringe infusion pump flow performance, and will permit significant design improvements. It may be possible to manufacture IV pumps incorporating such flow sensors integrated in the sterile tubing. Flow data from these sensors could provide real-time closed loop control of the drive mechanism offering shorter startup time, smoother steady state flow, and faster detection of occlusions.

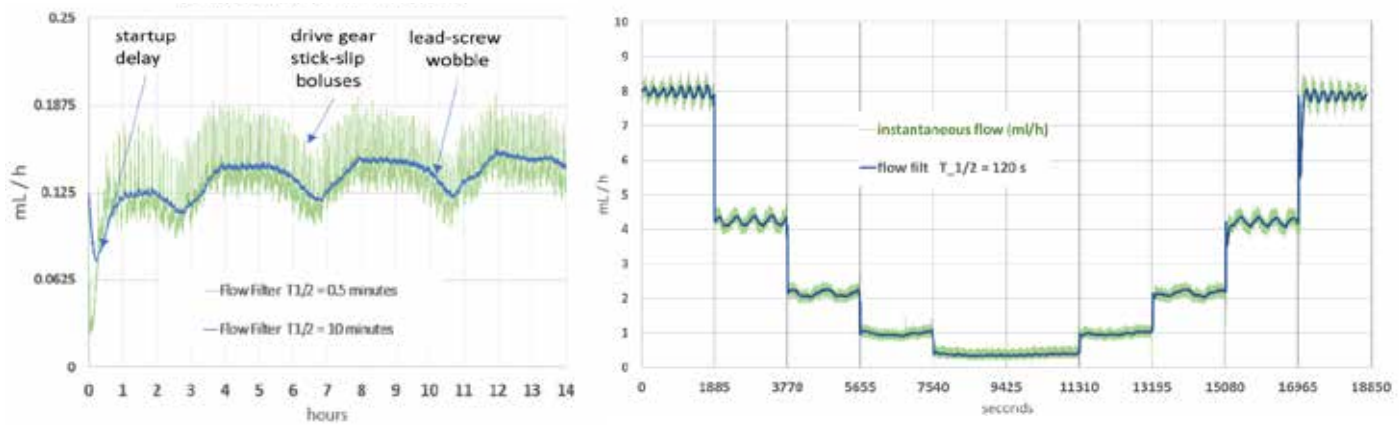

Figure 1: Measurement and characterization of a syringe pump flow by inline sensor and lowpass filtering.

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Detecting Abnormalities on Displays of Patient Information

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Objective: In the ICU, alarms have the important task of alerting clinicians about emergency events and keeping them apprised of patients with deteriorating physiological status. However, these alarms contribute to alarm fatigue (Meredith & Edworthy, 1995). Moreover, the current visual information displays used by clinicians represent patient data across multiple locations, which may hamper a clinician's ability to recognize ongoing patient physiologic trends and maintain a comprehensive view of a patient's state (Anders, 2012). We tested a new configural display that combines information about blood pressure, heart rate, and blood oxygen saturation into a single visual indicator represented as a colored rectangle on a two-dimensional graph (Drews & Doig, 2014). We examined whether the configural display can reduce emergency event detection time, improve detection accuracy, and reduce the number of threshold alarms triggered during patient monitoring. We also examined the impact of cognitive load on performance.

Methods: The study used a 2 (cognitive load) x 3 (display configuration) x 8 (emergency event) experimental design to examine the speed and accuracy of emergency event detection. Cognitive load was manipulated with an *N*-back task with two levels: $N = 1$ (low) or $N = 2$ (high) load. The display configuration compared detection performance with the configural display, a numerical display, or both. Eight emergency events were tested. Eight undergraduate students at Tennessee State University with normal or corrected to normal vision completed six ten-minute monitoring blocks in which they were asked to monitor the patient vital sign displays in peripheral vision while completing an *N*-back task in central vision. Each block used a combination of one of the two load conditions and one of the three display configurations. All eight emergency events occurred once during each block. Participants were asked to indicate whether any values were close to triggering an alarm, which monitored value was abnormal, and the direction of the abnormality. If a patient's vital sign values exceeded the alarm threshold, an auditory alarm, presented at 60 dB, was triggered.

Results: Results from preliminary data indicated that correct responses to emergency events were faster when the configural display was present (numerical and configural display together: $M = 3.33$ s, 95% C.I. [2.39, 4.27]; configural display only: $M = 3.44$ s, 95% C.I. [2.49, 4.40]) than when it was not (numerical display only: $M = 6.03$ s, 95% C.I. [3.15, 8.90], $F(2,12) = 6.12$, $p = 0.01$, $\eta^2_p = 0.50$). In addition, only 17.1% of correctly-detected emergency events required a triggered threshold alarm when both the configural and numerical display were shown (95% C.I. [2.5%, 31.7%]), in comparison with 28% of emergency events when only the configural display was shown (95% C.I. [14.2%, 41.9%]) and 57.2% when only the numerical display was shown (95% C.I. [28.0%, 86.4%], $F(2,7) = 7.52$, $p = 0.006$, $\eta^2_p = 0.52$).

Conclusion: Configural displays may reduce the time it takes to respond correctly to emergency events, and the combination of data from numerical displays and configural displays may reduce the number of alarms generated during patient care. Configural displays of patient physiological data have the potential to aid in the development of multisensory alarms that speed the detection of patient abnormalities and reduce the number of alarms.

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A Framework for Evaluating Healthcare Machine Learning Models: Application and Analysis Using Hospital Readmission

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Introduction: Most predictive algorithms requiring pathway implementations are evaluated using metrics focused on predictive performance, such as the *c* statistic/AUC (area under the curve). However, these metrics are of limited clinical value since they do not account for the algorithm's role within a provider's limited workflow. We propose a framework for simulating a fixed clinical resource using machine learning algorithms to predict unplanned emergency department (ED) surgical readmissions.

Methods: We extracted de-identified data corresponding to all surgical patients that were admitted at the UCLA Ronald Reagan Medical Center in 2017 and 2018 and underwent a procedure with anesthesia. The input to our simulation framework was a predictive model. We considered: lab-based (AUC: 0.85) and non-lab-based (AUC: 0.73) L1 regularized logistic regression models from Mišić et al, HOSPITAL score (AUC 0.72) and the LACE score (AUC: 0.74).[1-3]
We simulated a single provider following a weekly schedule with a limit on the number of patients that can be seen (*daily capacity)*. Secondly, the provider cannot was unable to engage a patient outside of an availability window, i.e. L1 models predict at 36 hours post-operatively while HOSPTAL and LACE require day-of-discharge data. Unseen patients were carried over to the subsequent day until the patient was discharged or seen. Lastly, as part of the cost model, an *effectiveness constant* was estimated to indicate what fraction of eventual readmissions a provider was likely to prevent.
Post-operative readmission costs were calculated using data from the Healthcare Cost and Utilization Project (HCUP).[4] Provider costs were derived from the public salaries for mid-level nurse practitioners at UCLA.

Results: Summary of predictive results for provider-seen patients is found in table 1. The difference between the lab-based and the non-lab-based model is driven by the difference in their predictive ability AUC 0.8541 vs. 0.7280. The difference between the non-lab-based model versus HOSPITAL and LACE, however, is not due to predictive ability since all achieve AUC in the range 0.71 to 0.74. The difference arises because of the provider's schedule and the patients' availability windows for the predictions.
Account of the prevented readmission savings and provider costs were calculated with similar schedules as Table 1. The break-even effectiveness constant for each of the models was calculated. In a minimal Monday-only schedule, the lab-based L1 logistic regression model leads to positive net cost savings when the effectiveness constant is 2%, where HOSPITAL and LACE needs to be 5.5% - 6%. Alternately, when increasing the provider schedule to all weekdays, the break-even effectiveness was 4.5% comparted to 6.5%-7.5%.

Discussion: We proposed a new framework to demonstrate the rich clinical and administrative value of machine learning models that is not captured by gold standard metrics for predictive performance, such as AUC. Factors such as the provider's schedule and postoperative prediction timing can have major effects on the pathway cohort size and potential cost

reductions from preventing hospital readmissions.

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Table 1

Schedule	Daily Capacity	Method	Patients Seen	Anticipated Readmission	Prevented with 10% Effective Constant
M	8	L1 LR (with labs)	867	260	26
M	8	L1 LR (no labs)	861	160	16
M	8	HOSPITAL (at discharge)	845	86	9
M	8	LACE (at discharge)	845	91	9
M W	8	L1 LR (with labs)	1705	423	42
M W	8	L1 LR (no labs)	1699	265	27
M W	8	HOSPITAL (at discharge)	1688	172	17
M W	8	LACE (at discharge)	1688	177	18
M T W R F	8	L1 LR (with labs)	4201	677	68
M T W R F	8	L1 LR (no labs)	4197	505	51
M T W R F	8	HOSPITAL (at discharge)	4213	433	43
M T W R F	8	LACE (at discharge)	4213	451	45

Improved Sedation Capnography and Enhanced Patient Safety For Sedation Anesthesia

Presenting Author: Michael A. Jach, MD

Abstract: The current state of monitoring in the USA: there is a widespread practice of improvisation due to lack of appropriate equipment for sedation capnography. It is estimated that in 30% of cases capnography is either absent or deficient. Below are three case reports making the case for a universal capnography adapter to enable capnography off multiple commonly used airway products. Each case demonstrates that the application of a universal capnography adapter meets clinical monitoring standards in situations where specialty airways are not available. A universal capnography adapter advances diagnostic capnography for multiple airway products used for procedural sedation and directly impacts patient safety.

Background: Capnography is a vital part of everyday practice. It is an invaluable safety monitor for both intubated and non-intubated patients. Despite its routine use for intubated patients and patients with supraglottic airways, there is a widespread lack of use for non-intubated patients. This occurs despite the current ASA mandate.

Method & Learning Objectives: The study usd obsoravtional data of three diffferent procedural sedation cases. The objectives of the study were:
1. Study the feasibility of a universal capnography adapter to advance diagnostic capnography for procedural sedation.
2. Establish a quick method of enabling capnography off the pre-existing airway Products

Results:

Table 1. Universal capnography adapter in procedural sedation - case reports

	Anesthesia	Airway Type	Capnography	Outcome
Case 1: 85-year-old male undergoing TAVR for critical aortic stenosis	Total intravenous anesthesia with Propofol infusion	Natural airway with a non-rebreather face mask	Universal capnography airway adapter applied to side perforations on the mask	Successful capnography off face mask
Case 2: 33-year-old male for right inguinal hernia repair	Local infiltration anesthesia with intravenous sedation	Natural with a nasal cannula with oropharyngeal airway to relieve airway obstruction	Universal capnography adapter applied to Guedel airway	Adequate oxygenation and high quality capnography tracing
Case 3: 66-year-old female undergoing transesophageal echocardiography	Intravenous sedation	Natural airway with a protective bite block	Rescue capnography achieved by applying universal adapter to the side aperture of the bite block	Successful capnography off bite block

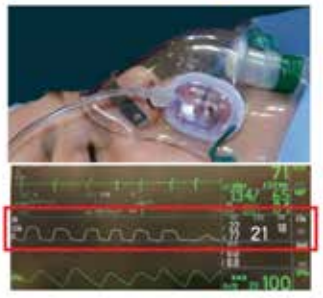

Figure 1. Case 1

Figure 2. Case 2

Figure 3. Case 3

Conclusions: A universal capnography adapter is a viable method to enable capnography off multiple commonly used airway products. It represents a significant diagnostic advance superseding the current practice of improvisation for procedural sedation. A universal adapter can rapidly convert multiple airway products to capnography capable products for enhanced patient safety.

Reduction of Preoperative Anxiety Using Virtual Reality vs Midazolam: A Randomized Controlled Trial

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Co-Authors: Sanjana Khanna, BS, Sarah Okot, BS, CCLS, Matthew Pankratz, PhD, Vanessa Pohl, BS, Neil Singhal, MD, Phoenix Children's Hospital

Background/Introduction: More than 50% of pediatric patients experience significant stress and anxiety prior to surgery[1]. High anxiety can result in increased postoperative pain, increased analgesic consumption and delayed recovery[2]. In order to reduce this preoperative anxiety, multiple therapeutic modalities have been developed, including the use of distraction, such as playing video games, watching movies, and listening to music. In severe cases of anxiety, anxiolytic and sedative medications like midazolam are used. However, given the acknowledged drawbacks of medications, including the risk of paradoxical reactions to the drug, alternatives to medication for reducing preoperative anxiety in patients may be useful. Our study compares the use of Virtual Reality (VR) to midazolam in reducing preoperative anxiety in surgical patients, and assesses differences in induction compliance, emergence delirium, pain scores, and opioid use in VR vs midazolam-treated patients.

Methods: 27 first-time surgical patients between the ages of 5-11 undergoing tonsillectomy or tonsillectomy and adenoidectomy procedures were randomly assigned to either receive midazolam (0.5mg/kg up to 25mg) or play an interactive underwater-themed immersion game using VR. The Modified Yale Preoperative Anxiety Scale (mYPAS) was administered by a single child life specialist preoperatively, and only patients who reached a threshold of >40 on mYPAS scoring were enrolled (scale range: 23-100). Additional anxiety measurement was tested using the adult and child State-Trait Anxiety Inventory (STAI). Midazolam or VR was administered prior to transport to the OR, and mYPAS was scored again at the time of separation from family. The Induction Compliance Checklist (ICC) was utilized for further data collection and assessment of patients at the time of anesthesia induction. VR-treated patients continued use of the VR headset up to and through mask induction. A standardized anesthesia induction protocol was used for all patients. The Pediatric Anesthesia Emergence Delirium scale (PAED) was administered at emergence, post-operatively. Postoperative nurses scored pain and administered IV pain medication as needed. Group means and standard deviations were reported and compared with 2-sided *t* tests.

Results: Interim results showed that 57% of first time surgery patients scored with mYPAS had scores >40, indicating anxiety. The mYPAS anxiety scores dropped 21.67 ±12.5 points following midazolam treatment ($p<0.001$) and dropped 28.3 ±9.2 points following VR treatment ($p<0.001$). There was no significant difference in mYPAS scores between groups following treatment (midazolam= 32.0±5.2; VR= 25.6±5.1; $p= 0.11$). There were no significant differences between midazolam and VR-treated groups in the Induction Compliance Checklist (ICC), emergence delirium (PAED), peak postoperative pain scores, and medication use for pain control, post-operatively. This study is currently ongoing.

Conclusion: Based on these results, VR appears to provide an equivalent alternative to midazolam in reducing preoperative anxiety. Distraction and immersion with VR can help minimize preoperative anxiety during peak stress events, including separation from parents, arrival in the OR, and anesthetic induction. VR was equivalent to midazolam in preoperative induction compliance, and, postoperatively, patients in both groups had similar emergence

delirium, pain scoring, and pain medication use. The patient population for this study was limited and additional studies will be necessary to confirm if the conclusions formed are generalizable to the entire pediatric population, including patients with developmental delays and previous surgical experience undergoing a variety of procedures.

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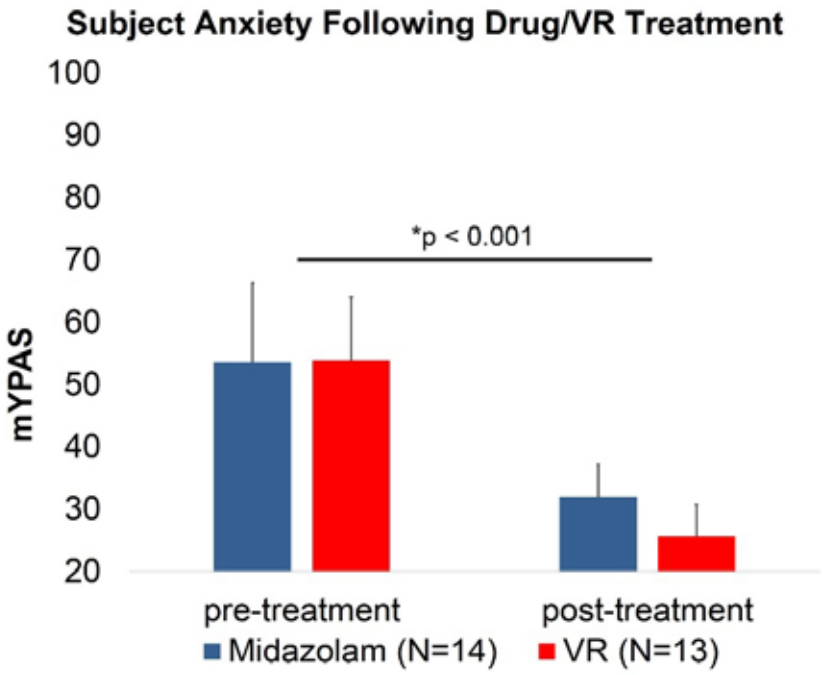

Leveraging the Human Digital Twin for Perioperative Monitoring of Pediatric Patients- An Early Case Study

Presenting Author: Hannah Yates, BS[1]
Co-authors: Mohamed Rehman, MD[1]; Giovanni Cucchiaro, MD[1]; Anna Varughese, MD[1]; Luis Ahumada[2]; Hannah Lonsdale[1]. Johns Hopkins All Children's Hospital, St Petersburg, Florida, USA. [1]Department of Anesthesia and Pain Medicine. [2]Predictive Analytics.

Introduction: The Internet of Medical Things (IoMT) connects patient devices with healthcare systems such as the electronic medical record (EMR). Wearable tracking devices such as Fitbit can contribute data to the IoMT, giving clinicians more information about a patient's baseline physiological levels known as a ***human digital twin*** **(HDT)**. This can then allow comparisons after an illness, treatment, or surgery and give a measure of how long it takes to restore the patient to a good level of daily physical function. It could lead to a precision medicine personalized post-operative recovery plan. A digital twin is an ultrahigh fidelity mathematical model of a system constructed from all available information. For medicine, the system is the human body. The available information might include fitness tracker metrics, EMR information, radiological imaging, genomics and exposomics- the non-genetic exposures that contribute to health, such as environmental pollution, weather, diet and psychosocial behaviors. This case study demonstrates an early use of the HDT to track a patient's recovery from major scoliosis surgery.

Methods: The patient wore a Fitbit Charge 3 device for several weeks prior to his posterior spinal fusion procedure, and 5 months postoperatively. A Fitbit app account was created and anonymously linked to Fitabase, a data collection platform which de-identifies and collects data from the Fitbit app in near real-time. From the Fitabase server, the patient's heart rate (HR), step count, active minutes, and sleep data were available to the clinical team. This data was used to establish the patient's preoperative HDT, identify post-surgery variability, and determine when the patient regained or exceeded their HDT baseline. This study is approved by the JHACH Institutional Review Board.

Results: The patient was an 18-year-old white, non-Hispanic male, who was otherwise well. He was compliant with both wearing the device and regularly syncing it to the Fitbit app. The measured baseline HDT and time for each metric to recover postoperatively are reported in table 1. Five months after surgery, he now exceeds his preoperative HDT by over 800 steps per day.

Metric	Baseline Human Digital Twin	Postoperative time to return to baseline
Mean daily step count	4471 steps	7 weeks
Resting heart rate	52 bpm	19 weeks
Daily moderate or very active movement	18 minutes	10 weeks
Mean nightly sleep duration	7 h 26 m	3 weeks
Nightly restless sleep	22 minutes	N/A

Table 1: Patient's baseline Human Digital Twin (HDT) and time taken to recover. Postoperative restless sleep was initially lower than baseline HDT but increased for several days when the acute prescriptions for diazepam and oxycodone were stopped.

Discussion: This case study demonstrates an early use of wearable technology to create a HDT that was used to track trends in recovery after major surgery. The Fitbit is a relatively inexpensive wearable consumer grade device that has been demonstrated to be the most accurate of commercially available fitness trackers[1] and therefore has potential clinical utility as a trend monitor. The measured elements of the patient's HDT varied considerably in their time to return to baseline- from 3 weeks for sleep to 19 weeks for resting heartrate. We can also measure the potential benefit of the surgery- the patient is now more active than his preoperative HDT as evidenced by an increased daily step count, perhaps as a result of increased FEV_1 and improved mobility.

Conclusion: The observations demonstrated in this single patient report reveal the start of the future potential of the HDT. With further study and the recording of many HDTs, it may be possible to use machine learning to discover new trends. We could predict delayed recovery or the early onset of postoperative complications, thereby allowing earlier intervention and improved patient outcomes.

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Modeling the Cost Savings of Continuous Pulse Oximetry and Capnography Monitoring of United States Hospital Ward Patients Receiving Opioids

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Background/Introduction: Respiratory depression occurs in up to 46% of hospital ward patients receiving opioids, based on continuous pulse oximetry and capnography monitoring data from the Prediction of Opioid Induced Respiratory Depression by Capnography (PRODIGY) trial.[1] Respiratory depression is also associated with significantly higher hospital costs.[2] The objective of this analysis was to develop a model to predict the investment break-even point and likelihood of cost savings associated with implementation of continuous pulse oximetry and capnography monitoring on the hospital ward.

Methods: A decision model was developed from a hospital administrator perspective for an average sized United States hospital medical/surgical ward, with an average of 2,447 patients receiving opioids per year. PRODIGY data was used as the basis for the incidence of respiratory depression, length of stay, and hospital costs per patient. Device costs were estimated for Nellcor™ pulse oximetry and Microstream™ capnography (Medtronic). The model compares costs and outcomes of intermittent pulse oximetry monitoring to continuous pulse oximetry and capnography monitoring of medical/surgical ward patients. The three modeled scenarios include continuous monitoring of patients with 1) high risk 2) high or intermediate risk, and 3) any risk (high, intermediate, or low) for respiratory depression, based on the PRODIGY risk assessment tool.[1] Break-even and probabilistic sensitivity analyses were performed to estimate the investment break-even point and the likelihood of cost savings, respectively, when respiratory depression cases decrease 0% to 100%.

Results: If continuous pulse oximetry and capnography monitoring are implemented on patients with high risk of respiratory depression, and respiratory depression incidence is reduced by 20%, the annual cost savings are projected to reach $535,531 (Figure), with a decreased cumulative length of stay of 103 days per average-sized United States hospital. Similarly, if continuous monitoring is implemented on patients at high or intermediate risk of respiratory depression or on all patients receiving opioids, the projected annual cost savings are $606,463 and $688,221, respectively (Figure), with cumulative length of stay reductions equaling 152 days and 204 days, respectively. The investment break-even points for implementation of continuous monitoring of patients at high risk, high or intermediate risk, or any risk for respiratory depression are predicted to occur if cases of respiratory depression decrease 1.5%, 2.5%, and 3.5%, respectively. Probabilistic sensitivity analysis identified a >80% probability of cost savings when high risk patients are continuously monitored and respiratory depression cases are reduced by ≥17%. Similarly, there is a >80% probability of cost savings if high and intermediate risk, or all risk-level patients are continuously monitored and respiratory depression incidence decreases by ≥27% and ≥31%, respectively.

Conclusion: This model sheds light on the cost benefit of implementing continuous pulse oximetry and capnography monitoring on United States medical/surgical ward patients receiving opioids who are at risk for respiratory depression. In each modeled scenario, the reduction in respiratory depression incidence needed to reach a break-even point is low, and there is a high probability of annual cost savings when respiratory depression decreases by ≥17%. Combined with use of the PRODIGY score to determine patient risk for respiratory depression, this model may assist clinicians and hospital administrators making decisions regarding the utilization of continuous pulse oximetry and capnography monitoring on hospital ward patients receiving opioids.

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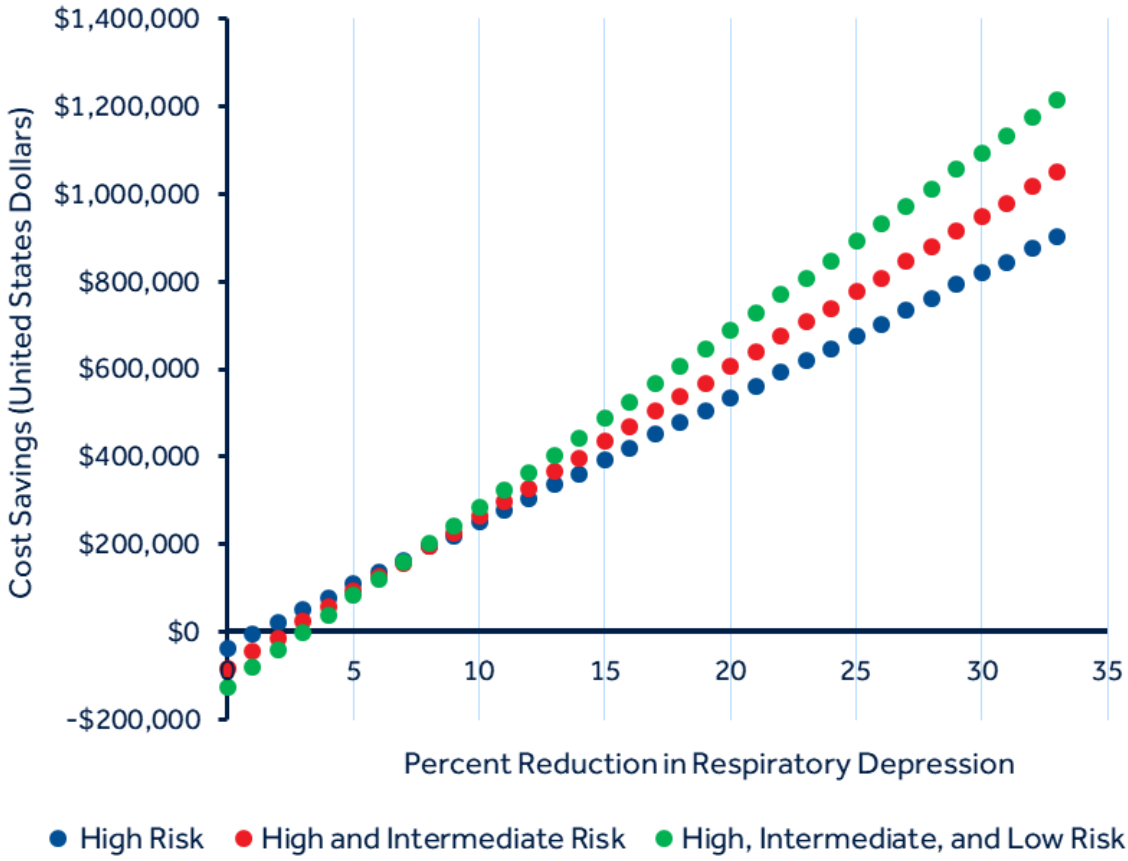
Figure. Projected cost savings of continuous pulse oximetry and capnography monitoring.



Defining Gender and Race/Ethnicity-Specific Laboratory Reference Ranges and its Impact on Predicting Post-Operative Acute Kidney Injury and Mortality Outcomes

Presenting Author: Andrew A. Lee, MS, UCLA David Geffen School of Medicine
Co-Authors: Ira Hofer, MD, UCLA Department of Anesthesiology and Perioperative Medicine; Tristan Grogan, MS, UCLA Division of General Internal Medicine and Health Services Research

Background: Defining laboratory reference ranges is critical to the medical decision-making process and ultimately patient care. Reference ranges are often defined distributionally by the 5th and 95th percentile values of healthy patient labs[1]. However, most laboratories use a single reference range for all patients, ignoring potential genetic differences amongst the population[2]. The goal of this study is to determine 1) if gender/ethnicity differences exist in lab reference ranges, and 2) if defining population-specific reference ranges are more associated with adverse postoperative outcomes as compared to the standard range.

Methods: Lab results from outpatient individuals with primary care providers were pulled from the UCLA electronic health record (EHR) to establish specific lab reference ranges based on patient gender and ethnicity for 37 labs, which we defined as the cohort reference range. In the event that patients had more than one visit, the results from the first visit were included in the analysis. In total 385,170 individuals met inclusion criteria, constituting 8,713,072 total lab results. The boundaries of the gender/ethnicity cohort reference ranges were set by the 5th and 95th percentiles of the lab value distribution. For the outcomes analysis, 100,208 anesthesiology cases were extracted including patient demographic data, most recent lab prior to procedure, and post-operative mortality and acute kidney injury (AKI). Patients included in the study were age 18 and older with a hospital length-of-stay greater than 1 day. Patients were then grouped into four categories based on their pre-op lab values: inside the reference range, outside the reference range, inside the cohort range, and outside the cohort range. A logistic regression was performed for each lab to assess the odds ratio of two postoperative outcomes, acute kidney injury and mortality, subsetted by patient gender and ethnicity.

Table 1: Clinical labs assessed in the study

LABS
ALBUMIN_SERUM
ALKALINE_PHOSPHATASEPLASMA
ALT_PLASMA
ANION_GAP
AST_PLASMA
BASE_EXCESS
BASOPHILS
BICARBONATE_ARTERIAL
BICARBONATE_VENOUS
BILIRUBIN_DIRECT_PLASMA
BILIRUBIN_TOTAL_PLASMA
CALCIUM_SERUM
CHLORIDE_SERUM
CREATININE_SERUM
EOSINOPHILS
FIBRINOGEN
GLUCOSE_SERUM_FASTING
GLUCOSE_SERUM_POSTPRANDIAL
HDL_PLASMA
HEMATOCRIT
HEMOGLOBIN_SERUM
IMMATURE_CELLS
INR
LDL_PLASMA
LYMPHOCYTES
MAGNESIUM_PLASMA
MONOCYTES
NEUTROPHILS
PARTIAL_THROMBOPLASTIN_TIME
PLATELET_COUNT
POTASSIUM_SERUM
PREALBUMIN
PROTHROMBIN_TIME
SODIUM_SERUM
TSH
UREA_NITROGEN_BLOOD
WHITE_BLOOD_CELL_COUNT

Results: We found that 25 out of the 37 labs demonstrated gender/ethnicity variation. Patients who fall outside of their gender/ethnicity cohort range have a significantly higher odds for postoperative AKI (84% of the time) and mortality (74% of the time) than if they were to fall outside the standard reference range.

Conclusion: Our results show that the standard reference ranges used in clinical settings do not always account for the gender and ethnic diversity of the patient population and that the population specific reference ranges are more closely associated with post-operative outcomes. There may be an opportunity to improve understanding of “normal” lab results by accounting for gender and ethnic diversity in our patient population.

References:

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MACHINE LEARNING APPROACHES TO PREDICT INTRAOPERATIVE TRANSFUSION

Presenting Author: Matthew Zapf, MD, Vanderbilt University Medical Center Department of Anesthesiology

Co-Authors: Daniel Fabbri, PhD, Vanderbilt University Medical Center Department of Biomedical Informatics; Jonathan P. Wanderer, MD, MPhil, FASA, FAMIA, Vanderbilt University Medical Center Department of Anesthesiology, Vanderbilt University Medical Center Department of Biomedical informatics

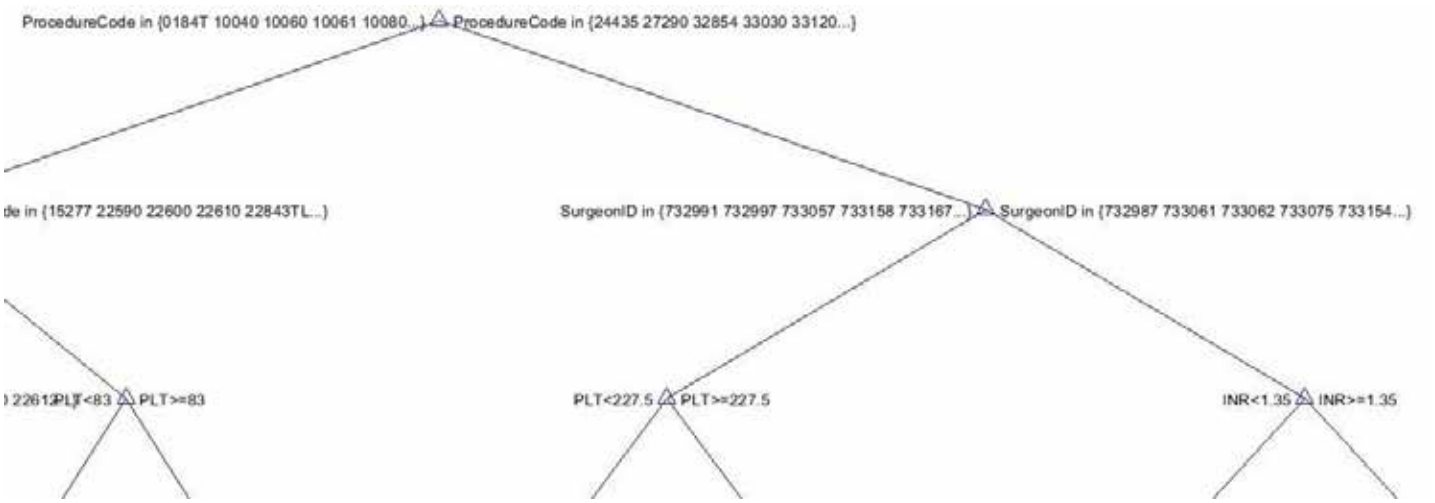
Background: Unnecessary laboratory tests are a source of significant cost and are a burden to health systems. Obtaining a preoperative type and screen expedites matched blood administration in the OR, however, obtaining type and screens for patients who are very unlikely to require blood administration represents an unnecessary expense. Currently, the maximum surgical blood ordering schedule (MSBOS) provides guidelines regarding preoperative pre-transfusion testing and blood product ordering. With the advent of machine learning approaches, opportunities exist to mine the vast amount of perioperative data and develop computationally optimized approaches to predict preoperative pretransfusion testing.

Methods: Data were retrieved from Vanderbilt University Medical Center's Perioperative Data Warehouse and included patients >18 years old, who underwent surgery at Vanderbilt's main operating rooms. Demographics, comorbidities, preoperative labs, medications, surgeon, procedure code and urgency of operation were collected. The response variable was intraoperative transfusion of any blood product.
The performance of the following machine learning algorithms were compared: logistic regression, decision tree, support vector machines, and Naïve Bayes classifiers. K-folds validation was used. RUSBoosting was used to compensate for class imbalance. F-score, precision, sensitivity, accuracy, and area under the receiver operating characteristic (AUROC) curve were assessed.

Results: The AUROC for the following models was logistic regression (0.66), support vector machines (0.88), Naïve Bayes classifiers (0.94), and decision tree (0.92). Class imbalance represented a challenge in this dataset as cases with transfusion represented only 2.3% of total OR cases. Decision trees with medium number of splits had the highest F1 score (0.52), which represents a balanced metric between positive predictive value and sensitivity. A RUSBoosted decision trees model was used with an improvement in sensitivity from 47% to 85%. Most important to the RUSBoosted decision tree model were primary procedure code, surgeon ID and laboratory results (e.g. Platelets < 83×10^9/L).

Conclusion: Machine learning approaches are a feasible way to predict preoperative pretransfusion testing needs. Optimizing machine learning models to specific test performance metrics can provide helpful models which may be incorporated in decision support.

Image: Root and Partial Nodes of Decision Tree Classifier Model.



Simulation Study to Evaluate Fidelity of Continuous Pulse Oximetry Recording in the Electronic Health Record

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Introduction: Patients undergoing general anesthesia are prone to rapid physiologic changes. Electronic health records (EHR) capture measurements from physiologic monitors at regular intervals, but pulse oximetry data is dynamic. The EHR data sampling rate can fail to capture transient hypoxemic events. Our study aims to examine the impact of a 1-minute EHR data sampling rate. Our hypothesis is that the EHR does not always record transient hypoxemic events.

Methods: Simulation experiments were conducted in a biomedical engineering laboratory using a vital sign simulator (VSS) (Index 2 SpO2 Simulator, Fluke Biomedical, Solon, OH), Solar B monitor (GE, Chicago, IL), Nuvon Medical Device Interface (MDI, Capsule Tech, Andover, MA), and EHR (Epic Systems, Verona, WI). The VSS generated a continuous pulse oximetry waveform that was recorded by the monitor. The monitor data was transferred to the MDI at a rate of one measurement every 6 seconds and EHR recorded data every 1 minute. Transient hypoxemia was simulated by alternating SpO2 between 100% and 40% every 30 seconds. A digital timer was synchronized with the EHR to guide the simulation scenarios. Scenarios were video recorded with an analog timer shown next to the monitor display.
Simulation protocol: SpO2 set to 100% for 30 seconds, then 40% for 30 seconds. The sequence was repeated over 4 minutes. Four sequences were completed with a 10-second frame shift for each subsequent sequence. Continuous pulse oximetry data from the monitor were transcribed from the video recording in 1-second intervals and linked with MDI data at 10-second intervals and EHR data at 1-minute intervals.

Results: Each episode of hypoxemia is represented by the data displayed in the GE monitor, the MDI (Fig 1). There was an 8- to 10-second delay between simulated hypoxemia and monitor-recorded hypoxemia. MDI-recorded hypoxemia episodes were shorter than simulated hypoxemia episodes. The low SpO2 values occurred between the sampling interval for the EHR and were not recorded.

Discussion: Our findings demonstrate that transient hypoxemia episodes lasting 30 seconds can be missed when recording EHR data at 1 minute intervals. Our study highlights the need for the EHR to record high-frequency data for improved record keeping. High frequency data can potentially improve the identification of acute events and facilitate the use of EHR data for research (e.g. machine learning) and quality improvement initiatives.

Conclusion: This experimental simulation testing for hypoxemia demonstrates the importance of physiologic data granularity and fidelity across EHR.

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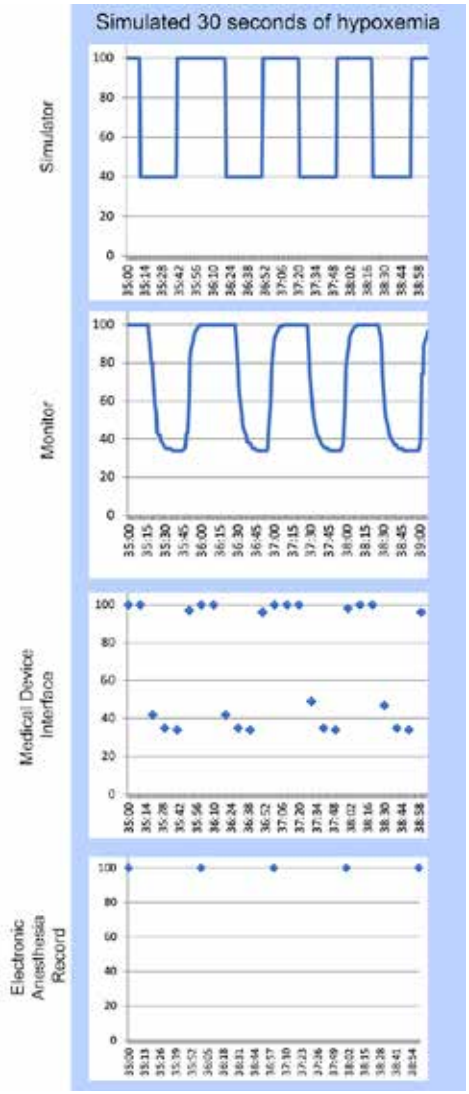
Figure 1



Development of a Novel and Racially Unbiased Deep Learning Algorithm to Predict Preterm Birth in Hypertensive Parturients: A Pragmatic Approach to De-biasing

Presenting Author: Raphael Cohen, BS[1]
Co-Authors: *Sonya Ye MS4[1,2], Kathryn Gray MD PhD[2,3], Vesela Kovacheva MD PhD[1,2]*

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Introduction: Hypertensive disorders of pregnancy affect 2-8% of all pregnancies and contribute to 15% of preterm births worldwide[1]. Complications from preterm births are responsible for 35.5% of neonatal deaths[2] and, in those who survive, the subsequent neurodevelopmental, gastrointestinal and pulmonary disorders result in significant healthcare resource utilization. In addition, there are substantial racial disparities in care, and black women have 50% higher rates for preterm birth than white or Hispanic women[3]. High-risk patients should be transferred to tertiary care hospitals, equipped with neonatal ICU (NICU), however, there are no predictive tools to aid physicians in timely risk prediction. Moreover, recent research has raised awareness about the potential for algorithms to perpetuate bias, including racial bias[4,5]. Thus, we sought to develop a fair, racially agnostic algorithm predicting the risk of preterm birth in patients with hypertensive disorders of pregnancy.

Methods: Using ICD 9/10 codes, under approved IRB protocol, we identified patients with hypertensive disorders of pregnancy who delivered in our tertiary care center over the period 1991-2019. We selected 14 features for each patient in the dataset, and trained a 6 layer fully connected deep neural network (FCDNN). The network used sigmoid activations with a final softmax layer and dropout every other layer and was optimized with an Adam optimizer according to a binary cross-entropy loss function. Subsequently, we balanced the dataset with equal weighting of white, black, and Hispanic patients and then removed race as a model input before training. The models were trained for 20 epochs on the data with an 80-20 split between the training and the test set. We compared the performance of the unbalanced and balanced model.

Results: We identified 35,955 patients in our dataset; of those, 7,263 (20%) had preterm birth. Of the total patient cohort, 20,401(56.74%) were white non-Hispanic, 6,530 (18.16%) were black and 3,937(10.95%) were Hispanic. In the initial model, we used all predictors, including race. The model had area under the receiver operating characteristic curve (AUC) of 0.723, accuracy - 74.3% and weighted F1 score-0.84. This model had unequal performance amongst racial groups of up to 10% difference in accuracy. After rebalancing and weighting white non-Hispanic, black, and Hispanic patients equally and removing race as a predictor, the subsequent model had equal performance across all races with no overfitting as well as slightly improved overall predictive performance. The AUC increased to 0.787, the accuracy – to 82.0%, and the weighted F1 score – to 0.86. We propose this approach (Fig. 1) as a quality control step to evaluate for bias during model development.

Conclusion: We report the development of a novel, racially agnostic preterm birth predictive tool in patients with hypertensive disorders of pregnancy using deep learning. This tool can be used to support clinicians in patient transfer decisions and NICU bed planning. We propose the adoption of this pragmatic method to evaluate, detect and resolve bias in model performance. This approach can be applied to achieve un-biased decision-making in models on any robust dataset.

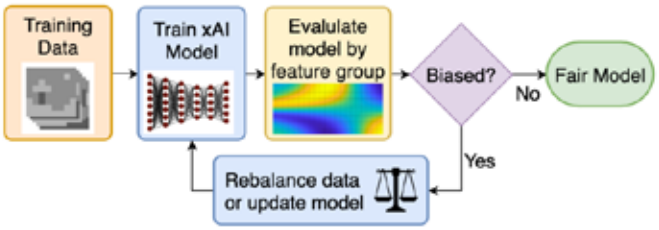

Fig. 1 Workflow to detect and resolve model bias.

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Influence of Air Pollution on Perioperative Outcomes & Potential for Big Data Driven Discoveries

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Background: Mounting evidence demonstrates that short-term and long-term exposure to air pollution increases the risk of cardiovascular mortality and reduces life expectancy.[1] These effects are especially pronounced in populations with chronic medical conditions, the elderly, and patients with low socioeconomic status.[1] While surgical populations, especially those with cardiovascular comorbidities, could constitute another population vulnerable to air pollution, to date this relationship has not been widely studied. Therefore, we performed a literature review aimed to understand the extent of current research that examines the influence of air pollution on perioperative outcomes.

Methods: Air pollution was used as a broad term or defined as any of the six principal air pollutants regulated by the EPA as part of the National Ambient Air Quality Standards (NAAQS). These included carbon monoxide, lead, ozone, nitrogen dioxide, sulfur dioxide, and particulate matter. Studies were identified by electronic database searches in PubMed and Scopus from 1960 to the present. Principal PubMed medical subject heading (MeSH) terms used were air pollution, carbon monoxide, ozone, particulate matter, lead, nitrogen dioxide, sulfur dioxide, perioperative period, postoperative complications, intraoperative complications, surgical procedures. This search yield over 2,000 results, so the MeSH terms were modified to include more relevant subheadings like adverse effects, toxicity, complications, and epidemiology. This search yielded n=80 results in the English language. Out of these articles, we manually identified the relevant ones, and performed citation chaining for each via Scopus. A total of n=12 studies were included in this review.

Conclusions: Based on the current literature review there seems to be a relationship between air pollution and increased adverse perioperative outcomes, however, a large gap in research still exists. The majority of studies examined the impact of residential air pollution levels on outcomes of organ transplants. Spencer-Hwang et al[2] found that in kidney transplant patients for each 10-ppb increase in ozone, the risk of fatal coronary heart disease increased by 35%. Moreover, studies of lung transplant recipients correlated residential proximity to major roads with increased risk of chronic lung allograft dysfunction and mortality.[3,4,5,6] However other data suggests that macrolide use likely ameliorated some of these effects.[6,7,8] In addition, recent data from Al-Kindi et al[9] identified that every 10-ppb increase in particulate matter was associated with a 26% increased risk of mortality among heart transplant patients.

Beyond organ transplantation, Li et al[10] found that increased levels of air pollution were associated with decreased clinical pregnancy rates among IVF patients, while increased ozone levels had a beneficial role.[11] Studies also shows that increased short-term air pollution may also be deleterious. Che et al[12] identified that the incidence of delirium in the surgical population increased with rising levels of air pollution in the hospital area. Moreover, Männistö et al found that increased ambient levels of nitric oxides prior to delivery were associated with a higher incidence of cardiovascular events especially in those delivering via caesarian section.[13]

This data suggests that there is a link between ambient air pollution and perioperative outcomes. However, the degree to which this relationship impacts the surgical population is well studied with only n=12 studies to date. Recent technological advances, including the decreasing cost of air quality equipment, public atmospheric pollution models, ubiquitous GPS in patient smartphones, and the advent of large scale electronic health records in the past decade, make it possible to better study the influence of air pollution on perioperative and other health outcomes both in acute and chronic timescales. Using these Big Data sources could elucidate the impact of air pollution on the surgical population and help us assess the health and financial burden placed on the system by poor air quality.

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Development of a Simple Risk Prediction Model for Excessive Postoperative Opioid Utilization in Inpatients

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Background: Chronic post-surgical pain (CPSP) - pain lasting for >3 months after surgery - affects up to 30% of patients [1]; 5-10% of patients report severe pain 1 year after major surgery [2]. CPSP increases the risk of prolonged opioid use; specifically, 3-10% of opioid-naïve patients have been found to have ongoing opioid use 3-6 months after surgery [1,3,4]. Risk factors for CPSP and long-term opioid use include current opioid or benzodiazepine use, a history of chronic pain or poorly controlled post-surgical pain, depression/anxiety, substance use disorder, recreational drug use, age, gender, and type of surgery [4-10].

Objective: To develop and refine an electronic pre-operative assessment tool for predicting the risk of prolonged post-surgical pain and opioid use.

Methods: The requirement for research ethics approval was waived for this quality improvement project. Patients presenting for colorectal surgery completed an online pre-operative questionnaire using the Thrive Health platform (Vancouver, Canada). It included demographic data, medication history, and screening questions for risk factors of CPSP and opioid use. A risk score was generated, with manually assigned weights: score range 0-35 points, high risk threshold ≥10 (Table 1). Initial clinical use suggested potential for optimization. High inpatient post-operative opioid utilization, defined as >90mg of morphine equivalents/day, was used as the primary outcome. A logistic regression model was created, using the same risk factors as the manual risk score; 60% of the data was used for training and 40% for testing. Performance of the two risk scores were compared on a test set of 49 patients using accuracy and positive *vs.* negative class predictions.

Results: Data from 122 patients, who completed the survey between April and October 2020, were available for model evaluation and optimization: 35/122 (29%) had a high manual risk score, and 22/122 (18%) had elevated post-operative opioid utilization. The manual risk score had an accuracy of 65% (95% CI 55% to 75%), the logistic regression 78% (95% CI 65% to 86%) of the test cases. History of chronic pain, antidepressant use, substance use disorder, and open surgery were the four most important risk factors in the regression model.

Conclusion: Based on this initial analysis, we will re-weight the factors used to create the risk score and collect additional data to identify a more optimal threshold. The "open surgery" risk factor may need removal, as it is not known to patients at the time of survey completion. Future steps include collecting longer term post-operative pain and opioid use data via the Thrive Health and Careteam Technology (Vancouver, Canada) online platforms, as part of the

Reducing Opioid Use for Pain Management Digital Technology Supercluster Project, and using these data for risk prediction modeling.

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Table 1: Risk factors for the significant postoperative opioid utilization risk score

Screening questions, dichotomized into risk factors for calculation	**Manually Tuned risk factor weights**	**Logistic Regression weights**
Score range	**0-35**	**0-2**
Score threshold	**10**	**0.5**
Current prescription opioid use	5	0.20
History of chronic pain	5	1.45
Current prescription benzodiazepines use	2	0.22
History of anxiety or panic attacks	2	0.42
Current prescription of antidepressants	2	-0.12
History of depression	2	-0.37
Substance use disorder (past or present)	5	1.09
Recreational drug use	5	0.07
History of poorly controlled pain after surgery	4	-0.36
Age <40 years	1	-0.03
Female sex	1	0.39
Open surgery	1	0.70

Pilot Implementation of a Clinical Research Data Warehouse Linking Intra-Operative Physiological Data With Post-Operative Outcomes

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Background: Improving access to clinical data is a key component of the research and quality improvement work at BC Children's Hospital (BCCH),[1] and likely many other academic medical centers. Informed by a recent narrative review of clinical data warehouse technologies,[2] we are developing a pediatric clinical research data warehouse using the i2b2 (Informatics for Integrating Biology and the Bedside) framework.[3] Here, we describe the development of the data model for our pilot implementation and our current data integration pipeline.

Methods: The source data included: (a) intra-operative physiological vital signs variables, captured from operating room (OR) Philips and GE/Datex patient monitors;[4] (b) a historic cohort of surgical outcomes with some custom fields[5] from the American College of Surgeons Pediatric National Surgical Quality Improvement Program (P-NSQIP);[6] and (c) a small selection of booking data, including demographic and procedure fields from the Operating Room Scheduling Office System (ORSOS). Having consulted with clinicians, we minimized the number of clinical variables to fields commonly captured or deemed particularly relevant and coded them using the SNOMED-CT terminology. We developed a custom data model capturing five broad categories of information: demographics, visit details (including surgery as well as pre- and post-surgery observations), laboratory tests, procedures (using the Current Procedural Terminology - CPT) and vital signs. Instead of incorporating raw vital signs data into the model, we included derived variables describing some basic data characteristics for each vital sign: percent case coverage with valid data, duration of valid data, median, low and high values (defined as 5th and 95th centile for the case). In addition, we limited the time frame to between the first and last valid SpO_2 and rejected simple data artifacts. Finally, we linked the OR vital signs data to the clinical information from P-NSQIP and ORSOS, where possible, using a probabilistic approach based on procedure date, location, and room entry and exit times.[5]

Results: The 2016 pilot data cohort included 6,432 vital signs casefiles from our main ORs and 1,590 cases with surgical outcomes from our P-NSQIP cohort. We were able to match 1,328 cases from these two datasets.[5] The data integration pipeline is shown in Figure 1, with part of the data model expanded in the i2b2 cohort creation tool.

Conclusion: The feasibility of this approach was established, yet its utility in supporting research or quality improvement initiatives has yet to be demonstrated. The usability of the user-facing component also remains to be determined. Future work includes: defining age-appropriate abnormality indicators for relevant outcomes such as hypotension, hypocarbia and hypothermia, by extending framework for neonatal anesthesia vital signs deviations;[7] improving the automated case matching tools; and incorporating additional outcome databases, such as those from the pediatric intensive care unit.

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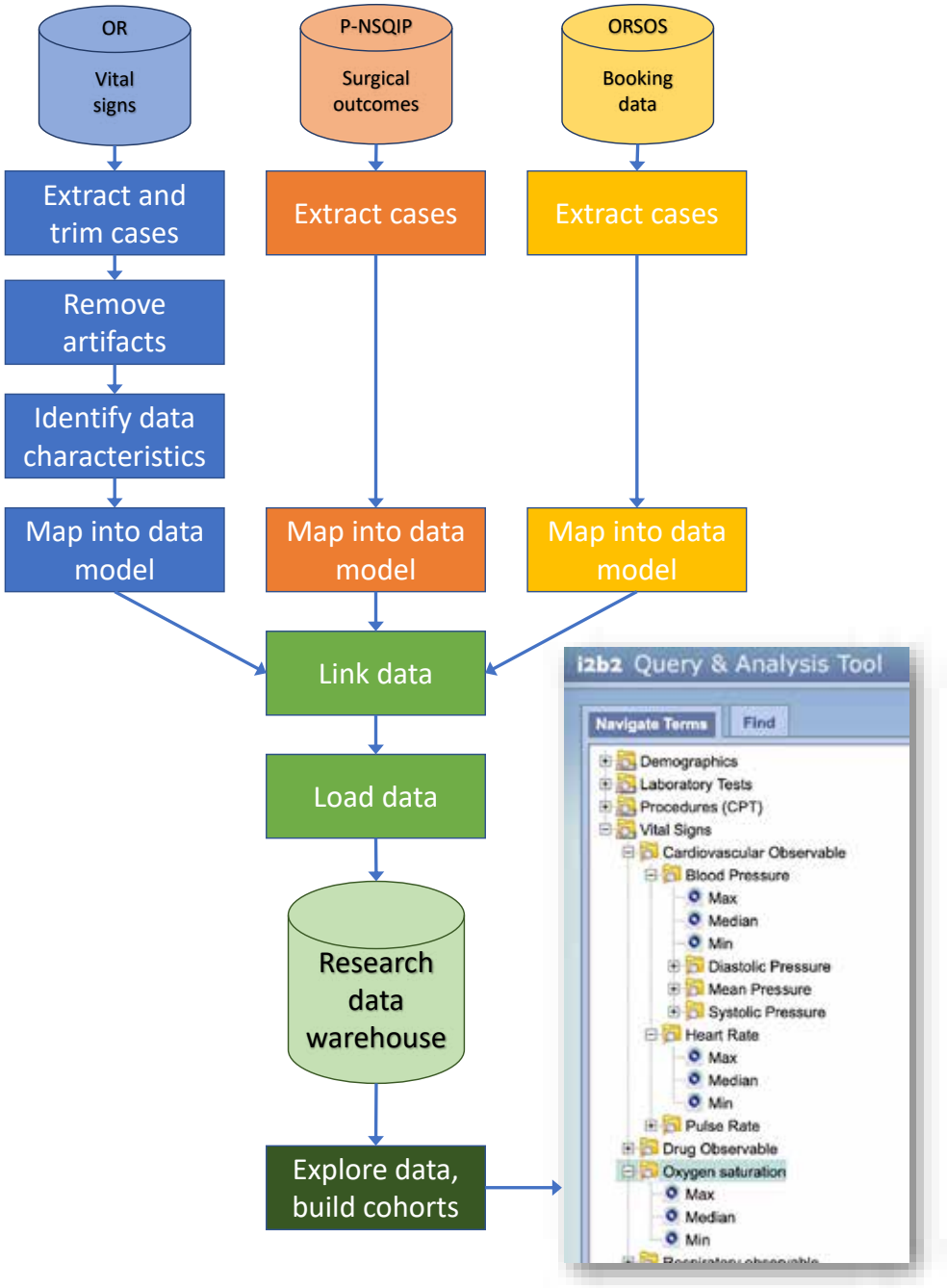

Figure 1: Data integration pipeline for pilot implementation.

Low Cost Ultraviolet Light Decontamination Chamber

Presenting Author: Alexander Abess, MD; Department of Anesthesiology, Dartmouth-Hitchcock Medical Center, Geisel School of Medicine, Dartmouth (*Lebanon, NH USA)*

Background: The SARS-COV2 pandemic created a global shortage of personal protective equipment (PPE) as demand surged beyond supply in late winter and early spring 2020. An acute need to reprocess PPE, particularly N95 respirators, existed across the nation and globe. We describe our efforts at creating a cost-effective ultraviolet (UV) light chamber to reprocess existing supplies of PPE, including N95 respirators.

Several methods of N95 decontamination have previously been described and evaluated.[1] Among these, vaporized hydrogen peroxide and ultraviolet germicidal irradiation (UVGI) became the predominant mechanisms whereby medical centers were decontaminating PPE because of their relative effectiveness whilst still maintaining fit and function of filtering facemask respirators.

Successful implementation of a PPE reprocessing program involves not only technical establishment of effective decontamination, but also a robust logistics operation to transport used/dirty PPE to and from the reprocessing center from the end users who may be in various units within a large medical center. They may also be in smaller affiliate hospitals or clinics within a healthcare system spread across a wide geographic area.

Methods/Results: Our approach was to create relatively inexpensive UVGI chambers that could be forward deployed to units within our medical center or at a number of our affiliate hospitals and clinics. We sourced our materials from readily available suppliers and endeavored for simple assembly of the chambers, with the intention of creating an open source design and approach.

Performance criteria of the chamber were based upon published and evolving data. UV-C (254nm wavelength) irradiation at $\geq$ 1J/cm^2 has been shown to result in $\geq$3 log reduction of viruses (H1N1, SARS-CoV1, and MERS-CoV) on the surface of N95 respirators without significant reduction in filtration performance of the respirator.[2-4]

We were able to accomplish this level of irradiation in a plastic storage container with 4 UV-C lightbulbs, aluminum foil reflectors, a removable rack (that would be preloaded with N95s for decontamination), basic wiring components, and a timer. We also implemented a safety switch that depowered the bulbs if the cabinet was opened during operation in order to protect users from accidental exposure. Total cost of materials for each cabinet was just under $500.

Conclusion: Energy levels were checked and validated using a handheld UV meter ($640). Multiple locations within the chamber, and within potentially "shadowed" areas of masks were mapped and assessed with the UV meter, ranging between 2000-3000μw. Assuming the lower end of power (2000μw), our chamber could deliver ≥ 1J/cm^2 to all surfaces in just over 8.3 minutes. We thus demonstrate feasibility of a low-cost decontamination chamber for PPE.

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Memsorb^{tm}, A Novel Co_2 Removal Device
Part I: In Vitro Performance With The Zeus Ie®

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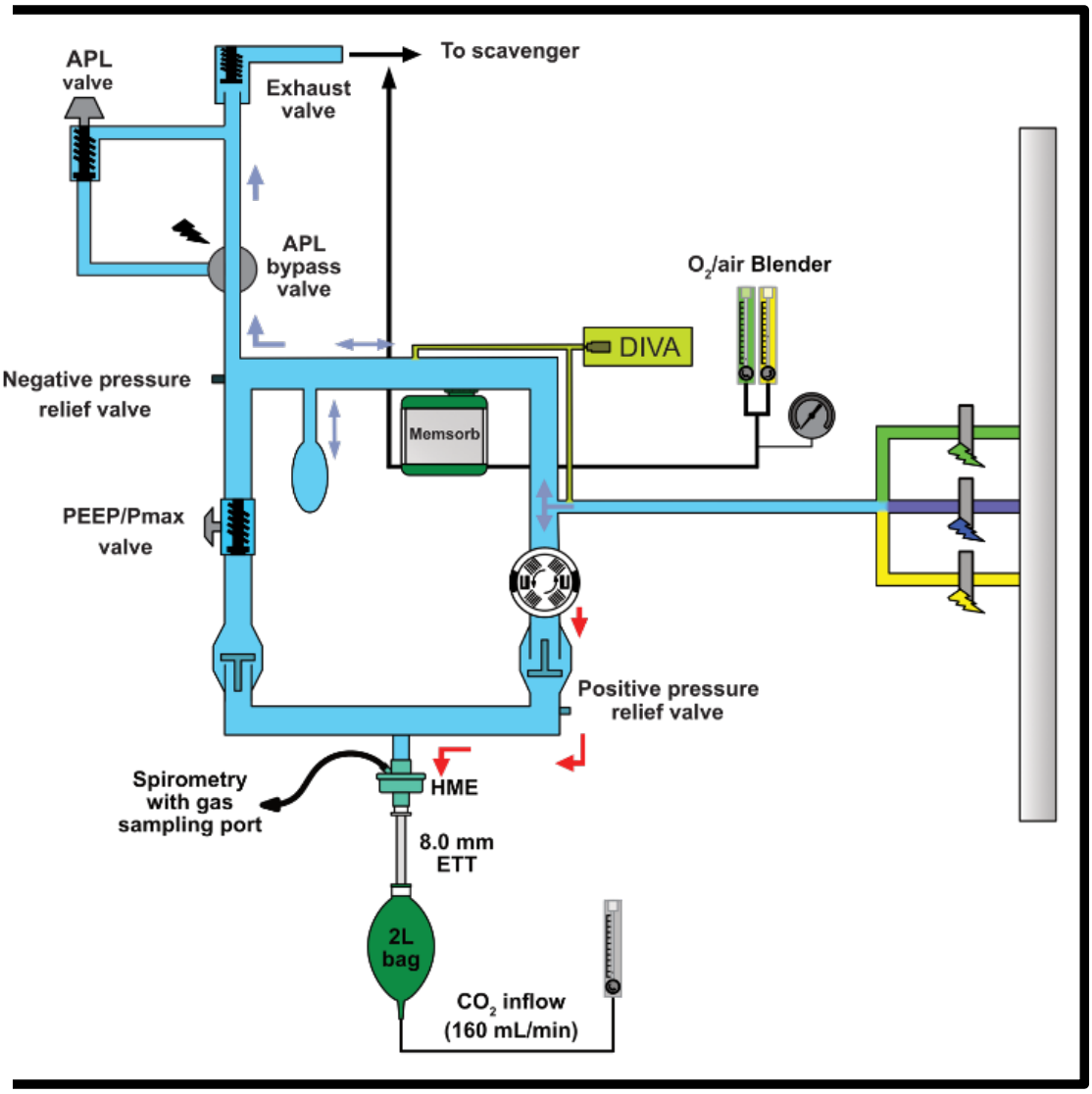
Introduction: Soda lime-based CO_2 absorbents are safe, but not ideal for reasons of ecology, economy, and dust formation. These drawbacks are absent in the Memsorb^{TM}, a new CO_2 removal device that uses cardiopulmonary bypass oxygenator technology: a sweep gas passing through semipermeable hollow fibers adding or removing gases from the circle breathing system. We studied the in vitro performance of a prototype Memsorb$^{™}$ with a Zeus IE® anesthesia machine when delivering sevoflurane and desflurane in O_2/air mixtures.

Methods: The Memsorb is attached to the Zeus IE® in place of the conventional CO_2 absorber. An O_2/air blender was connected to the Memsorb$^{™}$. A 2 L breathing bag was ventilated via a circle breathing system simulating the lung. CO_2 production (VCO_2) was simulated by feeding the breathing bag with 160 mL/min of CO_2 (Fig.1) with the following ventilatory settings: controlled mechanical ventilation, tidal volume 500 mL, respiratory rate 10/min, I:E ratio 1:1, and 5 cm H_2O PEEP. A set of seven experiments were done by altering the ventilatory settings to determine the effect of the Memsorb on kinetics of CO_2, O_2, and volatile anesthetic.

Results: CO_2 kinetics: F_ICO_2 is inversely related to the sweep flow, and proportional to the fresh gas flow (FGF). The relation between VCO_2 and sweep flow to maintain $F_ICO_2 \leq 0.5\%$ is proportional. Lowering respiratory rate while maintain MV seems to improve the CO_2 removal. O_2 kinetics: matching the O_2 concentration of the FGF and sweep flow ensures F_IO_2 will be the same. Volatile anesthetics kinetics: while using target control on the Zeus, agent usage per % end-expired agent increases with increasing agent target concentration and F_IO_2. Desflurane usage during target control is higher with Memsorb than with Dragersorb 800+.

Conclusion: The Memsorb offers an environmentally friendly solution. Yet, the complexity of the kinetics, although predictable, can limits its use in daily practice. The Memsorb CO2

removal capacity seems to be challenged with higher MV, VCO_2 > 250 mL/min and lower FGF. Such device needs to be incorporated in the anesthesia machine with an automated function.



Towards an AKI Monitor: Modeling Urinary Oxygen Changes Through the Urinary Tract

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Introduction: Up to 30% of cardiothoracic surgery patients develop acute kidney injury (AKI)[1]. Kidney hypoxia is recognized as an associated risk factor for AKI during surgery[2]. Currently, there is no intraoperative monitor or indicator of AKI or AKI risk. Studies suggest that urinary oxygen tension (PuO_2) may reflect renal oxygenation[3]. We have developed a prototype device which is placed between the urinary catheter and the tubing to the urine collection bag to measure PuO_2 noninvasively. However, one of the major limitations of the device is that the measurement may be affected by oxygen ingress from the tissue in the urinary tract and through the exposed section of the urinary catheter. The aim of this research is to model the change in PuO_2 as urine moves along the urinary tract based on urine flow rate, urine oxygen concentration and other parameters to better predict PuO_2 in the renal pelvis based on the measurement outside the body. Understanding how oxygen concentration changes based on parameters associated with this model will help improve the sensitivity and specificity of the prototype device.

Methods: A model developed by Evans et al. was expanded to fit the prototype device scenario.[4] Urine flow was modeled as a single bolus which traverses the urinary tract. First, the urinary tract was split into three different sections (Ureter, Urethra, and Catheter) and each section was modeled independently. The models were then combined to assess the change in oxygen along the entire urinary tract. The general equation for the individual models is included below, where $C_{outside}$ is the oxygen concentration in the surrounding environment, p_{epith} is the permeability of the material of the flow path, S_{bolus} is the surface area of the bolus, V_{bolus} is the volume of the bolus and $t_{bolus}^{transit}$ is the time it takes for the bolus to traverse the flow pathway. C_{urine}^{in}, the oxygen concentration in the renal pelvis, was set to 25 mmHg to assess the usefulness of the model

$$C_{urine}^{out} = C_{outside} - (C_{outside} - C_{urine}^{in})e^{(-\frac{p_{epith} S_{bolus}}{V_{bolus}} t_{bolus}^{transit})} \quad (1)$$

Underlying assumptions about model parameters were based on current literature.[5] In addition, the concentration of oxygen in the ureter and urethra tissue was considered equal to the mixed venous oxygen concentration. Also, $t_{bolus}^{transit}$ was estimated based on urinary flow rate. The flow rate was converted to average velocity based on the equation Q = Av, where Q is the volumetric flow rate, A is the cross-sectional area, and v is the average velocity. The bladder was not included in the model as it is assumed a urinary catheter is in place such that urine does not rest in the bladder.

Results: The four different models are shown in figure 1.

Discussion: These results indicate that oxygen ingress occurs primarily through the ureter and urethra. This could be because the oxygen permeability of latex is more than two times smaller than the reported oxygen permeability values of tissue. In addition, these results suggest that the prototype device is within 10 % measurement error when the urine flow rate is greater than 365 mL/hr. This is much larger than the cut off value for diagnosing AKI, which suggests the need for more research to improve and apply the model.

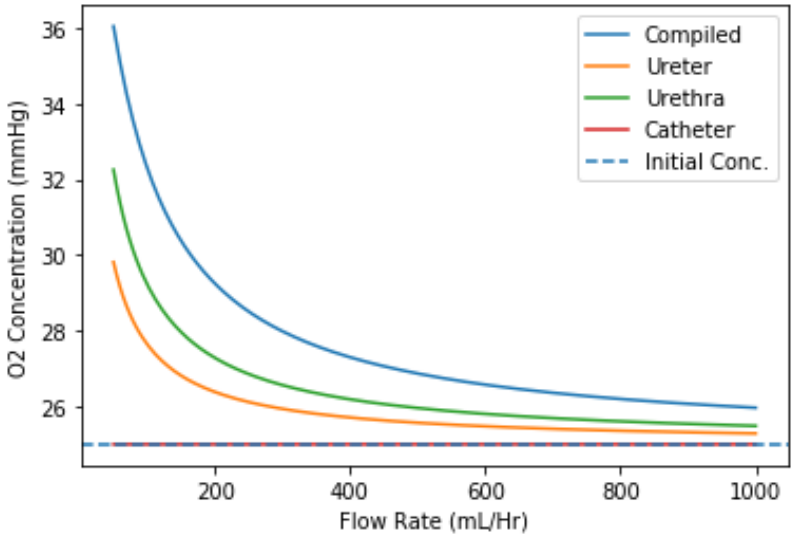

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Figure 1 - Summary of the four different models that were generated.

Pharmacokinetic Design of Closed Circle Sevoflurane Inhalational Sedation for COVID-19 Patients

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Introduction: During the COVID-19 pandemic the capacity for conventional ventilation and sedation has been challenged. Anesthesia providers have been conscripted to manage anesthesia machines and supplies of intravenous sedatives have been exhausted. Inhalational sedation has been proposed as a solution for these challenges[1], however, the methods employed may not be applicable to anesthesia machines available in ad hoc settings, and may require constant involvement of anesthesia providers in hazardous settings. The proposed system is comprised of the following features:

1) A closed circle system with the vaporizer set to a subhypnotic concentration
2) A liquid bolus calculated to achieve a peak concentration predicted to achieve a BIS of 50
3) Delivery of the bolus when patient response to command is observed by the ICU nurse

Methods: The Kennedy sevoflurane model[2] was implemented in state-space form and the Cortinez pharmacodynamic model [3]were implemented in MATLAB. Simplex minimization was employed to solve for the liquid bolus and vaporizer setting resulting in a BIS nadir of 50 and peak of 60 at 2 hour intervals.
Results: Stable cycles with periods of over 1 hour could be consistently produced.

Conclusions: Clinical validation will be required to determine the utility of this approach.

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Monitoring Respiratory Rate in Neonates Using the Rrate Mobile App

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Introduction: Monitoring the respiratory rate (RR) is an important part of the clinical assessment of neonates.[1] However, accurate RR measurement in clinical settings has been elusive. RR measurement is especially challenging in neonates because of their irregular and periodic breathing. There is no reference standard for RR measurement, and proposed methods like visual counting and the Acute Respiratory Infection timer do not yield readily reproducible results.[2] Capnography, though not the gold standard, attempts to give a reflection of physiological breathing by measuring expired carbon dioxide. There remains a need for a low-cost, simple and accurate tool to monitor RR in neonates. We undertook a study to evaluate the agreement between the RRate[3] mobile app timer and Masimo Rad97 capnography for RR measurement in neonates.

Methods: The study was conducted in the neonatal unit of Aga Khan University Hospital, Nairobi, where following informed consent, eligible neonates were enrolled. Data collected included gestational and current age, sex, diagnosis, anthropometric measurements, and socio-demographic details of the mother. Paired observations were made by 3 trained observers using the RRate mobile app, counting each neonate's RR over a full minute. Each neonate was also simultaneously connected to a Masimo Rad97 monitor and the capnography waveform continuously recorded. The capnography wave forms were digitized and recorded with a custom software application. These were then printed out and the breaths manually counted. All data were entered into a Microsoft Excel (Microsoft Excel, Washington, USA) spreadsheet. Bland-Altman analysis[5] for replicated measurements was used to calculate bias and limits of agreements between the average of the paired RRate observations and the manual counts from the capnography waveforms. The root mean square deviation was also calculated.

Results: Between June and August 2019, 27 neonates were enrolled into the study. A total of 130 paired observations were done but 7 were excluded from the final analysis: 5 were missing a paired RRate reading and 2 were identified as outliers by the interquartile range method.[4] 123 paired observations were analysed and a Bland Altman plot generated (Figure 1). The bias between the RRate measurements and the capnography breath counts was 1.88 (95% CI -1.17, 2.59) breaths per minute with limits of agreement of -9.75 (95% CI -8.53, -10.97) to 5.99 (95% CI 7.21, 4.77)breaths per minute. The root-mean-square deviation (RMSD) was ±4.4 (9.3%) breaths per minute.

Discussion: There appears to be good agreement (< 10% RMSD) between the RRate mobile app breath counts and Masimo Rad97 capnography. A few extreme outliers were observed on the Bland Altman plot where the RRate counts were undercounted, especially at higher rates. A larger study is needed to confirm these findings before the RRate Mobile App could be adapted as a clinical tool to measure RR in neonates.

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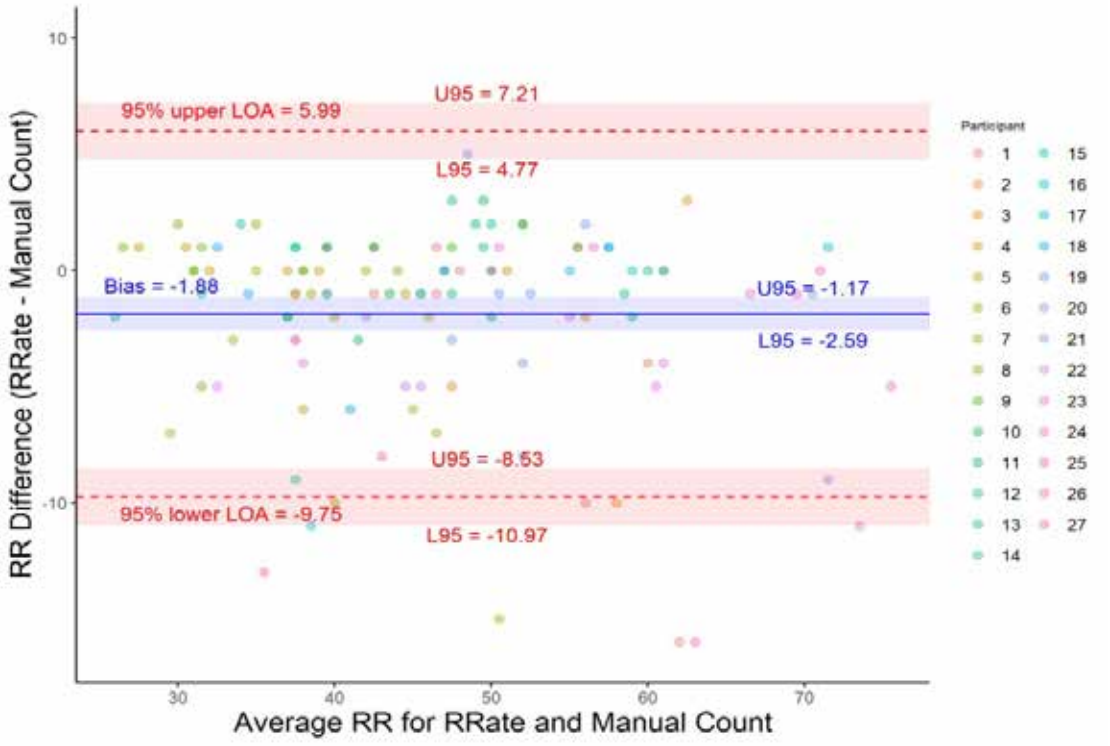

Figure 1. Bland-Altman plot comparing RRs measured using RRate mobile app to those measured using manual counts from the Masimo Rad97 capnography print out. Each dot represents a single observation with repeat observations in the same colour.

Instrumenting a Simple Lung Simulator for Digital Data Acquisition and Simulation of Spontaneous Breathing

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Background: We report modification of an IngMar Medical QuickLung™ (1) for quantitative recording of individual simulated patient ventilation useful for single- or multi-patient scenarios, also implementing limited simulation of spontaneous breathing.
The COVID-19 pandemic continues to produce a surge of patients needing ventilator support, and need of mitigation plans if conventional critical care ventilators cannot be sourced. (2) Many innovative single-patient ventilator implementations, and split breathing circuits for two or more patients sharing a single ventilator have been proposed or implemented. (2,3) Necessary quantitative test data to assess performance and potential patient hazards has been sparsely reported. (4) Split circuit validations require simultaneous data collection from two or more test lungs. (2)

Very simple, inexpensive inflating-bag test lungs have no variable controls or measurement capabilities. Sophisticated commercial test lungs with calibrated controls for compliance, gas flow resistance, and spontaneous breath triggering are expensive and not widely available. When available, digital data acquisition and control mechanisms may incur additional expense.

Methods: Modifications to a simple test lung allows for accurate volume, flow, and pressure measurement and the ability to simulate spontaneous inspirations. The system uses an infrared time-of-flight distance sensor to measure the test lung opening (the relative position of the test lung plates), a pressure sensor is attached to the port on the bottom of the test lung to determine test lung pressure. The time rate of change of the measured volume is used to determine flowrate. A small servo motor is mounted on the bottom plate and used to simulate spontaneous breathing by applying a force to the top plate of the test lung to generate a relatively negative breathing circuit pressure transient. The test lung is calibrated using a high-accuracy flow sensor and an external compressed air source.
The system employs an Arduino microcontroller to acquire measurements, control the servo motor, display system information on a small LCD display and record the information for later analysis. The individual components are integrated in a 3D printed housing that clips on the edge of the test lung. In this way, the size and shape of the test lung is minimally increased.

Three nominal values of test lung compliance and recoil are set by springs loading the hinged plates confining the test lung bellows. Three nominal flow resistances can be set by selection of 3 provided inflow ports of different diameters. These nominal values were used for computer simulation. (2) After calibration of volume sensing, several test lungs are being evaluated for accuracy of their nominal compliance and resistance values.

Results: Modifications for a QuickLung™ are shown in the images. Calibration procedures are ongoing.

Conclusion: Addition of measurement capabilities and characterization of QuickLung™ simulators will facilitate preclinical physical assessment of emergency ventilation alternatives for a modest investment.

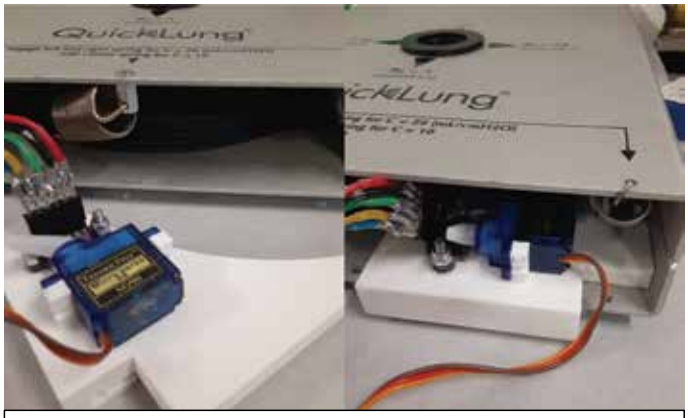

Figure 1: Left – Servo motor and distance sensor installed on a 3D printed mount. Right – 3D printed mount installed on the test lung.

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A Novel Quality Indicator for Displaying and Comparing the Missingness of the Ppg Derived Respiratory Rate

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Introduction: Respiratory rate (RR) is an important vital sign to assess the medical condition of a patient. RR can be estimated from the photoplethysmogram (PPG), which is increasingly available on wearable devices. Abnormal event detection relies on continuous RR measurements that are robust, i.e. of high accuracy and with low missing data points. Data gaps might lead to missed signs of abnormal events and cause failure in recognizing patient deterioration (1) . Therefore, it is crucial to retain as much continuous information as possible. When RR is assessed in real-time, it is important to, in addition to the estimated RR value, capture the robustness information. We present a novel method to provide the information of missingness (*missingness index*) as a quality indicator of the obtained RR extracted from PPG signal. We tested our approach on the benchmark CapnoBase dataset (2) and compared the result between fusing using different RR induced variations (3,4).

Methods: We adopted the pre-processing steps from (3) that included filtering, pulse segmentation and artifact detection. Respiratory induced multiple modulations on PPG waveform, such as the respiratory-induced intensity, amplitude, frequency, width (5) and slope transit time variation (6), were extracted. Each RR estimate was computed using FFT to find the maximum frequency component within the RR band. We computed the RR from the three original benchmark estimates (SF3), and all 5 of the above mentioned five estimates (SF5). The particularity of this fusion is that RR estimations with high disagreement are excluded from the result which could lead to severe missingness. Therefore, we calculated the number of previous cumulated consecutive missing RR estimation windows for each time window and defined it as the missingness index. At the beginning of each recording it is initialized with a -1 value. We compared the fusion algorithms with the CapnoBase TBME RR benchmark dataset, which contained 42 8-minute PPG recordings from 29 pediatric and 13 adult subjects undergoing elective surgery with either spontaneous or controlled ventilation. We evaluated the absolute missingness index for the recording, the overall missingness by computing the ratio of the number of RR windows that were not available to the total possible number of RR windows, and the missingness ratio for the longest missing for each recording.

Results: The missingness of the obtained RR (Fig. 1a) was adequately represented by the missingness index (Fig. 1b). The overall missing ratio in SF5 was higher except in 3 recordings (Fig. 1c).

Conclusion: We obtained a novel method to display the missingness of RR estimated from the PPG that adequately quantified the data gaps and enabled the objective comparison between RR estimation methods.

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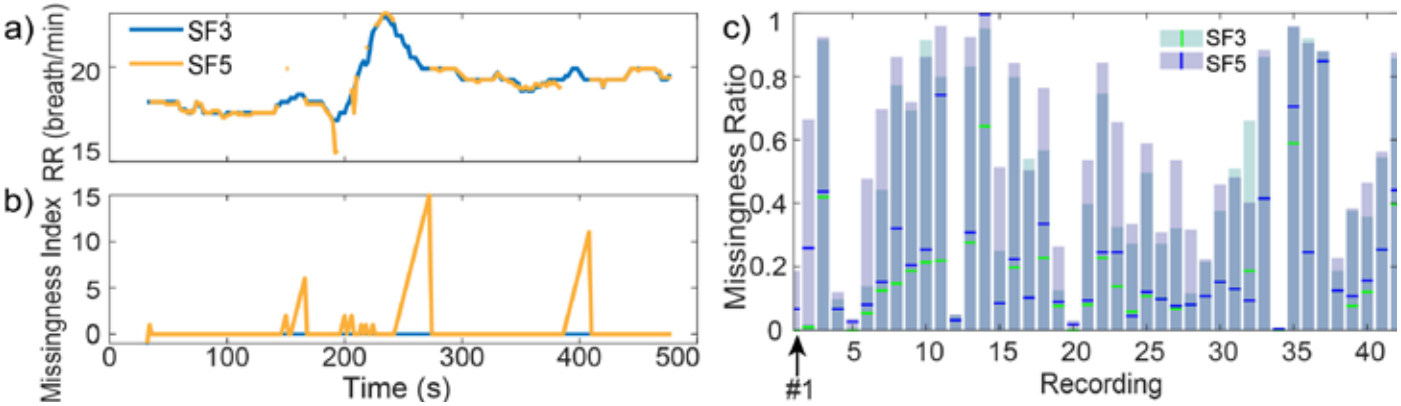

Figure 1: a) RR for the SF3 and SF5 for recording #1**,** and b) the corresponding missingness index. c) The missingness ratio per recording for SF3 and SF5 on the entire CapnoBase. The horizontal bar indicates the missingness ratio of the longest missing segment within each recording.