**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.


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.


Audiovisual alert for intraoperative hyperglycemia increased insulin treatment. Detection of glucose checks and insulin administration resulted in less intraoperative hyperglycemia. Postoperative improvement was detected in the Vanderbilt study, not Washington University.


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. However, electronic alerts for hypotension and low bispectral index did not reduce mortality. Electronic alerts for hypotension, low bispectral index, and minimum alveolar fraction less than 0.8 also did not reduce mortality.

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


Audiovisual alerts for lack of intraoperative temperature monitoring or hypothermia were associated with a greater percentage of cases with intraoperative normothermia. Telemedicine monitoring and notifications did not reduce postoperative hypothermia.


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.


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


Hoorweg AJ, Pasma W, van Wolswinkel 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

Manually record temperatures are less accurate, as well. Algorithms can prevent artifacts and automate the selection of intraoperative temperature sites for reporting presence or absence of hypothermia soon before or after the end of anesthesia. An algorithm using the slope of changes in temperature from observation to observation can identify artifacts from automated intraoperative temperature data sets.


Epstein RH, Dexter F, Hofer IS, Rodriguez LI, Schwenk ES, Maga JM, Hindman BJ. Perioperative temperature measurement considerations relevant to reporting requirements for national quality programs using data from anesthesia information management systems. Anesthesia & Analgesia 126:478-486, 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. Automated alerts for anesthesiologists not having completed the preoperative assessment before the anesthetic ends 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.


Prophylactic antibiotic received within 1 hour 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


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


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


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


O'Sullivan CT, Rogers WK, Ackman M, Goto M, Hoff BM. Implementation of a multifaceted program to sustainably improve appropriate intraoperative antibiotic redosing. American Journal of Infection Control 47:74-77, 2019
In addition, the same approach can be used to achieve desired (low) fresh gas flow rates and low tidal volumes for patients with acute lung injury.


From the preoperative evaluation database, structured data revealing pregnancy were used to initiate emails to obstetric anesthesiology fellows about a patient for a non-obstetric antenatal procedure. They completed progressively more cases and a larger percentage of those cases.

Ende HB, Richardson MG, Lopez BM, Wanderer JP. Improving ACGME compliance for obstetric anesthesiology fellows using an automated email notification system. Applied Clinical Informatics 12:479-483, 2021

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.


The combination of (1) preoperative message with risk stratification and (2) weekly emails to anesthesia providers with their personal PONV statistics was efficacious at reducing the incidence of PONV among patients at high-risk for PONV, but not among all patients.


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.


When reading, also see the following earlier article.


Enabling voluntary outcome reporting from within the AIMS (including no untoward anesthetic event) increased QA form completion and increased the number of adverse events captured.

Kristobak BM, Jabaut JM, Dickson CF, Cronin WA. Leveraging the existing anesthesia information management system to improve anesthesia quality assurance outcome reporting. Military Medicine 186:1001-1009, 2021

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


Quality assurance documentation for intraoperative care can be automated based on tolerances of vital signs and other signals, such as neuromuscular monitoring and tidal volumes. Monthly reports of these data to providers results in greater compliance with criteria, but no reduction in major postoperative complications other than potentially surgical site infections.


**Real time) 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.


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.


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


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.


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


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

An alternative web interface can be used.


**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.


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.


Automatic determination of when each patient has entered or left his/her OR can be determined automatically by real-time processing of networked S\textsubscript{p}O\textsubscript{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.

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.


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

Benefit accrues also when a daily e-mail is sent to the physician responsible for relief decisions:

Bhutiani M, Jablonski PM, Ehrenfeld JM, McEvoy MD, Fowler LC, Wanderer JP. **Decision support tool improves real and perceived anesthesiology resident relief equity.** Anesthesia & Analgesia 127:513-519, 2018

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

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.


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.


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


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.


Epstein RH. Postoperative nausea and vomiting, decision support, and regulatory oversight. Anesth Analg 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 (from the AIMS) must be calculated and compared in real time with data from the pharmacy systems. Using both e-mail and real-time feedback reduced discrepancies.


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).


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. There was significantly greater compliance with central venous pressure documentation requirements.


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. There can be especially more orthopedics cases logged (e.g., on-call). However, case log reminders were not associated with greater percentages of cases logged, and some residents had overall case-logging rates exceeding 100%.


Pregnall AM, Gruss CL, Ramanujan KS, Gelfand BJ, McEvoy MD, Wanderer JP. ACGME case log reminder does not improve resident accuracy in logging cases. Journal of Medical Systems 46:1, 2022

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).


Junior resident training progress can be quantified using the incidence of hypoxemia for at least one minute during the first ten minutes after tracheal extubation.


Other studies

Maximum surgical blood order schedule can be updated automatically from the AIMS using each facility’s recorded scheduled procedure(s), estimated blood loss, and erythrocyte transfusion records. The method of selecting which RBC transfusions are audited manually can be automated accurately using each patient’s recorded procedure(s) categorized by facility, estimated blood loss, and nadir hemoglobin. These methods are Bayesian because most procedures are performed uncommonly. Each patient’s risk of transfusion can be estimated using interpretable machine learning model including procedure, preoperative hemoglobin, and other variables.


Dexter F, Epstein RH, Ledolter J, Dasovich SM, Herman JH, Maga JM, Schwenk ES. Validation of a new method to automatically select cases with intraoperative red blood cell transfusion for audit. Anesthesia & Analgesia 126:1654-1661, 2018


Most words (76%) used in plain text for procedure descriptions are very uncommon, each observed in < 0.01% of cases. Nevertheless, machine learning can assist in choosing the anesthesia Current Procedural Terminology code:


Providing statistics on the use of different types of anesthetics for different surgical procedures resulted in trainees more closely matching their case planning to current departmental practice:


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


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.


Daily staff assignments can be imported automatically from QGenda to Epic.

Hoefnagel AL, McLeod C, Mongan PD. Daily anesthesia assignment schedule automation: utilizing an electronic scheduling system to export daily assignments into the electronic health record. Perioperative Care and Operating Room Management 21:100135, 2020
A binary flag helps the clinician making assignments to know which patients have unusual acuity.


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


Later survey estimated 50%.


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


In the Czech Republic in 2019, there were 5 of the 130 acute care hospitals at least partially equipped with an anesthesia information management system, with the principal perceived barrier to use being cost.

Bruthans J. Anesthesia Information Management Systems in the Czech Republic from the perspective of early adopters. Journal of Medical Systems 44:70, 2020

Among 23 European hospitals using anesthesia information management system, there were many (12) products.


There are 13 products with different features when considering both Canadian and US markets.


Among 63 Canadian academic hospitals only 21 (33%) had an anesthesia information management system in 2020. Among those, the most reported barrier to anesthesia information management systems was support dedicated specifically to these systems.


AIMS can contribute to the USA’s “meaningful use” criteria.

For hospitals with EPIC, creation of a data warehouse can be systematic, and the specifications successfully used at another hospital.


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


There is a public-access operating room database with high-fidelity physiological waveforms.

Samad M, Angel M, Rinehart J, Kanomata Y, Baldi P, Cannesson M. Medical Informatics Operating Room Vitals and Events Repository (MOVER): a public-access operating room database. JAMIA Open 6:00ad084, 2023

If planning to use the AIMS database for research, characteristics of a successful system were reviewed systematically to identify important features (e.g., timestamp resolution). Expect manual data entry fields such as airway and end of anesthesia details often to be incomplete without deliberate effort.

Epstein RH, Dexter F. Database quality and access issues relevant to research using anesthesia information management system data. Anesthesia & Analgesia 127:105-114, 2018


Articles summarize the experiences of many 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.


Simpao AF, Rehman MA. *Anesthesia information management systems*. Anesthesia & Analgesia 127:90-94, 2018

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.


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.


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


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


Automated screening for critical events during prior anesthetics and notifications of providers before subsequent anesthetics resulted in increased viewing of the prior anesthesia records. Providing access to historical anesthesia records but in an older AIMS is insufficient for us; there should be linked access to the historical 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

Epstein RH, Dexter F, Schwenk ES. *Provider access to legacy electronic anesthesia records following implementation of an electronic health record system*. Journal of Medical Systems 43:105, 2019
Default drug doses should be selected at each hospital based on local usage when a new AIMS is setup and periodically reassessed.


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.


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