



Society for Technology in Anesthesia

2016 Annual Meeting Syllabus

FAER



*Foundation for Anesthesia
Education and Research*

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

January 6-9, 2016

Four Seasons Resort

Palm Beach, Florida

18 AMA PRA Category 1 Credits™



***The Future of Anesthesiology and
Innovation in Perioperative Care***

Welcome

Welcome to the 26th Annual Meeting of the Society for Technology in Anesthesia (STA). STA is an exceptional and unique gathering for physicians, engineers and industry representatives. The annual meeting of the STA is a wonderful opportunity to stay abreast of new technologies, meet with colleagues and associates, and enjoy a pleasant venue and climate.

I am grateful to this year's Program Co-Chairs Jorge Galvez, MD, and Patrick McCormick, MD, for organizing the program. They have done an excellent job at selecting the speakers and the topics for the meeting. I look forward to some great sessions on entrepreneurship, the future of anesthesia (inhaled or otherwise), outcomes databases and others. I also look forward to viewing the abstract posters and discussing them with the presenters. I think you will agree that Dr. Jonathan Wanderer, MD, has done an excellent job as the Abstract Chair for this

meeting. The quality of abstracts presented at STA has continually improved over the 25 years that the meeting has been held and I expect to see high quality cutting-edge work presented in the poster sessions of this meeting as well.

I also want to thank the corporate sponsors for their support, without which this meeting would not be possible. I encourage all attendees to visit the exhibits, learn what is available and offer insights to the exhibitors where appropriate.

Sincerely,



Joseph Orr, PhD
President
Society for Technology in Anesthesia

Invited Faculty

Steven Barker, MD, PhD
University of Arizona College of Medicine

Kyle Burk, BS
University of Utah

Maxime Cannesson, MD, PhD
University of California, Irvine

Bimal Desai, MD, MBI, FAAP
Children's Hospital of Philadelphia

Yoav Dori, MD, PhD
Children's Hospital of Philadelphia

Richard Dutton, MD
US Anesthesia Partners

Jesse Ehrenfeld, MD, MPH
Vanderbilt University

David Feinstein, MD
Beth Israel Deaconess Medical Center

Jeffrey Feldman, MD, MSE
Children's Hospital of Philadelphia

Jorge Galvez, MD
STA Program Co-Chair
Children's Hospital of Philadelphia

Patrick Guffey, MD
Children's Hospital Colorado

Rajnish Gupta, MD
Vanderbilt University School of Medicine

Ali Hassanpour, MD
Children's Hospital of Pittsburgh

Thomas Hemmerling, MD, MSc, DEAA
McGill University

Jan Hendrickx, MD, PhD
OLV Hospital, Aalst, Belgium

Michael Hutchens, MD, MA
Oregon Health and Science University

Michael Jopling, MD
NorthStar Anesthesia, Springfield Regional Medical Center

Adam King, MD
Vanderbilt University School of Medicine

Barrett Larson, MD
Stanford University School of Medicine

Christine Lee, BS
University of California, Irvine

Jeff Mandel, MD, MS
University of Pennsylvania

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

Patrick McCormick, MD
STA Program Co-Chair
Icahn School of Medicine at Mount Sinai

Matthew McEvoy, MD
Vanderbilt University School of Medicine

Shoeb Mohiuddin, MD
University of Illinois Hospital

Andrew Norton, MBBS, FRCA, DEAA
United Lincolnshire Hospitals NHS Trust

Joseph Orr, PhD
STA President
University of Utah

Bahram Parvinian
FDA Center for Devices and Radiological Health

Jean-Francois Pittet, MD, ChB
University of Alabama at Birmingham

Christopher Quartararo, MD
Winchester Anesthesia Associates

Mohamed Rehman, MD
Children's Hospital of Philadelphia

David Reich, MD
Icahn School of Medicine at Mount Sinai

Brian Rothman, MD
Vanderbilt University Medical Center

Norma Sandrock, MD
Beth Israel Deaconess Medical Center

Steven Shafer, MD
Stanford University

Wei Sun, PhD
Drexel University

Meeting Accreditation Information

Activity Overview

The Society for Technology in Anesthesia (STA) 2016 Annual Meeting will provide a forum for discussion of the future of anesthesiology and innovation in perioperative care through information technology for perioperative medicine and big data, advances in respiratory monitoring, the perioperative surgical home and clinical applications of 3D printing.

Target Audience

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

Educational Objectives

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

- Discuss how anesthesia technology fits into major structural changes within the healthcare landscape
- Examine current problems facing anesthesiologists that can be addressed with technology, including quality improvement, outcome tracking and advances in inhalational agent monitoring
- Review cutting-edge research in the field of anesthesia technology
- Discuss the current state of perioperative surgical home (PSH) and how technology can be used to achieve PSH goals
- Discuss the peer-review process and how to be an effective reviewer for a scientific journal
- Networking for mentees and mentors, with didactic workshop to discuss mentorship
- Explore current and future clinical applications for 3D printing: medical device design, anatomic models, procedure planning, and bioprinting
- Investigate current big data applications designed to track anesthesia outcomes

Barriers to change:

- Integrating valid scientific evidence and cutting-edge technology into daily clinical practice

Accreditation Statement:

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

Credit Designation Statement:

IAHB designates this live activity for a maximum of **18.0 AMA PRA Category 1 Credits™**. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Continuing Medical Education Certificate:

IMPORTANT!

To obtain your Continuing Medical Education (CME) certificate, go to STA.CmeCertificateOnline.com. Click on the "STA 2016 Annual Meeting" link, complete the survey and print your certificate.

Questions? Email Certificate@AmedcoEmail.com

Schedule of Events

Wednesday, January 6, 2016

0700 - 0800 <i>Mizner</i>	Challenges and Opportunities Registration & Continental Breakfast
0800 - 1700 <i>Royal Poinciana I/II</i>	Exhibitor Registration & Setup
0800 - 1200 <i>Mizner</i>	Challenges and Opportunities in Developing Anesthesia Products (for industry ONLY) Jesse Ehrenfeld, MD, MPH, David Feinstein, MD, Christopher Quartararo, MD, Norma Sandrock, MD
1800 - 1930 <i>Royal Poinciana I/II</i>	Registration & Welcome Cocktail Reception

Thursday, January 7, 2016

0700 - 0800 <i>Royal Poinciana Foyer</i>	Registration & Continental Breakfast
0800 - 0815 <i>Royal Poinciana III</i>	Welcome Address Joseph Orr, PhD, STA President Jorge Galvez, MD & Patrick McCormick, MD, STA Annual Meeting Program Co-Chairs

Session 1: Keynote Address

0815 - 0930 <i>Royal Poinciana III</i>	Opportunities at the Intersection of Innovation, Entrepreneurship and Patient Care Bimal Desai, MD, MBI, FAAP
0930 - 1000 <i>Royal Poinciana I/II & Banyan</i>	Break with Exhibits & Posters

Session 2: Anesthesia 2025: Innovation and Inhaled vs. Intravenous Anesthetic Delivery

Moderator: Jeffrey Feldman, MD, MSE

1000 - 1030 <i>Royal Poinciana III</i>	Innovation Will Secure the Future of Inhalation Anesthesia Jan Hendrickx, MD, PhD
1030 - 1100 <i>Royal Poinciana III</i>	Innovation Will Eliminate the Need for Inhalation Anesthesia Steven Shafer, MD
1100 - 1130 <i>Royal Poinciana III</i>	Regulatory Considerations and Closed Loop Anesthetic Delivery Systems Bahram Parvinian
1130 - 1215 <i>Royal Poinciana III</i>	Panel Discussion

1215 - 1330 <i>Flagler I/II</i>	Luncheon
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Session 3: STA & FAER Joint Session

Moderator: Jean-Francois Pittet, MD, ChB



1330 - 1400 <i>Royal Poinciana III</i>	Peer Review Discussion Jean-Francois Pittet, MD, ChB
1400 - 1445 <i>Royal Poinciana III</i>	The Measures of a Man: Ty Smith Steven Shafer, MD
1445 - 1530 <i>Royal Poinciana III</i>	Cardiorenal Function Estimation Using Near-Infrared Fluorimetry Michael Hutchens, MD, MA
1530 - 1545 <i>Royal Poinciana I/II & Banyan</i>	Break with Exhibits & Posters

Session 4: Research Awards & Presentations

Moderator: Thomas Hemmerling, MD, MSc, DEAA

1545 - 1610 <i>Royal Poinciana III</i>	Excellence in Technology Award Presentation Shoeb Mohiuddin, MD
1610 - 1635 <i>Royal Poinciana III</i>	Best Clinical Application Award Presentation Kyle Burk, BS
1635 - 1700 <i>Royal Poinciana III</i>	Best of Show Award Presentation Michael Jopling, MD

Friday, January 8, 2016

0715 - 0815 <i>Royal Poinciana Foyer</i>	Registration & Continental Breakfast
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Session 5: Outcomes Databases

Moderator: Mohamed Rehman, MD

0815 - 0845 <i>Royal Poinciana III</i>	Flight Operational Quality Assurance (FOQA) Database and Outcomes Mohamed Rehman, MD
0845 - 0915 <i>Royal Poinciana III</i>	Using Anesthesia Data to Drive Outcomes Richard Dutton, MD
0915 - 0945 <i>Royal Poinciana III</i>	Twenty Years of ICU Outcome Development in the United Kingdom Andrew Norton, MBBS, FRCA, DEAA
0945 - 1000 <i>Royal Poinciana III</i>	Panel Discussion
1000 - 1030 <i>Royal Poinciana I/II & Banyan</i>	Break with Exhibits & Posters

Session 6: Perioperative Surgical Home

Moderator: Brian Rothman, MD

1030 - 1100 <i>Royal Poinciana III</i>	The Perioperative Surgical Home: Where Do We Stand? Adam King, MD
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Schedule of Events (continued)

1100 - 1130
Royal Poinciana III **Big Data, Hospital Metrics and the Anesthesiologist's Role in Pay for Quality**

David Reich, MD

1130 - 1200
Royal Poinciana III **Implementation of the Surgical Home and IT Implications**

Matthew McEvoy, MD

1200 - 1215
Royal Poinciana III **Panel Discussion**

1215 - 1330
Flagler I/II **STA Business Luncheon and J.S. Gravenstein Award Presentation**

Steven Barker, MD, PhD

Session 7: Concurrent Workshops

1330 - 1530
Mizner **1) Young Researchers Workshop**
Maxime Cannesson, MD, PhD,
Barrett Larson, MD, Ali Hassanpour,
MD, Christine Lee, BS

The objective of this workshop is to bring together a community of young research scientists. In this community, researchers will share their individual research experiences, as well as develop collaborative relationships to further promote the advancement of technology in anesthesia. The focus of this year's workshop will be on designing and developing technological solutions to fill unmet clinical needs, and will begin with a guest talk by Dr. Barrett Larson, Stanford University School of Medicine, on his personal experience with starting his company Leaf Healthcare.

1330 - 1530
Flagler III **2) Mobile App Development Workshop**
Rajnish Gupta, MD

In this session, attendees will discuss the current lack of high quality medical apps for the medical community. Learners will discuss the balance necessary to bridge in-depth medical information, guidelines and algorithms with user-centric interface design. They will look at examples of utilizing smartphone technologies to enhance written algorithms. Learners will discuss an example case of content that would be valuable in an always-present smartphone app and how to navigate transitioning that content to an easy to use app format. Learners will also discuss strategies to handle licensing and copyright issues with medical societies and publishers.

Session 8: Concurrent Workshops

1530 - 1730
Mizner **1) A&A Review Panel Workshop**
Maxime Cannesson, MD, PhD,
Jean-Francois Pittet, MD, ChB

In this interactive hands-on workshop, attendees will discuss the peer-review process from the editorial board perspective. The workshop will consist of an

overview discussion from Dr. Pittet, Editor-in-Chief for Anesthesia & Analgesia. Next, the audience will discuss the necessary steps in the peer review process and participate in hands-on manuscript review with a focus on providing structured feedback on manuscripts. The goal of the workshop is to provide an opportunity to critically review manuscripts for publication.

1530 - 1730
Flagler III **2) AIRS Integration with Epic Workshop**
Patrick Guffey, MD

This interactive workshop will explore why incident reporting by anesthesiologists for anesthesiologists can improve the quality and safety of your practice. We will review the theory and design of quality reporting systems and how to build them into your current workflow. How to integrate the Anesthesia Quality Institute's Anesthesia Incident Reporting System with your EMR will be demonstrated. Finally, in a collaborative format, we will explore ways to improve the capture of quality data, and build systems that allow for reliable capture of cases where patients experience preventable harm.

1800 - 1900
Pool Terrace/Graze **STA Cocktail Reception**

Saturday, January 9, 2016

0730 - 0830 **Registration**
Royal Poinciana Foyer

Session 9: STA Engineering Challenge
Moderator: Jeff Mandel, MD, MS

0830 - 1015 **Engineering Challenge**
Royal Poinciana III

1015 - 1030 **Break**

Session 10: 3D Printing
Moderator: Jorge Galvez, MD

1030 - 1100 **3D Printing in Congenital Heart Disease**
Royal Poinciana III Yoav Dori, MD, PhD

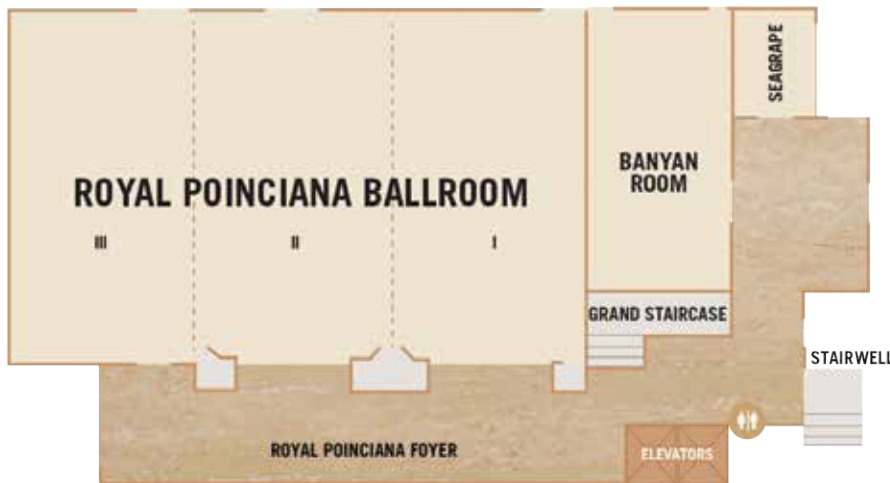
1100 - 1130 **3D Printing in Pediatric Anesthesiology: Experience, Opportunities and Challenges**
Royal Poinciana III Clyde Matava, MBChB, DA, Mmed

1130 - 1200 **3D Cell Printing for In Vitro Biological Model**
Royal Poinciana III Wei Sun, PhD

1200 **Adjourn**

Four Seasons Hotel & Resort Map

ROYAL POINCIANA CONFERENCE LEVEL 1



FOUR SEASONS
Hotels and Resorts

FLAGLER CONFERENCE LEVEL 2



WIFI Password:
8683

Commercial Supporters & Exhibitors

Commercial Supporters

- Becton Dickinson
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- GE Healthcare
- Masimo
- Medtronic
- Mindray North America
- Philips Healthcare
- Result Performance
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Exhibitors

- AlertWatch
- Codonics
- Feel Good, Inc
- Gauss Surgical
- MAQUET Medical Systems, USA
- Monitor Mask
- OpenTempo
- Respiratory Motion

Sponsorship Levels

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RESULT www.resultperformance.net
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Entrepreneur Gold

Gauss Surgical www.gausssurgical.com
MAQUET Medical
Systems, USA www.maquetusa.com
Monitor Mask..... www.monitormask.com

Entrepreneur Silver

AlertWatch..... www.alertwatch.com
Codonics..... www.codonics.com
Feel Good, Inc www.feelgoodinc.org
OpenTempo www.opentempo.com
Respiratory
Motion, Inc..... www.respiratorymotion.com

Company Descriptions



AlertWatch

AlertWatch develops mobile patient monitoring software to help anesthesiologists improve quality, efficiency, and revenue capture.



Becton Dickinson

BD is a leading medical technology company that partners with customers and stakeholders to address many of the world's most pressing and evolving health needs. Our innovative solutions are focused on improving medication management and patient safety; supporting infection prevention practices; equipping surgical and interventional procedures; improving drug delivery; aiding anesthesiology and respiratory care; advancing cellular research and applications; enhancing the diagnosis of infectious diseases and cancers; and supporting the management of diabetes. We are more than 45,000 associates in 50 countries who strive to fulfill our purpose of "Helping all people live healthy lives" by advancing the quality, accessibility, safety and affordability of health care around the world. In 2015, BD welcomed CareFusion and its products into the BD family of solutions. For more information on BD, please visit www.bd.com.



Codonics

Codonics Safe Label System (SLS) sits conveniently on anesthesia workstations and uses barcode technology and multiple visual and audible safety checks to remove human error during medication preparation and administration. An FDA class II device, SLS helps eliminate the three most common errors made in the OR, including vial and ampoule swaps, mislabeling and illegible labeling, and syringe swaps. The system ensures TJC compliance with best practices and standards to improve patient safety and workflow efficiency, ultimately reducing medication errors. As a final output, SLS provides compliant, full-color medication labels complete with 1D and 2D barcodes that enable BPOC confirmation when integrated with EMR and AIMS.

Company Descriptions (continued)



Draeger Medical

For more than a century, Draeger has been providing anesthesia technology clinicians can count on. As a leader in medical and safety technology, Draeger employs more than 10,000 people worldwide and is present in more than 190 countries. From anesthesia machines to anesthesia monitors to anesthesia information management systems, no other company is more focused on anesthesia care than Draeger.



Edwards Lifesciences

Experience the clarity and control to consistently maintain your moderate and high-risk surgery patients in the optimal volume range. Edwards provides a choice of advanced hemodynamic monitoring solutions, including the ClearSight, FloTrac and Swan-Ganz systems, which provide continuous, dynamic and flow-based parameters to enable you to make more informed volume administration decisions. Know more visit Edwards.com/ESRsolutions



Feel Good, Inc

Feel Good, Inc. provides portable TENS (transcutaneous electrical nerve stimulation) units that offer a wide variety of benefits, including alleviating back, nerve, post-op, and diabetic pain, and migraines. Our units can also improve circulation and sleep patterns, and have been shown to decrease the use of pain relievers that can cause negative side effects. The ability to target specific areas with low-voltage impulses can result in long term pain relief, and can be used independently or in conjunction with other pain relief methods. Anyone looking for a safe, non-invasive solution to their pain can find relief in our TENS units.



Gauss Surgical

Gauss Surgical has developed the first real-time monitoring technology for surgical blood loss. Utilizing the iPad as a medical device, the intuitive user interface allows for minimal training and seamlessly integrates into the surgical workflow. The Triton Sponge and Canister apps have received FDA clearance and several clinical studies have demonstrated that the system can monitor hemoglobin loss with high accuracy and in real-time. Gauss Surgical has found early clinical partners at Cedars-Sinai, UC Irvine, and Hackensack UMC with focus within obstetrics, burns, and several other surgical areas. For more information, visit www.gausssurgical.com.



GE Healthcare

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



MAQUET Medical Systems, USA

MAQUET Medical Systems, USA is a market leader offering a comprehensive portfolio of products designed for use in the Hybrid OR, ICU, Cath Lab and Cardiovascular Therapies.



Masimo

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

Company Descriptions (continued)



Covidien is joining Medtronic

Medtronic

As a global leader in medical technology, services and solutions, Medtronic improves the health and lives of millions of people each year. We believe our deep clinical, therapeutic and economic expertise can help address the complex challenges—such as rising costs, aging populations, and the burden of chronic disease—faced by families and healthcare systems today. But, we can't do it alone. That's why we're committed to partnering in new ways and developing powerful solutions that deliver better patient outcomes.

Founded in 1949 as a medical repair company, we're now among the world's largest medical technology, services and solutions companies, employing more than 85,000 people worldwide, serving physicians, hospitals and patients in more than 160 countries. Join us in our commitment to take healthcare Further, Together. Learn more at www.Medtronic.com.



Mindray North America

Mindray, established in 1991, is a leading international manufacturer of medical equipment with global headquarters in Shenzhen, China, North American headquarters in Mahwah, NJ, and R&D centers on 3 continents. We offer a broad range of medical solutions to clinicians including medical imaging, patient monitoring & life support, and diagnostic products. Anesthesia products include a range of anesthesia delivery systems and patient monitors for various acuities. Mindray's recent acquisition of Zonare, a leader in innovative ultrasound technology, leverages a compendium of imaging products designed to meet our customer's evolving needs for high-end image quality, clinical versatility, and unparalleled value.



Monitor Mask

Monitor Mask® was founded by a practicing anesthesiologist to reinvent standard respiratory devices for sedation anesthesia. Our first products are patented oxygen face masks that monitor patient breathing for capnography. The masks provide easy to use, reliable and consistent sampling of the patient's exhaled carbon dioxide, with standard luer ports to interface with most capnography and gas sampling systems. Its design provides optimized performance for nearly all patient positions and procedural arrangements. The CapnoVue® M1 is currently being sold for use in standard sedation anesthesia procedures. Pediatric sizes of the M1 will be available soon. The Scope face mask will be introduced for trans-oral procedures in Q1 2016.



OpenTempo

OpenTempo provides automated staff scheduling and workforce optimization tools to help private and academic anesthesiology practices cost-effectively manage their team.

Our approach results in easy, accurate tools for staff and call scheduling, differential & incentive pay calculation, time/attendance and payroll, workforce analytics and patient demand forecasting. You get mobile access to schedules and can track differential pay in real time! Typical ROIs are 200-800% in the first year.



Philips Healthcare

Philips Healthcare develops innovative solutions across the continuum of care in partnership with clinicians and our customers to improve patient outcomes, provide better value, and expand access to care. www.healthcare.philips.com.

Company Descriptions (continued)



Respiratory Motion, Inc

Improved Patient Safety –Predictive, Early, and Cost Effective monitoring. The ONLY Non-invasive ventilation monitor, ...*ExSpirom™1Xi* Respiratory Volume Monitor provides continuous non-invasive, measurement of respiratory status by delivering real-time, quantitative monitoring of Minute Ventilation, Tidal Volume and Respiratory Rate. *ExSpirom 1Xi* provides a direct measurement of breathing which best addresses ASA guidelines for ventilation monitoring in the PACU, Endoscopy and beyond for patients undergoing sedation or opioid pain control therapy. Using *ExSpirom 1Xi* can improve patient safety and enable individualized care with objective measures of respiratory status.



RESULT

RESULT, LLC is the premier provider of practice management solutions to healthcare practices in the Mid-Atlantic. Our comprehensive suite of services build the infrastructure offices need so that physicians and practice administrators can do what they do best: focus on the best outcomes for their patients. Our services include:

- Billing and coding
- AIMS/EHR/EMR
- Human resources support
- Staffing
- Office based anesthesia
- Quality metric capture and analytics
- IT Support



Spacelabs Healthcare

With over 60 years' experience in providing anesthesia delivery solutions, Spacelabs provides perioperative solutions from low to high acuity. See ARKON™, our “evolutionary” anesthesia delivery system that pushes the boundaries to provide advanced flexibility, ventilation and ergonomics for you, the people that use these machines. Our solutions are assembled in the U.S.A. and backed by an award winning service team.

Mission Statement

The Society's mission is to improve the quality of patient care by improving technology and its application. The Society promotes education and research, collaborates with local, national, and international organizations, sponsors meetings and exhibitions, awards grants, and recognizes achievement.

Save the Date! 2017 Annual Meeting



**January 11-14, 2017
Hilton San Diego Bayfront
San Diego, California**

Abstract Table of Contents

Abstract #	Full Abstract Title	First Name	Last Name	Degree(s)	Institution
1	Heart Rate and Respiratory Rate Derived from Video	Paul	Addison	PhD	Medtronic
2	NIRS-Based Measurement of Cerebral Autoregulation Using Data Clustering Techniques	Paul	Addison	PhD	Medtronic
3	Technological Infrastructure Standards of Anesthesiology Departments in Teaching Hospitals: Compliance with National and International Standarts	Zekeriyya	Alanoglu	Prof	Medical School of Ankara University
4	Impact of Surgical Stimulation and Vasodilators on Pulse Oximetry-Derived Left Ventricular Function Data Sets	Aymen	Alian	MD	Yale University School of Medicine
5	Comparison of Different Methods of Frequency Analysis of the Clinical Waveforms	Aymen	Alian	MD	Yale University School of Medicine
6	Raman Spectroscopy Identifies Each Tissue in the Path of an Epidural Needle	T. Anthony	Anderson	PhD, MD	Massachusetts General Hospital
7	Life Span and Efficiency Analysis of a Solid Phase Lithium Hydroxide CO2 Absorber-Spiralith™	Fawn	Atchison	MD, PhD	Cuyuna Regional Medical Center
8	Signal Processing Methods to Improve Concordance of Bispectral Index (BIS) with End-Tidal Anesthetic Concentration	Marcus	Badgeley	MEng, MSIII	Mount Sinai Hospital
9	Creation of a Digital iBook Curriculum for Anesthesiology Residents	David	Berman	MD	Icahn School of Medicine at Mount Sinai
10	The Anesthesia Hub: A Centralized Mobile Platform with Vital Information Available at One's Fingertips - What Are Users Really Looking For?	Nirav	Bhavsar	MD	University of Miami/Jackson Memorial Hospital
11	Continuous Respiratory Status Visualization Technique: Leveraging High-Fidelity Continuous Respiratory Volume Monitoring for Rapid Patient Assessment	Jordan	Brayanov	PhD	Respiratory Motion, Inc
12	Quality Indicator for Capnometry Parameters	Lara	Brewer	PhD	University of Utah
13	Respiratory Well-Being Index Calculated from Capnometry Waveform and Parameters	Lara	Brewer	PhD	University of Utah
14	Continuous Sedation Monitoring in Critically Ill Patients Using the WAVCNS Index	Sonia	Brodie	MSc	University of British Columbia
15 *	Reduced Operating Room Fire Hazard Using Intelligent Supplemental Oxygen Delivery	Kyle	Burk	BS	University of Utah
16	Supplemental Oxygen Delivery Method Affects Comfort Level in Volunteers	Kyle	Burk	BS	University of Utah
17	Effectiveness of a New Method for Endotracheal Tube Pilot Balloon Repair	Amir	Dayan	MD	Thomas Jefferson University Hospital
18	Anesthesia Quality May Be Improved Through Mandatory Reporting of Intraoperative Adverse Events	Richard	Epstein	MD	Thomas Jefferson University Hospital
19	Analysis of Central and Obstructive Apnea Detection Using Combination Sensors	Sean	Ermer	BS	University of Utah
20	External Beam Radiation Therapy Treatment Interruptions Associated with Change in Airway Management in Pediatric Radiation Oncology - A 4-Year Retrospective Cohort Study	Jorge	Galvez	MD	Children's Hospital of Philadelphia
21	The Development of the US Health IT Safety Framework	Julian	Goldman	MD	Massachusetts General Hospital
22	Trusted Timestamps - A New (Old) Tool to Ensure Integrity and Authenticity of Research and Clinical Data	Matthias	Görges	PhD	University of British Columbia
23	PACE Intubation Effort Android Wear Application	Ali	Hassanpour	MD	Children's Hospital of Pittsburgh
24 **	Mathematical Modeling of Endotracheal Intubation in Children	Ali	Jalali	PhD	Children's Hospital of Philadelphia
25 ***	Capnography Reduces the Risk of Adverse Outcomes During Gastrointestinal Endoscopic Procedures with Sedation Administration	Michael	Jopling	MD	NorthStar Anesthesia, Springfield Regional Medical Center
26	Real-Time Perioperative Web-Based Anesthesia Information System	Thomas	Joseph	MD, PhD	Icahn School of Medicine

* **Best Clinical Application Award**

** **Honorable Mention**

*** **Best of Show Award**

Abstract Table of Contents (continued)

Abstract #	Full Abstract Title	First Name	Last Name	Degree(s)	Institution
27	An Experiment of Clinicians and Usability in a Patient-Controlled Epidural Analgesia Pump	Matthew	Julian	Mb ChB, BSc (Hons)	Royal Army Medical Corps
28	Development of Vital Recorder®, a Time-Synced Biosignal Data Acquisition Software	Hyung-Chul	Lee	MD	Seoul National University Hospital
29	A Framework for Using Electronic Intraoperative Anesthesia Records for Genomic Discovery	Matthew	Levin	MD	Icahn School of Medicine at Mount Sinai
30	Automated Titration of Vasopressor Infusion	Michael	Ma	BS	University of California, Irvine Medical Center
31	Target Controlled Infusion American Style	Jeff E	Mandel	MD, MS	University of Pennsylvania
32	Air Eliminating Filters that Allow Air to be Entrained When Negative Pressure is Applied	Roger	Marks	MD	University of Miami
33	Uncalibrated Pulse Contour Techniques for Perioperative Goal Directed Therapy: A Meta-Analysis of Randomized Controlled Trials	Frederic	Michard	MD, PhD	Edwards Lifesciences
34	Cardiac Output Monitoring Technologies During Major Surgery: A Nationwide Economic Evaluation	Frederic	Michard	MD, PhD	Edwards Lifesciences
35 ****	Utilization of Immersive 360 Degree Spherical Videos and Google Cardboard in Medical Training and Simulation: A Novel and Multi-Dimensional Way of Learning	Shoeb	Mohiuddin	MD	University of Illinois Hospital & Health Sciences System
36	Towards an Ultra-High Resolution Signal Converter for Electroencephalogram Monitoring	Christian	Petersen	PhD	British Columbia Children's Hospital
37	Droplet-Based Simulation of Photoplethysmogram Waveforms and Oxygen Saturation	Christian	Petersen	PhD	British Columbia Children's Hospital
38	Electronically Mediated Time-Out Reduces the Incidence of Wrong Surgery: An Intervention Observation Study	Brian	Rothman	MD	Vanderbilt University Medical Center
39	Design and Evaluation of a New Sonification for Pulse Oximetry	Penelope	Sanderson	PhD	University of Queensland
40	Vibrotactile Displays for Conveying Pulse Oximetry Information	Penelope	Sanderson	PhD	University of Queensland
41	Attitudes on Prevention of Respiratory Compromise	Greg	Spratt	BS, RRT, CPFT	Medtronic
42	Broadband Near Infrared Spectroscopy Can Detect Cyanide-Induced Cytochrome AA3	Robert	Thiele	MD	University of Virginia
43	Development and Use of Standardized Reports for Data Analysis of the MHS Epic OpTime EMR	Karl	Wagner	MD	MetroHealth Medical Center
44	Development of an Automated System for Tracking Bundle Compliance and Patient Outcomes for an Anesthesia Perioperative Consult Service	Jonathan	Wanderer	MD, MPhil	Vanderbilt University
45	Are Patient Risk Factors Consistent Across Data Sources: A Comparison of EMR, Billing and Clinician-Abstracted Data	Theodora	Wingert	MD	Ronald Reagan UCLA Medical Center
46	Improving Transitions of Care in the Perioperative Setting: Developing Hand-off Tools in the Age of the Electronic Health Record	James	Xie	MD	Brigham and Women's Hospital
47	Use of Big Data and Machine Learning for Prediction of Hypotensive Events in High Risk ICU Patients from the MIMIC II MIT Database	Christine	Lee	BS	University of California, Irvine
48	Clinical Decision Support System for Outcome Prediction in Intensive Care Units	Ali	Jalali	PhD	Children's Hospital of Philadelphia
49	A Systematic Comparison of Depth of Hypnosis Indices during Intravenous and Volatile Anesthesia by Electroencephalogram Replay	Christian	Petersen	PhD	British Columbia Children's Hospital
50	Epochs of Clinically Relevant Disagreements in Depth of Hypnosis Monitors Observed by Replay of the Electroencephalogram	Christian	Petersen	PhD	British Columbia Children's Hospital
51	A Year of Experience Using Spiralith, A Lithium Hydroxide Carbon Dioxide Absorbent	S. Mark	Poler	MD	Geisinger Health System
52	Automated Method for Confirming Epidural Catheter Location	Zachary	Walton	MD, PhD	Yale New Haven Hospital
53	Comparison of Blood Glucose Determination from Earlobe Capillary Blood and Arterial Blood Specimens	S. Mark	Poler	MD	Geisinger Health System

**** Excellence in Technology Award

Heart Rate and Respiratory Rate Derived from Video

Presenting Author: Paul S. Addison, PhD, Technical Fellow. Medtronic Respiratory & Monitoring Solutions, Edinburgh, Scotland, UK.

Co-Authors: Dominique Jacquell, PhD, David M.H. Foo, PhD. Medtronic Respiratory & Monitoring Solutions, Edinburgh, Scotland, UK.

Introduction: Non-contact patient monitoring (NCM) is a rapidly growing area driven by the potential to reduce cost, reduce cabling, improve work flow, and free up the patient. We report here on technical work to extract a full range of pulse oximeter parameters from a standard camera set up, thus enabling real time contactless monitoring.

Method: Facial recognition software is used to localize regions on the body for use in extracting the parameters of interest. Figure 1 contains a screen shot of the acquisition panels. The video segmentation grid and face tracking region (pink box) are evident in the video image. The face box is used to acquire cardiac pulsatile signals from a localized forehead region. A chest box is located relative to the face box and used to collect respiratory modulation signals.

Results:

A screen shot of a Nellcor Pulse Oximeter device running concurrently with the video acquisition is shown below the video image in the lower right panel of figure 1. The left vertical panel shows both the acquisition controls at the top and the acquired signals below. A clear respiratory modulation is evident in the chest region signal and distinct cardiac pulses may be observed in the forehead region signals: these are summed to provide a single pulsatile signal shown just below the respiratory signal. The pulse and respiratory rates determined from a FFT (Fast Fourier transform) of the video acquired signals coincide with those displayed on the oximeter.

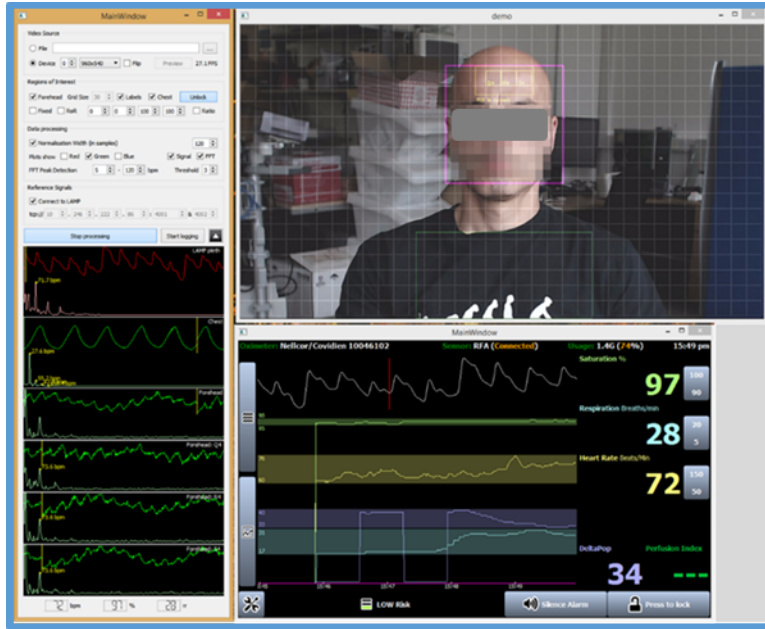


Figure 1: Screen Montage. Top: Camera Image. Bottom: Pulse Oximeter screen showing signal and SpO₂, RR and HR. Vertical Panel: Control buttons at top. Signals from top to bottom: captured oximeter signal (red), video respiratory modulation (top green signal) combined forehead signal and three component forehead signals. The associated FFT spectra are plotted at the bottom left of each signal panel. Note that the spectral peak frequencies are in agreement with the pulse oximeter device RR and HR.

Conclusions: Respiratory rate (RR) and heart rate (HR) may be easily extracted from standard video signals during non-challenging conditions using relatively simple signal extraction and processing algorithms. This confirms the findings of others in this regard [1-6]. Current work focuses on simultaneously determining RR from the chest signal and HR from the forehead region signals in more challenging conditions. This will be followed by work to determine the feasibility of calculating SpO₂ [7]. A number of sophisticated signal analysis methods will be assessed for these tasks (e.g. continuous wavelet transforms, independent component analysis etc.) in order to enhance the extraction of subtle physiological information from these relatively noisy signals. Future work will involve animal models and human breathe-down studies, utilizing enhanced hardware (including scientific cameras) and automated calibration methods for color, greyscale, orientation, etc.

References

1. Verkruyse, W., Svaasand, L. O., & Nelson, J. S. (2008). Remote plethysmographic imaging using ambient light. *Optics Express*, 16(26), 21434–21445.
2. Poh, M. Z., McDuff, D. J., & Picard, R. W. (2011). Advancements in noncontact, multiparameter physiological measurements using a webcam. *IEEE Transactions on Biomedical Engineering*, 58(1), 7–11.

3. Abbas, A. K., Heimann, K., Jergus, K., Orlikowsky, T., & Leonhardt, S. (2011). Neonatal non-contact respiratory monitoring based on real-time infrared thermography. *BioMedical Engineering OnLine*, 10(1), 93.
4. Scalise, L., Bernacchia, N., Ercoli, I., & Marchionni, P. (2012). Heart rate measurement in neonatal patients using a webcam. *MeMeA 2012 - 2012 IEEE Symposium on Medical Measurements and Applications*, 6–9.
5. Meredith, D. J., Clifton, D., Charlton, P., Brooks, J., Pugh, C. W., & Tarassenko, L. (2012). Photoplethysmographic derivation of respiratory rate: a review of relevant physiology. *Journal of Medical Engineering & Technology*, 36(1), 1–7.
6. Freitas, U. S., (2014). Remote Camera-based Pulse Oximetry. *eTELEMED 2014, The Sixth International Conference on eHealth, Telemedicine, and Social Medicine*, (c), 59–63.
7. Tarassenko, L., Villarroel, M., Guazzi, A., Jorge, J., Clifton, D. A., & Pugh, C. (2014). Non-contact video-based vital sign monitoring using ambient light and auto-regressive models. *Physiological Measurement*, 35, 807–31.

NIRS-Based Measurement of Cerebral Autoregulation using Data Clustering Techniques

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Co-Author: Dean Montgomery. Algorithm Engineer. Covidien Respiratory & Monitoring Solutions, Edinburgh, Scotland, UK.

Introduction: Cerebral blood flow is regulated over a range of systemic blood pressures through the Cerebral Autoregulation (CA) control mechanism [1]. The near infrared spectroscopy (NIRS)-based COx measure has been proposed as a suitable proxy for blood flow in the analysis of CA. Data binning is employed as standard in the method, and a thresholding is then employed to determine the transition between intact and impaired autoregulation zones. We have developed novel data clustering techniques based-on the raw (unbinned) COx data to delineate impaired and intact CA regions.

Method: K-means and Gaussian mixture model algorithms were used to analyze a porcine data set. The determination of the lower limit of autoregulation (LLA) was compared to a traditional binned COx approach. The algorithms are more fully described by the author's elsewhere [2]. The k-means algorithm was run 10 times to reduce the risk of being caught in local minima. The square of the Euclidean distance was employed as the distance metric. In the GMM model two Gaussian distributions were fit to the data using an expectation maximization algorithm. The posterior probability of membership for each point was calculated for the resulting two Gaussian distributions. A point is then said to be a member of the cluster for which it has the highest posterior probability. The whole algorithm was repeated in a similar manner to the k-means method to mitigate the effect of falling into local minima in the optimization process.

Results: Figure 1(a) shows the traditional COx curve from an animal study. This binned format, is traditional for viewing COx data [3-6]. However, we have found that binning often makes it difficult to produce a robust automated algorithm to determine LLAs due to the granular nature imposed on the bin-aggregated data. The raw (unbinned) data used to construct the COx curve is also given in figure 1(b). We can see by eye that the data is clustered into two distinct regions: one below the lower limit of autoregulation (LLA) where the data is tightly packed around a value of unity. This denotes the impaired CA region where blood pressure and flow are linearly correlated. In this region BP is driving flow through the brain, i.e. the brain is not regulating flow. The second region comprises data spread across the COx limits between 1 and -1: this denotes the intact region where there is no distinct correlation between blood pressure and flow. The LLA's are set automatically by the clustering methods: shown in figure 1(c) and 1(d).

Conclusions: Good agreement was found between the LLA determined by the k-means method, GMM method, the traditional COx method and that determined by visual inspection

of the data (agreement between 3 observers). The work highlights the potential application of using data clustering tools in the monitoring of cerebral autoregulation function.

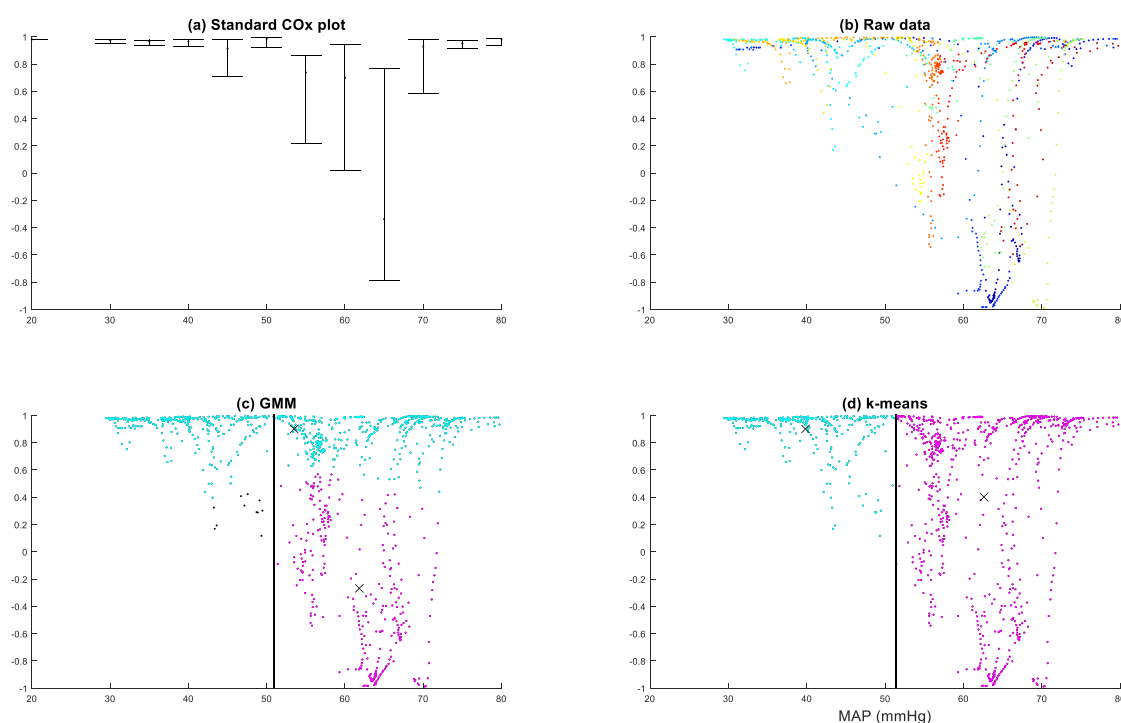


Figure 1. (a) Standard COx curve (b) The raw COx data (c) GMM clustering applied to the raw data (d) K-means clustering methods. LLAs are denoted by the vertical lines.

References:

- [1] M. J. H. Aries, J. W. Elting, J. De Keyser, B. P. H. Kremer, and P. C. a J. Vroomen, "Cerebral autoregulation in stroke: A review of transcranial doppler studies," *Stroke*, vol. 41, no. 11, pp. 2697–2704, 2010.
- [2] D. Montgomery, P. S. Addison, U. Borg, "Data Clustering Methods for the Determination of Cerebral Autoregulation Functionality," *J. Clin. Monit. Comput.*, *In Print*.
- [3] K. M. Brady, J. K. Lee, K. K. Kibler, R. B. Easley, R. C. Koehler, and D. H. Shaffner, "Continuous measurement of autoregulation by spontaneous fluctuations in cerebral perfusion pressure: comparison of 3 methods.," *Stroke.*, vol. 39, pp. 2531–2537, 2008.
- [4] K. Brady, B. Joshi, C. Zweifel, P. Smielewski, M. Czosnyka, R. B. Easley, and C. W. Hogue, "Real-time continuous monitoring of cerebral blood flow autoregulation using near-infrared spectroscopy in patients undergoing cardiopulmonary bypass," *Stroke*, vol. 41, pp. 1951–1956, 2010.
- [5] K. M. Brady, J. O. Mytar, J. K. Lee, D. E. Cameron, L. a. Vricella, W. R. Thompson, C. W. Hogue, and R. B. Easley, "Monitoring cerebral blood flow pressure autoregulation in pediatric patients during cardiac surgery," *Stroke*, vol. 41, pp. 1957–1962, 2010.

- [6] K. M. Brady, J. O. Mytar, K. K. Kibler, C. W. Hogue, J. K. Lee, M. Czosnyka, P. Smielewski, and R. B. Easley, "Noninvasive autoregulation monitoring with and without intracranial pressure in the naïve piglet brain," *Anesth. Analg.*, vol. 111, no. 1, pp. 191–195, 2010.

Technological Infrastructure Standards of Anesthesiology Departments in Teaching Hospitals: Compliance with National and International Standards

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Turkish Society of Anesthesiology and Reanimation Multicenter Clinical Study Coordination Task Force

Background: In August 2014 the new curriculum for Anesthesia Training in Turkey was declared by the Ministry of Health of Turkey in conjunction with the Turkish Society of Anesthesiology and Reanimation (TARK). The new curriculum necessitates certain technological and infrastructural standards for the Teaching Anesthesiology Departments and TARK Multicenter Clinical Study Coordination Task Force initiated a survey to assess and discuss the current situation in Turkey. The results of the survey is briefly reviewed.

Methods: An online survey was initiated according to the requirements of new curriculum and department Heads were asked to answer the questions in the survey. Forty two departments answered completely the survey. The identities of the departments were kept anonymous. The results of the survey was assessed for the Departments of Ministry of Health (MOH) vs University Hospitals (UH).

Results: All departments comply with the standards of basic anesthesia monitoring (SpO₂, EtCO₂, NIBP, ECG, inspired gas mont.) mentioned by ASA except body temperature monitoring. Almost all departments of MOH (90.9%) and University Hospitals (94.1%) have routine temperature monitoring and a patient warming system. The other results of the survey were reviewed in Table 1.

Table 1. Specific monitoring options of Anesthesiology departments of MOH and University Hospitals.

	Departments of Ministry of Health	Departments of University Hospitals
Bispectral index mon.	100 %	87.5 %
Number of Device (min-max)	2.18 ± 2.64 (1-10)	4.5 ± 3.61 (1-11)
Transcranial Doppler	20 %	42 %
Number of Device (min-max)	1 (1-1)	1.17 ± 0.41 (1-2)
Cerebral Oximetry	45 %	37 %
Number of Device (min-max)	1.8±1.1 (1-3)	1.33±0.52 (1-2)

Objective NMTM	100 %	82 %
Number of Device (min-max)	1.45±0.69 (1-3)	4.86±3.82 (1-13)
Ultrasound Device*	81 %	81 %
Transesophageal ECHO	27 %	52 %
Device	1.33±0.35 (1-2)	1.11±0.33 (1-2)
Number of Device (min-max)		
Fiberoptic bronchoscope for intubation	72 %	76 %
Videolaryngoscope	45 %	47 %

*US for regional anesthesia, vascular access,

Conclusion: The technological infrastructure of the teaching departments in Turkey comply with the basic requirements mentioned by ASA and Helsinki Declaration for safe anesthesia. However, more funding is needed in both type of departments to require more up to date technologies.

Impact of Surgical Stimulation and Vasodilators on Pulse Oximetry-Derived Left Ventricular Function Data Sets

Authors: Terence Rafferty, MD, MBA, Kirk Shelley, MD, PhD, Aymen Alian, MD
Department of Anesthesiology, Yale University School of Medicine, New Haven, CT

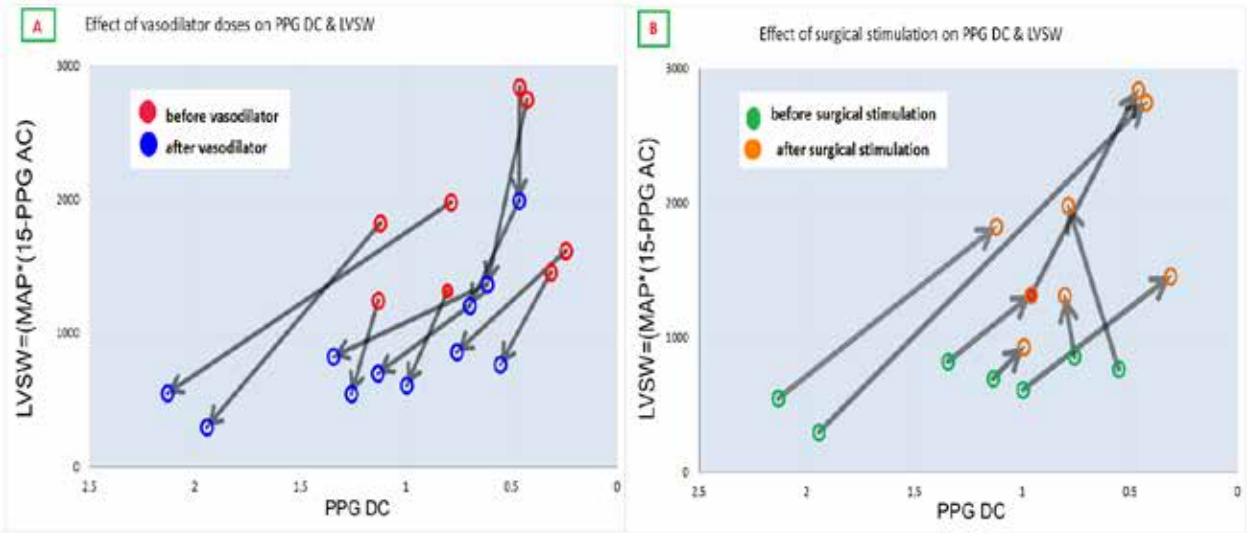
Introduction: Pulse oximeter (PPG) amplitude modulation (mod) is related to stroke volume variability, while baseline PPG respiratory modulation reflects changes in blood volume (preload)^{1,2}, as evidenced by changes with assumption of beach chair position and during lower body negative pressure interventions. Ventricular function sets express cardiac work as a function of preload. The classic left ventricular stroke work (LVSW) per beat formula consists of mean systemic arterial blood pressure minus mean left atrial pressure*body surface area indexed stroke volume*K.³ This work measurement (pressure gradient*volume*K) can be shortened to mean systemic blood pressure*stroke volume. Accordingly, mean systemic arterial blood pressure*PPG AC mod as a function of PPG DC mod should provide the data required to evaluate Starling curve left ventricular function. This premise was tested by evaluating the impact of vasodilators on mean systemic arterial blood pressure*PPG AC mod as a function of PPG DC mod.

Methods: A pheochromocytoma patient was studied in depth during laparoscopic resection of the tumor. Vasodilators (phentolamine, nitroglycerin, sodium nitroprusside and hydralazine) were administered to normalize blood pressure during the course of the procedure. Systemic arterial blood pressure and pulse oximetry data were measured pre-vasodilator and post-vasodilator (33 data sets). The study was approved by the Institutional Review Board. Frequency analysis of the PPG waveforms was used to determine amplitude modulation of PPG (PPG AC) and baseline modulation (PPG DC).

Results: It is proposed that increases in AC mod represent decreases in stroke volume. LVSW was expressed by the following equation: $LVSW = MAP - (15 - PPG\ AC\ modulation)$. It is also hypothesized that increases in DC mod represent decreases in preload. DC mod values were normalized by inverting the numeric scale (X axis values). Vasodilator administration was associated with preserved ventricular function. The directional changes in the data were consistent with established cardiac physiology principles. Relationships are presented in figure (1-A), while during sympathetic surge associated with surgical stimulation the directional change in the Starling curve data reversed as shown in figure (1-B).

Conclusion: A series of left ventricular function data sets were constructed from systemic arterial blood pressure and PPG AC mod and PPG DC mod measurements. Findings infer that the combination of PPG AC, PPG DC modulation and systemic arterial blood pressure measurements may provide the data required to construct a non-invasive ventricular function Starling curve. The precise numeric impact of changed PPG modulation as a result of changes in the caliber of the microvasculature requires further study.

References: 1. JCMC 2014; 28,(6): 591-596, 2. JCMC 2011;25 (6); 387-396, 3. Circulation 1964; 29: 739-749



Comparison of Different Methods of Frequency Analysis of the Clinical Waveforms

Authors: Aymen Alian, MD, Kirk Shelley, MD, PhD; Department of Anesthesiology, Yale University School of Medicine, New Haven, CT

Introduction: Frequency analysis of the pulse oximeter waveform (PPG) is a powerful method used to detect changes in the waveform at the respiratory and cardiac frequencies.¹ It is less prone to artifact, compared to time domain techniques, because it allows for examination of physiologic phenomena specifically at the respiratory frequency. Different types of frequency analysis include amplitude, amplitude density (which accounts for the size of the window), power (square of the amplitude) and power density measurement. One of the most frequently used methods of frequency analysis is the calculation of the power spectrum. This is used to improve the signal to noise ratio. This is done at the expense of low amplitude background signals (such as respiration when compared to the cardiac modulations). This abstract examines some of the technical aspects of these types of calculations.

Methods: Finger PPG and airway pressure were recorded at 100 Hz from operating room clinical monitors (GE; Fairfield, CT) with a data acquisition system (Collect 5/S – GE; Fairfield, CT). We used LabChart 7.37 (ADInstruments, Boulder CO) to analyze these waveforms as shown in figure (1). Frequency analysis of the PPG waveforms was performed using amplitude modulation of PPG (PPG AC) and baseline modulation (PPG DC). Fast-Fourier Transform (FFT) with a spectrum view setting as shown in figure (1), [spectrum, 4K (40 second@100 Hz) Hamming window, amplitude density (AD), 93.75% window overlap] over 3 minute windows. Modulations of the PPG waveform at respiratory and cardiac pulse frequency were isolated where the respiratory frequency was defined as the same frequency as the airway pressure waveform and cardiac pulse frequency was defined as the highest peak between 1-2.5 Hz. The strength of the waveform's modulations was measured as either the peak value of amplitude, amplitude density, power or power density or the area under the curve of the corresponding frequency. Data presented as mean \pm SD, paired t-test was used and P value <0.01 was considered significant.

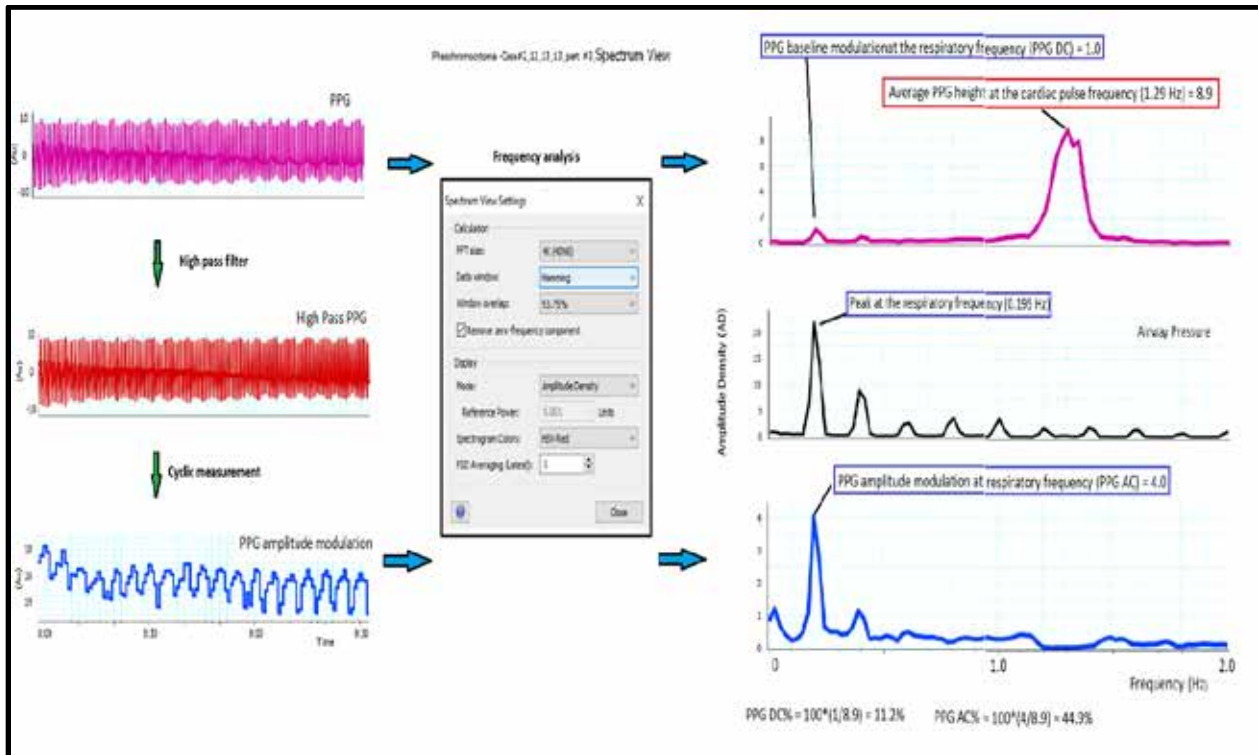
Results: Frequency analysis of the PPG was performed on 30 different waveform segments. In table 1-A, there was a significant increase in the peak values of PPG DC% and AC% amplitude and amplitude density when compared to the peak values of power and power density. In table 1-B; there was a significant increase in peak value when compared to the area under the curve for the amplitude, amplitude density, power and power density of PPG DC% and AC%.

Conclusion: The peak value of amplitude density (AD) appeared to be the most sensitive measurement of the respiratory modulation in the PPG. We attributed this to a number of factors. Amplitude measurement (as opposed to Power) assures that the respiratory signal does not become overpowered by the cardiac signal in the PPG. A density measurement corrects for window size and allows for the comparison of uneven windows. In this study it did not appear to impact on the sensitivity of the method. Finally, the peak measurement,

when compared to area, appears to be superior because of its ease of calculation and its sensitivity to subtle changes.

References: 1. JCMC 2011;25(6); 387-396

Figure (1):



A	Peak value	Amplitude	Power	Amplitude Density (AD)	Power Density (PD)
	PPG DC%	5.2 (2.6)	0.34 (0.37)	5.2 (2.7)	0.34 (0.37)
	<i>p value</i>		<0.01		<0.01
	PPG AC%	19.6 (10.6)	4.96 (5.46)	19.7 (10.7)	4.81 (5.51)
	<i>p value</i>		<0.01		<0.01
B					
	PPG	Variables	Peak value	Area	<i>P value</i>
	PPG DC%	Amplitude	5.2 (2.6)	3.2 (1.5)	<0.01
		Amplitude Density (AD)	5.2 (2.7)	3.1 (1.4)	<0.01
		Power	0.34 (0.37)	0.19 (0.18)	<0.01
		Power Density (PD)	0.34 (0.37)	0.19 (0.19)	<0.01
	PPG AC%	Amplitude	19.6 (10.6)	11.7 (5.1)	<0.01
		Amplitude Density (AD)	19.7 (10.7)	11.7 (5.1)	<0.01
		Power	4.96 (5.46)	2.72 (2.79)	<0.01
		Power Density (PD)	4.81 (5.51)	2.65 (2.75)	<0.01

Raman Spectroscopy Identifies Each Tissue in the Path of an Epidural Needle

Authors: T. Anthony Anderson, PhD, MD; Massachusetts General Hospital

Background: Neuraxial anesthesia and epidural steroid injection techniques require precise anatomical targeting to ensure successful and safe analgesia. Previous studies suggest that only some of the tissues encountered during these procedures can be identified by spectroscopic methods, and no prior study has investigated the use of Raman, diffuse reflectance, and fluorescence spectroscopies. We hypothesized that real-time needle-tip spectroscopy may aid epidural needle placement and tested the ability of spectroscopy to distinguish each of the tissues in the path of neuraxial needles.

Methods: For comparison of detection methods, the spectra of individual *ex vivo* paravertebral and neuraxial porcine tissues were collected using Raman spectroscopy (RS), diffuse reflectance spectroscopy (DRS), and fluorescence spectroscopy (FS). Real-time spectral guidance was tested using a 2.7-mm outer diameter fiber optic probe-in-needle device. RS spectra were collected during the needle's passage through intact paravertebral and neuraxial porcine tissue and analyzed afterward. The RS tissue signatures were verified as mapping to individual tissue layers using histochemical staining and widefield microscopy.

Results: Raman spectroscopy revealed a unique spectrum for all *ex vivo* paravertebral and neuraxial tissue layers (Figure 1); DRS and FS spectra were not distinct for all tissues. Moreover, real-time Raman spectra gathered during needle insertion also permitted identification of each paravertebral and neuraxial porcine tissues.

Conclusions: This study demonstrates Raman spectroscopy can distinguish all tissues encountered during epidural needle procedures. This technology may prove useful during needle placement by increasing the confidence of its anatomical localization.

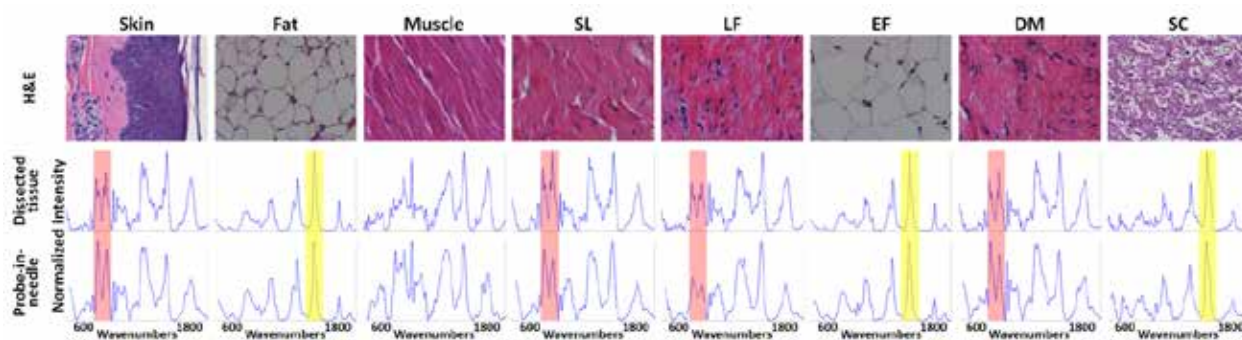


Figure 1. Each tissue from the skin to the spinal cord has a unique Raman spectrum. Hematoxyline and eosin stained tissue scanned by RS (top row). Magnification = 40X.

Corresponding Raman spectra from dissected tissues (bottom row). Highlighted band in red color (939 cm^{-1}) indicates collagen-specific Raman signal, yellow color (1450 cm^{-1}) indicates lipid-specific Raman signal.

Life Span and Efficiency Analysis of a Solid Phase Lithium Hydroxide CO₂ Absorber-Spiralith™

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Co-Author: Sarah VanGeest Cer.A.T., Cuyuna Regional Medical Center, Crosby, MN 56441

Background/Introduction: Traditional CO₂ absorbers use calcium hydroxide-based soda lime as absorbent and can generate compound A and carbon monoxide (1, 2). Other disadvantages of soda lime granules are desiccation and random channeling, leading to inconsistent life span and volatile anesthetic waste. Spiralith is a solid phase CO₂ absorbent comprised of pure lithium powder bound to a polymer matrix engineered in solid sheets with pre-formed channels. Solid lithium hydroxide absorbent does not desiccate nor generate compound A and CO at any fresh gas flow rates (1). We aim to evaluate the performance of Spiralith under normal fresh gas flow and low flow conditions. To our knowledge, this is the first clinical study of the lithium absorbent Spiralith in terms of absorber life span and efficiency of volatile anesthetic usage with Sevoflurane (3).

Methods: General anesthesia cases utilizing Sevoflurane were included in the study using Drager Apollo machine with Spiralith absorber. Normal Flow group (n=45 cases); Low Flow group (n=36 cases). Preoxygenation was conducted with oxygen flow at 10 L/min. After IV induction and airway establishment, oxygen flow was reduced to 4 L/min until patients achieve 0.5 MAC as calculated by age on the anesthesia machine. Then, combined O₂ and air flow was reduced to 2 L/min for Normal Flow, 1 L/min for Low Flow, until all patients reach 1 MAC. The 1 MAC volatile anesthesia was maintained at the respective flow rates while intraoperative care continued by IV balanced technique until emergence, at which time the total fresh gas flow was turned up to 10 L/min until extubation. Data points were collected from the Drager Apollo machine DataLog, including duration of general anesthesia, O₂ and air consumption, Sevoflurane consumption and uptake in liquid ml. The time from surgery end to extubation was also collected. Data were entered and analyzed in Excel spreadsheet. Statistical analysis was performed using unpaired Student's t-Test in Excel; statistical significance is defined as $p < 0.01$.

Results: The average life span of Spiralith absorber was 1668 min for Normal Flow, 1120 min for Low Flow. The efficiency of Low Flow resulted in Sevoflurane waste of only 28%, compared to 57% Sevoflurane waste for Normal Flow ($p < 0.001$). The average case length was similar, 111 min Normal Flow, 124 min Low Flow ($p = 0.13$), and the average time to extubation

was not significantly different (4.7 min Normal Flow vs. 6.2 min Low Flow, $p=0.11$).

	Normal Flow	Low Flow	p value
n (# cases)	45	36	
Case length (min)	111	124	0.13
Absorber life span (min)	1668	1120	<0.001
Sevoflurane waste (%)	57	28	<0.001
Time to extubation (min)	4.7	6.2	0.11

Conclusion: We have now defined the life span of SpiraLith absorber in two commonly used clinical settings. More importantly, SpiraLith absorber has significantly lower Sevoflurane volatile anesthetic waste at low flow conditions, potentially saving overall anesthetic cost by employing low flow technique with Sevoflurane, without the risk of toxic by-product generation using the solid lithium CO₂ absorber.

References:

1. Stabernack CR et al: Absorbents differ enormously in their capacity to produce compound A and carbon monoxide. *Anesth Analg*. 2000 Jun;90(6): 1428-35.
2. Kharasch ED et al: Comparison of Amsorb, soda lime, and Baralyme degradation of volatile anesthetics and formation of carbon monoxide and compound A in swine in vivo. *Anesthesiology*. 2002 Jan;96(1):173-82.
3. Hendrickx JF et al: In Vitro performance of prefilled CO₂ absorbers with the Aisys. *J Clin Monit Comput*. 2015 May 8 (Epub ahead of print).

Signal Processing Methods to Improve Concordance of Bispectral Index with End-Tidal Anesthetic Concentration

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Co-Authors: Joel Dudley, PhD, Dept of Population Health Science and Policy, Mount Sinai Hospital, New York, USA; Matthew A Levin, MD, Dept of Anesthesiology, Mount Sinai Hospital, New York, USA

Introduction: The titration of inhaled anesthetics is often guided by either measuring end-tidal anesthetic concentrations (ETAC) or an EEG-based surrogate of anesthetic concentration at the effect-site, the bispectral index (BIS). The relative effectiveness is equivocal and debated [1][2]. Patients have widely variable relationships between ETAC and BIS response, which has been used in some studies as a surrogate for anesthetic susceptibility. The largest concordance analysis to date showed that the B-Unaware population had a median intraindividual ETAC – BIS correlation of -0.16 (interquartile range -0.031, -0.50)[3]. BIS has been shown to be susceptible to noise from various artifacts, including muscle activity and experimental sound[4]. Noise in the BIS signal, particularly around anesthesia induction and emergence, produces significant biases in the statistics relating these markers of sedation. Here, a low-pass butterworth filter was optimized to improve the signal-to-noise of the BIS signal and maximize concordance between BIS and ETAC.

Methods: We identified general anesthesia cases with at least 5 minutes of simultaneous BIS and ETAC measurements, excluding pediatric and cardiac cases, resulting in 21,766,061 BIS/ETAC measurement pairs across 32,667 cases. Sampling rate for BIS and ETAC was q15 seconds. ETAC was age and equivalence adjusted. Data analysis was performed in R, with the 'data.table' package leveraged for column-oriented data storage. The cross correlation of each individual's BIS and ETAC datastream was calculated to assess concordance. We evaluated cross correlations as a function of offsets between ETAC and BIS to assess for a lag between ETAC change and BIS response. A butterworth filter was used to design a low-pass filter to eliminate the high frequency noise from both datastreams. This filter was then used with original data and event information to create case visualizations and produce processed datastreams. Nonparametric distributions are reported as median value [interquartile range] and evaluated for differences with a Wilcoxon paired signed rank test.

Results: The optimized butterworth filter has an order of 1 and critical frequency of $.22 \text{ min}^{-1}$. This suggests that signal components with frequencies on the order of seconds are largely noise, and robust changes in BIS occur on the order of minutes. As shown in Figure 1b, the intra-case BIS-ETAC cross correlations were significantly different when calculated on filtered versus raw datastreams with the median filtered datastreams more concordant than raw datastreams (correlation coeff -0.53 [-0.75 to -0.19] versus -0.43 [-0.64 to -0.17], respectively, $p < 2.2 \times 10^{-16}$). Correlations for both raw and filtered datastreams are much higher than previously reported.[3]

Conclusions: Although BIS and ETAC are both surrogate measures for depth of anesthesia when titrating anesthetics, they have variable relationships to each other on a case-by-case

basis. Here we optimize butterworth filter parameters to remove the high frequency noise components of these datastreams and find improved concordance. Developing signal filters can increase sensitivity and enable analysis of induction and emergence trends to provide further insights into anesthetic sedation responses.

References:

- [1] E. Ben-Menachem and D. Zalcberg, "Depth of anesthesia monitoring: a survey of attitudes and usage patterns among Australian anesthesiologists.," *Anesth. Analg.*, vol. 119, no. 5, pp. 1180–5, 2014.
- [2] Y. Punjasawadwong, A. Phongchiewboon, and N. Bunchungmongkol, "Bispectral index for improving anaesthetic delivery and postoperative recovery (Review)," *Cochrane database Syst. Rev.*, vol. 6, no. 10, pp. 10–12, 2014.
- [3] E. L. Whitlock, A. J. Villafranca, N. Lin, B. J. Palanca, E. Jacobsohn, K. J. Finkel, L. Zhang, B. A. Burnside, H. A. Kaiser, A. S. Evers, and M. S. Avidan, "Relationship between bispectral index values and volatile anesthetic concentrations during the maintenance phase of anesthesia in the B-Unaware trial.," *Anesthesiology*, vol. 115, no. 6, pp. 1209–18, Dec. 2011.
- [4] D. W. Kim, H. Y. Kil, and P. F. White, "The effect of noise on the bispectral index during propofol sedation.," *Anesth. Analg.*, vol. 93, no. 5, pp. 1170–3, Nov. 2001.

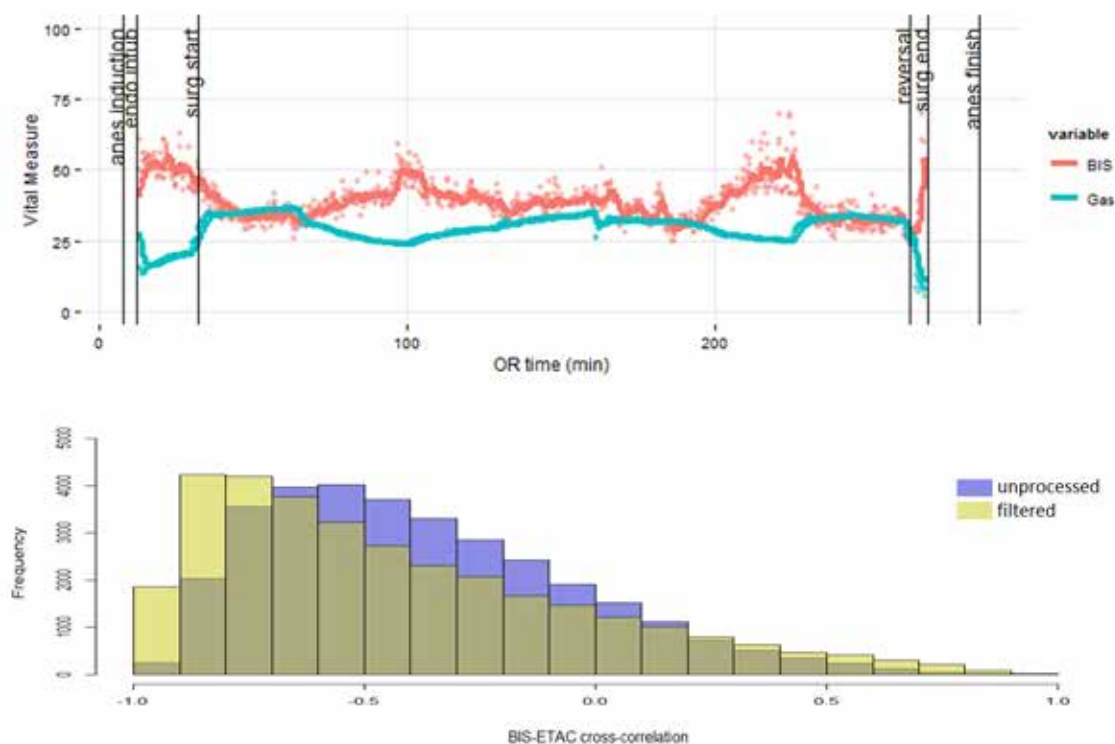


Figure 1: a) Representative case showing BIS (red) and ETAC (blue). Unprocessed measurements are plotted as points, and the filtered signal is plotted as a line. ETAC is scaled by 25. **b)** Distribution of case-by-case BIS-ETAC cross-correlations with unprocessed (purple) and filtered (yellow) datastreams. Filtering shifts the distribution to the left, indicating improved cross-correlation.

Creation of a Digital iBook Curriculum for Anesthesiology Residents

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Co-Author: Adam Levine, MD, Department of Anesthesiology, Icahn School of Medicine at Mount Sinai

Background/Introduction: Today's resident is a product of the millennial generation, a group notorious for the reliance on digital technology and the utilization of social networks and online resources in order to learn new things, share content and produce original work. This poses challenges for residency programs, as these learners challenge the existing paradigms for education that have been in place for decades. Residency programs have responded by instituting daily lectures, simulation sessions, case discussion and problem-based learning. While these serve an excellent purpose, they largely do not utilize technology pervasive throughout the rest of the millennial's life.

Among the most stressful periods in an anesthesiology resident's career is the beginning of the introduction to residency; this period is marked by a steep learning curve, the introduction of an entirely new set of agents and techniques and the first time residents will be left alone with patients undergoing anesthesia. There is no standardized curriculum; training programs around the country use their own individual lecture series, usually alongside pairing with faculty. This experience predisposes residents to have varied experiences depending on their attending preceptor and case mix.

Methods: Our team's aim was to create a curriculum using the iPad to encourage resident self-education. This resource was hand-coded from scratch, covering the basics of anesthesiology using our curriculum as a framework. This resource contains interactive, rich media allowing for self-evaluation and further study and is flexible to the learner. It includes a number of different features to allow residents to quiz themselves and review material.

Results: While data is still being collected, our residents averaged approximately 18 hours of studying with the book over the first two weeks of July (and a total of 31 hours by the time our study concluded 6 weeks into CA-1) and report a high satisfaction with the product. Attending preceptors have reported that the residents' knowledge base seems to be above the level of prior residents.

Conclusion: The presence of an iBook curriculum for the beginning of residency served to augment clinical learning, and was favorably received by residents and their attending preceptors alike. Further directions include expanding this curriculum to other programs or areas of anesthesiology education.

CHAPTER 3 Pharmacology

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The Anesthesia Hub. A Centralized Mobile Platform with Vital Information available at one's fingertips. What are users really looking for?

Presenting Author: Nirav P Bhavsar, MD, University of Miami / Jackson Memorial Hospital

Co-Authors: Frank Gencorelli, MD, Luis I Rodriguez, MD

Introduction: Technology is ever-changing the way medicine is practiced and accessed. Information Technology, particularly in the mobile sector, has become an invaluable tool to physicians and other health care providers for fast and easy access to critical information in the palm of their hands. Mobile health, known as mHealth, is paving new avenues for data presentation and communication for health care providers as well as patients. Our previous abstract outlined a mobile web platform created for a large multicenter academic program via Hubspring.com known as the Anesthesia Hub with vital information including, but not limited to, contacts, schedules, protocols, and an array of other resources. We showed the increase in total usage of the platform over time, but not regarding what type of data was particularly accessed. (1) With quick adoption of such technologies, there is evidence for a need for secure, reliable, and easily available tools for access to this information.

Methods: With the use of the Anesthesia Hub platform via Hubspring.com, we collected access data of the top 20 specific nodes. These nodes represent a particular data area of the Anesthesia Hub application. The node data was then stratified into major categories: Contacts, OR Board, Provider Schedule, Break Coordination, Clinical Resources (includes protocols, policies, guidelines), and Provider Resources (includes Facility, Resident, and SRNA/CRNA resources, either hospital related or academic). The number of data views of each node were totaled within each category and compared against each other. This allowed us to have a snapshot, since deployment, of the most viewed data among anesthesia providers.

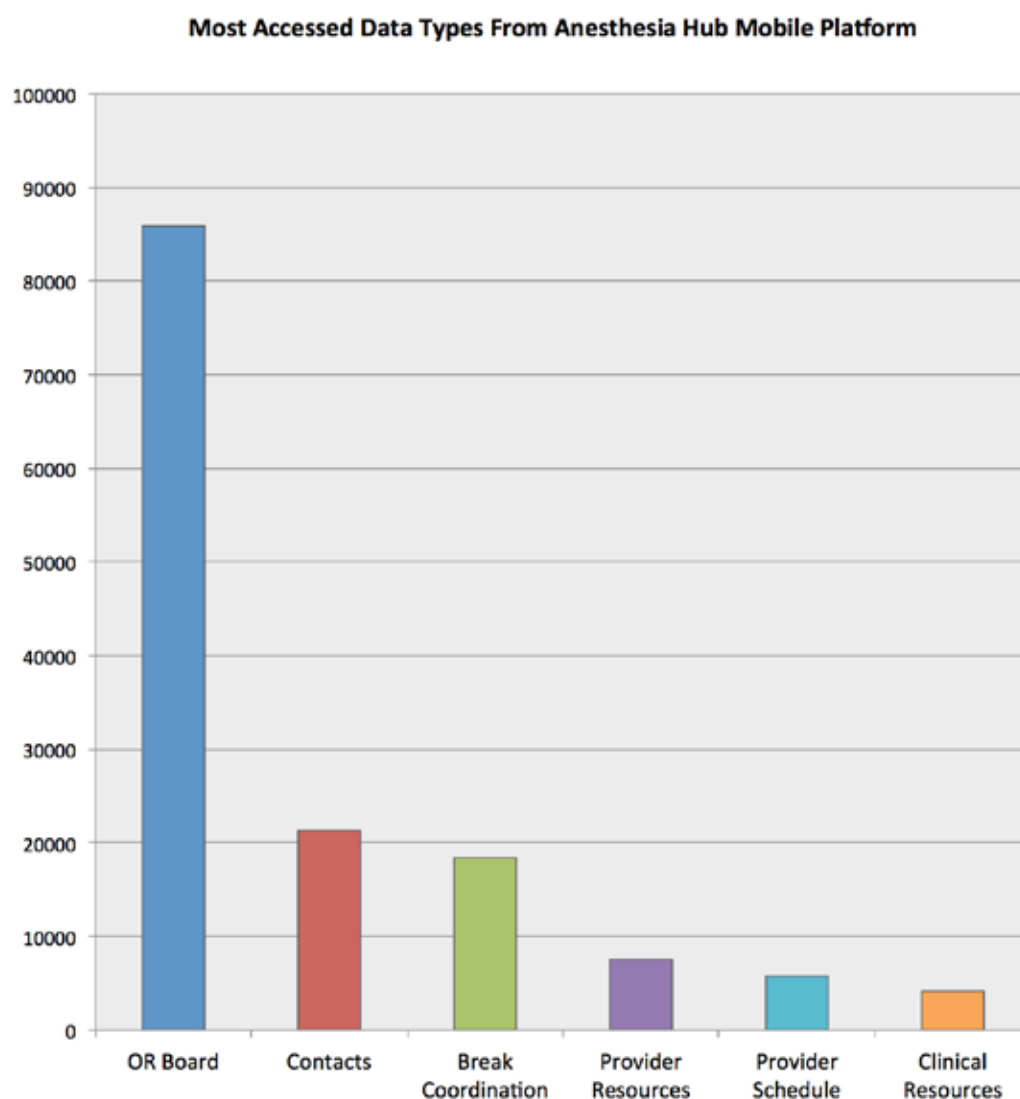
Results: The top 20 nodes accessed were split into 6 major categories. A total of 143,085 data points (currently averaging 3,500 hits per week) were accessed since deployment of the Anesthesia Hub in June 2014. After splitting into categories, the most accessed data type was that of the OR Board (85,902). This was followed by Contacts (21,321), Break Coordination (18,396), Provider Resources (7,548), Provider Schedule (5,749), and Clinical Resources (4,169). This data was then formatted graphically.

Discussion: The ability to have quick and easy access to vital information is of great importance, especially in the setting of a large multicenter academic program. Currently, the tools available include websites and mobile technology, while the latter being the most easily accessible. Our data shows that users, anesthesia providers, are particularly interested in the operating room board and contact information. The implementation of a live OR board data facilitates OR management and helps to increase efficiency with OR coordination and staffing. Contact resources are vital to any group, particularly with regards to potential emergency situations. The Contacts node reflects communication between the different levels of anesthesia providers: attending physicians, residents, CRNAs, SRNAs, and administration. This data shows that a centralized mobile platform can facilitate management and efficiency in

areas of healthcare combined with improved communication between healthcare providers, either on a daily basis or in crisis situations. (2)(3).

References:

1. Rodriguez, L. I., Gencorelli, F., & Lubarsky, D. (2015). The Anesthesia Hub – A Mobile Tool Launched to Improve Access to Critical Information. The Experience of a Large Multicenter Anesthesia Academic Practice [Abstract]. Society for Technology in Anesthesia 2015 Annual Meeting. Jan 7-10, 2015. Phoenix, AZ. Abstract nr 2.
2. Case, T., Morrison, C., & Vuylsteke, A. (2012). The clinical application of mobile technology to disaster medicine. *Prehospital and Disaster Medicine*, 27(5), 473-80.
3. Prgomet, M., Georgiou, A., & Westbrook, J. I. (2009). The Impact of Mobile Handheld Technology on Hospital Physicians' Work Practices and Patient Care: A Systematic Review. *Journal of the American Medical Informatics Association*, 16(6), 792-801.



Continuous Respiratory Status Visualization Technique: Leveraging High-Fidelity Continuous Respiratory Volume Monitoring for Rapid Patient Assessment

Presenting Author: Jordan Braynov, PhD, Respiratory Motion Inc.

Co-Author: Ed George, MD PhD, Massachusetts General Hospital, Harvard Medical School

Introduction: Respiratory monitoring and assessment is crucial for improved patient outcomes in most hospital settings. Higher acuity settings like ICUs employ more staff, additional monitoring equipment, and sophisticated data collection and processing systems capable of gathering, aligning, and processing numerous data streams. Data interpretation is often more challenging than collection, as nearly all interpretations are performed by highly-trained clinicians who often need to review substantial amounts of data to make correct clinical decisions. Such an approach is not sustainable in the majority of lower-acuity settings, like the post anesthesia care unit (PACU) or the general hospital floor (GHF), where patient monitoring and decision making is often based on “spot-checks” and sparse data, rather than continuous data trends. This problem is further complicated by the current monitoring standards which are either subjective (e.g. visual assessment by an RN) or based on secondary measures of respiratory status (e.g. SpO₂ or EtCO₂). Here we demonstrate a novel visualization technique, based on continuous respiratory volume monitoring (RVM) data, which allows clinicians to assess patient respiratory status quickly and efficiently. By reducing the variability of the high-fidelity RVM data while preserving key temporal and dimensional features, we were able to synthesize hours of patient data into simple and easy-to-interpret plots, allowing clinicians to make clinical decisions faster, with improved patient safety, reduced staff workload, and healthcare cost-savings.

Methods: Continuous RVM data (ExSpiron, Respiratory Motion, Inc.), O₂ supplementation status, SpO₂ alarm records and PCA opioid administration data were collected from 12 patients (5 females; mean age: 69yrs, range: 58-84; mean BMI: 31.2 kg/m² range: 22.0-49.1kg/m²) during their stay in the PACU following orthopedic surgery. Note that these patients were part of a much larger observational IRB-approved study, but for the purposes of this demonstration, we present only a small subset of the enrolled patients. Here, a low MV event (LMVe) was defined as $MV < 40\% MV_{PRED}$ (based on the patient’s BSA) sustained for at least 60 seconds. Low SpO₂ alarm limit was set at <90% and sporadic low SpO₂ readings (<2 min) were considered “false alarms.”

Results: Each patient is visualized along an individual axis, parallel to the Y-axis (see Fig 1). The dashed blue line represents each patient’s timeline in the PACU, with arrival at the PACU aligned with the X-axis. Supplemental O₂ is displayed as a solid red line overlaid on top of the dashed blue, spanning the regions where supplemental O₂ was delivered. Along each patient axis we display LMVe with red ellipses. The length of each ellipse (along the y-axis) denotes the temporal duration of an LMVe or a cluster of LMVe (if in close succession), whereas the width of each ellipse corresponds to the severity of each event with wider ellipses corresponding to more severe (i.e. lower MV) LMVe. In addition, PCA opioid doses are visualized as green asterisks, apneic pauses longer than 30-sec as black dots, and Low SpO₂

alarms as purple diamonds. “False SpO₂ alarms” are displayed with hollow symbols and SpO₂ alarms lasting > 2min are displayed with solid symbols.

Conclusions: As more clinical decisions are driven by quantitative data, new ways of synthesizing and visualizing data can assist with interpretation and quicker patient assessment. This is particularly important when working with high-fidelity respiratory volume data in non-intubated patients. The naturally occurring variability in these data can make it challenging for a clinician to combine trends and correlative or causal effects from the raw metrics alone, which is why we propose that a synthesized visualization may be able to assist not only with clinical decision making, but may also reduce workload and associated healthcare costs.

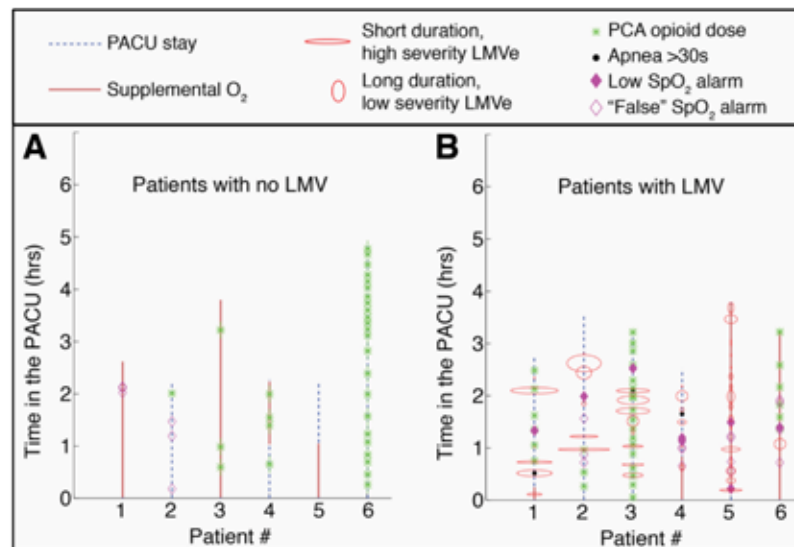


Figure 1: Visualization of patient respiratory status in the PACU. PACU stay is displayed as a dashed blue line, with arrival at the PACU aligned with the X-axis. Supplemental O₂ is displayed solid red on top of the dashed blue. An LMVe is represented by a red ellipse. This visualization allows for easy differentiation between LMVe with less than 10% difference (i.e. 40% MVpred vs 30% MVpred) and with temporal spacing of less than 10 minutes on an axis that spans a full 8-hour shift. Green asterisks represent PCA opioid doses, apneic pauses are displayed as black dots, and Low SpO₂ alarms as purple diamonds (solid for alarms >2min, hollow for “False SpO₂ Alarms” <2min).

Quality Indicator for Capnometry Parameters

Presenting Author: Lara Brewer, Ph.D.

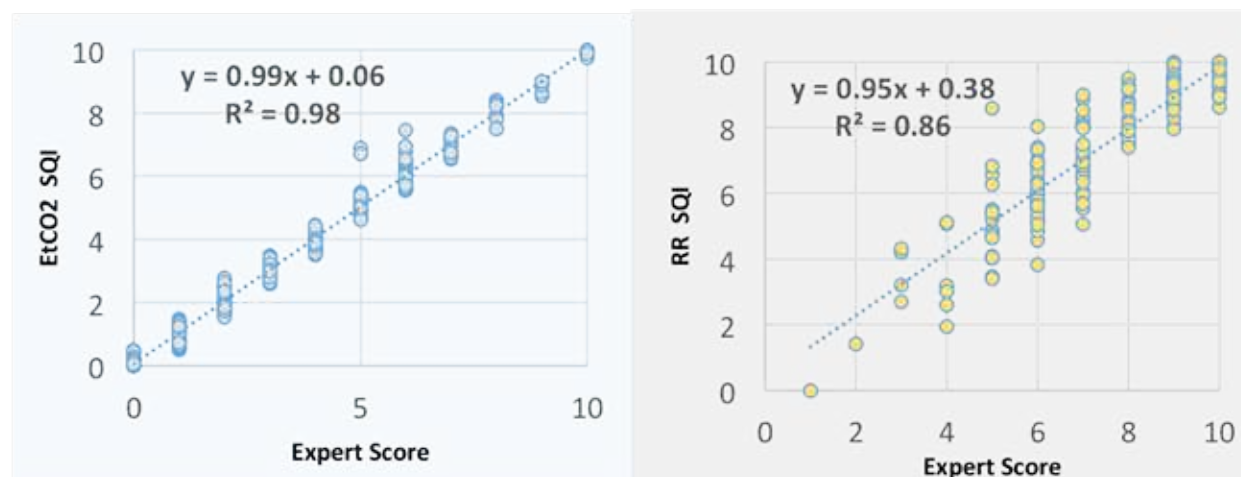
Co-Author: Joseph Orr, Ph.D.

Background: When a clinician or smart advisory system makes use of capnometry parameters such as respiratory rate and end-tidal carbon dioxide (etCO₂) for decision making, and before these parameters are stored in automated patient records, it is important to first know how reliable the parameters are. Historically, clinicians evaluated the corresponding capnogram for waveform quality before recording the respiratory rate and etCO₂ in a patient record. For example, if cardiogenic oscillations caused a high number of breaths to be detected, the anesthesiologist knew the displayed respiratory rate was too unreliable for use in decision making and the high rate was not recorded.

As capnometry monitoring moves to areas of use outside of the operating room, several challenges are encountered. The clinicians have less capnometry expertise and less time to evaluate the capnogram waveform quality. Meanwhile, the capnogram waveforms are more likely to be unreliable, so a clinician may not know if the reported parameters can be relied upon for decision making. We have developed an automated system that evaluates the expired CO₂ waveform and calculates a quality score to indicate if the respiration rate and etCO₂ measurements from that waveform are reliable for decision making. A quality indicator (SQI) could be displayed next to each parameter to indicate how dependable it is. In addition, we expect that these reliability scores could accompany parameters stored in anesthesia information systems to prevent incorrect conclusions from being reached from these parameters when the patient records are analyzed. We developed and evaluated quality indicators for etCO₂ and respiratory rate parameters.

Methods: An automated system extracts numeric descriptive features from the CO₂ waveform. These descriptive features are the input to a scoring algorithm. Scores of the parameter signal quality for respiratory rate and etCO₂ are in a range of 1-10 for each breath. Algorithm scores and expert opinion were recorded for a set of capnograms which had been recorded from patients in the OR, ICU and during procedural sedation. The algorithm was modified to better match expert opinion and the data were re-evaluated. The automated system scores were compared to the expert scores using linear regression analysis.

Results: Figure 1 shows the linear regression analysis of the quality indicator score and the expert score for the etCO₂ and respiration rate signal quality



indicators.

Figure 1: EtCO₂ and RR SQI vs. Expert score

Discussion: The automated system scores correlated well with the experts' scores in this initial study. We are currently evaluating the automated scoring system in an expanded study.

Respiratory Well-being Index Calculated from Capnometry Waveform and Parameters

Presenting Author: Lara Brewer, Ph.D.

Co-Author: Joseph Orr, Ph.D.

Background: During sedation, a patient's breathing pattern may be unstable and their ventilation may be impaired. We have developed a decision support system designed to use parameters derived from capnometry to inform clinicians when ventilation is not optimal. The system provides both an index score (called Respiratory Wellbeing Index, RWI) and a message to help the clinician identify and troubleshoot the problem quickly. The underlying algorithm applies features calculated from the shape of the capnogram and clinical parameters (respiration rate and etCO_2) to calculate the index value and select the displayed message.

Methods: Brief epochs of capnometry data collected in various clinical settings were evaluated and scored by two pseudo-experts. The expert opinion data were used as the reference measure against which we compared performance of the RWI algorithm. The RWI algorithm was iteratively modified to improve agreement with expert opinion. In addition, the RWI system provides advisory messages based on extreme values of the input features. Examples of these messages might include “no breaths detected”, “ etCO_2 low” or “prompt patient to breathe”.

Results: Figure 1 shows the linear regression analysis of the RWI score and the expert reviewer scores.

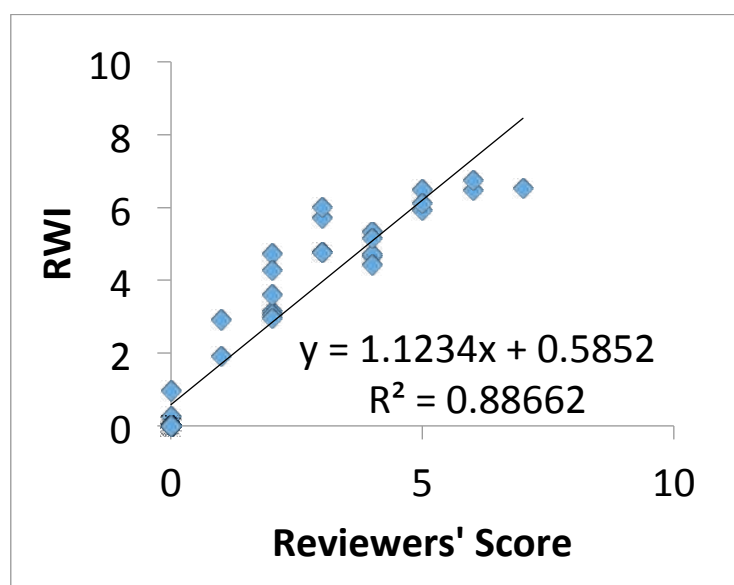


Figure 1. Comparison of the RWI and reviewer scores.

Discussion: The automated system's displayed scores and messages compared well with the pseudo-expert reviewer's scores and expected messages in this preliminary study. We are currently conducting an expanded study of a comparison of the system's outputs with true clinical experts' scores and expected messages.

Continuous Sedation Monitoring in Critically Ill Patients Using the WAV_{CNS} Index

Presenting Author: Sonia M Brodie*

Co-Authors: Klaske van Heusden**, Nicholas West*, Matthias Görges*, Sarah Sunderland*, Paul B McBeth***, J Mark Ansermino*, Guy A Dumont**, Donald E G Griesdale*

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Introduction: Achieving appropriate sedation in the intensive care unit (ICU) is challenging, as both over- and under-sedation are detrimental^{1,2}. Current strategies involve sedation scoring systems such as the Richmond Agitation Sedation Scale (RASS)⁴. These scales rely on patient response to a stimulus, and are hence insensitive to change for deeper levels of sedation⁵. Furthermore, scoring is intermittent leading to prolonged periods of unmeasured sedation depth. Several processed electroencephalography (pEEG) monitors have been developed to continuously measure depth of hypnosis during general anesthesia⁶. In the ICU, correlation between bispectral index (BIS) and sedation scales has been low, and is negatively affected by muscle activity, a known confounder in BIS monitoring⁷. Thus far, no pEEG monitor is routinely used in the ICU¹. The aim of this observational pilot study was to assess the feasibility of using the NeuroSENSE monitor (NeuroWave, Cleveland, USA⁶) WAV_{CNS} index in the ICU. We hypothesized the WAV_{CNS} can distinguish between consciousness (RASS goal ≥ -2) and unconsciousness (RASS goal ≤ -3).

Method: With Research Ethics Board approval, adults admitted to the ICU on continuous propofol sedation with ventilator support were screened for eligibility. Informed consent was deferred to the substitute decision maker, and obtained post-hoc from participants if possible. WAV_{CNS} values were obtained from the NeuroSENSE, to which clinicians were blinded. Bedside ICU nurses performed RASS assessments every 4 hours or more frequently when clinically indicated, and the sedation regimen was adapted to clinical need. Propofol infusion rates and RASS scores were recorded manually. Participants were monitored for duration of their propofol infusion, up to 24hrs.

Results: Of 93 ICU patients screened, 47 patients were ineligible due to neurological diagnoses, and 16 were weaned off propofol within the first hour. In 21 cases, sensor placement was deemed impractical (due to facial bandaging, diaphoresis, etc), and consent could not be obtained for 9 cases. Sixteen patients were included in the analysis (mean age 59 ± 12 years, 12 male, monitoring time 14.0 ± 7.7 hrs). Only 3 cases consistently had RASS scores equivalent to

their sedation goals during the study period. These cases had the deepest sedation goals (i.e. $RASS \leq -4$).

Table 1. WAV_{CNS} indices grouped by RASS goal

	WAV_{CNS} minimum	WAV_{CNS} maximum	WAV_{CNS} median	WAV_{CNS} MAE	BSR maximum
Conscious (n=7) <i>RASS goal ≥ -2</i>	35 [29, 40]	95 [94, 95]	57 [54, 66]	8.6 [7.0, 11]	1.3 [0.15, 3.4]
Unconscious (n=6) <i>RASS goal ≤ -3</i>	29 [22, 35]	81 [78, 87]	48 [42, 62]	4.3 [4.2, 6.2]	11 [7.4, 18]

Values are median [IQR], from 4hr intervals (standard time between RASS assessments). RASS goal was not documented for 2 cases (excluded). (MAE: median absolute error; RASS: Richmond Agitation Sedation Scale; BSR: burst suppression ratio)

The remaining 13 cases were frequently scored higher or lower than their RASS goals. Overall, in the 4 hour intervals between scheduled RASS assessments, those who were lightly sedated showed higher, but more variable, WAV_{CNS} indices, and less burst suppression than those who were deeply sedated [Table 1].

Conclusion: The use of pEEG monitoring in the ICU is challenging due to a high prevalence of neurological diagnoses and impracticality of placing sensors. However, these preliminary results reflect sedation inadequacy obtained using current methods. RASS scores were more stable in deeply sedated patients. However, unconscious patients had a higher prevalence of burst suppression, a sign of overly-deep sedation, which has been associated with an increased risk of delirium⁸. The variability in WAV_{CNS} values between RASS assessments highlights the limitations of the RASS as a stand-alone measure of sedation levels, and suggests a potential benefit of adjunct continuous brain monitoring.

References: [1] Crit Care Med 2013;41:278–80.[2] Curr Opin Crit Care 2011;17:43–9.[3] Anesth Analg 2011;112:1202–11.[4] Am J Respir Crit Care Med 2002;166:1338–44.[5] Crit care 2000;4:217–25.[6] J Clin Monit Comput 2011;25:81–7.[7] Br J Anaesth 2015;115:i95–103.[8] BMC Anesthesiol 2015;15:61.

Reduced Operating Room Fire Hazard Using Intelligent Supplemental Oxygen Delivery

Authors: Kyle Burk B.S., Joseph Orr Ph.D., Derek Sakata M.D.; University of Utah, Departments of Anesthesiology and Bioengineering

Introduction: Fires in the operating room are a major hazard [1]. Mehta et al. reported that 1.9% of all operating room adverse events that resulted in closed insurance claims were caused by fires with electrocautery as the ignition source for 90% of these fires. Most (85%) of electrocautery fires occurred during head, neck, or upper chest procedures (high-fire-risk procedures) [2]. Delivered O₂ served as the oxidizer in 95% of electrocautery-induced OR fires and 84% of these occurred when oxygen was given with an open delivery system (nasal cannula or mask) [2]. A significant hazard for fire exists with a 26% or greater oxygen concentration [3]. Using standard oxygen flowmeters, O₂ flows continuously into the patient's nostrils even during exhalation resulting in wasted O₂ that flows between the surgical drapes and into the room greatly increasing the amount of fire promoting oxidizer in the operating room.

We have developed an intelligent oxygen flowmeter that reduces the volume of open source O₂ delivered by carefully limiting O₂ flow to periods during the early phase of inhalation, stopping O₂ flow completely during expiration and limiting the rate and duration of oxygen flow during the pause phase of breathing. In our tests, the novel system achieves superior oxygen delivery while using only 60% less oxygen thereby reducing the amount of possible oxidizer by 60% and as much as 90% as respiration rate decreases. The prototype determines respiration rate (RR) and inspiratory effort by measuring intranasal pressure through a cannula port. The system uses measured RR to adjust the O₂ volume delivered during each inspiration.

Methods: We used a 3-D printed model of the human airways placed under simulated surgical drapes to compare delivery modes. The model was connected to a test lung that was configured to breathe spontaneously at various rates and volumes. Oxygen was delivered through a nasal cannula at 2 and 4 L/min. Oxygen was given at flow rates of 2 and 4 L/min using both conventional (constant flow) and controlled (pulsed inspired) mode. We analyzed the oxygen concentration at specific places on the face of the model under the drapes (red circles on figure) and interpolated to build a concentration map on the face.

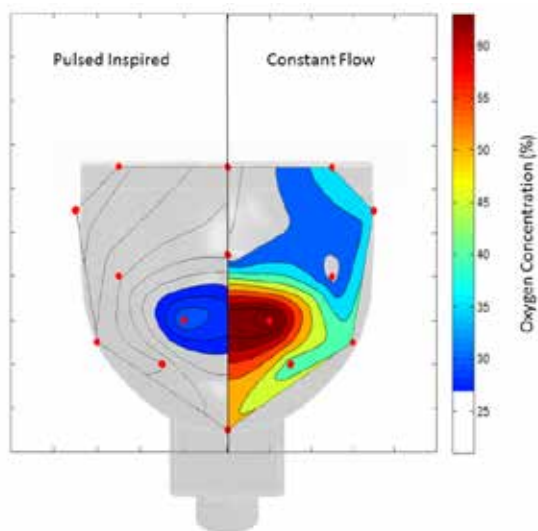
Results: Across all settings and flow rates, the average oxygen concentration under the drapes using pulsed flow was 38% lower than when using continuous flow oxygen. The average oxygen concentration under the drapes using the pulsed oxygen was 25.0% while it was 40.6% using constant flow. The maximum observed oxygen concentration was 83.27% when using constant flow of 2 l/min and was 35.36% using pulsed flow. We measured the oxygen concentration in the lung simulator to assess oxygenation. Pulsed oxygen resulted in 88% higher average oxygen concentration in the lung. The plot below shows a map of oxygen concentration under surgical drapes on a 3-D printed model of

the face at 4 breaths per minute and 2 L/min oxygen flow. The left side of the plot corresponds to pulsed flow delivery and the right plot corresponds to conventional (constant) flow. Note that oxygen delivery to the simulated lung was higher using pulsed flow for every simulated setting.

Discussion: Using intelligent control of oxygen flow allows for a reduction in oxygen waste and hazard while increasing the amount of oxygen inhaled by the patient. Intelligent pulsed oxygen delivery may keep oxygen levels below the 26% threshold for significant fire hazard.

References:

- [1] Eichhorn JH., A burning issue: preventing patient fires in the operating room. *Anesthesiology*. 2013 Oct;119(4):749-51.
- [2] Mehta SP, Bhananker SM, Posner KL, Domino KB., Operating room fires: a closed claims analysis. *Anesthesiology*. 2013 May;118(5):1133-9.
- [3] Tao JP, Hirabayashi KE, Kim BT, Zhu FA, Joseph JM, Nunery W, The Efficacy of a Midfacial Seal Drape in Reducing Oculofacial Surgical Field Fire Risk. *Ophthal Plast Reconstr Surg*. 2013;29(2):109-12.



Supplemental Oxygen Delivery Method Affects Comfort Level in Volunteers

Authors: Kyle Burk B.S., Joseph Orr Ph.D.; University of Utah, Departments of Anesthesiology and Bioengineering

Introduction: Supplemental oxygen is often given to awake, sedated patients in order to decrease the frequency and depth of oxygen desaturation caused by periods of respiratory depression and airway obstruction. When sedation is minimal, patients may complain of discomfort caused by high flow oxygen delivered into the nares by nasal cannula. Discomfort may be more severe when the patients are monitored using cannulas designed to sample CO₂ since the cross-sectional area of the oxygen delivery port is smaller causing oxygen to jet into the nostril(s).

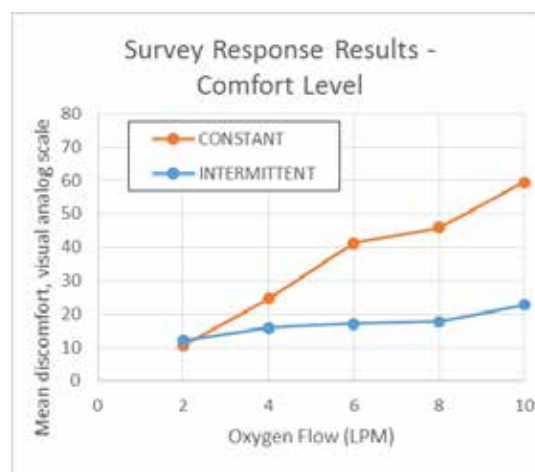
We hypothesized that the majority of discomfort associated with oxygen delivery is experienced when the patient is breathing out against the oxygen flow. During the expiratory phase of respiration, as the patient is breathing out, the supplemental oxygen flowing into the nares raises intra-nasal pressure increasing discomfort. Furthermore, high flow during the expiratory pause adds to the perceived discomfort by drying the nasal mucosa. We have developed an intelligent supplemental oxygen flowmeter that only gives oxygen at during the start of inspiration and at low flows for a brief period during the expiratory pause. The amount of flow given by the system varies according to the respiration rate so that as the respiration rate slows, the amount of inhaled oxygen is increased so that the volume of inhaled O₂ remains constant regardless of breath rate.

We evaluated how well high flow nasal oxygen is tolerated if it is only given during inspiration in volunteers.

Methods: Thirty healthy volunteers (21 Male, 9 female, average age = 34.4) were fitted with a nasal cannula while seated before a laptop computer. A semi-automated system administered nasal oxygen through the cannula at various flow rates using either continuous flow or pulsed inspiratory flow. After breathing under each condition, the volunteers entered their level of discomfort into the computer using a sliding scale between 0 and 100 where 0 indicates no discomfort and 100 indicated pain.

Results: The plot below shows the average relative discomfort for each of the tested flow rates for both conventional (constant flow) and intermittent (inspiratory only) oxygen delivery modes. The average perceived discomfort was similar at 2 L/min. At flow rates of 4 l/min and above, intermittent inspiratory-only flow the average discomfort was significantly less ($P = 0.05$).

Discussion: At low flow rates, there is no difference between the perceived discomfort of the two modes. When supplemental oxygen flow is constant, discomfort increases with



increasing flow rates. When oxygen flow is turned off during exhalation, the average level of perceived discomfort does not change significantly regardless of the flow rate. Using a time controlled oxygen delivery scheme creates the possibility of giving high flows of oxygen without additional patient discomfort. Using inspiratory only oxygen delivery, it may be possible to “pre-oxygenate” patients prior to administering sedatives and opioids during procedural sedation.

Effectiveness of a New Method for Endotracheal Tube Pilot Balloon Repair

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Introduction: An intact pilot balloon is crucial to proper function of a cuffed endotracheal tube (ETT). The one-way valve allows for maintenance and measurement of cuff pressure. Failure of the pilot balloon or disruption of the inflation tubing results in cuff deflation which may lead to inadequate ventilation and aspiration of oropharyngeal secretions. Replacement of the ETT in the presence of a failed pilot balloon can be done, but in the presence of airway edema or an anticipated difficult intubation, such an intervention may present a patient safety risk. We recently encountered a patient in whom the pilot balloon tubing was inadvertently transected during transfer to the ICU bed, resulting in a large leak. We describe the method that we employed using readily available components to repair the pilot balloon and inflation tubing, and report on the effectiveness of the repair method, as tested in vitro.

Methods: A 22 g IV catheter with the hub cut off was inserted into the severed end of the inflation tubing and cut just distal to the end of the catheter. A new pilot balloon assembly was cut off from an intact ETT and guided over the catheter, with the catheter serving as a stent. A ¼" Steri-Strip™ (3M™; MN, USA) was then wrapped around the repaired segment to mitigate against separation of the stented tubing. We tested the ability of the repaired ETTs to maintain cuff pressures of 20-30 cm H₂O measured with a Cufflator (Posey, CA, USA), over an 8-hour interval in an artificial trachea model (20 ml syringe) and the integrity of the repaired segment to high-pressure inflation (measured by placing the repaired segment under water and looking for air bubbles). In addition, we measured the static tensile strength of intact and repaired ETT inflation tubing. To assess generalizability of our repair method, we evaluated ETTs from Mallinckrodt as well as from Smiths Medical, Parker Medical and Sun Med.

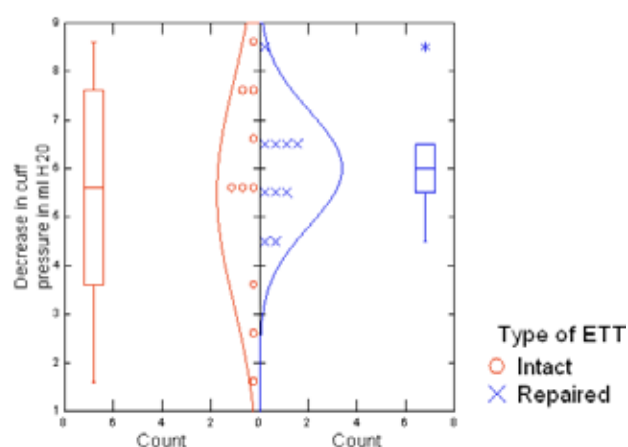
Results: Data (mean ± standard deviation) from 10 unaltered ETTs were compared to 10 repaired ETTs.

Eight-hour interval measurement demonstrated a mean pressure drop of 5.5 cm H₂O (SD 2.28) in the unaltered ETTs in comparison to a mean pressure drop of 6.0 cm H₂O (SD 1.18) in the repaired ETTs representing a difference in means of 0.5 cm H₂O (p value = 0.54).

There was no visible air leak from the repaired inflation line segments at a pressure of 120 mm Hg. In addition, tensile strength testing revealed that the mean force needed to break brand new inflation tubing was 36.4 N (SD 2.69). Repaired inflation tubing was able to withstand a mean force of 14.5 N (SD 3.70) before disruption, representing a difference of means of 21.9 N (p value = <10⁻⁶). Repairs using ETTs ranging in size from 3.0 to 8.0 and various manufacturer were successful in all cases; in some cases, a 24g IV catheter was required as the stent.



Two-sample t-test



Conclusion: Our method for ETT repair allows for quick, reliable repair of the pilot balloon using readily available supplies. A commercial product, BE 409 Pilot Tube Repair Kit (Instrumentation Industries Inc.; PA, USA) is available which uses a metal tapered needle as the stent, similar to our method. However, the assembly is not MRI compatible and may not be available. Our described method can be effectively used as a temporizing measure in a situation where ETT exchange would be difficult or risky. Due to the reduced tensile strength of the repaired segment, it is our recommendation to identify the repaired tubing with a marker, such as colored tape, in order to alert practitioners.

Anesthesia Quality May Be Improved Through Mandatory Reporting of Intraoperative Adverse Events

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Introduction: Major anesthetic complications coded in the hospital discharge records of surgical patients are uncommon ($\approx 0.9/1000$ discharges).¹ However, little is known about the prevalence of intraoperative complications that may not be serious enough to be reported at discharge. We previously described the development of a process within our anesthesia information management system (AIMS) to record intraoperative adverse events (AEs).² We report on the prevalence of intraoperative AEs noted over the 2 years that our process has been in place.

Methods: Intraoperative AEs, selected from an extensive list of potential complications, are recorded by anesthesia providers in our AIMS as a Quality Assessment (QA) activity and reported daily by secure e-mail to the department's quality officer (DMG). Outcomes for all cases performed at the Thomas Jefferson University Hospital (TJUH) and TJUH Ambulatory Surgical Center between July 1, 2013 and June 30, 2015 were retrieved from the AIMS database. Each anesthesia-related outcome, associated free text comment, and other chart documentation were examined independently by RHE and DMG, and grouped into categories. Each outcome was characterized as being "likely not preventable" or "possibly preventable". Data were analyzed using the method of batch means. The numbers of adverse events and cases during each 3-month quarter were computed. The prevalence of adverse events was computed as the number of events divided by the number of cases (overall complication rate), and as the number of cases with at least 1 adverse event divided by the number of cases (patient complication rate). Trends were assessed via the Mann-Kendall Test using Systat® 12 (Systat Software, Inc., San Jose, CA), with $P < 0.05$ required for significance.

Results: The AE completion rate was 96.7% (N=25 4-week bins, 95% CI 96.5% to 97.3%, $P=NS$ for trend). There was an overall reduction in the number of AEs in all categories between Year 1 and Year 2 (Fig. 1), despite no change in case volume, and an overall decrease in the case AE rate from 1.2% to 0.6% (Fig. 2). Among all AEs, airway issues and physical injuries were reported most commonly, but the overall incidence of any specific AE was low. A significant linear decrease was noted in both the overall AE rate and the rate of AEs judged to be possibly preventable by approximately 50% (Fig. 2).

¹ Agency for Healthcare Research and Quality. 2005 National Healthcare Quality Report. Complications of Anesthesia. Available at <http://archive.ahrq.gov/qual/nhq05/safety/T2-8.htm> Last accessed December 8, 2015

² Zhou J et al. Development and Implementation of a Process within an Anesthesia Information Management System (AIMS) to Record Intraoperative Complications. 2014 Annual Meeting of the Society for Technology in Anesthesia. Available at http://www.stahq.org/files/3913/9171/8008/11_Abstract_Zhou.pdf Last accessed December 8, 2015

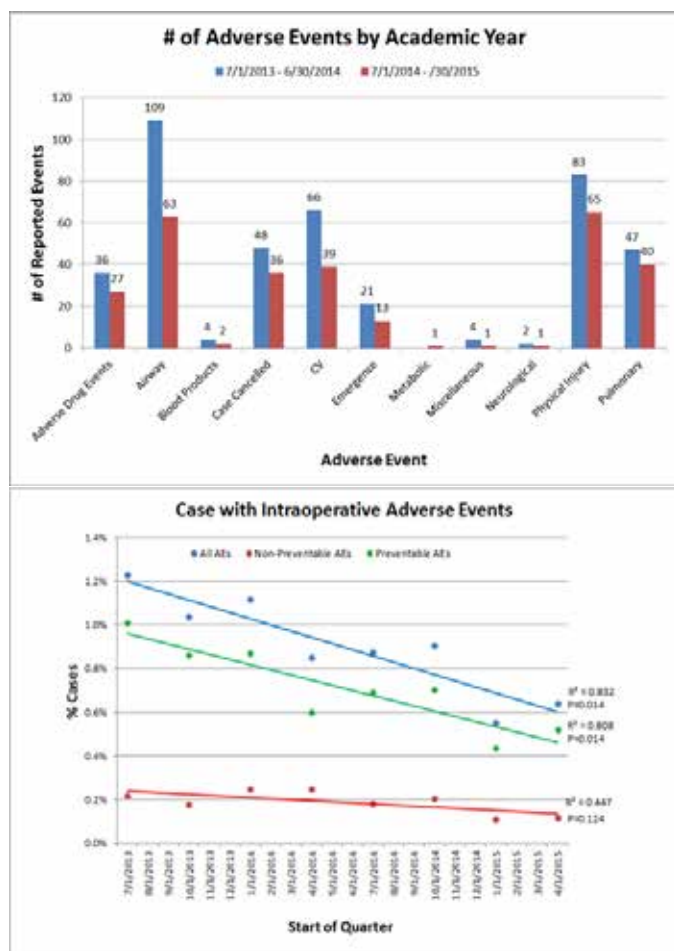


Figure 1. Adverse events by academic year

Figure 2. Patient complication rate by quarter.

Conclusion: Our providers maintained a high level of compliance with our non-punitive process of mandatory intraoperative AE reporting. Unexpectedly, the rate of potentially avoidable AEs decreased linearly over time, which suggests that the self-reflective process of AE reporting itself may have lead to a reduction in complications through increased attention to the quality of care. This cannot be explained simply by progressive underreporting, as the rate of AEs classified as likely not preventable did not change over the study interval. If a reduction in complications as a byproduct of mandatory QA reporting of intraoperative AEs is confirmed at other institutions, such reporting should be considered for adoption as a standard of care.

Analysis of Central and Obstructive Apnea Detection Using Combination Sensors

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Introduction: The first 24 hours after surgery represent a high-risk period for adverse respiratory events in patients being treated for postoperative pain [1]. Despite these patients' high propensity for respiratory depression, the current standard of care for postoperative monitoring is intermittent spot-checking of respiratory rate and/or pulse oximetry performed by hospital staff. In addition, traditional spot-checking monitors do not differentiate between central and obstructive apnea, which is critical for adjusting care to keep the patient safe (e.g., adjust drug levels or provide CPAP, respectively). We combined data from novel sensors placed above and below the point of obstruction—the trachea—in order to differentially identify both central and obstructive apnea, and compared each sensor combination's effectiveness in detecting each event type.

Methods: With IRB approval, fifteen healthy volunteers (Ages 19-41, BMI 20.9-28.4) were administered target-controlled infusions of remifentanyl (0.75-5 ng/mL) and propofol (0.75-5 mcg/mL) to achieve increasing levels of sedation and induce apnea, hypopnea, and airway obstruction—both individually and in combination. Respiratory data were collected from nasal pressure (1 INCH-D-4V, All Sensors, Morgan Hill, CA), nasal/oral thermistor (Disposable Adult Airflow Sensor, Braebon Medical Corporation, Kanata, ON, Canada), capnometry (LoFlo, Philips, Wallingford CT), respiratory inductance plethysmography (Q-RIP, Braebon Medical Corporation, Kanata, ON, Canada), impedance respiratory rate (Datex Ohmeda, GE Healthcare, Louisville, KY), and abdomen accelerometer sensors (ADXL345, Analog Devices, Norwood, MA). During the study, periods of central and obstructive apnea were identified by capnography and respiratory inductance plethysmography data in combination with comments from two concurring anesthesiologists who had access to breath sounds recorded at the trachea and direct auscultation. We identified thirty epochs each of apnea, airway obstruction, and normal breathing. The duration of normal breathing epochs was defined as the average length of the apneic periods. Data recorded from sensors placed at the head and the chest were then combined to classify the events as normal, obstructive apnea or central apnea. If breaths were identified at the chest with no matching breaths at the head, the epoch was classified as obstructive apnea. If neither sensor identified a breath in the last thirty seconds, the epoch was classified as central apnea. We calculated sensitivity and specificity for each sensor combination.

Results: The results are provided in Table 1.

Sensor Combination		Obstructive Apnea		Central Apnea	
Body Signal	Head Signal	Sensitivity	Specificity	Sensitivity	Specificity
Accelerometer	Nasal Pressure	0.933	1.000	1.000	1.000

Accelerometer	Thermistor	0.800	0.867	0.700	0.867
Impedance RR	Nasal Pressure	0.833	0.967	0.733	0.967
Impedance RR	Thermistor	0.267	0.933	0.500	0.933

Table 1. Sensitivity and specificity for event detection by each sensor combination.

Discussion: The combination of nasal pressure and chest accelerometer sensors showed the best sensitivity and specificity for differentially identifying central and obstructive apneic periods. Combining these cost-effective sensors may help improve postoperative care by informing the clinician about the type of ventilation problem so that they may treat it more efficiently. In the future, we plan to include a wider array of sensors, and expand the 'gold standard' data set to include all events during the study.

- [1] Taylor, Shiv, Orlando C. Kirton, Ilene Staff, and Robert A. Kozol. "Postoperative Day One: A High Risk Period for Respiratory Events." *The American Journal of Surgery* 190, no. 5 (November 2005): 752–56. doi:10.1016/j.amjsurg.2005.07.015.

External Beam Radiation Therapy Treatment Interruptions Associated with Change in Airway Management in Pediatric Radiation Oncology – A 4-Year Retrospective Cohort Study

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Background: Children undergoing external beam radiation therapy for cancer often require general anesthesia. Radiation therapy protocols vary in complexity and typically range from 3 to more than 40 treatment sessions. Patients must be positioned exactly the same way each treatment session in order to deliver radiation accurately to the targeted area. Positioning devices such as thermoplastic masks are individually molded to ensure accurate positioning. Failure to achieve the treatment position may interrupt treatment while a new radiation protocol is configured.

Objective: The primary aim of this study was to determine whether airway management device changes between natural airway, laryngeal mask airway, endotracheal tube and tracheostomy over the course of external beam radiation therapy contributed to prolonged treatment interruptions.

Methods. With IRB approval, we performed a retrospective cohort study children younger than 18 years of age who underwent GA (minimum 4 sessions) for photon or proton beam therapy at a single institution between 7/1/2011 and 6/30/2014. We identified the airway management device (natural airway, laryngeal mask airway, oral endotracheal tube, or tracheostomy) used for each treatment session for each patient. Patients were classified in three EBRT groups: Group A) supine without a thermoplastic mask; Group B) supine with a thermoplastic mask; or Group C) prone with a thermoplastic mask. Prolonged interruptions were defined as 5 or more days and evaluated for co-occurrence with airway management device change. We designed a visual analytics dashboard to evaluate the relationship between treatment interruptions and airway device change.

Results: 182 courses (Group A: 57, Group B: 106, Group C: 19) of external beam radiation therapy for children receiving general anesthesia were included in the study. Interruptions to EBRT occurred in 11 courses (17.2%) in Group A, 58 courses (54.2%) in Group B, and 11 courses (57.9%) in Group C.

Three patients in Group B required unplanned CT simulation to make a new thermoplastic mask and EBRT protocol. Two of these patients required a new airway device and received photon EBRT while a new proton EBRT plan was finalized. There was an association between

unplanned CT simulation and airway device change during EBRT in Group B (Fisher's exact test w-sided $p=0.045$, odds ratio 9.4, confidence interval [0.407-501.190]). All patients with prolonged EBRT interruptions were scheduled to receive more than 20 EBRT sessions. The treatment interruptions associated with airway device change occurred within the first 10 EBRT sessions.

Conclusion: Patients that require different airway devices during the course of external beam radiation therapy may experience prolonged treatment interruptions due to failure to achieve the prescribed position with a thermoplastic mask.

Anesthesiologists caring for children undergoing radiation therapy should carefully consider the length of the treatment protocol when designing the anesthetic plan. Airway management should focus on optimizing the patient's position and ventilation at the time the thermoplastic mask is made.

The Development of the US Health IT Safety Framework

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Background: Health Information Technology (HIT) is becoming essential to the modern practice of anesthesiology. HIT includes the use of Anesthesia Information Monitoring Systems “AIMS” as well as smartphone apps, data warehouses, and tools for advanced data analytics. HIT offers the promise of improving the safety, quality, and efficiency of current approaches to anesthetic care, while setting the stage for personalizing care based on genomic evidence and “big data” analytics. [1]

Members of the Society for Technology in Anesthesia have developed and enthusiastically led the adoption of technologies that held promise to improve patient safety, such as pulse oximetry and respiratory gas monitoring. In contrast to stand-alone technologies, HIT is inherently a pervasive system-level technology with effects (called “emergent behavior”) that are difficult to anticipate. A recent Joint Commission Sentinel Event Alert reported on emergent behaviors, and proposed approaches for the safe use of HIT. [2] The socio-technical aspects of HIT are part of a complex adaptive system that has spurred the development of new conceptual models of technology implementation to facilitate research. [3]

Methods: The US Congress developed legislation to address the need to balance patient safety with HIT based innovation. The FDA Safety and Innovation Act (FDASIA) of 2012 charged the FDA, HHS Office of the National Coordinator for HIT (“ONC”), and the FCC to develop a risk-based framework for HIT [4,5].

Results: The FDA, ONC, and FCC convened public working groups to inform the development of the FDASIA risk-based framework.[6] The FDASIA framework recognizes three categories of HIT products.

1. Administrative HIT products will remain unregulated (e.g. billing)
2. Health-management HIT, that is unlikely to lead directly to patient harm, will be managed with a yet to be finalized oversight structure anticipated to be led by ONC (e.g. medication management, and most clinical decision support apps).
3. Medical HIT software (e.g. physiologic monitor display or an alarm app) that will remain under FDA regulatory purview.

Implementation of the FDASIA framework is evolving. Products that fall under FDA purview can be reviewed and cleared by an established process. In contrast, other HIT products do not have a pathway to report and share software defects or patient injuries.

References:

1. A New Initiative on Precision Medicine, N Engl J Med 2015; 372:793-795
2015/observations-symbolism-and-practice-management
2. Sentinel Event Alert, Issue 54, March 31, 2015: Safe use of health information technology
3. A New Socio-technical Model for Studying Health Information Technology in Complex Adaptive Healthcare Systems. Qual Saf Health Care. 2010 Oct; 19(Suppl 3): i68–i74.

4. <https://www.gpo.gov/fdsys/pkg/BILLS-112s3187enr/pdf/BILLS-112s3187enr.pdf>
5. <http://www.fda.gov/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDRH/CDRHReports/ucm390588.htm>
6. <https://www.healthit.gov/facas/health-it-policy-committee/hitpc-workgroups/fdasia>

Trusted Timestamps – A new (Old) Tool to Ensure Integrity and Authenticity of Research and Clinical Data

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Background: Trusted timestamps [1] are digital markers that can be used to prove the existence of data before a specific time and preventing the owner from modifying the data at a later time without invalidating the timestamp. Trusted timestamps are issued by a third party, typically a certificate authority. Their integrity is based on the application of hash functions (to summarize the data content without revealing its content) and digital signatures (to prove the validity of an issued timestamp). As such, they provide strong evidence that data files have not been altered since the time they were protected with the trusted timestamp.

This idea was first used by Robert Hooke in 1660 who published an anagram of what eventually became Hooke's law. Without disclosing its content at a specific time he was able to claim priority to his finding [2]. Nowadays, trusted timestamps are used to claim priority of code, inventions and other documents. Yet, they also have applications relevant to clinical research and medicine in general: a) to verify data integrity in sponsored research studies, and b) to ensure the integrity of data collected as part of a patient's medical record. Of particular relevance to anesthesia are vital signs data, drug administration records, and descriptions of other interventions as documented in an anesthesia information management system.

Methods: We use the LambdaNative software development framework [3] to integrate Trusted Timestamps with our existing medical data collection software, to provide a modular software block that can be dropped into future research projects and/or back-ported into our existing data collection systems. The implementation uses industry standard public key encryption and cryptographic hashing technology and provides a mechanism for securely submitting requests to a time stamp authority and for verifying the returned timestamps.

Results: We have implemented trusted time stamping, using the German National Research and Education Network (DFN), Time Stamp Authority server (zeitstempel.dfn.de, freely available for non-commercial use) and made it publicly available under a liberal open source license [4]. The software enables trends and waveforms files to have trusted timestamps automatically applied at the time of collection. Using this technology will therefore inherently ensure data integrity from the source at a specific point in time and potentially eliminate the need for medical records affidavits and other means of certifying the validity of medical data after the fact.

Conclusion: Trusted timestamps serve an increasingly important role in many areas of society, but have yet to become an integral component of data collection and management in medicine. Use of this technology in anesthesia may prove to be a useful way to safeguard against accidental and/or intentional alteration of research and clinical data, to strengthen litigation evidence, and to improve the overall quality of data in the field. We encourage all medical researchers to consider adopting this technology in their data collection systems.

References: [1] C Adams, P Cain, D Pinkas, R Zuccherato, Internet X.509 Public Key Infrastructure Time-Stamp Protocol (TSP), *Internet Engineering Task Force*, 2001:RFC 3161; [2] H Petroski, Invention by Design: How Engineers Get from Thought to Thing, *Harvard University Press*, 1996:10-11; [3] CL Petersen, M Görges, D Dunsmuir, M Ansermino, GA Dumont, Experience report: functional programming of mHealth applications, *Proc 18th ACM SIGPLAN Int Conf Funct Program*, 2013:357–62 [4] <https://github.com/part-cw/lambda-native/wiki/Index-of-Module-timestamp>

PACE Intubation Effort Android Wear Application

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Background: The goal of the Society for Technology in Anesthesia's 2015 engineering challenge was to use commercially available technologies to show that the effort is greater during difficult intubations. As wearable devices have become commonplace amongst Anesthesiologists, in participation in this challenge we developed an Android smart watch application and an algorithm to measure the amount of effort required for various intubations.

Methods: In order to collect data from the intubation process, we used sensor data from an Android watch worn on the left wrist of the person doing the intubation. The sensor data reflects changes in the movements of the left hand over time. The characteristics of an intubation lie in those changes. There are multiple sensors on an Android watch, but we only focused on the signals from the Gyroscope and Rotation sensors (as they reflect more significant changes compared to other sensors, e.g., the Accelerometer).

Results: From empirical data we gathered from a set of intubations, we learned that hand movements in any type of intubation occur with a frequency component of less than 10 Hz. In other words, we saw at most 10 movements per second when an intubation was in progress. As a result, and according to Nyquist-Shannon Sampling Theorem, we only needed to sample the sensor signal at a rate of 20 Hz (20 samples per second). Using a Fourier transform algorithm, we obtained the frequency components of all signals, (from the X, Y, and Z axis of the two sensors) and constructed a score for each intubation.

We included 5 metrics in constructing a score:

- (i) The frequency components of the Y-axis data from the Gyroscope sensor
- (ii) The frequency components of the X-axis data from the Gyroscope sensor
- (iii) The frequency components of the Y-axis data from the Rotation sensor
- (iv) The frequency components of the X-axis data from the Rotation sensor
- (v) The length of the intubation

The threshold, which we used to distinguish between difficult and easy intubations, was found based on a supervised machine learning technique called Classification. We ran the measurements multiple times and minimized the output error by gauging the threshold as well as the weights we assigned to each metric.

Conclusion: Our hypothesis was that a difficult intubation would have more periodic changes compared to an easy intubation. These periodic changes are best captured with the

Gyroscope and Rotation vector sensors. By looking at the frequency component of the signals from Gyroscope and Rotation vector sensors, we were able to construct a score. If the score was above a certain threshold, we called the intubation difficult, otherwise, we called it easy. The Android smart watch application that we developed can be downloaded at <http://play.google.com/store/apps/details?id=com.hassanpour.pace.intubation>

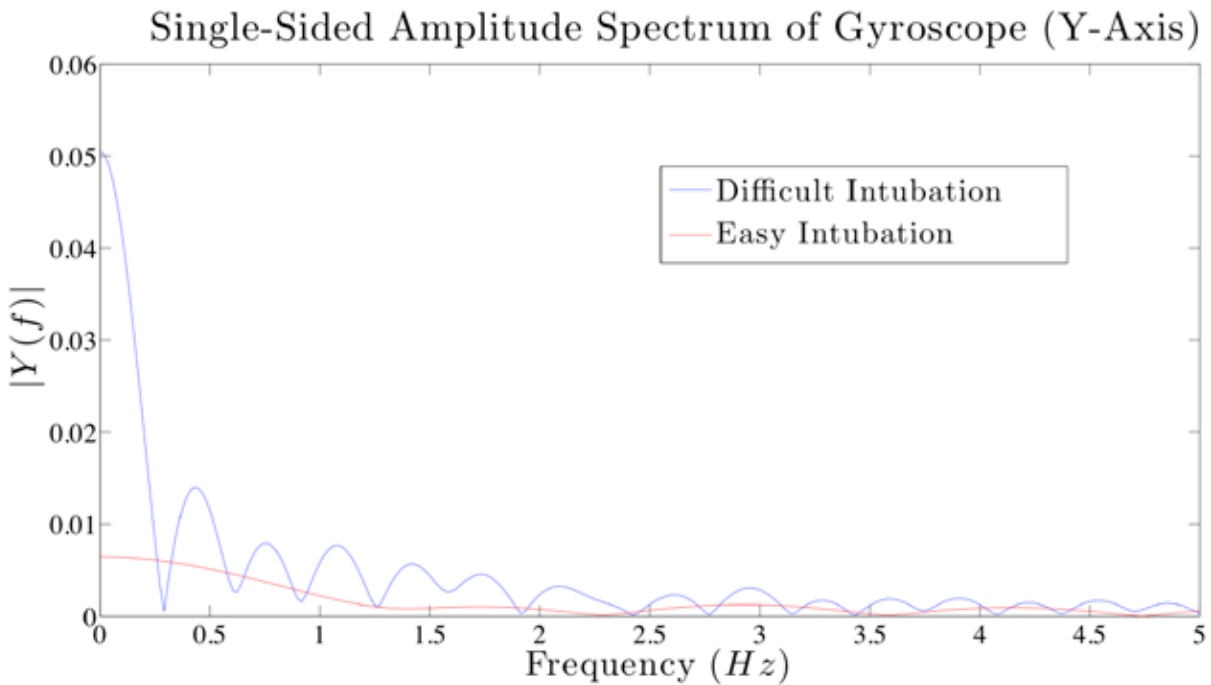


Figure 1. Fourier Transform of the two signals generated from the Gyroscope data

Mathematical Modeling of Endotracheal Intubation in Children

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Co-Authors: Mohammed Rehman¹ MD, C. Nataraj² PhD

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Introduction: In major pediatric surgeries, the airway is often secured with an endotracheal tube (ETT), and mechanical ventilation is subsequently initiated. Clinicians utilize auscultation of breath sounds and capnography to verify correct ETT placement. However, anesthesia providers often delay timely charting of endotracheal intubation. Event documentation latency results in decreased efficacy of clinical decision support systems (CDSS). Automatic detection of endotracheal intubation time would thus enhance better real time data capture to support CDSS.

Data: We gathered retrospective data from 100 randomly selected children who received endotracheal intubation at our institution, a tertiary care pediatric hospital. Each patient's data included ventilator parameters (peak inspiratory pressure [PIP], positive end-expiratory pressure [PEEP] & tidal volume [TV]) and vital sign measurements (respiratory rate [RR], end tidal carbon dioxide [EtCO₂], heart rate [HR], and blood pressure [BP]).

Methods: The morphology of most of the ventilation variables such as RR, PIP, PEEP and TV depends heavily on the ventilator mode and settings. For instance, breathing could be spontaneous or under ventilator control. Moreover, controlled forms of ventilation could deliver either a preset peak inspiratory pressure or tidal volume. Hence, we were able to develop an algorithm using only EtCO₂. EtCO₂ data from mask ventilation in children is noisy since patient movement and inaccurate mask placement will result in leakage thus affecting the recordings. EtCO₂ from ETT recordings on the other hand are more robust. To detect this transition from high frequency noisy recording to lower frequency stable recordings, we apply the continuous wavelet transform (CWT) on the data. The CWT is capable of locating the temporal shift in frequency, which makes it feasible for this study. We use Haar mother wavelet function for CWT and then calculate the CWT coefficients at level 50. We then define variation index as $C_v = \frac{\sigma^2}{\mu^2}$ where, σ and μ are standard deviation and mean values of the CWT coefficients respectively. The steps of the designed algorithm are as follows:

- (i) set $i=1, C_v^0 = 0, \Delta C_v = 0,$
- (ii) initial window length N
- (iii) while $\Delta C_v > \epsilon$

- (iv) calculate CWT coefficients at scale 50 (x),
- (v) $s = (x(1), x(2), \dots, x(N))$
- (vi) calculate C_v^i ,
- (vii) calculate $\Delta C_v = C_v^i - C_v^{i-1}$,
- (viii) $N=N+1, i=i+1$
- (ix) end,
- (x) return N

The time at sample N is the intubation time.

Results: For this problem we set initial $N = 10$ samples (1 sample = 15 seconds), and $\varepsilon = 0.05$. Our results show that the algorithm can correctly detect intubation time in 78 cases. In 17 cases it can detect intubation time within 3 samples of the actual time. The algorithm fails to converge and does not flag intubation in only 3 cases. In other words, results show that the algorithm is capable of detecting intubation in 97% of cases, and it can correctly detect intubation time within one minute in 95% of cases. Figure (1) represents a sample of results where algorithm correctly picks up the intubation time.

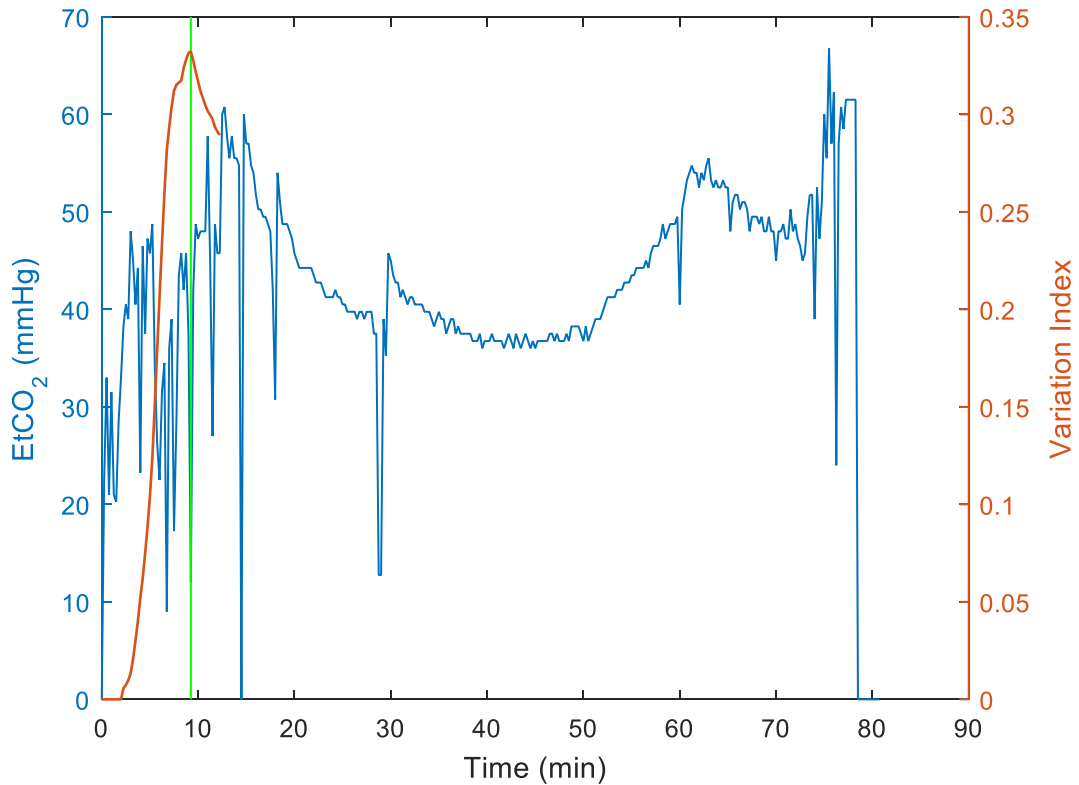


Figure (1): The plot of variation index shows that the maximum variation happens at the

time of endotracheal intubation (denoted by the green line).

Discussion: Mathematical modeling of the endotracheal intubation is valuable clinically since it is the first necessary step in automatic detection of tube malpositioning (i.e. inadvertent supraglottic ETT placement or mainstem intubation), which may have life-threatening consequences. Future directions of work will focus on validating the algorithm on prospective data. Eventually, we hope to increase the accuracy of the detector by developing a hybrid algorithm using machine learning techniques and utilize the detector to guide real-time CDSS.

Capnography Reduces the Risk of Adverse Outcomes During Gastrointestinal Endoscopic Procedures with Sedation Administration

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Background/Introduction: While published evidence to date suggests that capnography monitoring during gastrointestinal endoscopic procedures reduces the incidence of hypoxemia, the association of capnography sensor use with incidence of adverse outcomes during these procedures has not been studied. Thus, our aim was to investigate the incidence of rescue events and adverse outcomes during gastrointestinal endoscopic procedures performed with sedation administration for an overall hospital patient population and for matched patients with and without capnography sensor utilization.

Methods: This was a retrospective analysis of all hospital patients between 2008 and 2013 reported in the Premier Database. Inpatients and outpatients undergoing diagnostic and procedural esophagogastroduodenoscopy (EGD), endoscopic retrograde cholangiopancreatography (ERCP), and colonoscopy were identified using a combination of CPT/ICD-9 codes. Analysis inclusion criteria also included patients with report of sedative medications, but excluded patients who received inhaled anesthesia agents on the procedure day. Patients were grouped into four mutually exclusive categories: (1) pulse oximetry (SpO₂) only, (2) capnography only, (3) SpO₂ and capnography, and (4) neither SpO₂ nor capnography. Comparisons between groups were made using multivariate logistic regression (MLR) analysis adjusted for age, gender, race, comorbid conditions, and hospital characteristics. Propensity-score matching was also used to compare patients with capnography sensor use to patients on whom only a SpO₂ sensor was used. The standard differences were calculated to measure how well the matched groups balanced. Key outcome measures included the incidence of rescue events, defined by administration of naloxone and/or flumazenil, and death.

Results: The inpatient analysis population included 258,262 patients and the outpatient population included 3,807,151 patients. Overall, capnography sensors (with and without SpO₂ sensors) were used in approximately 2% of patients, regardless of inpatient/outpatient classification. As expected, the inpatient population tended to be older (mean age: 64.3 years vs. 57.4 years) with a higher mean Charlson Comorbidity Index (2.53 vs. 0.39). For both the inpatient and outpatient populations, patients were predominantly white and approximately 50% male/female. For the inpatient population, MLR analysis for the PS matched samples indicated that the capnography sensor use was associated with 47% reduction in the odds of death (OR: 0.528 [95% CI: 0.401, 0.696]; p<0.0001), and 10% reduction in odds of naloxone and/or flumazenil administration (OR: 0.905 95% CI: [0.645, 1.271]; p=0.5661), compared to patients using SpO₂ sensor only. For the outpatient population, the MLR analysis using PS matched samples indicated that capnography sensor use was associated with 82% reduction in the odds of death (OR: 0.178 [95% CI: 0.016, 1.990]; p=0.16), and a 62% reduction in the odds of naloxone and/or flumazenil use compared to patients with SpO₂ sensor use only (OR: 0.385 [0.286, 0.520]; p<0.0001).

Conclusions: In hospital inpatients and outpatients undergoing gastrointestinal endoscopic procedures performed with sedation administration, capnography sensor use was associated with a reduced likelihood of rescue events and death. The use of capnography in these procedures is warranted.

Real-time Perioperative Web-Based Anesthesia Information System

Presenting Author: Thomas T. Joseph, MD, PhD, Icahn School of Medicine at Mount Sinai

Co-Authors: Matthew Levin, MD, Icahn School of Medicine at Mount Sinai; Patrick McCormick, MD, Icahn School of Medicine at Mount Sinai

Background/Introduction: Anesthesiologists and other providers are able to utilize a variety of information during a typical day in the operating room to facilitate safe and expedient patient care. This information includes the OR schedule, vital signs and other elements of anesthetic records, the locations of patients, who is on call, et cetera. However, this information is often located in disparate locations and is not integrated, making it relatively difficult to access.

Methods: We created a web-based system that draws on a variety of institutional databases that provides real-time monitoring of:

- Vital signs, lab values, drug administration records, and other elements of the anesthetic record in ORs
- Operating room schedule, dynamically updated to show which cases are in progress or finished, along with locations of patients and one-click access to prior anesthetic records
- Locations of anesthesia providers and membership of the call team

The site was designed specifically for anesthesia workflows, and to be easily usable on modern smartphones as well as the legacy desktop web browsers available on hospital workstations. Access is controlled using the institution-wide single sign-on system.

Results: Easy access to prior anesthetic records now allows quick preoperative evaluation, especially for add-on or emergency cases. The system allows anesthesiologists to monitor the ORs they are supervising from their phones: roughly half of accesses are from phones, which improves their mobility. In our institution, the need for the anesthesiologist on overnight call to make phone calls to ~50 anesthetizing locations in the afternoon to help determine evening staffing needs and assign the on-call team appropriately is now minimized, as the relevant information is shown on one screen, which improves efficiency of staff management.

Conclusion: Our web-based perioperative information system offers easy access to relevant perioperative information to improve expediency of patient care.

[illegible]

An Experiment of Clinicians and Usability in a Patient-Controlled Epidural Analgesia Pump

Authors: Maj MD Julian Mb ChB BSc (Hons); Royal Army Medical Corps and University Hospital Southampton, UK

Introduction: Usability error (UE) testing and design has been recognised by regulators, including the International Safety Organisation, as a significant safety concern and relevant standards have been devised^{1 2}. Devices which came to market prior to these standards may still be in clinical use. If action is not taken to ensure that unsafe devices are identified and improved, or replaced, then morbidity associated with them will occur. Robust collection of adverse event reports could assist in this issue. Concerns over the reporting of device safety led the Medicine and Healthcare Product Regulatory Agency (MHRA) and NHS England – UK government agencies with responsibilities in healthcare safety and outcomes - to release an alert³. However, the focus of this alert was on device failure and omitted UE.

I sought to assess the ability of clinicians to solve a UE problem found when inadequate analgesia was delivered by a patient-controlled analgesia pump. A patient-controlled bolus of 0ml was set, not the intended 10ml. The pump accepted this and so administered no dose when the bolus was requested.

Method: 15 anesthesiologists were asked to investigate a pump programmed with the above error. It was primed with saline and not connected to a patient. Subjects were informed of the clinical scenario (a labour epidural which was inadequately effective after 90 minutes) and were asked to resolve the issue.

The process for programming the pump was recorded and analysed to identify the number of inputs required.

Results: 15 anaesthesiologists were assessed. Five failed to identify the fault and only achieved a temporary resolution – often by syringe injection of local anaesthetic down the catheter. One subject suggested re-siting the epidural and re-programming the pump.

39 inputs were required to setup the pump, of these 36 could have a direct impact on the resulting infusion.

Conclusion: 1/3 clinicians inadequately resolved the issue, resulting in unnecessary pain for the patient. One clinician proposed replacing the epidural, re-exposing the patient to the procedure's risks. This study is clearly limited by a small sample, subjective data collection and its unblinded nature. However, it shows that poor interface design can have significant impact on patient safety. Even when familiar with the device, clinicians did not know less commonly used functions. A replacement pump is now in use, with three user sensitive steps to confirm pre-programmed protocols.

In the UK procurement procedures vary dependent on size of the financial transaction and between institutions. Routine replacement of medical devices is often at the local/institutional level. This might involve setting up a project group, to establish

specifications and evaluation criteria prior to submitting to industry for tender. Potential devices are then evaluated.

MHRA guidance proposes that procurement processes should ensure that 'precautions are incorporated into the design to guard against misuse'⁴ of the device. I propose that procurement of better and safer devices could be encouraged by mandating direct comparison of devices during the evaluation phase. A simulation environment should be used, where end-users deliberately stress the protective measures of the systems. By using more objective evaluation, including usability testing, safer devices would be selected. I believe a more unified, evidence-based approach to procurement could drive safety innovation faster than regulation.

¹ ISO. 2007 *Medical devices -- Application of usability engineering to medical devices* [IEC 62366:2007] Available from: http://www.iso.org/iso/catalogue_detail.htm?csnumber=38594

² ISO. 2015 *Medical devices -- Part 1: Application of usability engineering to medical devices* [IEC 62366-1:2015] Available from:

http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=63179

³ NHS England/MHRA. 2014. *Patient Safety Alert - Improving medical device incident reporting and learning* [NHS/PSA/D/2014/006] Available from: <https://www.england.nhs.uk/wp-content/uploads/2014/03/psa-med-device-incr.pdf>

⁴ MHRA. 2015. *Managing Medical Devices: Guidance for healthcare and social services organisations*. Available from:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/421028/Managing_medical_devices_-_Apr_2015.pdf

Development of Vital Recorder®, a Time-Synced Biosignal Data Acquisition Software

Presenting Author: Hyung-Chul Lee, M.D., Seoul National University Hospital

Co-Author: Chul-Woo Jung, M.D., Seoul National University Hospital

Background/Introduction: Currently, many anesthesiology investigators have lots of trouble in conducting researches regarding perioperative biosignal data because of high cost and complexity of commercial data acquisition systems. In addition, integrating data from patient monitor with those from additional medical devices such as bispectral index monitor, cardiac output monitor, anesthesia machine and infusion pumps requires more expensive and sophisticated hardware and software. In this study, we developed a low-cost medical data acquiring software that can obtain time-synced biosignal data from multiple medical devices, process the data in real-time and store raw or processed data.

Methods: The program (Vital Recorder®) written in C++ language runs on Windows® operating system. Hardware requirements are a low-performance computer, serial (either direct or cross type) cables and/or Arduino (<http://arduino.cc>) based analog-to-digital converter. Captured data are stored at local or cloud storage as a form of single data file that contains every data from multiple devices. The data can be processed in real-time with an open source script engine (Google V8, <https://developers.google.com/v8/>). By means of Vital Recorder®, we implemented a pilot study of data capturing and processing with algorithms in literature: calculating pulse pressure variation from arterial blood pressure wave and T-wave alternans from electrocardiography.

Results: Overall cost of the system was less than 100 dollars except the laptop computer. The system gathered time-synced data from 4 medical devices (GE Solar 8000M®, Covidien BIS vista®, Fresenius Kabi Base Primea®, Edward lifesciences Vigilance®) that were applied to a patient under general anesthesia. The acquired data were easily handled during data acquisition or after storing of the data. The wave data of arterial pressure captured at a frequency of 100 Hz were processed in real time and created pulse pressure variation track that parallels the moving arterial wave. T-wave alternans was successfully calculated using stored electrocardiography waves.

Conclusion: Vital Recorder® showed good performance with easy operability. Flexibility and low cost of the system was enhanced by the adoption of open source hardware and software. The software is going to be released for free to help investigators perform biosignal data researches. We also expect that stored biosignal big data can be used as a redundant source of evidence-based medical research.

Image



A Framework for Using Electronic Intraoperative Anesthesia Records for Genomic Discovery

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Co-Authors: Thomas T. Joseph, MD, PhD Icahn School of Medicine at Mount Sinai, New York NY; Janina Jeff, PhD, Icahn School of Medicine at Mount Sinai, New York NY; Eimear E. Kenny, PhD, Icahn School of Medicine at Mount Sinai, New York NY

Introduction: During the perioperative period, patients are routinely monitored to ensure their safety and well-being. This monitoring generates a wealth of clinical and physiological data. To date, few if any researchers have fully utilized this rich source of data for genetic discovery. We have developed a framework that integrates physiologic data from our institution's electronic intraoperative anesthesia record with data from our genetic repository.

Methods: The framework integrates data from two primary sources: The Charles F. Bronfman Institute for Personalized Medicine (IPM) Biobank (BioMe) and our operating room data warehouse (ORDW). BioMe is an ongoing, consented Electronic Health Record linked bio- and data repository that integrates phenotypic data from clinical systems with detailed ancestry information obtained via questionnaire, and genomic data derived from banked blood samples taken at the time of patient enrollment. ORDW is a comprehensive data warehouse that contains detailed physiological data from our Anesthesia Information Management System (CompuRecord, Philips Healthcare, Andover MA) along with perioperative clinical, laboratory and administrative data. The pipeline for integrating these two data sources is implemented in SQL and Python, and automated using cron. Key design goals were to create an idempotent, automated, secure, unidirectional data pathway with robust logging and a clear audit trail. Briefly, a list of patient identifiers for current BioMe participants is pushed on a bi-weekly basis to a secure separate database within ORDW. A Python job uses these identifiers to find anesthetic records. Each BioMe participant may have had zero, one, or more anesthetics. An opt-out flag set by BioMe identifies patients who should be removed. Simple set arithmetic is then used to identify new, old, and disappeared cases, and a timestamp and status set accordingly. Once per quarter a list of HIPAA compliant identifiers is pushed from ORDW back to BioMe, and detailed phenotype and ancestry data as well as flags indicating the availability of genotype data are extracted. This data set is pushed back to ORDW. Subsequently, detailed intraoperative physiologic and clinical data is extracted using standardized Python scripts and combined with genotype data on a per project basis.

Results: The pipeline went live in June 2015. At that time, there were 31,797 patients in BioMe; 15,891 had at least one anesthetic (49.9%). Total number of anesthetics administered to these patients was 42,260 (mean 2.7, median 2 anesthetics per patient, range 1 – 130 anesthetics). Collectively there were 38,149,718 vital signs and 414,709 bolus drug administrations recorded. As of October 2015, an additional 521 patients were enrolled in BioMe, bringing the total number of BioMe patients to 32,318; 16,164 (50%) had at least one

anesthetic. The total number of anesthetics increased by 479 to 42,739, of which 248 were on new patients, and 231 were on existing patients. 12,757 (80.3%) of patients that have had an anesthetic have genotype data. Historical analysis indicates an anticipated yearly growth rate of approximately 5% for both patients and anesthetics.

Conclusion: We have implemented a robust, scalable pipeline to find and extract intraoperative anesthetic data for participants and merge it with genetic data from our institutional biobank. This pipeline will enable us to investigate the relationship between genotype and the response to anesthetic and surgical stress.

Automated Titration of Vasopressor Infusion

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Background: Automated titration of vasoactive medications is not a novel concept, but it may be a concept that is due for reexamination for intensive care unit settings. Blood pressure management in critical care often requires a vasopressor support that is usually hand titrated by a bedside provider in response to clinical need. Hypotension risks ischemia due to inadequate perfusion pressure, while high drip rates risk ischemia of the viscera and digits. Even a simple self-titrating system could provide significant clinical benefit over hand titration in terms of provider workload and infusion accuracy.

Methods: We developed an automated infusion controller using a PID closed-loop which informs a rules-based decision engine. The controller is “allowed” to titrate infusion rate within preset guardrails (upper and lower limits). The objective of the controller is not tight continuous control, but rather loose adaptivity that is nevertheless better than hand titration that might occur every 30 to 60 minutes in practice. The controller was experimented with using a previously developed hemodynamic simulator. The controller was set to manage mean arterial pressure (MAP) in two settings: 1) Steady MAP from 40-80, in which the simulated patient was stable and had no hemodynamic perturbations; 2) Highly variable MAP, in which the simulated patient was wildly unstable and fluctuated at random. Both scenarios were also run without management as “controls”. Each simulation also had a random ‘infusion delay’ set from 5 to 60 seconds to simulate lag time from tubing length.

Results: 250 trials were run in each of the four conditions. In the steady MAP condition, the MAP in the unmanaged group was 56.2 ± 9.3 , and patients spent 79% of case time outside of the target MAP zone of 65-75. In the managed group, MAP was 70.8 ± 4.4 and patients spent 9.4% of case time outside of the target range. In the variable MAP condition, the unmanaged group had an MAP of 56.2 ± 12.2 and spent 80% of case time outside of target range. The managed group had an MAP of 71.2 ± 6 and spent 29% of time outside of the target range.

Conclusion: This initial feasibility study showed that our hybrid controller is capable of managing a vasopressor infusion to control blood pressure. The data is currently being reviewed to better understand the limitations of the controller and the conditions under which oscillations occur (present in 10% of the managed cases). Following this we plan to undertake a control-engineering approach to tuning the controller and optimizing its performance.

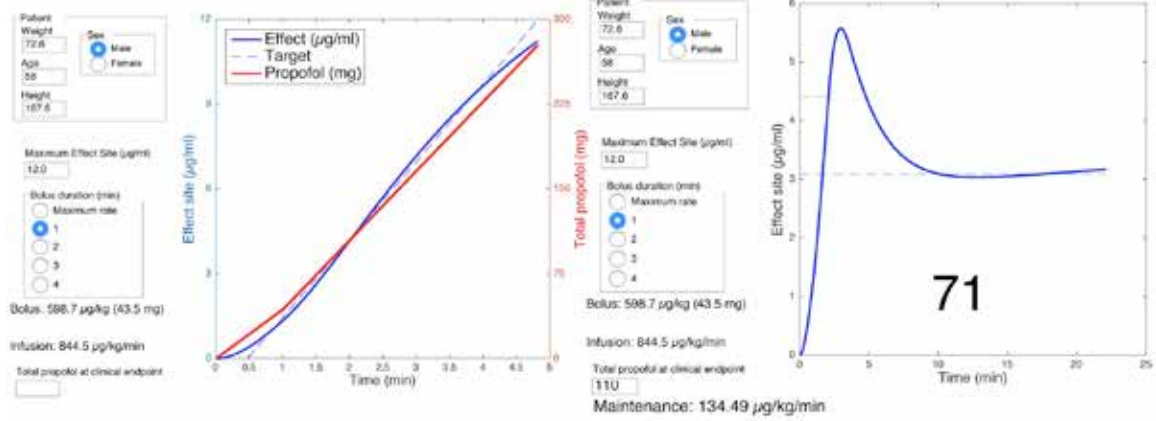
Target Controlled Infusion American Style

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Target controlled infusion is a mature technology, although the regulatory obstacles for FDA approval have not yet been met¹. Target controlled infusions systems use published pharmacokinetic models to calculate infusion rates at regular intervals. While it is possible to perform the calculations to achieve stable effect site concentrations using small boluses delivered by a PCA pump², this is not practical for most clinicians. A system that permits titration to a clinical endpoint and subsequent transition to a stable effect site concentration corresponding to that endpoint that can be achieved using an FDA-approved pump is described.

The Alaris Medley 8100 pump is used as the predicate device. This pump is capable of delivering a bolus over an integer number of minutes (or at the maximum rate of 999 ml/hr) followed by an infusion. This represents three degrees of freedom. For each bolus duration, the optimum bolus size and infusion rate to achieve an increase in effect site from zero to a specified maximum at a constant rate of increase is determined for the specified patient using constrained linear minimization. These rates are entered into the pump, and the volume totalizer zeroed. When the clinical endpoint is observed, the total propofol given at that point is entered, and the propofol infusion is paused for a specified time and resumed at a specified rate. All entries to the pump are made manually by the clinician, and the total propofol dose is depicted prior to induction. In addition to providing a predictable titration schedule, the system estimates the effect site concentration at the time of the clinical transition. The system is written in Matlab 2015b, and can be accessed remotely via a web interface. The regulatory status of the system has not yet been determined.

1. Dryden PE. Target-Controlled Infusions: Paths to Approval. *Anesth Analg*. 2015;
2. Mandel JE, Lichtenstein GR, Metz DC, Ginsberg GG, Kochman ML. A prospective, randomized, comparative trial evaluating respiratory depression during patient-controlled versus anesthesiologist-administered propofol-remifentanyl sedation for elective colonoscopy. *Gastrointest Endosc*. 2010;72:112-7.



Air Eliminating Filters that Allow Air to be Entrained When Negative Pressure is Applied

Presenting Author: Roger Marks, M.D. Assistant Professor of Clinical Anesthesia. University of Miami Miller School of Medicine. Miami, Florida.

Co-Author: Keren Marks, Medical Student. Hadassah School of Medicine. Jerusalem, Israel.

Introduction: A 27 yr old women with a tectal glioma presented for occipital craniotomy. Her past medical history included Factor V Leiden Heterozygosity, PFO with syncope and was further complicated by her now also being 26 weeks pregnant.

Methods: She was prepared with perioperative steroid therapy, lovenox and placement of an IVC filter. Intraoperatively, we placed a multi-lumen CVP catheter, precordial Doppler and fetal monitors before positioning the patient in the left lateral decubitus for surgery. At the recommendation of Cardiology, we also placed air-eliminating filters (Filtered Extension Set, B. Braun, PA, USA) on all her IV's, including the CVP, in order to reduce the risk of venous air embolism (VAE).

Results: During the procedure, while testing the CVP line for the ability to extract air from the right atrium, we noticed that air was being entrained into the line. We removed the filters, which solved the problem. We subsequently tested the filters and noted that air could be entrained by applying negative pressure, both proximal and distal to the filter.

Discussion: The fact that the air-eliminating filter allowed air to be entrained could have put this patient at risk for VAE, because we would not have been able to remove air via the CVP. Additionally, we avoided using muscle relaxants after induction in order to allow for monitoring of transcranial motor evoked potentials. This means that the patient could theoretically have begun to breath spontaneously, in which case she could "suck air" directly in to her heart via the filter that was attached to her central line. In conclusion, the air-eliminating filter should not be used on a port that is connected to a central line as this puts the patient at risk for VAE. We recommend that the manufacturer add this warning to the packaging.



Uncalibrated Pulse Contour Techniques for Perioperative Goal Directed Therapy: A Meta-Analysis of Randomized Controlled Trials

Presenting author: Frederic Michard, MD, PhD, Critical Care, Edwards Lifesciences, Irvine, CA

Co-Authors: Nicola Brienza, MD, Department of Anesthesia, Bari, Italy, Maria Teresa Giglio, Department of Anesthesia, Bari, Italy

Introduction: Perioperative goal directed therapy (GDT) has been shown to be useful to decrease the clinical and economic burden of postsurgical complications. Many GDT outcome studies have been done with the esophageal Doppler. Uncalibrated pulse contour (uPC) techniques are more easy to use, not operator dependent and not influenced by electric cautery, but their accuracy and precision has been questioned. Whether uPC techniques can be used to guide hemodynamic therapy and improve postsurgical outcome has been investigated by several but mainly small randomized controlled trials producing conflicting results. Therefore, we performed this meta-analysis to investigate whether the use of GDT with uPC techniques is associated or not with a decrease in post surgical morbidity, hospital LOS and mortality.

Methods: A systematic literature review, using MEDLINE, EMBASE, and The Cochrane Library databases through June 2015 was conducted. Data synthesis was obtained by using odds ratio (OR) and weighted mean difference (WMD) with 95% confidence interval (CI) by random-effects model.

Results: In total, 16 studies met the inclusion criteria (1713 patients). uPC methods were the FloTrac (Edwards Lifesciences), the LiDCOrapid (LiDCO Ltd) or the ProAQT (Pulsion Medical Systems). The proportion of patients with at least one complications (post-operative morbidity) was reduced by GDT (OR 0.31; CI 0.16 to 0.60; $p < 0.001$). This effect was related to a significant reduction in infectious (OR 0.54; CI 0.42 to 0.70; $p < 0.001$), and abdominal (OR 0.46; CI 0.26 to 0.80; $p < 0.001$) complications (figures 1 & 2). It was associated with a significant decrease in hospital length of stay (WMD -1.74 days; CI -3.38 to -0.11; $p = 0.04$). Mortality was not affected (OR 0.86; CI 0.45 to 1.64).

Conclusion: Perioperative GDT with uPC techniques decreased post-surgical morbidity and length of stay. Because of the heterogeneity of studies analyzed, large prospective clinical trials would be useful to confirm our findings.

Cardiac Output Monitoring Technologies During Major Surgery: A Nationwide Economic Evaluation

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Background: The cost of cardiac output (CO) monitoring technologies is often perceived as a significant barrier to their adoption. A fair economic evaluation should take into account savings related to the decrease in postoperative morbidity usually associated with CO-guided therapy. A recent meta-analysis (1) showed a 17-29% decrease in postoperative morbidity with CO-guided therapy. Our objective was to predict the economic impact of CO-guided therapy by comparing potential savings and costs.

Methods: We studied 204,680 adult patients from 541 US hospitals who had a major non-cardiac surgical procedure between January 2011 and June 2013. Hospital costs (including 30-day readmission costs) in patients with and without complications were extracted from the Premier Inc. research database. Potential cost-savings associated with a 17-29% decrease in postoperative morbidity were estimated. Average cost of CO monitoring technologies was estimated at \$300 per patient (\$250 per disposable sensor + \$48 for the amortization of a \$15,000 monitor used two times a week over 3 years).

Results: A total of 76,807 patients developed one or more post-surgical complications (morbidity rate 37.5%). In patients with and without complications, hospital costs were \$27,607 ± 32,788 and \$15,783 ± 12,282 ($p < 0.0001$), respectively. According to Pearse et al. (1) morbidity rate was anticipated to decrease to 26.6-31.1% with CO-guided therapy, yielding potential gross costs savings of \$153-263M for the study period, \$61-105M per year, or \$754-1,286 per patient. Potential savings per patient were highly variable from one surgical procedure to the other, ranging from \$354-604 for femur and hip fracture repair to \$3,515-5,996 for esophagectomies (Table 1). Therefore, our findings suggest that for each \$ spent to implement CO-guided therapy, hospitals could save in return between \$1-2 for femur and hip fracture and up to \$12-20 for esophagectomies.

Conclusion: Postsurgical complications occurred in more than one third of our study population and had a dramatic impact on hospital costs (+75%). With CO-guided therapy, potential cost savings per patient were \$754-1,286, i.e. 2.5 to 4 times higher than the average cost of CO monitoring techniques. These projections must be confirmed by large prospective studies. But in the meantime, they should help hospitals estimate the potential return on investment when considering the purchase of CO monitoring technologies.

References:

1. Pearse et al. Effect of perioperative cardiac output-guided hemodynamic therapy algorithm on outcomes following major gastrointestinal surgery. JAMA 2014

Utilization of Immersive 360 Degree Spherical Videos and Google Cardboard in Medical Training and Simulation: A Novel and Multi-Dimensional Way of Learning

Presenting Author: Shoeb Mohiuddin, MD

Co-Authors: Danial Roshan, MD; Heike Knorpp, MD

All authors are from the University of Illinois at Chicago, Department of Anesthesiology

Background: The current Millennial generation of medical residents more often use online and mobile devices to access key information and resources compared to the use of textbook sources employed by the previous Gen X population. Many of these trainees have used online media for the majority of their education and are skillfully adept at employing electronic hardware and software. Currently, there is a second emergence for consumer virtual reality (VR) which has not generated this much interest since the 1990s. Compared to that time, huge technological advancements have been made to develop standards, convincing levels of immersion, and content. While not VR, 360 degree videos serve as an affordable and easily reproducible gateway to the immersive experience which VR poises to offer. Use of this new medium, creates a whole new opportunity to enhance the resident's educational experience that was not previously able to be achieved.

Methods: A 360 degree video spherical camera was utilized to record a two minute video demonstration of Basic Life Support training from a certified ACLS instructor. The video was edited using video software that rendered the video in a 360 degree video mp4 format. The video was subsequently upload to popular video website, YouTube, which accepts and plays the 360 video format standard (link for video listed below). Mobile smartphones using both Apple iOS and Android operating systems were placed in a Google Cardboard Version 2.0 approved cardboard box viewer. Testers loaded the previously recorded video using the YouTube app on their smartphones, secured their phones in the cardboard box viewer, and either held the cardboard box viewer to their face or secured the viewer with a Velcro head strap. Testers were freely able to view the training video in any 360 degree direction from the fixed standpoint of the camera by just turning their head. This was accomplished using the smartphones built in accelerometers which is used frequently to re-orientate the screen as users move the device. This feature was utilized by the YouTube app to coordinate head movement and rotation around the video.

Results: The initial trial to develop a basic 360 degree medical video was successful. Testers displayed ease of use playing the 360 degree video using the YouTube app in both iOS and Android operating systems. Testers also reported satisfaction with viewing the 360 degree video on their smartphones without a cardboard box viewer. However, they acknowledged using a cardboard box viewer creates a more immersive environment which is not able to be accomplished just using a smartphone alone.

Conclusions: A novel method for medical training was explored. The advantages of 360 degree videos over conventional 2D videos include the ability to view multiple apparatuses and events concurrently, improve situational awareness, and mimic the ability for the viewer

to be physically present in the room. Future work will aim to optimize video quality and hardware to enhance the viewers immersion. Further medical curriculum development will aim to not only produce videos for procedures but also develop actual medical simulation as well.

Video link: https://youtu.be/Wfs_MqaaXkE

*For optimal viewing of 360 degree video, please view in the YouTube app on both iOS/Android smartphone/tablet devices or using the Google Chrome Browser for desktop.



Towards an Ultra-High Resolution Signal Converter for Electroencephalogram Monitoring

Authors: Christian L Petersen¹, Martin Mallinson, Richard Venn, Guy A. Dumont², J. Mark Ansermino¹ Departments of Anesthesiology, Pharmacology & Therapeutics¹, and Electrical and Computer Engineering², University of British Columbia, Vancouver, BC, Canada

Background: Electroencephalography (EEG) is an important tool in understanding the effects of anesthesia on the central nervous system. The EEG signal itself has immense non-linear complexity, and is known to contain fine structure such as spindles [1] that are reflective of anesthetic state. It is possible that other, more subtle, features of the EEG are presently missed due to the limitations of current EEG data acquisition technology.

Objective: Our goal is to facilitate new insights into the effects of anesthesia by vastly improving the performance of the EEG data acquisition subsystem and implementing corresponding novel digital processing algorithms.

Methods: We have designed a custom sigma-delta Analog to Digital Converter (ADC) using state-of-the-art design and simulation tools. The new ADC employs advanced noise shaping concepts to move noise away from the clinically relevant regions of the signal spectrum, thereby obtaining an effective resolution considerably greater than previously seen. An ultra-low-noise differential front end will send signals to the ADC from the patient forehead (Figure 1a), and the bitstream output of the ADC processed by a custom field programmable gate array (FPGA) on a Xilinx Zync™ System-on-Chip board. FPGA logic will be used to compute and output trends to the Zync ARM host processor for display and further analysis.

Results: The analog circuit simulation of the first prototype design has been completed using manufacturer component models, and shows performance to be approaching 140dB (Figure 1b), better than any ADC currently available. With a root-mean-square (RMS) error of only 268nV on a 1KHz reference sinusoidal signal of $\pm 2.4V$ (1.7V RMS) amplitude, this corresponds to resolving the signal to 1 part in 30,000,000. This is approximately 300x better than the theoretical maximum resolution of 16bit converters used in current EEG equipment.

Conclusions: The application of advanced signal converter technology is found to potentially improve EEG signal acquisition resolution by almost three orders of magnitude. Work is in progress to implement a discrete version of the medical ADC and an FPGA backend, with a longer-term view to realize a fully integrated single-chip medical ADC for a next generation of ultra-high resolution anesthesia monitoring systems.

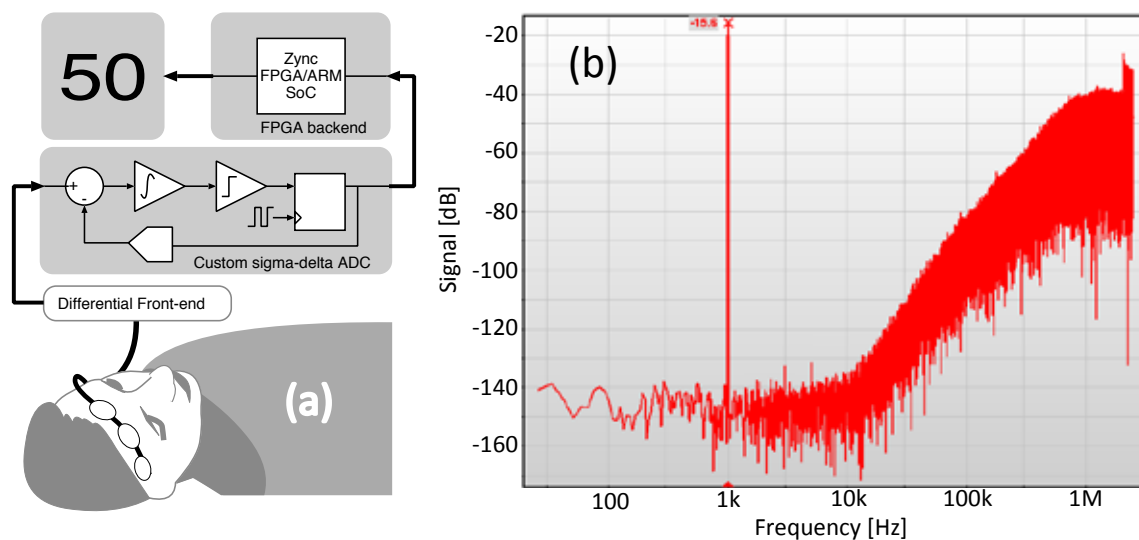


Figure 1: Medical sigma-delta ADC for EEG monitoring: EEG setup (a) and simulation results (b).

[1] Wolter S, Friedel C, Böhler K, Hartmann U, Kox WJ, Hensel M. Presence of 14Hz spindle oscillations in the human EEG during deep anesthesia. Clin Neurophysiol. 117(1):157-68 2006

Droplet-based Simulation of Photoplethysmogram Waveforms and Oxygen Saturation

Authors: Christian L Petersen¹, Zachary Katz¹, Matthias Görges¹, Guy A. Dumont², J. Mark Ansermino¹ Departments of Anesthesiology, Pharmacology & Therapeutics¹, and Electrical and Computer Engineering², University of British Columbia, Vancouver, BC, Canada

Background: Pulse oximetry is an important monitor in anesthesia, as it provides an early indicator of hypoxemia. Pulse oximetry is also being increasingly used in other monitoring and screening applications. Many new devices are coming to market, and the challenges of calibration and testing are a significant barrier to implementation. Regulatory approval of new pulse oximeters requires expensive and invasive tests to be performed on human subjects. It is possible that physical simulations can ease the testing requirements, but such simulators have so far been too complicated [1] to be of general availability and use. Commercially available simulators are electronic rather than physical, and require a priori manufacturer specific calibration that makes them of limited use for testing new devices.

Objective: To realize a simple physical simulation of the pulsatile light absorption as captured by a pulse oximeter using repetitive droplet formation of a non-toxic water-based dye solution.

Methods: A pulse oximeter clip is mounted on a transparent test tube, in which a vertically mounted tapered tip is set to form droplets (Figure 1a & b). The infusion rate relates to the measured heart rate through the rate of droplet formation (Figure 1c). Water is inherently absorbent in the infrared range, and changes in oxygen saturation can be simulated simply by changing the concentration of green or blue food dye with a dual syringe pump mixer.

Results: The droplet-forming tip made acceptable artificial PPG waveforms, as the gradual formation of the drop gives rise to a broad peak in the pulse oximeter sensor signal. The simulated heart rate can be varied over the clinical range (30-235 bpm) by changing the pump infusion rate, and oxygen saturation can be changed by varying the concentration of dye in the liquid, ranging from 100% to below 30%. The pump infusion rate (ml/h) has very little effect on the PPG waveform and SpO₂. However, the setup is sensitive to the alignment of the sensor and the site of drop formation, as well as to the size of the drop itself.

Conclusions: The use of infusion pumps and a water-soluble dye represents a novel and practical way to physically simulate arterial peripheral pulsation, and can be used advantageously in situations where the calibration curve of the oximeter under test is unknown. Work is underway to relate dye concentration to SpO₂ value and minimize ambient light interference, to realize an accurate and robust instrument based on this technology.

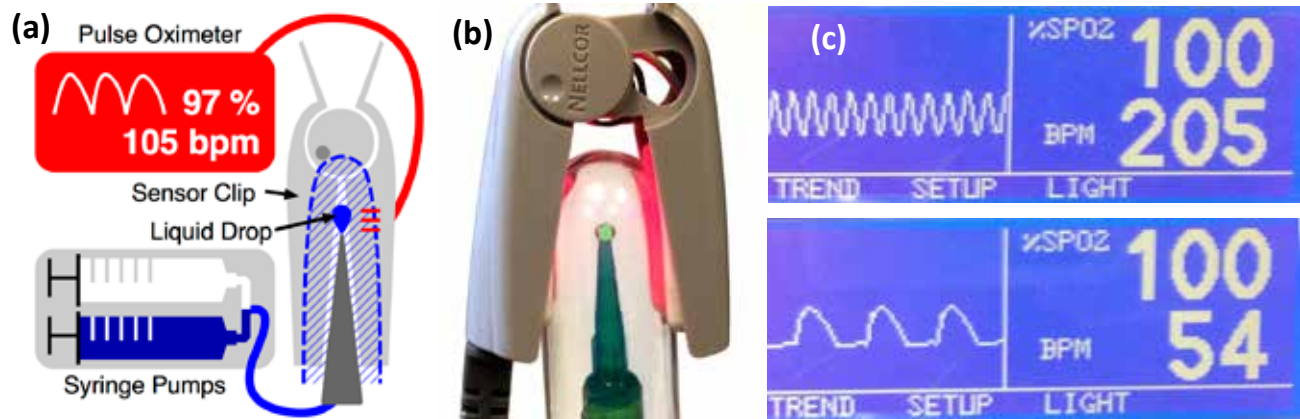


Figure 1: Drop based pulse oximeter simulator: Setup (a), drop chamber (b), and example waveforms (c).

[1] Oura M, Kobayashi N, Yamamori S, Takeda S, Iwasaki K, Umezu M. Calibration System for Pulse Spectrophotometry using a Double-Layer Pulsation Flow-Cell. ConfProc IEEE Eng Med Biol Soc. p. 8962009.

Electronically Mediated Time-Out Reduces the Incidence of Wrong Surgery: An Intervention Observation Study

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Introduction: Nearly half of surgical hool of Medicine, Nashville, TNnderbilt University School of Medicine, Nashville, TNng surgeriesof surgical hool of Medicine, Nashville, TNnderbilt University School of Medicine, Nashville, TN Wrong surgery often results in patient death and is devastating to the care team. Wrong surgery incidence estimates range from 1:112994¹ to as high as 1:5000² and may be on the rise. Checklist application^{3,4} has reduced the frequency of complications previously resulting injury and death and has been a requirement by the Joint Commission since 2003. However, checklists must be performed reliably to be effective, which, in turn, requires the care team to consistently achieve optimal performance. This is a potential vulnerability.

To create a technological backstop to team performance, we used automated process monitoring & process control, as well as forced function concepts to implement an electronic timeout checklist to reduce the wrong surgery rate.

Methods: We created an electronic timeout checklist mediated via the intraoperative nursing documentation module of our Vanderbilt Perioperative Information Management System (VPIMS). The questions are sequentially displayed to the entire care team on a large in-room monitor, interposed as a required documentation step between the tpatient-in-OR" and "incision" events. System development costs were compared to the cost of a wrong surgery. Poisson approximation of the binomial probability was used to estimate the wrong surgery rate and compare this to wrong surgery rate estimates from observed performance reported in the literature. We used Clopper-Pearson (exact) 95% confidence interval for the observed wrong surgery rate.

Results: All 243,939 main campus OR cases between July 30, 2010 and April 7, 2015 were subject to the electronic time-out procedure. Total development costs were \$34,000 and used existing hardware. In a *de novo* installation, the additional hardware cost would have been \$2500 per OR.

The rate of time-out failure (where a time-out is either not performed or performed after procedure start) is between 1 per 140 (Bulka, et al, manuscript in prep) and 1 per 1250 (Vanderbilt University Medical Center, Center for Clinical Improvement, performance tracking

data) cases. There was an extremely low documentation failure rate; failures were due to either a planned, documented second time-out or an accidental mouse click. Since implementation there have been no wrong surgeries (0 in 243,939 cases) in the Vanderbilt ORs (Clopper-Pearson 95%CI: $0.0 \text{ to } 2.17 \times 10^{-5}$ wrong surgeries per case). The CI does not encompass the expected rate of wrong surgery based on current national performance (1 wrong surgery per 23,600 cases, or 4.24×10^{-5} wrong surgeries per case).

Conclusion: Technology can be used to support and enforce a thoughtfully developed perioperative systems design element. After implementation of an electronically mediated hard-stop timeout before incision, no wrong surgeries occurred, both during the observation period nor afterwards. Despite limitations, the study suggests that the system reduced wrong surgeries in our environment beyond that expected based on chance alone, and the most conservative time return on investment estimate is approximately 2 years.

References:

1. Kwaan MR, Studdert DM, Zinner MJ, et al. Incidence, patterns, and prevention of wrong-site surgery. *Arch Surg.* 2006;141:353-357; discussion 357-358.
2. Rothman G. Wrong-site surgery. *Arch Surg.* 2006;141:1049-1050; author reply 1050.
3. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med.* 2006;355:2725-2732.
4. Haynes AB, Weiser TG, Berry WR, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. *N Engl J Med.* 2009;360:491-499.

Design and Evaluation of a New Sonification for Pulse Oximetry

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Background: The auditory display of the pulse oximeter is invaluable for providing information on a patient's heart rate and saturated oxygen levels when a clinician is engaged in tasks that divert attention from the visual display, or when the visual display is temporarily out of the line of sight, or when the clinician is overtaxed with visual information [1, 2]. The auditory display of the pulse oximeter is a sonification: a continuous mapping of numerical data into one or more auditory dimensions [3]. Sonification allows the clinician to monitor a patient's well-being in the periphery of attention while the clinician performs other visually demanding tasks [4]. The sonification used in current commercial pulse oximeters is relatively simple: the rate of tones is mapped to heart rate and the pitch of the tones is mapped to oxygen saturation levels. Unfortunately, without regular checks of the visual monitor, clinicians' estimates of oxygen saturation can diverge considerably from the actual values, especially as noise levels increase [5]. We designed a new sonification to make clinically important oxygen saturation thresholds and ranges more discernable, and we performed an initial evaluation of its effectiveness.

Methods: We added sound dimensions of tremolo and brightness to a conventional pulse oximetry sonification so that three clinically relevant ranges were distinguished (in principle the range boundaries could be adjusted for different monitoring contexts). In a randomised controlled trial comparing the new sonification and the conventional sonification, non-clinical participants listened to short simulated pulse oximetry scenarios. We measured participants' (1) accuracy at identifying oxygen saturation ranges, (2) accuracy at detecting transitions into and out of an oxygen saturation target range and (3) reaction time to detect transitions.

Results: Participants using the new sonification identified oxygen saturation ranges and detected threshold transitions significantly better than those using the conventional sonification, with performance reaching maximum possible levels with the new sonification. Participants using the new sonification detected threshold transitions significantly faster than those using the conventional sonification.

Conclusion: In simple perceptual classification and discrimination tasks, the new sonification supported faster and more accurate identification of general oxygen saturation ranges and threshold transitions than the conventional pulse oximetry sonification. We are currently testing whether the new sonification retains its benefits when participants are distracted by other tasks and by ambient noise. Subsequently we will test the new sonification with clinicians in more clinically representative situations.

References:

- [1] Craven, R. M., & McIndoe, A. K. (1999). Continuous auditory monitoring--how much information do we register? *British Journal of Anaesthesia*, 83(5), 747.
- [2] Sanderson, P. M., Watson, M. O., Russell, W. J., Jenkins, S., Liu, D., Green, N., . . . Krupenia, S. S. (2008). Advanced auditory displays and head-mounted displays: Advantages and disadvantages for monitoring by the distracted anesthesiologist. *Anesthesia and Analgesia*, 106(6), 1787-1797.
- [3] Sanderson, P. M., Liu, D., & Jenkins, S. A. (2009). Auditory displays in anesthesiology. *Current Opinion in Anesthesiology*, 22(6), 788-795.
- [4] Woods, D. D. (1995). The alarm problem and directed attention in dynamic fault management. *Ergonomics*, 38(11), 2371-2393. doi: 10.1080/00140139508925274
- [5] Stevenson, R. A., Schlesinger, J. J., & Wallace, M. T. (2013). Effects of divided attention and operating room noise on perception of pulse oximeter pitch changes: A laboratory study. *Anesthesiology*, 118(2), 376. doi: 10.1097/ALN.0b013e31827d417b

Vibrotactile Displays for Conveying Pulse Oximetry Information

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Background: Several studies have tested if vibrotactile displays can convey information about patient vital signs to anesthesiologists. Results have been promising [1][2][3]. However most studies have used complex sets of vital signs and complex patterns. In the present experiments, we explored the potential for a vibrotactile display of HR and SpO₂ ranges to be conveyed effectively via three tactors (vibrotactile motors) on a sleeve worn on the upper arm [4][5].

Methods: HR range was mapped to the locations of three tactor(s) on the upper arm, the middle tactor indicating normal HR, middle and high tactors indicating high HR, and the high tactor indicating very high HR. The pattern was similar for low and very low HR, but using middle and low tactors. SpO₂ range was mapped to the number of times each tactor was activated: once for normal SpO₂, twice for low SpO₂, and three times for very low SpO₂. Non-clinical participants attended to sequences of the vibrotactile patterns. They tapped on a footpedal when the HR and SpO₂ value changed, and identified the new HR and SpO₂ values vocally. Under no load, participants identified vibrotactile signals only; under low load participants also moved small pellets between two locations; and under high load participants also moved small pellets between locations using laparoscopic graspers. Expt 1 tested with no load, Expt 2 and 3 compared performance under low and high load and in Expt 3 HR and SpO₂ changes were very infrequent.

Results: Participants could invariably detect changes in HR and/or SpO₂, and they identified those changes with accuracy significantly above 90% (Expt 1)[4]. With high load, identification dropped significantly compared with low load, but did not differ statistically from 90% (Expt 2). When changes in HR and/or SpO₂ occurred only every three minutes, and participants worked under low or high load conditions, participants' ability to identify SpO₂ did not differ from 90% in any condition, except when participants tried to identify HR under the high load, where accuracy dropped to 72.5% (Expt 3) [5].

Conclusions: Non-clinicians can identify vibrotactile pulse oximetry ranges with acceptable levels of accuracy, except when task load is high and signals become infrequent. Further testing should be performed with clinician participants. Improved mapping of vibrotactile patterns to vital sign ranges may also help. At present we are testing an alternative mapping of HR and SpO₂ to tactors that may support robust identification even with high task load and rare changes in vital sign values.

References:

- [1] Dosani, M., Hunc, K., Dumont, G. A., Dunsmuir, D., Barralon, P., Schwarz, S. K. W., . . . Ansermino, J. M. (2012). A vibro-tactile display for clinical monitoring: Real-time

- evaluation. *Anesthesia & Analgesia*, 115(3), 588-594
510.1213/ANE.1210b1013e31825d31638c.
- [2] Ferris, T., & Sarter, N. (2011). Continuously informing vibrotactile displays in support of attention management and multitasking in anesthesiology. *Human factors*, 53(6), 600-611. doi:10.1177/0018720811425043
- [3] Ng, J. Y. C., Man, J. C. F., Fels, S., Dumont, G., & Ansermino, J. M. (2005). An evaluation of a vibro-tactile display prototype for physiological monitoring. *Anesthesia & Analgesia*, 101(6), 1719-1724. doi:10.1213/01.ANE.0000184121.03150.62
- [4] McLanders, M., Santomauro, C., Tran, J., & Sanderson, P. (2014). Tactile displays of pulse oximetry in integrated and separated configurations. *Proceedings of the 58th Annual Meeting of the Human Factors and Ergonomics Society (HFES 2014)*. Chicago, IL: 17-21 October.
- [5] Shapiro, J., Santomauro, C., McLanders, M., Tran, J., & Sanderson, P. (2015). Tactile displays of pulse oximetry: An exploratory vigilance study. *Proceedings of the 59th Annual Meeting of the Human Factors and Ergonomics Society (HFES 2015)*. Los Angeles, CA: 26-30 October.

Attitudes on Prevention of Respiratory Compromise

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Background: Respiratory Compromise (RC), defined as respiratory decompensation through insufficiency, failure, and/or arrest, occurs in nearly 1 of 8 elective surgery patients and 1 in 14 of all Medicare patients.ⁱ It is projected that RC costs will reach \$37 billion annually by 2019^j, ranking in the AHRQ's top 5 most rapidly increasing hospital costs.ⁱⁱ Patients that develop RC while on the General Care Floor have a mortality rate 29 times that of other patients.ⁱⁱⁱ Currently, a standardized method of RC risk assessment leading to appropriate monitoring of those at increased risk does not exist.

Methods: In 2014, a survey was performed at two international congresses to determine attitudes toward Respiratory Compromise and the potential for improved solutions in management. Surveys were completed by 144 clinicians including 121 anesthesiologists, 12 nurses, and 9 intensivists from North American, Europe, and Asia. Survey respondents were asked to rate a series of statements on a 5 option Likert scale ranging from Strongly Disagree to Strongly Agree.

Results:

% Agreement ¹	Statement
77%	Risk for development of Respiratory Compromise can be assessed and guide the need for continuous electronic monitoring.
83%	All patients should be assessed for risk of Respiratory Compromise and monitored according to their level of risk.
77%	Standardized assessment of those 'at risk' for developing Respiratory Compromise resulting in continuous electronic monitoring for those at higher levels of risk would prevent more patients from deteriorating.
92%	Continuous monitoring of patients who are at higher levels of risk or in early stages of Respiratory Compromise can lead to earlier interventions, preventing further deterioration.
84%	Continuous monitoring of patients who are at higher levels of risk or in early stages of Respiratory Compromise can save money by preventing the need for more complex, costlier levels of care.

Those that responded continuous electronic monitoring of these parameters would be 'somewhat' or 'very' helpful in early identification and earlier intervention for those at risk or with early Respiratory Compromise

- Respiratory Rate – 97%
- Oximetry – 99%
- Capnography – 97%

¹ Response of 'Somewhat Agree' or 'Strongly Agree'

- Index of multiple parameters – 98%

Conclusion: Clinicians surveyed generally agreed that it is possible to assess risk of Respiratory Compromise and that all patients should have their risk assessed. More than 9 in 10 agreed that continuous monitoring of those at higher risk can lead to earlier identification and intervention, preventing further deterioration. More than 8 in 10 agree that monitoring those at increased risk can reduce the total cost of care. Further studies should explore a standardized tool for RC risk assessment leading to a level of monitoring commensurate with RC risk.

References:

ⁱ Agarwal SJ, Erslon MG, Bloom JD. Projected incidence and cost of respiratory failure, insufficiency, and arrest in Medicare population, 2019. Abstract presented at Academy Health Congress, June 2011.

ⁱⁱ Torio CM, Andrews RM. . National Inpatient Hospital Costs: The Most Expensive Conditions by Payer, 2011 - STATISTICAL BRIEF #160. August 2013. <https://www.hcup-us.ahrq.gov/reports/statbriefs/sb160.jsp>. Accessed December 14, 2015

ⁱⁱⁱ Kelley SD, Agarwal S, Parikh N, Erslon M, Morris P. Respiratory insufficiency, arrest and failure among medical patients on the general care floor. Crit Care Med 2012; 40(12):764.

Broadband Near Infrared Spectroscopy Can Detect Cyanide-Induced Cytochrome AA₃ Inhibition in Rats

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Introduction: Clinically available near infrared spectroscopy (NIRS) devices are based on the Beer-Lambert law and are designed to measure the hemoglobin saturation in tissue (StO₂). The outcome data to support using these devices is not strong. The oxidation state of cytochrome aa₃ (Cyt_{aa3}), the terminal component of the electron transport chain, reflects the state of subcellular energetics directly, and may be a more physiologically relevant chromophore than hemoglobin. Cyt_{aa3} absorbs near infrared radiation (NIR) with a peak around 820 nm, and thus the oxidation state of Cyt_{aa3} (Cyt_{ox}) can be measured using NIRS. Measurement of Cyt_{ox} using NIRS is technically challenging, and several investigators have developed “broadband” techniques to improve signal-to-noise ratios. The purpose of this study was to verify the ability of broadband NIRS to measure Cyt_{ox} independent of changes in hemoglobin saturation by manipulating Cyt_{ox} and StO₂ independently.

Methods: We developed a 301 wavelength broadband NIRS device and algorithm based on the previously-validated UCL_n algorithm using primarily commercial off-the-shelf components. NIR radiation was provided by a single halogen light source coupled to a single emitting fiber optic cable with an attached prism at the end to transmit near infrared radiation to the subject. Three receiving fiber optic cables were utilized – one was directed at the light source to continuously measure the intensity of light at all wavelengths, while the other two were directed at the base of the skull. Each receiving fiber was connected to an independent spectrometer. Intensity data was exported into MATLAB for analysis.

Results: Twenty two-month-old male 300g Sprague-Dawley rats were anesthetized with isoflurane, intubated, and ventilated with 100% O₂ containing 2% isoflurane. Sodium cyanide (NaCN) was intravenously injected at 5 mg/kg in order to produce cytochrome reduction independent of hemoglobin. Two to three minutes after NaCN injection, oxygen supply was eliminated and 100%-N₂ with isoflurane was used for ventilation (anoxia), in order to induce a reduction in both cytochrome and hemoglobin. Twenty rats completed the study. Ninety seconds after injection of cyanide, Hgb decreased in 80% of animals (median -0.014, range -0.056 to 0.22, $p < 0.001$), Hgb-O₂ increased in 75% of animals (median 0.013, range -0.059 to 0.073, $p < 0.001$), and cytochrome reduction occurred in 100% of animals (median -0.015, range -0.028 to -0.0012, $p < 0.001$). Ninety seconds after initiation of anoxia, Hgb increased in 95% of animals (median 0.13, range -0.026 to 0.21, $p < 0.001$), Hgb-O₂ decreased in 95% of animals (median -0.17, range -0.24 to 0.024, $p < 0.001$), and cytochrome reduction occurred in 100% of animals (median -0.04, range -0.069 to -0.0065, $p < 0.001$).

Conclusions: By demonstrating independent manipulation of Cyt_{ox} and hemoglobin oxidation state, this data demonstrates that accurate trending of changes in Cyt_{ox} is possible

using readily available equipment, lowering the barrier to further development of devices designed to measure electron transport chain dysfunction / subcellular energy derangements in real-time.

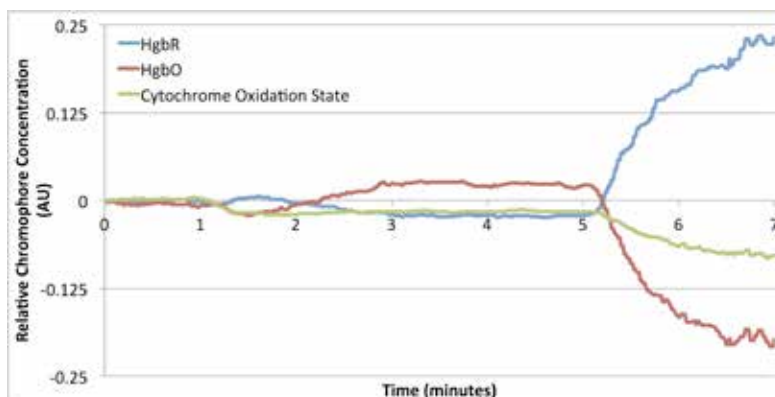


Figure 1. Injection of NaCN (1 min) leads to cytochrome desaturation and increase in tissue oxygen saturation. Subsequent exposure to 100% N₂ (anoxia, 5 min) leads to additional cytochrome desaturation and tissue hypoxia.

Development and Use of Standardized Reports for Data Analysis of the MHS Epic OpTime EMR

Authors: Rebecca Dodson, Michael Hopkins, Karl Wagner MD, Alfred Pinchak MD

Introduction: In February 2014, our institution implemented a new electronic Surgical/Anesthesia clinical records systems. Limited provisions were made enabling the searching and downloading of surgical documented data. The previous system, Philips CompuRecord (PCR), had the advantage of a separate, dedicated server to handle all the Anesthesia Data coming from all the ORs as well as remote locations where anesthesia was needed. With the current Epic Optime Module (EOM) all of the information was scattered throughout the enterprise wide servers handling all of the hospital information. Hundreds of man hour efforts were required to restore the same capabilities that we had previously. A positive outcome of this exercise is we were able to incorporate data that was missing from some of the previous systems standard reports. This enabled us to improve the EOM to surpass the capabilities of what we had with the PCR system.

Methods: The previous system mapped all stored data to a unique case number. With the research module software tool the end user was able to quickly download all of the data from an individual case (3-5 second), including all vital signs. For a typical case this data was housed in 20 tables (linked via ODBC using MS Access). Simple sequel queries were written to join subsets of the different tables including the cross tabulated vital signs. In addition to the Research Module Output the PCR was able to put out standardized reports which were put in an excel spreadsheet and were continuously updated. All OR cases were available in the PCR standardized reports from the time of system startup until the last case completed. We decided to emulate these PCR standard reports in EOM. When we started the work on this Epic project we had Crystal Reports and Reports available from the EOM Clarity Database (CD). However, the CD which accepts sequel queries, was divided into approximately 32,000 different tables available.

Results: We were able to improve data recovery in multiple areas. 1) Clinical Documentation to Professional revenue reconciliation – Reporting tool developed to reconcile 100% of clinical documented procedure where the anesthesia area was involved. As an example it was discovered there was an issue with C-Section procedures not making it from the clinical documentation module to our Professional Billing module. This issue has since been fixed. This reconciliation tool is reviewed by the Periop Administration as well as our revenue cycle team on a bi-weekly basis. 2) Anesthesia Operational Report - Shows volume trending over each of the areas that are serviced by the Anesthesia Department. 3) Research Data Sets.- Seven EPIC OPTIME Anesthesia Tables were designed to mirror the previous Anesthesia System. Such as case tracking time events, meds administered, vital signs measures, etc.

Conclusions: Through several months of collaboration between our Anesthesia physician staff, Medical Operations, Information systems and their EPIC counterparts we were able to produce many of the same standard reports that we had with our previous Anesthesia system

as well as increase and improve upon the accuracy of the data that was populating these reports.

Development of an Automated System for Tracking Bundle Compliance and Patient Outcomes for an Anesthesia Perioperative Consult Service

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Background: A key aspect of improving patient care through the Perioperative Surgical Home (PSH) model is having the ability to track compliance with care bundles and determine impact on patient outcomes over time. These data are an essential input to Plan-Do-Study-Act cycles. To have a sustainable implementation plan, it is important to have these data generated in a manner that requires minimal effort, preferably one that is automated. We describe here our experience creating a PSH through our Anesthesia Perioperative Consult Service (APCS), focused on the supporting technology we developed.

Methods: We identified 6 surgical services lines for inclusion in our APCS, and defined the participating surgeons and pertinent surgical procedures. An automated system was established that scanned the surgical schedule for qualifying cases, determined the current APCS staff from our staff scheduling system, and emailed a summarized case list to the APCS team a day in advance (Figure 1). Separately, a Tableau dashboard was created which tracked bundle compliance and patient outcomes (Figure 2). Bundle compliance included utilization of multimodal analgesia, utilization of post-operative nausea and vomiting prophylaxis and perioperative narcotics administered. Outcomes included length of stay, case mix index, postoperative intensive care unit admission, extubation in the OR and hospital readmission.

Results: After 50 weeks of operation, the automated email system identified 1,081 surgical cases. By notifying both the APCS and holding room staff in advance, the system has facilitated timely administration of preoperative multimodal analgesia, including regional blocks. Ten minor revisions of the automated system have been implemented as the APCS inclusion criteria have been iteratively refined. User feedback has been largely positive. Requested enhancements include adding available coagulation testing and identifying anticoagulants in preoperative medication lists. Based on pre- and post-implementation median length of stay differences and case volume, the projected savings in bed-days is estimated at 391 per year.

Discussion: Implementation of a PSH requires a structured approach to identifying specific surgical populations, targeting those populations with standardized care bundles, monitoring compliance with bundles and tracking outcomes to demonstrate value. We have demonstrated that electronic tools can be developed that facilitate these activities and function in an automated fashion. These types of technologies are essential for supporting the sustained outcome improvements possible with the PSH.

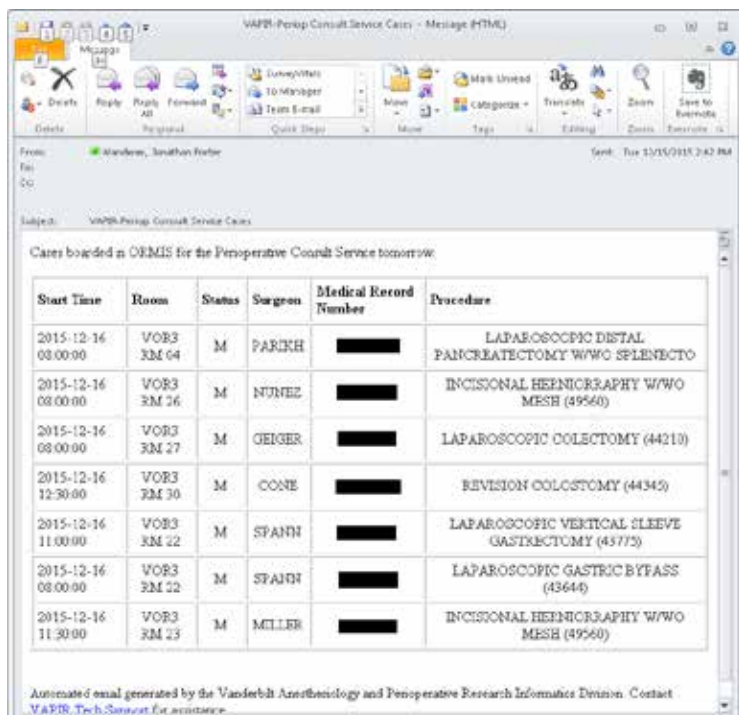


Figure 1: Example of an automatically generated email identifying cases for the Anesthesia Perioperative Consult Service for the next day.

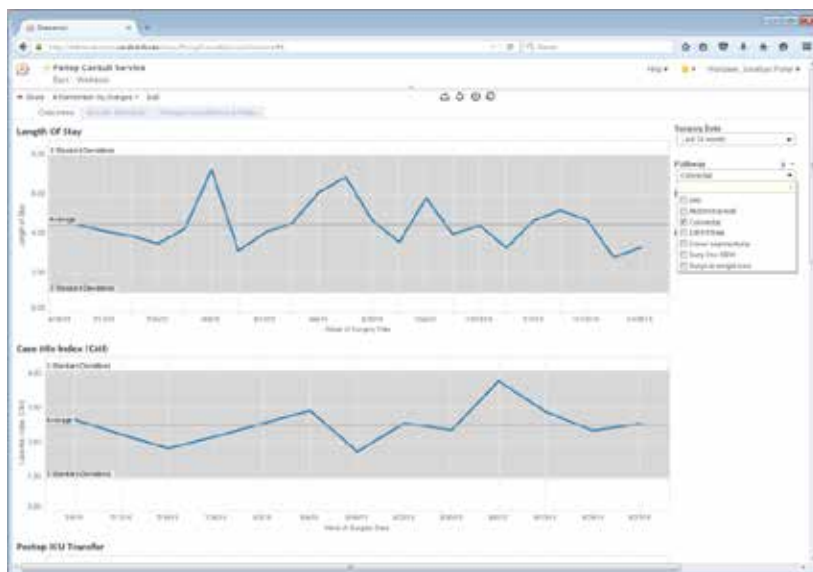


Figure 2: Example of the Anesthesia Perioperative Consult Service Tableau dashboard, demonstrating tracking of length of stay for the colorectal surgery service line.

Are Patient Risk Factors Consistent Across Data Sources: A Comparison of EMR, Billing, and Clinician-Abstracted Data

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Background: Widespread implementation of electronic medical records (EMR) and improved statistical techniques have created an explosion in the amount of health data available to researchers. Although these advances open new avenues for researchers, minimal endeavors have been made to establish quality and assess correlation between the various data sources. We aim to evaluate the consistency of data across administrative, research, and clinical data sources and hypothesize that data will be well correlated.

Methods: After IRB approval, patients who underwent cardiac surgery between April 1, 2013 and March 26, 2014 were identified from our institutional submission to the Society for Thoracic Surgery (STS) registry. Patient data from the “Risk Factor” and “Operative Description” sections of the STS database were mapped to one of 15 comorbidities (Table 1). EMR documentation of these comorbidities was obtained from the “Past Medical History” and “Problem List.” Lastly, ICD-9 billing data were obtained by mapping codes to the 15 comorbidities. STS was considered the gold standard for statistical analysis as all data was clinician-abstracted and it was presumed to be the highest quality, sensitivities and specificities were calculated accordingly. Fleiss kappa coefficients were calculated to assess concordance between the data sets with adjustment for prevalence. In order to examine the impact of misclassification on risk stratification models, a linear regression analysis of a risk-adjusted length of stay (LOS) for patients using each of the three data sets was performed.

Results: The STS database contained 431 patients, 388 were successfully matched to corresponding records in the EMR. The prevalence of comorbidities varied across data sources, with a ten-fold difference in valvular disease and smoking history. Sensitivity ranged from a low of 7% for substance abuse to a high of >90% for diabetes and coronary artery disease, averaging 59% for both EMR and ICD-9 (Table 1). Specificity measures were higher, averaging 82% for EMR and 79% for ICD-9 (Table 1). Kappa coefficients ranged between -0.19 and 0.74, and were higher for EMR compared to STS than ICD-9 compared to STS (0.39 vs. 0.23). In our regression model using STS data only, history of arrhythmia and hyperlipidemia were found to be significantly associated with LOS. However in the model using EMR data, history of arrhythmia, cerebrovascular disease, and congestive heart failure (CHF) were associated with LOS, and using ICD-9 data, history of arrhythmia, CHF, substance abuse, diabetes, end-stage renal disease, hypertension, and chronic obstructive pulmonary disease were associated with LOS.

Discussion: Comparison of comorbidities between STS, EMR, and ICD-9 data demonstrated significant variability in prevalence and at best, fair agreement between the data sets. In contrast to previous reports of the reliability of ICD-9 data, we found data validity varied with the comorbidity evaluated. Similarly, comorbidities predictive of LOS varied based on the data set utilized for modeling. Although the relatively small sample size limits this retrospective study, we believe continued efforts to validate data accuracy are vitally important to the future of research studies using data obtained from administrative and billing sources.

Table 1.

	Prevalence (%)			EMR (%)		ICD9 (%)		Fleiss kappa coefficient	
	STS	EMR	ICD9	Sensitivity	Specificity	Sensitivity	Specificity	EMR	ICD9
Diabetes Mellitus	29.1	37.1	65.5	93.8	86.2	64.1	74.5	0.738	0.147
Valvular Disease	51.3	54.9	5.4	79.3	47.1	20.7	95.8	0.721	-0.193
Coronary Artery Disease	45.9	58.0	27.1	96.2	56.2	76.4	50.2	0.644	0.271
Obstructive Sleep Apnea	7.5	10.1	11.3	75.9	95.3	79.3	94.2	0.613	0.592
End Stage Renal Disease	5.2	7.7	8.8	75.0	95.9	65.0	94.3	0.572	0.443
Hypertension	51.0	59.3	72.2	81.3	63.7	84.8	41.1	0.448	0.226
Cerebrovascular Disease	8.5	13.7	18.0	63.6	91.0	67.6	88.0	0.425	0.34
Hyperlipidemia	44.3	42.0	51.0	64.5	75.9	74.4	67.6	0.406	0.411
Liver Disease	3.9	5.7	9.0	53.3	96.2	60.0	93.0	0.404	0.316
Arrhythmia	16.8	35.8	53.6	72.7	70.3	89.4	44.4	0.308	0.045
Chronic Obstructive Pulmonary Disease	10.1	19.3	29.4	53.8	84.5	52.5	55.7	0.26	0.161
Congenital Heart Disease	0.8	2.6	3.6	33.3	97.7	66.7	86.5	0.139	0.0979
Substance Abuse	3.4	0.8	4.1	7.7	99.5	15.4	96.3	0.107	0.104
Congestive Heart Failure	41.2	30.7	47.7	35.6	72.8	33.3	96.6	0.077	0.076
Smoking	27.6	2.6	22.9	8.4	99.6	46.7	86.1	0.003	0.345
Average	23.1	25.3	28.6	59.6	82.1	59.8	77.6	0.391	0.225

Improving Transitions of Care in the Perioperative Setting: Developing Handoff Tools in the Age of the Electronic Health Record

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Background: Medical errors are a leading cause of morbidity and mortality in the United States. Handoffs and transitions of care are events during which communication failures may lead to errors. In the perioperative setting, surgical patients undergo multiple transitions of care in a short period of time involving multiple providers including the surgical and anesthesiology teams and perioperative and inpatient nursing. Handoff improvement programs have been shown to reduce medical errors and elements of high quality oral handoffs have been well described¹. For surgical patients, structured handoff tools for transitions from the operating room (OR) to the intensive care unit² (ICU) and to the post anesthesia care unit³ (PACU) increase the quality and reliability of information transferred. As hospitals adopt integrated electronic healthcare records (EHRs), there is a need for well designed tools that facilitate handoffs of care by improving communication and decreasing cognitive burden on healthcare providers.

Methods: As part of the Brigham and Women's Surgical QUALity REDesign (BSQUARED) program, a multidisciplinary team was formed to develop a tool for improving handoffs between the OR, PACU, and inpatient care areas. In conjunction with the ongoing development of the electronic health record, workflows were developed for the handoff process using iterative plan-do-study-act cycles. Reliability of the handoff process will be measured via surveys of care team members including PACU nursing team, PACU anesthesia team, and the surgical ward team. Adverse event and safety reports will be monitored during the implementation of the tool to understand its effect on patient safety.

Results: The first iteration of this quality improvement project involved the implementation of a new EHR chart review tool. The tool pulls together a summary of the procedure, associated staff and care team members, contact information for pass-off, vital signs, fluid totals, active lines/drains/airways, imaging, nursing notes, discharge planning information, active and last administered medications, and a link to the anesthesia record.

Conclusion: Clear and efficient communication in patient handoffs can be facilitated with electronic tools that pull together disparate but crucial information. By providing the right information at the right time, errors in communication can be averted. By including

stakeholders from all areas of perioperative care there is great opportunity to develop tools to improve the reliability of patient care handoffs, streamline clinical workflow, and improve patient outcomes.

References:

- 1) Starmer AJ, Spector ND, Srivastava R, et al. Changes in medical errors after implementation of a handoff program. *N Engl J Med*. 2014;371(19):1803-12.
- 2) Gardiner TM, Marshall AP, Gillespie BM. Clinical handover of the critically ill postoperative patient: An integrative review. *Aust Crit Care*. 2015 Nov;28(4):226-34.
- 3) Robins HM, Dai F. Handoffs in the Postoperative Anesthesia Care Unit: Use of a Checklist for Transfer of Care. *AANA J*. 2015 Aug;83(4):264-8.

Use of Big Data and Machine Learning for Prediction of Hypotensive Events in High Risk ICU Patients from the MIMIC II MIT Database

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Background: Patients in high risk settings are often at risk of developing hemodynamic instability. Current methods of identifying such instability rely on the monitoring of invasive and noninvasive hemodynamic parameters that exhibit pronounced changes only when a critical event is already occurring. However, a number of published studies have recently demonstrated that hemodynamic instability can be detected earlier by analyzing the subtle complex changes in multiple hemodynamic variables and their relationships. The main objective of this preliminary study was to evaluate the feasibility of the early detection of hypotensive events in patients admitted to the ICU.

Methods: Data used in this study came from the MIMIC II MIT Research Database. Arterial pressure waveforms of 181 patients were analyzed and over 700 waveform features were extracted (Edwards Lifesciences, Irvine, CA). Mild hypotensive events were defined as a 10% drop of MAP from a moving average window of 60 minutes, MAP < 65 mmHg, and a minimum event duration of 15 minutes. Severe hypotensive events were defined as a 40% drop of MAP from a moving average window of 15 minutes, MAP < 50 mmHg, and a minimum event duration of 5 minutes. Only patients with severe events (n=122) or no events (n=59) were used for training the models. Sequential feature selection with logistic regression with a 10 fold cross validation was performed to narrow the number of features to be used in each model. Four models built with incrementally increasing training data sets were assessed in this study: Model 1) Severe events vs all non event patient data, 2) 5 minutes prior to severe event + event vs all non event data, 3) 10 minutes prior, and 4) 15 minutes prior. Leave-one-out cross validation was performed on all the data of each patient to validate the model. ROC analysis was performed to assess sensitivity and specificity of each model and AUC was calculated for 0, 5, 10, and 15 minutes prior to event to determine predictive value.

Results and Conclusion: 7 features were selected in Model 1, 14 in Model 2, 13 in Model 3, and 14 in Model 4. While all 4 models appear to have similar sensitivity and specificity (AUC > 0.85), with each increasing amount of event data added to the training set, the predictive value of the model also slightly increases with not much difference between Models 3 and 4 (Figure 1).

In conclusion, these preliminary results indicate that detection and prediction of severe hypotensive events is feasible. Further analysis will need to be done on more patients, with a completely independent validation set. In addition, other machine learning methods such as support vector machine, discriminant analysis, random forest, etc will also need to be assessed. Also, utilizing the clinical records of the MIMIC II patients to confirm events will also need to be assessed. Finally, due to the inherent nature of ICU patients receiving arterial lines, the training data was skewed towards the severe event category, and thus methods of balancing the data set, such as undersampling, will need to be performed and assessed as well.

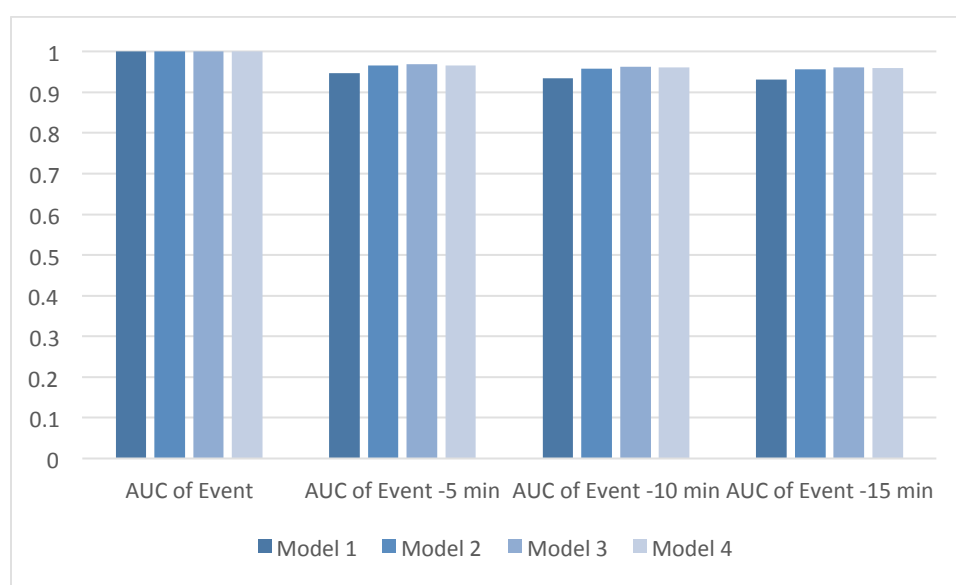


Figure 1. AUC results for Models 1 – 4, to assess sensitivity and specificity of model's ability to identify and predict severe events 0, 5, 10 and 15 minutes prior.

Clinical Decision Support System for Outcome Prediction in Intensive Care Units

Presenting Author: Ali Jalali PhD¹

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Background: Patients in the intensive care units (ICU) are among the most critically ill patients in any hospital. Those at higher risk (of cardiac arrest, for example) would be in immediate need for extensive monitoring and direct attention from healthcare providers. Most of the clinically based studies on outcome prediction have focused on providing simplistic scores that focus on the severity of disease or illness. There are two fundamental problems with these acuity scoring methods. Firstly, they are population based and are not patient-specific. Secondly, the scores are not developed for real-time evaluation of the patients but rather for estimating risk in the first 24 hours after ICU admission. Hence they fail to provide real-time predictive power

Objective: The objective of this paper is to address the problem of data driven outcome prediction in the ICU, and proposes the development of a machine learning based clinical decision support system for patient-specific prediction of in-hospital mortality of ICU patients.

Methods: The data used in this paper is gathered from the publicly available Physionet database, and consists of 4,000 patients. All patients were adults who were admitted for a wide variety of reasons to ICUs. ICU stays of less than 48 hours have been excluded from the dataset. Patients with directives of Do Not Resuscitate (DNR) or Comfort Measures Only (CMO) were not excluded, hence making the prediction task much more complex. 512 patients among the collected data died during their stay at ICU. For each patient, up to 42 variables were recorded at least once during the first 48 hours after admission to the ICU. The outcome of this study is "In-hospital-mortality" so the outcome is 1 if the patient dies in the hospital even if outside ICU, and it is 0, if patient survives during the hospitalization.

Clinical Decision Support System: Based on expert medical knowledge and opinion, we have hence divided the collected data into different groups based on their relationship to a particular organ. The grouping of the variables into these different organ-groups helps the algorithm to better understand the physiological state of each organ and hence guarantees improved decision support. We then extract various mathematical features from the data including statistical, physiological and mathematical based features. Some of these features include: (i) minimum, maximum, mean, variance of the variable, (ii) out of range value, number of alarms, daily trend, (iii) sample entropy (iv) demographic features. The out of range index (ORI) is a measure of both the amplitude differences of a measurement within its normal range and the time that the measurement goes out of normal physiological range. Sample Entropy, is defined as a measure of signal complexity and irregularity

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We then ranked the extracted features for each organ based on their mutual information with the outcome. Finally we designed a neural network classifier to predict the probability of the death for each patient.

Results: The evaluation metric used in this paper is the F-score, which is a measure of a classifier's accuracy. It is the harmonic mean of the positive predictive value and sensitivity of the predictor. We use eight-fold validation for testing the accuracy of the algorithm. The F-score result of the algorithm is 42% accuracy while this score for the widely used acuity scoring systems Sequential Organ Failure (SOFA) and Simplified Acute Physiology Score (SAPS) III are 27% and 29% respectively. The comparison of our results with SOFA and SAPS scoring systems shows approximately 55% and 45% of improvement in the outcome prediction accuracy.

Conclusion: In this work we addressed the problem of ICU outcome prediction. One of the main objectives of this study is to increase ICU outcome prediction accuracy in order to help clinicians identify patients at high risk of mortality and morbidity and hence enable them to plan possible treatments in a timely manner to avoid losing the patient. The algorithm that we presented in this paper is able to outperform standard acuity scoring systems in the ICU such as SOFA and SAPS-III by more than 45%. Although this algorithm has similarities with the acuity scoring systems, which makes it acceptable for clinical use, it is capable of analyzing the data at deeper levels to extract the hidden information that exists in the data.

A Systematic Comparison of Depth of Hypnosis Indices during Intravenous and Volatile Anesthesia by Electroencephalogram Replay

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Background: Commercially available Depth of Hypnosis (DoH) monitors are based on the processing of electroencephalography (EEG) data. Each manufacturer uses different signal processing algorithms, and for most monitors the details of implementation are not fully disclosed. Little is known about how these DoH indices compare with respect to bias and noise, or if the choice of anesthetic agent affects the output.

Objective: Differences between DoH monitor indices were investigated by replaying previously-recorded EEG to a DoH monitor through a simulator [1] that mimics the impedance of the patient forehead and delivers electrical signals to the monitor's electrodes.

Methods: Approval for secondary use of EEG data, collected under previous studies, was obtained from our Research Ethics Board. EEG data was taken from 24 patients, who had undergone general anesthesia using either a volatile anesthetic with desflurane (DES) plus fentanyl, or Total Intravenous Anesthesia (TIVA) with propofol and remifentanyl. This data had been recorded at 16 bit resolution and 256 Hz sampling rate with a NeuroSENSE (WAV; NeuroWave Systems Inc., Cleveland Heights, OH) monitor. The collected data was replayed to two other DoH monitors: BIS (BIS; Covidien, Mansfield, MA) and M-Entropy (ENT; GE Healthcare, Little Chalfont, Bucks., UK). The resulting indices were compared, using Bland-Altman analysis (Fig. 1a), and evaluated with respect to bias and root mean square error (RMS).

Results: A total of 40,241 DoH samples were analyzed at a rate of 0.2 Hz. Of these 47% were DES anesthetics, and the rest TIVA. For each combination of monitor (WAV, BIS, ENT) and anesthetic (DES, TIVA), the calculated bias was too small to be of clinical relevance (-1.1–1.1 points), but the RMS error large (7.3–12 points) (Fig. 1b). The DES and TIVA results were similar.

Conclusions: The large RMS errors suggest that there may be prolonged periods with significant deviations between the three DoH monitor readings [2]. We plan to expand this analysis to include more than 300 additional cases and to investigate the monitor differences during specific phases of anesthesia. This work was supported in part by the STA 2015 Fresenius Award.

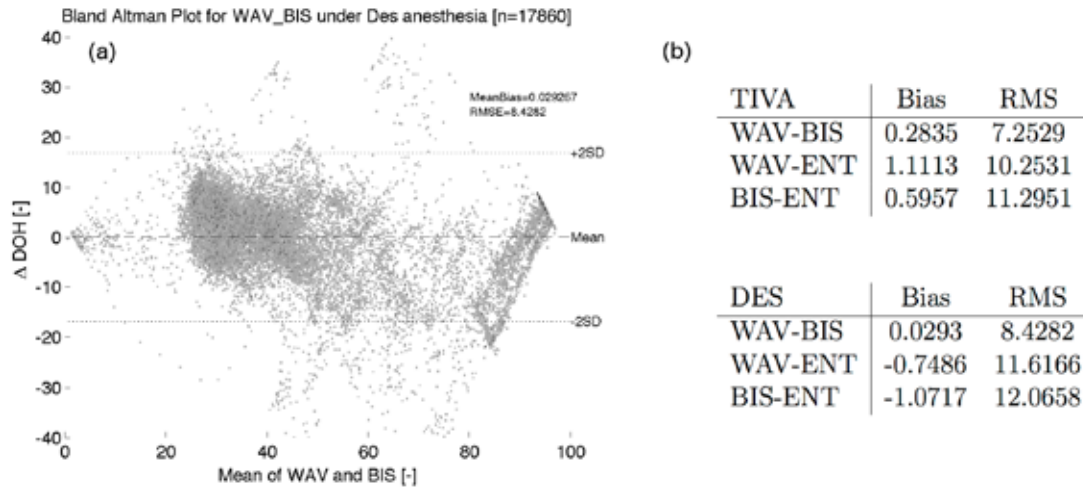


Figure 1: Comparison between WAV, BIS and ENT monitors. Example Bland-Altman (a) and overall bias/RMS (b).

[1]Petersen CL, Görges M, Massey R, Dumont GA, Ansermino JM. A procedural electroencephalogram simulator for evaluation of anesthesia monitors. Submitted to Anesthesia & Analgesia, 2015.

[2]Petersen CL, Katz Z, Görges M, West N, Dumont GA, Ansermino JM. Epochs of Clinically Relevant Disagreements in Depth of Hypnosis Monitors Observed by Replay of the Electroencephalogram. Submitted to STA, 2016.

Epochs of Clinically Relevant Disagreements in Depth of Hypnosis Monitors Observed by Replay of the Electroencephalogram

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Background: Commonly used electroencephalogram (EEG) based anesthesia monitors rely on EEG measurements to determine a Depth of Hypnosis (DoH) index, a dimensionless number between 100 (awake) and 0 (comatose). The algorithms used in these monitors differ greatly and it is possible that the same EEG episodes can lead to quite different DoH values, even if the measures are otherwise statistically comparable.

Objective: We investigate whether episodes of clinically relevant deviations occur in different anesthesia EEG monitor readings, by replaying the EEG data, previously recorded from patients under general anesthesia, to multiple anesthesia monitors.

Methods: EEG data was collected from anesthetized patients with approval from the local research ethics board and written informed consent from the patients. The data was acquired with the NeuroSENSE (NeuroWave Systems Inc., Cleveland Heights, OH) monitor (WAV), and saved as a raw continuous two-channel 256 Hz 16 bit signal. It was next replayed to two other DoH monitors: BIS (Covidien, Mansfield, MA) and M-Entropy (GE Healthcare, Little Chalfont, Bucks., UK) (ENT), and visually inspected for periods of disagreement in DoH readings.

Results: Approximately 56 hours of EEG data were evaluated. Episodes were found with significant deviations between monitors. In one case, the BIS and ENT monitors registered a drop in DoH during emergence from anesthesia, while the WAV was unaffected (Fig. 1a). The BIS appears to lock onto a fixed level/state, a behavior previously predicted from procedural simulations [1]. In another instance, the WAV and ENT saw a rapid drop in DoH while the BIS was unaffected, for a divergence of approximately 20 DoH points (Fig. 1b). In cases with Burst Suppression (BS) the ENT would sometimes fail to register the BS periods, resulting in a strong divergence between ENT and WAV/BIS, reaching up to 30 DoH points (Fig. 1c).

Conclusions: The results indicate that there are sustained epochs with significant disagreement in DoH between monitor brands. When DoH is used as a guide to administer anesthesia, this could adversely affect drug dosing and outcomes. More work is needed to understand what triggers these disagreements, and if measures can be developed to warn clinicians in situations where the DoH readings become less reliable.

This work was supported in part by the STA 2015 Fresenius Award.

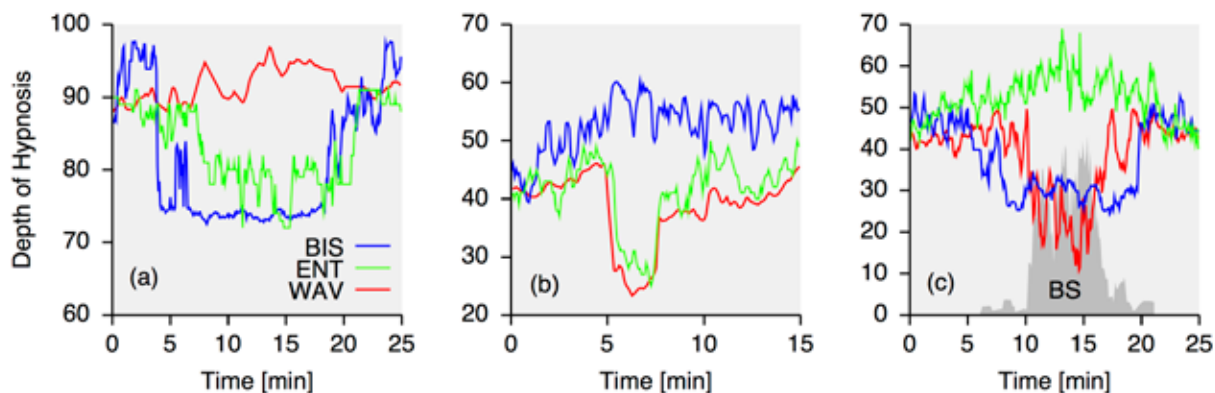


Fig 1: Comparison of DoH and the effect of BS on readings from WAV, BIS and ENT monitors.

[1]Petersen CL, Görges M, Massey R, Dumont GA, Ansermino JM. A procedural electroencephalogram simulator for evaluation of anesthesia monitors. Submitted to *Anesthesia & Analgesia*.

A Year of Experience Using SpiraLith, A Lithium Hydroxide Carbon Dioxide Absorbent

Presenting Author: S. Mark Poler MD, Anesthesiology, Geisinger Health System, Danville, PA

Background/Introduction: Little information describing implementation and use of SpiraLith² products is available. This abstract summarizes about 15 months use in a single hospital. Recirculating “circle” anesthetic circuits require removal of respired carbon dioxide to prevent rebreathing. Granular, disposable products have been long used. One of the identified problems with many products is production of potentially toxic degradation products, limiting practice of low-flow anesthesia. SpiraLith² is an alternative product employing lithium hydroxide suspended in a polymer matrix that does not produce toxic byproducts. One publication has compared characteristics of several products.¹ Greenhouse gas emissions are another concern addressed by low-flow.³

Methods: Because lithium hydroxide is relatively expensive and recyclable, a log of every unit has been kept to account for returns. There is no color indicator to indicate exhaustion of CO₂ absorbing capacity, so clinicians are to request replacement of the cartridge units when inspired CO₂ concentration reaches 5-7 torr, or about 1%. The log records 1251 units since initiation of use on 3 Sep 2014. Large units fit tandem cylindrical modules (Aestiva), or smaller units fit in custom-made “stein” modules (Aespire, Aisys) for GE anesthesia machines.

Results: The log was created for tracking of recycling. It suffers from missing data and unstandardized reporting of the inspired CO₂ at the time of replacement. Figure 1 illustrates that the smaller stein cartridges have had a median service of about 1 week, while the larger tandem cartridges have a broader distribution, with median service about twice as long. There is a strong dependency measured inspired CO₂ on fresh gas flow, approximately doubling with halving of flow. Also, more cartridges are consumed with high CO₂ loads (e.g. laparoscopy) or low-flow. The second figure illustrates a modest downward trend in total volatile anesthetic agent consumption since introduction of SpiraLith absorbers.

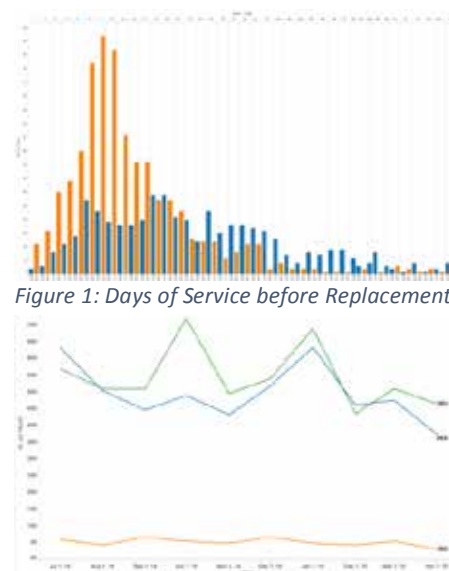


Figure 1: Days of Service before Replacement

Conclusion: Lithium hydroxide absorbing cartridges are a viable alternative to granular CO₂ absorbents. Preliminary results may demonstrate a trend to use of lower total gas flows with corresponding decrease in volatile anesthetic agent consumption and waste volatile agent discharge to the atmosphere.

References:

- 1.Hendrickx et al., J Clin Monit Comput. 2015
- 2.www.spiralith.com, accessed 28 Dec 2015
- 3.Sherman et al., A&A 114:1086, 2012

Automated Method for Confirming Epidural Catheter Location

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Introduction: Inadequate epidural analgesia or anesthesia among parturients has been reported to be as high as 17%, with the most common reason for failure being improper location of the catheter tip [1]. Malposition of the catheter increases the risk of serious complications. These complications can include a high spinal with intrathecal placement and local anesthetic toxicity with intravascular placement. There is currently no convenient and reliable method of confirming proper position of the tip of the epidural catheter.

As a first step in improving safety and efficacy of epidural analgesia/anesthesia, we have developed a new method for detecting migration of the epidural catheter, from the epidural space, into the subcutaneous tissue. Our method is based on a technique known as epidural pressure waveform analysis (EPWA). With this technique, a transducer is connected to the hub of the epidural catheter. A pulsatile pressure wave synchronous with the cardiac pulse suggests that the catheter is in the epidural space; lack of pulsatility suggests that the catheter is not in the epidural space [2,3,4]. The epidural pressure wave measured through the catheter is low amplitude (1-5 mmHg). Distinguishing pulsatility from noise is difficult, leading to limitations in sensitivity and specificity (sensitivities in the above citations range between 55.6% and 88.9%). Previous investigators have only used human judgment to decide if a pressure waveform is pulsatile or not. Here we report the results of our effort to use digital signal processing to automate the EPWA technique.

Methods: We collected waveforms on 20 obstetric patients who all had successful epidural analgesia/anesthesia. At the time of epidural catheter removal, we connected a standard disposable transducer to the epidural catheter and made a digital recording of the pressure wave as the catheter was removed. The catheter was withdrawn incrementally, approximately 1 cm every 30 seconds. Later on, we analyzed the digital pressure waveform by first attempting to visually identify the transition between pulsatility (catheter tip in the epidural space) and no pulsatility (catheter tip in the subcutaneous tissue). We applied a digital signal processing algorithm which was designed to automatically detect this loss of pulsatility. The algorithm works by analyzing a moving 30-second window of data. For each 30-second window, the algorithm uses time domain analysis to extract a single number (i.e., the Epidural Pulsatility Index [EPI]), which is low for a pulsatile signal (the pressure waveform in the epidural space) and high for a signal with nonpulsatile noise (the pressure waveform in the subcutaneous tissue). By plotting EPI versus time, we attempt to identify the moment the epidural catheter leaves the epidural space by associating it with a transition between low EPI and high EPI.

Results: Upon visual inspection, 14 of the 20 waveforms showed a clear transition between pulsatility and no pulsatility. An example of this transition is shown in Fig. 1. Figure 2 shows

the EPI versus time for the 14 waveforms that were found to have the clear transition in pulsatility by visual inspection.

Conclusions: Our algorithm for automated confirmation of epidural catheter location worked in the sense that for each waveform, with a visually identifiable transition between pulsatility and nonpulsatility, the EPI makes a clear transition across a threshold value ($EPI=40$), as seen in Figure 2. It is interesting to speculate why only 14 of the 20 waveforms showed pulsatility, given that all of the catheters were successfully used for epidural analgesia/anesthesia. One possibility is that the catheters were dislodged between the time of delivery and catheter removal (which sometimes occurred the following day). We hypothesize that by modifying the design of our algorithm based on a large library of waveforms and associated clinical outcomes (i.e., failure/success of the epidural), this automated technique will be able to achieve higher sensitivity and specificity than simple human judgment.

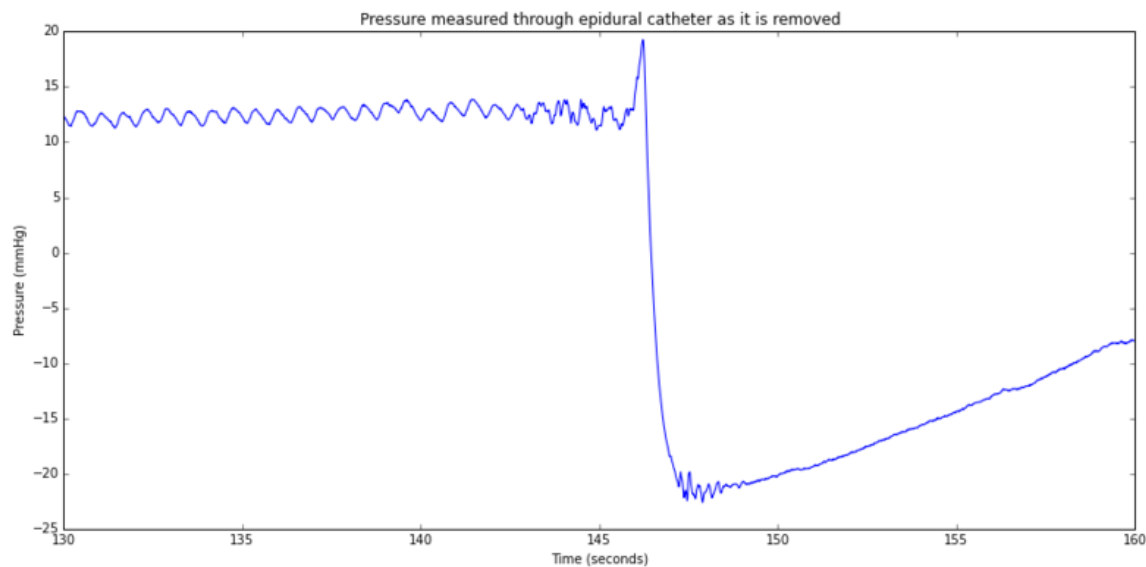


Figure 1. Pressure wave measured through the epidural catheter as it is removed.

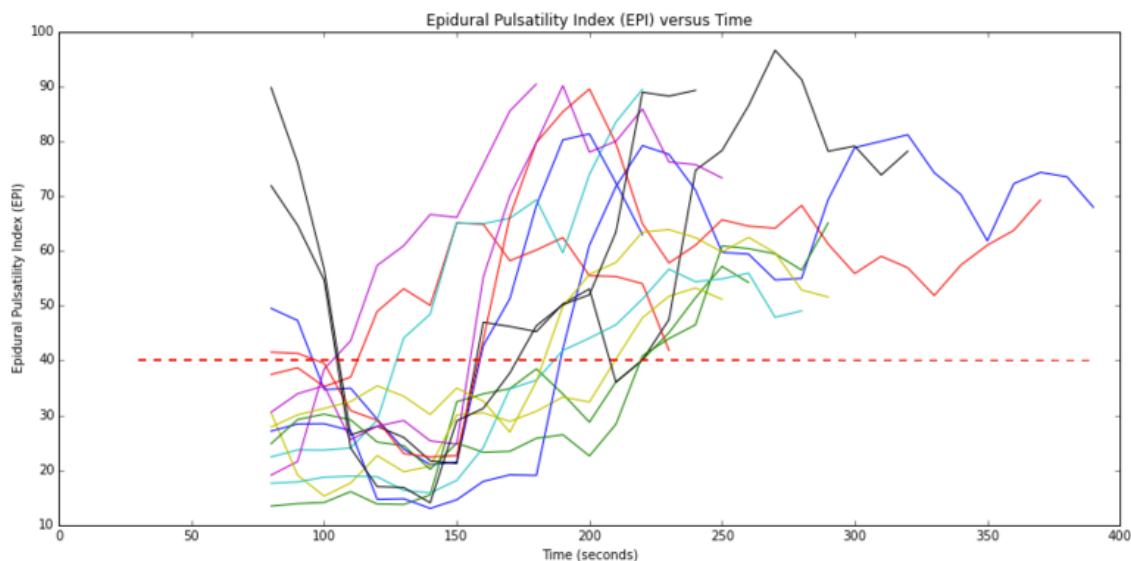


Figure 2: Epidural Pulsatility Index (EPI) for 14 epidural catheters as they are removed. EPI=40 is a threshold that provides reasonable discrimination between low EPI (epidural space) and high EPI (subcutaneous space).

References:

- [1] Crosby, Edward T. "Epidural catheter migration during labour: an hypothesis for inadequate analgesia." *Canadian Journal of Anaesthesia* 37.7 (1990): 789-793.
- [2] Ghia, J. N., et al. "Confirmation of location of epidural catheters by epidural pressure waveform and computed tomography cathetergram." *Regional anesthesia and pain medicine* 26.4 (2001): 337-341.
- [3] De Medicis, Etienne, et al. "A prospective comparative study of two indirect methods for confirming the localization of an epidural catheter for postoperative analgesia." *Anesthesia & Analgesia* 101.6 (2005): 1830-1833.
- [4] Lennox, Pamela H., et al. "A pulsatile pressure waveform is a sensitive marker for confirming the location of the thoracic epidural space." *Journal of cardiothoracic and vascular anesthesia* 20.5 (2006): 659-663.

Comparison of Blood Glucose Determination from Earlobe Capillary Blood and Arterial Blood Specimens

Presenting Author: S. Mark Poler MD¹

Co-Authors: Hoi Ying Yu PhD², Michael P. Scholtis CRNA DNP¹, Thomas M. Schieble MD¹

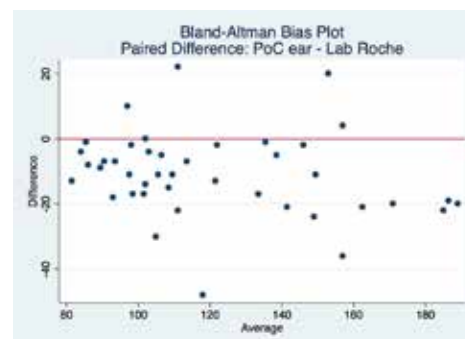
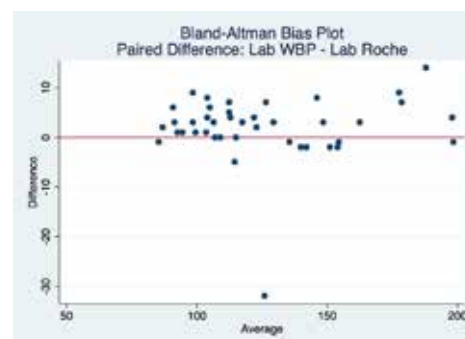
Affiliation: Divisions of Anesthesiology¹, and Pathology and Laboratory Medicine², Geisinger Health System, Danville, PA

Background/Introduction: Glycemic management during the perioperative period has been correlated with surgical outcomes. Laboratory serum glucose testing is the gold standard. Point-of-care testing (POCT) is often used. However, fingertips are often inaccessible during surgery. Earlobes may be more accessible, but are not approved for POCT, and have no published data to support testing at that site, while fingertips capillary glucose testing has been published. We are obtaining data to evaluate earlobe capillary POCT as an alternative for intraoperative glycemic management.

Methods: This study was approved by the Geisinger IRB. The study population includes consenting adult surgical patients having an *in situ* arterial line for anesthetic or surgical indications. Participants consent to an additional earlobe POCT capillary blood glucose determination. The same FDA CLIA-waived StatStrip Nova glucose meter calibrated daily (standard two-point calibration and standard device at Geisinger) was used for all POCT tests. Laboratory results are from a Radiometer analyzer for whole blood gas with glucose, and a Roche analyzer for plasma glucose. Results are reported in mg/dL. Four glucose measurements were obtained and compared as 3 pairs: ear lobe capillary (POCT), whole arterial blood (WB, POCT), glucose by Radiometer Whole Blood ABG analyzer, and Roche plasma glucose. Paired differences subtracting the Roche result from the other 3 results were analyzed. Data were analyzed for laboratory quality assurance using EP Evaluator 11.1.0.26 (Data Innovations, LLC). Statistical analysis was with Stata 13.1

Results: To date 44 paired specimens have been obtained. Procedural and analytic errors resulted in 3 missing data. Correlation coefficients between POCT ear and arterial line was 0.9361; 0.9167 between ear and Roche (lab); 0.9799 between WBP and Roche (labs). Bland-Altman bias plots show that the glucose from whole blood modestly over estimates the standard Roche plasma result. The earlobe POCT results progressively underestimate Roche plasma results as glucose concentration increases.

Conclusions: POCT capillary blood glucose and arterial specimens determined at bedside underestimate paired laboratory values on average by about 10%, but suffer greater variation



between determinations. Thus the POCT values would in general lead to undertreatment guided by insulin treatment protocols, but spuriously high POCT values could lead to overtreatment. Repeated, serial determinations will avoid excessive dependence on sometimes misleading results. Periodic correlation of POCT and laboratory results would be wise precaution.