Real Time Checks for Clinical Care and Billing

AIMS did not check for and detect loss of incoming data resulting in an incomplete record. The patient became quadriplegic during the period without data and the quality of the anesthetic was claimed to be poor. Because data were missing, quality of care could not be assessed.

> Vigoda MM, Lubarsky DA. Failure to recognize loss of incoming data in an anesthesia record-keeping system may have increased medical liability. Anesthesia & Analgesia 102:1798-1802, 2006

AIMS can improve incidence of use of monitor alarm systems, but there should be substantial caution in using them for sending alerts to anesthesiologists supervising multiple cases.

> Eden A, Pizov R, Toderis L, Kantor G, Perel A. The impact of an electronic reminder on the use of alarms after separation from cardiopulmonary bypass. Anesthesia & Analgesia 108:1203-1208, 2009

> Epstein RH, Dexter F. Implications of resolved hypoxemia on the utility of desaturation alerts sent from an anesthesia decision support system to supervising anesthesiologists. Anesthesia & Analgesia 115:929-933, 2012

The mean number of alphanumeric paging alerts to anesthesia providers for median BIS values more than 60 or median age-adjusted MAC level of less than 0.5 was associated with reduced incidences of definite and possible awareness events.

> Mashour GA, Shanks A, Tremper KK, Kheterpal S, Turner CR, Ramachandran SK, Picton P, Schueller C, Morris M, Vandervest JC, Lin N, Avidan MS. Prevention of intraoperative awareness with explicit recall in an unselected surgical population: a randomized comparative effectiveness trials. Anesthesiology 117:717-725, 2012

Audiovisual alert for intraoperative hyperglycemia increased insulin treatment. Detection of glucose checks and insulin administration resulted in less hyperglycemia.

> Sathishkumar S, Lai M, Picton P, Kheterpal S, Morris M, Shanks A, Ramachandran SK. Behavioral modification of intraoperative hyperglycemia management with a novel real-time audiovisual monitor. Anesthesiology 123:29-37, 2015

> Ehrenfeld JM, Wanderer JP, Terekhov M, Rothman BS, Sandberg WS. A perioperative systems design to improve intraoperative glucose monitoring is associated with a reduction in surgical site infections in a diabetic patient population. Anesthesiology 126:431-440, 2017

Audiovisual alert for intraoperative hypotension reduced the number of minutes that patients had a mean arterial blood pressure less than 55 mmHg.

> Kheterpal S, Shanks A, Tremper KK. Impact of a novel multiparameter decision support system of intraoperative processes of care and postoperative outcomes. Anesthesiology 128:272-282, 2018

AIMS can reduce the incidence of inaccurately (manually) recorded hemodynamic data and gaps in measuring blood pressure. Manual invalidation of the automatically recorded data was done at one facility for 19% of cases. The edits usually result in smoothing of the anesthesia record. The loss of information is sufficient for chart review to result in different clinical inference. Comparing patients undergoing esophageal surgery under general anesthesia with manual data entry versus AIMS, use of AIMS has a 1.88 relative rate ratio of hypotensive episodes. Gaps of ≥ 10 minutes with no blood pressure checked occur in 1% to 7% of cases depending on monitor and AIMS configuration. Absence from manual records is an artifact of clinicians' manual smoothing. When comparing hospitals, the incidences of gaps should be measured, as well as the incidences of manual editing of automatically recorded vital signs. From AIMS, almost all heart rate and SpO2 measurements are accurate. Arterial line blood pressures have the largest incidences of artifacts recorded in AIMS, with non-invasive blood pressures a distant second. Most artifacts are caused by physical dislocations and events such as surgeon pushing on the blood pressure cuff or relocating the arterial pressure sensor. Among pediatric patients, ETCO2 can also have many artifacts.

Wax DB, Beilin Y, Hossain S, Lin HM, Reich DL. Manual editing of automatically recorded data in an anesthesia information management system. Anesthesiology 109:811-815, 2008

van Schalkwyk JM, Lowes D, Frampton C, Merry AF. Does manual anaesthetic record capture remove clinically important data? British Journal of Anaesthesia 107:546-552, 2011

Epstein RH, Dexter F. Mean arterial pressures bracketing prolonged monitoring interruptions have negligible systematic differences from matched controls without such gaps. Anesthesia & Analgesia 113:267-271, 2011

Ehrenfeld JM, Epstein RH, Bader S, Kheterpal S, Sandberg WS. Automatic notifications mediated by anesthesia information management systems reduce the frequency of prolonged gaps in blood pressure documentation. Anesthesia & Analgesia 113:356-363, 2011

Kool NP, van Waes JA, Bijker JB, Peelen LM, van Wolfswinkel L, de Graaff JC, van Klei WA. Artifacts in research data obtained from an anesthesia information and management system. Canadian Journal of Anesthesia 59:833-841, 2012

Nair BG, Horibe M, Newman SF, Wu WY, Schwid HA. Near real-time notification of gaps in cuff blood pressure recordings for improved patient monitoring. Journal of Clinical Monitoring and Computing 27:265-271, 2013

Shear TD, Deshur M, Lapin B, Greenberg SB, Murphy GS, Szokol J, Ujiki M, Newark R, Benson J, Koress C, Dwyer C, Vender J. Documentation and treatment of intraoperative hypotension: electronic anesthesia records versus paper anesthesia records. Journal of Medical Systems 41:86, 2017

Hoorweg AJ, Pasma W, van Wolfswinkel L, de Graaff JC. Incidence of artifacts and deviating values in research data obtained from an anesthesia information management system in children. Anesthesiology 128:293-304, 2018

Lack of accuracy and completeness of handwritten anesthesia records are well known. Free text entry fields in electronic systems is inaccurate (e.g., > 1/3rd of required fields not completed), resulting in bills not sent because of lack of required documentation. Manually entered drug administration also is inaccurate (e.g., 25.0% omission, wrong dose, or timing inaccurate by > 10 minutes). Use of mandatory fields increases compliance, and entries are >98% accurate. Automated electronic alerts for anesthesia providers entering start times that were inconsistent with other periods (e.g., not before room entry) resulted in increased compliance. Alphanumeric pages and email sent automatically and repeated at least daily until documentation was completed increased billing. For example, if there was an invasive arterial blood pressure tracing present, there also had to be a corresponding procedure note. Subsequently, the process was revised for the anesthesia record to be scanned in real-time for missing documentation (e.g., patient allergy not listed within 15 min of the start of the anesthetic) and an alphanumeric page sent to the anesthesia provider, rather than after the case was completed.

Driscoll WD, Columbia MA, Peterfreund RA. An observational study of anesthesia record completeness using an anesthesia information management system. Anesthesia & Analgesia 104:1454-1461, 2007

Spring SF, Sandberg WS, Anupama S, Walsh JL, Driscoll WD, Raines DE. Automated documentation error detection and notification improves anesthesia billing performance. Anesthesiology 106:157-163, 2007

Kheterpal S, Gupta R, Blum JM, Tremper KK, O'Reilly M, Kazanjian PE. Electronic reminders improve procedure documentation compliance and professional fee reimbursement. Anesthesia & Analgesia 104:592-597, 2007

Sandberg WS, Sandberg EH, Seim AR, Anupama S, Ehrenfeld JM, Spring SF, Walsh L. Real-time checking of electronic anesthesia records for documentation errors and automatically text messaging clinicians improves quality of documentation. Anesthesia & Analgesia 106:192-201, 2008

Avidan A, Weissman C. Record completeness and data concordance in an anesthesia information management system using context-sensitive mandatory data-entry fields. International Journal of Medical Informatics 81:173-181, 2012

Freundlich RE, Barnet CS, Mathis MR, Shanks AM, Tremper KK, Kheterpal S. A randomized trial of automated electronic alerts demonstrating improved reimbursable anesthesia time documentation. Journal of Clinical Anesthesia 25:110-114, 2013

Edwards KE, Hagen SM, Hannam J, Kruger C, Yu R, Merry AF. A randomized comparison between records made with an anesthesia information management system and by hand, and evaluation of the Hawthorne effect. Canadian Journal of Anaesthesia 60:990-997, 2013

Avidan A, Dotan K, Weissman C, Cohen MJ, Levin PD. Accuracy of manual entry of drug administration data into an anesthesia information management system. Canadian Journal of Anesthesia 61:979-985, 2014

Prophylactic antibiotic received within 1 hr before surgical incision is a JCAHO core measure. Hospitals must report their rate of compliance. Automatic AIMS messages sent if the antibiotic was not administered resulted in increased compliance rate. Near 100% compliance can be achieved when there is email feedback, summary reports by provider, and real-time alerts.

O'Reilly M, Talsma A, VanRiper S, Kheterpal S, Burney R. An anesthesia information system designed to provide physician-specific feedback improves timely administration of prophylactic antibiotics. Anesthesia & Analgesia 103:908-912, 2006

Wax DB, Beilin Y, Levin M, Chadha N, Krol M, Reich DL. The effect of an interactive visual reminder in an anesthesia information management system on timeliness of prophylactic antibiotic administration. Anesthesia & Analgesia 104:1462-1466, 2007

Nair BG, Newman SF, Peterson GN, Wu WY, Schwid HA. Feedback mechanisms including real-time electronic alerts to achieve near 100% timely prophylactic antibiotic administration in surgical cases. Anesthesia & Analgesia 111:1293-1300, 2010

See also: Nair BG, Peterson GN, Newman SF, Wu WY, Kolios-Morris V, Schwid HA. Improving documentation of a beta-blocker quality measure through an anesthesia information management system and real-time notification of documentation errors. Joint Commission Journal on Quality and Patient Safety 38:283-288, 2012

The smart anesthesia manager server repeatedly queries the AIMS database. The decision rules engine operates on the anesthesia manager server. A thin client application on the AIMS workstations displays messages overlaid on the AIMS screen.

Nair BG, Newman SF, Peterson GN, Schwid HA. Smart Anesthesia Manager - a real-time decision support system for anesthesia care during surgery. IEEE Transactions on Biomedical Engineering 60:207-210, 2013

Schwann NM, Bretz KA, Eid S, Burger T, Fry D, Ackler F, Evans P, Romancheck D, Beck M, Ardire AJ, Lukens H, McLoughlin TM. Point-of-care electronic prompts: an effective means of increasing compliance, demonstrating quality, and improving outcome. Anesthesia & Analgesia 113:869-876, 2011

The same effective approach can be used for antibiotic re-dosing.

St Jacques P, Sanders N, Patel N, Talbot TR, Deshpande JK, Higgins M. Improving timely surgical antibiotic prophylaxis redosing administration using computerized record prompts. Surgical Infections 6:215-221, 2005

Nair BG, Newman SF, Peterson GN, Schwid HA. Automated electronic reminders to improve redosing of antibiotics during surgical cases: comparison of two approaches. Surgical Infections 12:57-63, 2011

Hincker A, Abdallah AB, Avidan M, Candelario P, Helsten D. Electronic medical record interventions and recurrent perioperative antibiotic administration: a before-and-after study. Canadian Journal of Anesthesia 64:716-723, 2017

In addition, the same approach can be used to achieve desired (low) fresh gas flow rates and tidal volumes in patients with acute lung injury.

> Nair BG, Peterson GN, Neradilek MB, Newman SF, Huang EY, Schwid HA. Reducing wastage of inhalation anesthetics using real-time decision support to notify of excessive fresh gas flow. Anesthesiology 118:874-884, 2013
>
> Blum JM, Stentz MJ, Maile MD, Jewell E, Raghavendran K, Engoren M, Ehrenfeld JM. Automated alerting and recommendations for the management of patients with preexisting hypoxia and potential acute lung injury: a pilot study. Anesthesiology 119:295-302, 2013

Quality assurance documentation is required of anesthesia groups. A hospital's completion rate did not meet benchmark standards. They changed the AIMS to open the QA form automatically if it had not yet been completed and the AIMS was accessed from a workstation in the PACU or ICU. Thus, to finish handoff of patient in the PACU or ICU, the QA form had to be completed. The paper shows that the sequence of AIMS forms should depend on the workstation location.

> Vigoda MM, Gencorelli F, Lubarsky DA. Changing medical group behaviors: increasing the rate of documentation of quality assurance events using an anesthesia information system. Anesthesia & Analgesia 103:390-395, 2006
>
> When reading, also see the following earlier article.
>
> > Feldman JM. Do anesthesia information systems increase malpractice exposure? Results of a survey. Anesthesia & Analgesia 99:840-843, 2004

Use of such a system substantially increases the number of adverse events captured. Long-term, over years, the systems are associated with decreases in the adverse event rates.

> Peterfreund RA, Driscoll WD, Walsh JL, Subramanian A, Anupama S, Weaver M, Morris T, Arnholz S, Zheng H, Pierce ET, Spring SF. Evaluation of a mandatory quality assurance data capture in anesthesia: a secure electronic system to capture quality assurance information linked to an automated anesthesia record. Anesthesia & Analgesia 112:1218-1225, 2011
>
> Wanderer JP, Gratch DM, Jacques PS, Rodriguez LI, Epstein R. Trends in the prevalence of intraoperative adverse events at two academic hospitals after implementation of a mandatory reporting system. Anesthesia and Analgesia 126:134-140, 2017

Quality assurance documentation for intraoperative care can be automated based on tolerances of vital signs.

> Grant C, Ludbrook G, Hampson EA, Semenov R, Willis R. Adverse physiological events under anaesthesia and sedation: a pilot audit of electronic patient records. Anaesthesia and Intensive Care 36:222-229, 2008

During the preanesthesia evaluation, each patient's risk for postoperative nausea and vomiting was calculated, and a message appeared as soon as the anesthetic plan was specified inquiring as to whether the anesthesiologist wanted to prescribe PONV prophylaxis. The rate of administration was increased for patients with the message, but not for those without. After discontinuation of the messages, prophylaxis use returned to baseline showing that it was the messaging itself that was helpful, not learning. Later implementation resulted in increased prophylactic medication use among high-risk patients and less among low risk patients. However, this may not reduce the incidences of PONV.

Kooij FO, Klok T, Hollmann MW, Kal JE. Decision support increases guideline adherence for prescribing postoperative nausea and vomiting prophylaxis. Anesthesia & Analgesia 106:893-898, 2008

Kooij FO, Vos N, Siebenga P, Klok T, Hollmann MW, Kal JE. Automated reminders decrease postoperative nausea and vomiting incidence in a general surgical population. British Journal of Anaesthesia 108:961-965, 2012

Kappen TH, Moons KGM, van Wolfswinkel L, Kalkman CJ, Vergouwe Y, van Klei WA. Impact of risk assessments on prophylactic antiemetic prescription and the incidence of postoperative nausea and vomiting: a cluster-randomized trial. Anesthesiology 120:343-354, 2014

Real Time Management Calculations

When AIMS are installed, they are often accompanied by status displays (e.g., at OR control desk and on computers). Anesthesiologists, OR nurses, and housekeepers were given nine simulated scenarios involving multiple ORs to study their decision-making based on AIMS real-time data. Participants were randomized to one of four groups, all with the hospital's current paper OR schedule: with/without command display and with/without passive status display. Participants making decisions without command displays performed no better than random chance in terms of increasing the predictability of work hours, reducing over-utilized OR time, and increasing OR efficiency. Status displays had no effect on these end-points, whereas command displays improved the quality of decisions.

Dexter F, Willemsen-Dunlap A, Lee JD. Operating room managerial decision-making on the day of surgery with and without computer recommendations and status displays. Anesthesia and Analgesia 105:419-429, 2007

OR control desks use paper with colored pens or white boards with magnets. Installation of AIMS often involves creation of simple status displays. However, the anesthesia coordinators are using their multiple paper artifacts to link staff schedules, staff assignments, and case schedules in the presence of the frequent changes and updates. The marks communicate the linkages and bases for decisions asynchronously to the broad social audience.

Nemeth C, O'Connor M, Klock PA, Cook R. Discovering healthcare cognition: the use of cognitive artifacts to reveal cognitive work. Organization Studies 27:1011-1035, 2006

Decision-support relies on matching patients to specific anesthetizing locations. Routine use of radiofrequency identification (RFID) was found to be impractical because the location of where each patient should be located had to be updated by clerks in real-time. For RFID and patient bar coding to be practical, there needs to be use of automated staff assignment software.

> Egan MT, Sandberg WS. Auto identification technology and its impact on patient safety in the Operating Room of the Future. Surgical Innovation 14:41-51, 2007

Automatic determination of when each patient has entered or left his/her OR can be determined automatically by real-time processing of networked S_pO_2, EKG heart rate, and temperature. This depends highly on the latency of updates on the server. If rapid, identification of patient in and out times can be as accurate as those recorded by staff on paper.

> Xiao Y, Hu P, Hao H, Ho D, Dexter F, Mackenzie CF, Seagull FJ, Dutton R. Algorithm for processing vital sign monitoring data to remotely identify operating room occupancy in real-time. Anesthesia & Analgesia 101:823–829, 2005

Upon AIMS implementation, listed anesthetic locations required to assess concurrency (i.e., for billing) were incorrect for 10% of cases. Most of these errors occurred 7 AM to 5 PM on workdays, when OR secretaries were present. A 1.5 yr effort of educating secretaries, formally reprimanding individuals, etc., resulted in a reduction in the percentage of cases moved after the start from 12% to 2%. However, this meant that the residual AIMS error rate was still 4% of cases. The hospital started to infer the actual location of cases for billing from the physical location of the workstation recording the majority of pulse oximetry saturations, achieving 99.9% accuracy. In real time, the anesthetic location was obtained using the workstation transmitting S_pO_2, EKG heart rate, and end tidal CO_2 partial pressures.

> Epstein RH, Dexter F, Piotrowski E. Automated correction of room location errors in anesthesia information management systems. Anesthesia & Analgesia 107:965-971, 2008

The system was combined with the use of historical case duration data to provide autonomous updating of OR whiteboards (status displays) with the times remaining in cases. The method is needed for decisions, because once a case scheduled for 2 h has been on-going for 1.5 h, the median time remaining is not 0.5 h but longer, and the amount longer differs substantially among procedures.

> Dexter F, Epstein RH, Lee JD, Ledolter J. Automatic updating of times remaining in surgical cases using Bayesian analysis of historical case duration data and "instant messaging" updates from anesthesia providers. Anesthesia & Analgesia 108:929-940, 2009

For relief (assignment) decisions, it is not that vital signs and other sensor data need to be analyzed in real-time. Rather, just temporal events (e.g., start of surgery) are sufficient.

> Epstein RH, Dexter F. Mediated interruptions of anaesthesia providers using predictions of workload from anaesthesia information management system data. Anaesthesia and Intensive Care 40:803-812, 2012

Relief decisions more often match departmental objectives when a real-time display is used:

> Wax DB, McCormick PJ. A real-time decision support system for anesthesiologist end-of-shift relief. Anesthesia & Analgesia 124:599-602, 2017

The recommendations in decision-support systems driven by AIMS are sensitive to missing or delayed documentation and to the interval between successive queries (e.g., q 1 min or q 10 min on the server). For each automatic recommendation applied to each facility, the latency needs to be measured and its impact on the performance of the system's recommendations should be assessed. Appropriate statistical methods have been developed.

> Epstein RH, Dexter F, Ehrenfeld JM, Sandberg WS. Implications of event entry latency on anesthesia information management decision support system. Anesthesia & Analgesia 108:941-947, 2009
>
> Ledolter J, Dexter F, Epstein RH. Analysis of variance of communication latencies in anesthesia: Comparing means of multiple lognormal distributions. Anesthesia & Analgesia 113:888-896, 2011

Calculations Made When an Anesthetic is Complete

The audit trail of time stamps events showed that attending physicians were documenting presence at emergence before emergence (i.e., there was an appearance of fraudulent billing). Automated email performance feedback with Cc of Chair corrected the behavior.

> Vigoda MM, Lubarsky DA. The medicolegal importance of enhancing timeliness of documentation when using an anesthesia information system and the response to automated feedback in an academic practice. Anesthesia & Analgesia 103:131-136, 2006

Multiple implementations of AIMS lack processes to validate attending physician attestations (e.g., both within cases and among cases to which the attending is assigned) – see preceding paper. They also lack process to annotate artifacts resulting in the false impression that they are absent because they do not appear in printouts.

> Epstein RH, Vigoda MM, Feinstein DM. Anesthesia information management systems: a survey of current implementation policies and practices. Anesthesia & Analgesia 105:405–411, 2007

To calculate costs for each case to a useful accuracy, AIMS must have detailed pharmacy information systems data (e.g., vial sizes are combined with amount of drug administered to estimate wastage). Daily AIMS feedback to clinicians resulted in reduced drug costs per case. E-mail can be used and is highly suitable for such purposes.

Lubarsky DA, Sanderson IC, Gilbert WC, King KP, Ginsberg B, Dear GL, Coleman RL, Pafford TD, Reves JG. Using an anesthesia information management system as a cost containment tool. Description and validation. Anesthesiology 86:1161–1169, 1997

Epstein RH, Dexter F, Patel N. Influencing anesthesia provider behavior using anesthesia information management system data for near real-time alerts and post hoc reports. Anesthesia and Analgesia 121:678-692, 2015

Malapero RJ, Gabriel RA, Gimlich R, Ehrenfeld JM, Philip BK, Bates DW, Urman RD. An anesthesia medication cost scorecard – concepts for individualized feedback. Journal of Medical Systems 39:48, 2015

Quarterly feedback was provided on compliance with postoperative nausea and vomiting prophylaxis guidelines, resulting in significant improvement in compliance rates. The accompanying editorial reviews regulatory requirements in developing real time versus delayed feedback to providers on clinical care.

Frenzel JC, Kee SS, Ensor JE, Riedel BJ, Ruiz JR. Ongoing provision of individual clinician performance data improves practice behavior. Anesthesia & Analgesia 111:515-519, 2010

Epstein RH. Postoperative nausea and vomiting, decision support, and regulatory oversight. Anesthesia & Analgesia 111:270-271, 2010

Discrepancies in controlled substances were present in more than 10% of cases. Wastage check in pharmacy information system did not check total drug administration reported in AIMS. Some AIMS records had too little or much controlled substance reported. Thus, the running total of drug administered must be calculated and compared in real time to pharmacy system. Providing e-mail and then real-time feedback reduces discrepancies.

Vigoda MM, Gencorelli FJ, Lubarsky DA. Discrepancies in medication entries between anesthetic and pharmacy records using electronic databases. Anesthesia & Analgesia 105:1061-1065, 2007

Epstein RH, Dexter F, Gratch DM, Perino M, Magrann F. Controlled substance reconciliation accuracy improvement using near real-time drug transaction capture from automated dispensing cabinets. Anesthesia & Analgesia 122:1841-1855, 2016

AIMS are used to monitor anesthesia providers' drug diversion by detecting (e.g., frequent checkout of drugs from dispensing systems in locations differing from where the anesthetics were performed and/or checkout much earlier or later than the start of cases). These rely on accuracy in the AIMS of the principal location of the case and tracking of all locations where the anesthetic was performed (e.g., holding area to block room to OR #1 to PACU).

Epstein RH, Gratch DM, Grunwald Z. Development of a drug diversion surveillance system based on an analysis of atypical drug transactions. Anesthesia & Analgesia 105:1053-1060, 2007

Tetzlaff J, Collins GB, Brown DL, Leak BC, Pollock G, Popa D. A strategy to prevent substance abuse in an academic anesthesiology department. Journal of Clinical Anesthesia 22:143-150, 2010

Epstein RH, Gratch DM, McNulty S, Grunwald Z. Validation of a system to detect scheduled drug diversion by anesthesia care providers. Anesthesia & Analgesia 113:160-164, 2011

Billing elements are extracted automatically from the AIMS record (e.g., personnel, relief to check concurrency, surgical procedure, patient information, anesthetics administered, modifiers such as deliberate hypotension, and procedures such as central line). There were significant reductions in charge lag, days in accounts receivables, and labor costs.

Reich DL, Kahn RA, Wax D, Palvia T, Galati M, Krol M. Development of a module for point-of-care charge capture and submission using an anesthesia information management system. Anesthesiology 105:179–186, 2006

Residents in anesthesia training programs throughout the world are required to document their clinical cases to help ensure that they receive adequate training. Case logs generated automatically from an AIMS can replace manual processes, improve accuracy, and decrease residents' clerical burden. The case logs can be used subsequently to guide anesthesia resident daily case assignments.

Simpao A, Heitz JW, McNulty SE, Chekemian B, Brenn BR, Epstein RH. The design and implementation of an automated system for logging clinical experiences using an anesthesia information management system. Anesthesia & Analgesia 112:422-429, 2011

Wanderer JP, Charnin J, Driscoll WD, Bailin MT, Baker K. Decision support using anesthesia information management system records and accreditation council for graduate medical education case logs for resident operating room assignments. Anesthesia and Analgesia 117:494-499, 2013

If choosing to monitor recovery times by using the AIMS record, the accurate endpoint to use is the percentage of times that are prolonged (e.g., > 15 minutes).

Dexter F, Bayman EO, Epstein RH. Statistical modeling of average and variability of time to extubation for meta-analysis comparing desflurane to sevoflurane. Anesthesia & Analgesia 110:570-580, 2010

Communication systems

Anesthesia group developed and tested a staff recall system using Short Message Service (SMS) text messaging. Their AIMS is used as the source for contact information and from which the messages are sent, making the process inexpensive and easy to implement.

> Epstein RH, Ekbatani A, Kaplan J, Shechter R, Grunwald Z. Development of a staff recall system for mass casualty incidents using cell phone text messaging. Anesthesia & Analgesia 110:871-878, 2010

SMS would function well for days then have latencies of hours. This was because of substantial correlation among latencies for sequential cell phone text messages when binned by hours ($P < 0.0001$), but not by days ($P = 0.61$). Different devices tested using Internet pathways outside the hospital's local network had 1% to > 10% of latencies exceeding 100 seconds. Testing over weeks is necessary to "rule in" a communications system.

> Epstein RH, Dexter F, Rothman B. Communication latencies of wireless devices suitable for time-critical messaging to anesthesia providers. Anesthesia and Analgesia 116:911-918, 2013

Apple Push Notification messages sent via wireless local area network pathways have virtually no latencies exceeding 100 seconds.

> Rothman BS, Dexter F, Epstein RH. Communication latencies of Apple push notification messages relevant for delivery of time-critical information to anesthesia care providers. Anesthesia & Analgesia 117:398-404, 2013

Approximately half of messages to supervising anesthesiologists are for activity originating from outside ORs being supervised. Slightly less than half of emergency pages in ambulatory facilities are from outside ORs. Thus, the AIMS alone should not be the focus of automation.

> Smallman B, Dexter F, Masursky D, Li F, Gorji R, George D, Epstein RH. Role of communication systems in coordinating supervising anesthesiologists' activities outside of operating rooms. Anesthesia and Analgesia 116:898-903, 2013

> Warner ME, Chong EY, Lowe ME, Sprung J, Weingarten TN. Emergency pages using a computer-based anesthesiology paging system in ambulatory surgical centers: a retrospective review. Anesthesia and Analgesia 119:145-150, 2014

Emergency messages are disproportionately made for infants. Consequently, pediatric facilities likely should pay particular attention to latencies and process of communications.

> Weingarten TN, Abenstein JP, Dutton CH, Kohn MA, Lee EA, Mullenbach TE, Narr BJ, Schroeder DR, Sprung J. Characteristics of emergency pages using a computer-based anesthesiology paging system in children and adults undergoing procedures at a tertiary care medical center. Anesthesia and Analgesia 116:904-910, 2013

The preceding two papers are based on the architecture described a decade before.

> Abenstein JP, Allan JA, Ferguson JA, Deick SD, Rose SH, Narr BJ. Computer-based anesthesiology paging system. Anesthesia and Analgesia 97:196-204, 2003

Other studies

Automatic quality of care review was based on the vital signs from the AIMS.

> Dexter F, Penning DH, Lubarsky DA, DeLong E, Sanderson I, Gilbert BC, Bell E, Reves JG. Use of an automated anesthesia information system to determine reference limits for vital signs during cesarean section. Journal of Clinical Monitoring and Computing 14:491-498, 1998

Maximum surgical blood order schedule can be updated automatically from the AIMS recorded scheduled procedure(s), estimated blood loss, and erythrocyte transfusion records.

> Dexter F, Ledolter J, Davis E, Witkowski TA, Herman JH, Epstein RH. Systematic criterion for type and screen based on procedure's probability of erythrocyte transfusion. Anesthesiology 116:768-778, 2012

> Frank SM, Rothschild JA, Masear CG, Rivers RJ, Merritt WT, Savage WJ, Ness PM. Optimizing preoperative blood ordering with data acquired from an anesthesia information management system. Anesthesiology 118:1286-1297, 2013

Heterogeneity in the lowest hemoglobin value, before the beginning of the first erythrocyte transfusion of a case, can be compared among surgeons.

> Frank SM, Savage WJ, Rothschild JA, Rivers RJ, Ness PM, Paul SL, Ulatowski JA. Variability in blood and blood component utilization as assessed by an anesthesia information management system. Anesthesiology 117:99-106, 2012

Anesthesia staffing calculated from AIMS are interchangeable with that calculated using OR information system data for locations with OR data. Since all locations in the AIMS, the results mean that the AIMS will generally be best for anesthesia decision-making. Surgical workload for each anesthetizing location can also be calculated using AIMS data.

> Dexter F, Epstein R. Optimizing second shift OR staffing. AORN Journal 77:825-830, 2003

> Junger A, Benson M, Quinzio L, Michel A, Sciuk G, Brammen D, Marquardt K, Hempelmann G. An Anesthesia Information Management System as a tool for controlling resource management of operating rooms. Methods of Information in Medicine 41:81-85, 2002

Survey of US academic anesthesia departments revealed that 44% have installed or are installing an AIMS.

> Egger Halbeis CB, Epstein RH, Macario A, Pearl RG, Grunwald Z. Adoption of anesthesia information management systems by academic departments in the United States. Anesthesia & Analgesia 107:1323-1329, 2008

Later survey estimated 50%.

Trentman TL, Mueller JT, Ruskin KJ, Noble BN, Doyle CA. Adoption of anesthesia information management systems by US anesthesiologists. Journal of Clinical Monitoring and Computing 25:129-135, 2011

Next 67% and the progressive adoption was following typical logistic relationship.

Stol IS, Ehrenfeld JM, Epstein RH. Technology diffusion of anesthesia information management systems into academic anesthesia departments in the United States. Anesthesia and Analgesia 118:644-650, 2014

AIMS can contribute to the USA's "meaningful use" criteria.

Gálvez JA, Rothman BS, Doyle CA, Morgan S, Simpao AF, Rehman MA. A narrative review of meaningful use and anesthesia information management systems. Anesthesia and Analgesia 121:693-706, 2015

For hospitals with EPIC, creation of a data mart can be systematic:

Hofer IS, Gabel E, Pfeffer M, Mahbouba M, Mahajan A. A systematic approach to creation of a perioperative data warehouse. Anesthesia and Analgesia 122:1880-1884, 2016

If make some data publically available (e.g., journal secondary material), do so while considering what other data might be available from other sources:

O'Neill L, Dexter F, Zhang N. The risks to patient privacy from publishing data from clinical anesthesia studies. Anesthesia & Analgesia 122:2016-2026, 2016

Articles summarize the experiences of a large number of AIMS experts and highlights essential considerations for selection and implementation of an AIMS. Practical aspects of the processes are emphasized. The principal data expected of an AIMS include patient identifier, procedure, S_pO_2, and blood pressure. When training participants in use of the AIMS, consider using a realistic patient simulator and, once the participant is acclimated, have typical intraoperative urgent events occur like bronchospasm. Evaluate the quality of the documentation. Expect greater lateness of first cases of the day during the 1st month after implementation.

Muravchick S, Caldwell JE, Epstein RH, Galati M, Levy WJ, O'Reilly M, Plagenhoef JS, Rehman M, Reich DL, Vigoda MM. Anesthesia information management system implementation: a practical guide. Anesthesia & Analgesia 107:1598-1608, 2008

Herasevich V, Ellsworth MA, Hebl JR, Brown MJ, Pickering BW. Information needs for the OR and PACU electronic medical record. Applied Clinical Informatics 5:630-641, 2014

Weintraub AY, Deutsch ES, Hales RL, Buchanan NA, Rock WL, Rehman, MA. Using high-technology simulators to prepare anesthesia providers before implementation of a new electronic health record module: a technical report. Anesthesia & Analgesia 124:1815-1819, 2017

Wu A, Kodali BS, Flanagan Jr. HL, Urman RD. Introduction of a new electronic medical record system has mixed effects on first surgical case efficiency metrics. Journal of Clinical Monitoring and Computing 31:1073-1079, 2017

AIMS was used as a software platform for a computerized system to convey frequently used prerecorded phrases in the languages most often encountered in their patients.

Taicher BM, Alam RI, Berman J, Epstein RH. Design, implementation, and evaluation of a computerized system to communicate with patients with limited native language proficiency in the perioperative period. Anesthesia & Analgesia 112:106-112, 2011

In a randomized simulation study, embedded hard stop use of the Anesthesia Patient Safety Foundation's pre-anesthesia induction checklist decreased residents missing critical items such as working suction and backup airway device.

Wetmore D, Goldberg A, Gandhi N, Spivack J, McCormick P, DeMaria S Jr. An embedded checklist in the Anesthesia Information Management System improves pre-anaesthetic induction setup: a randomised controlled trial in a simulation setting. BMJ Quality & Safety 25:739-746, 2016

Process is explained for wireless adapters to be used to transmit data from bedside monitoring equipment to a portable AIMS thick client workstation.

Simpao AF, Galvez JA, England WR, Wartman EC, Scott JH, Hamid MM Sr, Rehman MA, Epstein RH. A technical evaluation of wireless connectivity from patient monitors to an anesthesia information management system during intensive care unit surgery. Anesthesia and Analgesia 122:425-429, 2016

Free text (unstructured) entries about food and drug allergies can be processed to obtain codified allergy information.

Epstein RH, St Jacques P, Stockin M, Rothman B, Ehrenfeld JM, Denny JC. Automated identification of drug and food allergies entered using non-standard terminology. Journal of the American Medical Informatics Association 20:962-968, 2013

Automated screening for critical events during prior anesthetics and notifications of providers before subsequent anesthetics resulted in increased viewing of the prior anesthesia records.

Wax DB, McCormick PJ, Joseph TT, Levin MA. An automated critical event screening and notification system to facilitate preanesthesia record review. Anesthesia & Analgesia 126:606-610, 2018

Default drug doses should be selected at each hospital based on local usage when a new AIMS is setup and periodically reassessed.

Rodriguez LI, Smaka TJ, Mahla M, Epstein RH. Default drug doses in anesthesia information management systems. Anesthesia & Analgesia 125:255-260, 2017

Documentation accuracy should be tested, because it differs among user interfaces. For example, among touch-screen user interfaces, arranging medications in a categorical display provided for faster data entry compared to an alphabetical display, with no differences in error rates. For example, the type and design of the electronic anesthesia record influences recorded American Society of Anesthesiologists' Physical Status scores.

Wanderer JP, Rao AV, Rothwell SH, Ehrenfeld JM. Comparing two anesthesia information management system user interfaces: a usability evaluation. Canadian Journal of Anesthesia 59:1023–1031, 2012

Marian AA, Dexter F, Tucker P, Todd MM. Comparison of alphabetical versus categorical display format for medication order entry in a simulated touch screen anesthesia information management system: an experiment in clinician computer interaction in anesthesia. BMC Medical Informatics and Decision Making 12:46, 2012

Marian AA, Bayman EO, Gillett A, Hadder B, Todd MM. The influence of the type and design of the anesthesia record on ASA physical status scores in surgical patients: paper records vs. electronic anesthesia records. BMC Medical Informatics and Decision Making 16:29, 2016