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Using Real Time Clinical Decision Support to Improve Performance on Perioperative Quality and Process Measures

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Overview

Anesthesia information management systems (AIMS) are becoming more commonplace in operating rooms across the world and have the potential to help clinicians measure and improve perioperative quality. In order for this to occur, however, clinicians must first understand the capabilities and limitations of AIMS. This article reviews the literature on AIMS, focusing on areas where they have been shown to have a meaningful impact on quality, safety, and operational efficiency.

Introduction to Anesthesia Information Management Systems

History and Market Penetration

Since days of Harvey Cushing at the beginning of the twentieth century, the maintenance of an accurate and detailed perioperative patient record has been a foundation for providing safe anesthetic care. (1) Handwritten paper records have historically been the sole means of documenting events during an anesthetic and are still the method of data collection in many parts of the world. However, monitoring systems in the operating room have become progressively more complex, and the amount of real-time physiologic data continues to expand exponentially. In response to the information overload, new computer systems have been developed to help collect, manage, store, and interpret the exponential amount of data that is now available to clinicians. Today, anesthesia providers worldwide are gradually adopting Anesthesia Information Management Systems (AIMS) in order to aid with the collection and interpretation of perioperative data through a set of tools collectively known as clinical decision support.

Modern day AIMS are a combination of hardware and software systems that are designed to facilitate the automatic recording, storage and retrieval of perioperative patient data. (2) Although AIMS have been around in various forms for several decades, widespread adoption has been hindered mostly by financial barriers, the complexities of system

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installation, and a perceived lack of proven benefits. (3) In 2001, no more than 1% of all departments in the United States (U.S.) were utilizing AIMS. Five years later, this number had increased to only 5%. (4) As of 2007, along with the digitization of other parts of most hospitals, such as radiology and pharmacy, a major paradigm shift began to occur and more U.S. academic anesthesia departments were beginning to adopt AIMS. (5) By 2008, at least 14% of the anesthesia departments in U.S. were already using AIMS and 44% of academic anesthesia departments either had or were planning to implement an AIMS. (3,6) Outside of the U.S., similar trends have been seen in Europe and the most recent survey of European university-affiliated hospitals revealed that 15% of the anesthesia departments had already adopted AIMS. (6)

Core Functionality

Since their inception, AIMS have been designed to accurately capture intraoperative data and events in real-time in order to reliably manage charting duties. Most AIMS allow for both the automatic transcription of data from intraoperative physiologic monitors (e.g. vital signs and ventilator settings) and the manual entry of case events (e.g. start of surgery, estimated blood loss, and drugs administered) into the electronic record. Critical data elements are often highlighted for the end-user to view, and in some cases, respond to through an electronic acknowledgement.

Current systems have expanded their functionality by incorporating pre- and postoperative information. The more advanced versions are further equipped with clinical decision support capabilities that interact with end users to facilitate prompt, safe and accurate decision making. For example, some preoperative evaluation modules provide robust electronic history-taking questionnaires and suggest preoperative laboratory tests based on customizable algorithms that take into account the specific procedure and any comorbidities for a particular patient. (3) Complex scoring systems for patient risk stratifications such as the Euroscore in cardiac surgery, MELD score for liver resection or revised cardiac risk index can be easily and rapidly calculated using existing laboratory data or by providing end-user with a drop-down menu for quick data entry. (7) AIMS are also capable of rapid integration of internal data with data from external databases. For example, AIMS can facilitate information flow to providers downstream of the operating room (i.e. recovery rooms and intensive care units) to improve continuity in patient care.

The major advantage of collecting data through AIMS is that the data are consistent, legible and reliable. (8) Multiple studies have shown that information technology can reduce the frequency of a variety of different types of errors and probably the frequency of associated adverse events. (8–11) For instance, dosing of a drug can be accurately calculated, continuously infused medications can be monitored in real-time, and algorithms can be installed to provide decision support and real-time notifications throughout the perioperative period. Figure 1 is a schematic overview of an AIMS which demonstrates how OR physiologic monitors, AIMS workstations, AIMS servers, hospital enterprise wide clinical systems, and hospital paging functions can be integrated to provide clinical decision support.

Major Vendors and Systems

A large amount of initial capital is typically required to install an AIMS, and cost is by far the single biggest factor involved in the purchasing decision. Costs are highly dependent on the vendors and a wide range of systems from a variety of vendors are currently available. In 2010, an AIMS workstation and server software alone cost around \$4,000 to \$9,000 per clinical workstation. (12)

Additional expenses such as software licenses, training and support, maintenance and servicing, warranty and implementation are further added costs that impact overall system installation. It is important to note that systems vary widely in terms of their overall ease of use, functionality, display of and access to intraoperative data, system stability, and security. (3)

AIMS-Based Event Reporting and Tracking to Improve Quality

The ability of an AIMS to accurately and reliably capture intraoperative events is the fundamental strength upon which AIMS are able to help clinicians improve quality of anesthesia care. Compared to hand written records, electronic reports of the timeframe around periods of interest (e.g. an adverse event such as a cardiac arrest or desaturation) can provide high resolution details that can help clinicians understand and ultimately improve their practice. Additionally, AIMS can simplify the process of giving regular feedback to providers regarding their clinical care on an individualized basis.

Improvements in data capture and record quality

Most authors would agree that AIMS records are more reliable, less biased, and more accurate than paper records (see Table 1). In fact, the question of whether it is possible for an anesthesia provider to maintain an accurate intraoperative record while simultaneously exercising clinical vigilance had been challenged by multiple studies. As a result of different definitions used in different studies, it has been difficult to appreciate the true rate of inaccuracy found in written anesthesia records. (13) However, studies have found that the difference in accuracy and completeness between written and electronic records is most evident during induction and emergence from anesthesia. (14) During these instances, charting has a low priority compared with accomplishing more urgent direct patient care tasks. In a study of 30 patients undergoing eye surgery, Lerou et. al. illustrated that there are a large amount of missing and erroneous data in hand-written records during the induction of anesthesia and towards the end of the case. (14) The missing data during those periods appear to be similar and anesthesiologists did not return to fill in the missing information after the case had concluded.

In more time pressing situations, such as during cardiac resuscitation, a large amount of rapidly changing physiologic and event data are generated in a short period of time. Although most code teams assign one individual to be a “data recorder” this rarely happens in the operating room during acute situations. However, AIMS are able to markedly enhance the capture of large volumes of data – while the anesthesia provider concentrates on clinical activities – at all points within the perioperative period. (15) In addition to providing reliable data capture, AIMS-based charting has the further advantage of allowing clinicians to view the accumulating anesthesia record in real-time in a legible, customizable format that can facilitate the recognition of critical pieces of information which might otherwise remain undiscovered. (16)

Several studies have shown that manually documented anesthesia records often lack sufficient details and valuable information when compared to those done electronically. (1,8,14,17) Additionally, handwritten records may be biased due to how the anesthesia provider interprets or recalls a situation from memory – with a tendency to record data that make sense as opposed to data actually provided by an intraoperative monitor. According to a study by Sanborn et al., only 4.1% of 434 adverse events detected with an AIMS were reported voluntarily. (13) Hollenberg et. al. compared hand-written anesthesia records with a computerized record during coronary artery bypass surgery and found that significant systematic biases were detected in the blood pressure data in the hand-written records. (18) They found lower values were recorded higher and higher values were recorded as lower.

Because of the minimization of the extremes otherwise seen on the computerized record (known as “smoothing”), the authors advised that information from hand-written records lack accuracy and should not be used for research purposes. (18) One center undertook a retrospective study evaluating gaps in vital signs recording. In that study, a series of 200 consecutive hand-written records were found to have no gaps in vital signs recording, whereas an equivalent sample of electronic records from the same time period had gaps in vital signs recording ranging from 1 to 14% depending on the parameter evaluated – reflecting such periods as when monitors were disconnected to turn a patient prone.(19) This finding is again consistent other work demonstrating that hand written records are not as accurate as electronic records due to “smoothing.” (20–22)

Improvements in adverse event tracking

The ability of AIMS to record large volumes of patient and event information with high resolution and fidelity is particularly useful for adverse event investigation and tracking, as well as in the realm of quality assurance research. The utility stems from the fact that the data collected are consistent, reliable, comprehensive, and most importantly unbiased.

Rohrig et. al. performed a retrospective analysis of AIMS data from 58,458 patients undergoing noncardiac surgery. (9) In this study, the authors detected 17.5% of intraoperative cardiovascular events using AIMS as opposed to the 6–15% described in prior studies using manual recordings. (23–27) The higher incidence of cardiovascular events was most likely secondary to more accurate and automatic record-keeping and hence, more available data for adverse event detection. (9)

Provider level reporting of quality measures

Many departments are now using AIMS to facilitate reporting of an increasing number of quality measures that would otherwise be difficult and expensive to perform manually. Because of their ability to store and generate reports electronically, AIMS can also facilitate the dissemination of quality measures at the provider level under many circumstances. This type of individual reporting has been shown in a number of studies to be a successful technique to encourage providers to improve their performance and change their behavior. (3,16,28,29)

Timely administration of prophylactic antibiotics has been closely examined and used by national quality assurance programs such as Surgical Care Improvement Project and Agency for Healthcare Research and Quality as a quality measure within perioperative medicine. (10) Surgical site infections are frequent cause of morbidity and mortality and contribute to prolonged length of hospital stay and increased cost of care. It is believed that antibiotic prophylaxis is most effective when administered 30–60 minutes before incision. At the University of Michigan Health System, O'Reilly et. al. found on manual chart review that only 69% of eligible patients received prophylactic antibiotics as per the accepted guideline. (16) Subsequently, the authors designed a project, using an AIMS to investigate whether such a computerized reporting system would improve anesthesia provider's adherence to clinical guidelines. The first automated analysis showed that 70% of all surgical patients received antibiotics as per accepted guideline. The AIMS database tracked antibiotic administration and generated reports from the database to provide specific feedback to individual care providers. Further analysis found that operating rooms that required extensive surgical setup, positioning and anesthetic induction, such as cardiac surgery, neurosurgery and orthopedics surgery were less likely to be compliant with the antibiotics guideline. One year after implementing the system, 92% of the eligible patients received antibiotics as per accepted guideline. (16) Unfortunately, further analysis was not done in this study to explain the residual non-adherence rate of 8% and to determine factors that

prevented the operating rooms from reaching the desired > 99% compliance. Nevertheless, the key element of success in this project was that individual anesthesia providers were not merely being reported and forced to change their practice; instead, they were able to view and compare their own performance with others in a blinded fashion. (16)

By monitoring individual clinical practice patterns, AIMS can in some circumstances provide quality control and ensure compliance to standards and recommended guidelines. Even in cases where there are no adverse events, processes and behaviors can be improved. (15)

AIMS-Based Decision Support to Improve Quality

Reminders for Adherence to Clinical Guidelines

Physicians tend to be poorly compliant with published recommendations. (30–34) Beyond after-the-fact reporting, AIMS also have the ability to provide real-time decision support during the perioperative period in ways which can significantly impact quality. For example, AIMS-based alerts have been created to remind clinicians shortly after the induction of anesthesia to provide prophylactic antibiotics, if none have been documented in the chart. (35) Likewise, an AIMS can improve prophylaxis for nausea and vomiting. Kooij et al found that at baseline 38% of patients at high risk of post-operative nausea and vomiting were prescribed prophylaxis. After introduction of an electronic decision support, the rate increased to 73%, and decreased back to 37% when the system was removed. (36)

At the Massachusetts General Hospital, the practice around maintenance of intraoperative normothermia has been studied and modified using data collected by their AIMS. The AIMS in each operating room automatically records temperature information when a temperature probe is connected to the physiologic monitor. (3) When the temperature falls below a certain threshold (36 °C), the providers then receive a prompt (see Figure 2) to encourage them to take additional action to maintain normothermia (such as by applying forced air warming devices or connecting an in-line fluid warmer).

Utilizing the same automatic reminder capability, a potential area where AIMS can be useful perioperatively is providing drug-redosing reminders. For example, repeated anticoagulation is often required during prolonged vascular surgery. In other circumstances, multiple antibiotics with different administration schedules may be needed to be re-dosed after the start of surgery. In these scenarios, an accurate and faithful system which prompts the provider to complete certain clinical tasks may be effective at improving quality and reducing patient morbidity, particularly when clinicians are being asked to administer drugs which they only occasionally encounter in their practice (see Figure 3).

Operational Decision Support

In addition to helping clinicians achieve better adherence with clinical guidelines, AIMS are also able to facilitate improvements in patient flow and operational throughput under the right circumstances. Additionally, AIMS can improve institutional resource utilization by assisting in many different tracking functions where it would be otherwise tedious and imprecise to perform those tasks manually.

One major area in which tracking is able to improve drug utilization is around the evaluation of pharmaceutical wastes. Gillerman et al. recorded drug waste data for six anesthetic drugs commonly used in their department using an AIMS (atracurium, thiopental, succinylcholine, propofol, midazolam and rocuronium) for 25,481 patients over one year and surveyed providers' knowledge of departmental drug waste. (37) They discovered that the total cost of unadministered study drugs was \$165,667, which was 26% of the expenditure for all drugs.

(37) The reason most cited for drug waste was the disposal of full, or partially full, syringes. (37) What was more surprising to learn was that anesthesia providers in this study had a correct perception of relative cost of drugs – such as thiopental – but felt little need to conserve it. The data collected raised the issue that perhaps smaller multi-dose vials should be used than large stock solutions. Additionally, education of providers about use, waste, and cost was found to be helpful because these perceptions influenced handling of drug waste and conservation behaviors.

AIMS data has also been used by some to assess how efficiently an operating room is being run. For instance, the time when a patient enters and leaves the operating room can be accurately tracked and used by OR managers to reallocate resources, identify rooms where turn-over is problematic, or otherwise manage patient flow. (3,6)

At Massachusetts General Hospital, the AIMS is able to facilitate OR throughput via a custom display that has been installed in the anesthesia workroom (see Figure 4). This display allows anesthesia technicians to track the status of all 51 operating rooms. The technicians also receive automatic alert pages, generated by the AIMS, when cases are finishing. Other hospitals, notably Thomas Jefferson University and the University of Michigan, have utilized their AIMS to send automatic notifications regarding patient flow to the OR team. Notifications have ranged from “patient arrived in holding area,” to “patient ready for surgery,” to “next scheduled case cancelled.” (3)

Detection of Outliers

Because the only means to compare individual providers’ practice patterns is often from the anesthetic record, it is impractical to perform these kinds of analysis in the absence of an AIMS. Manual records written by different anesthesiologists are inconsistent and the information recorded is often biased, as previously discussed. AIMS, however, can provide automatically acquired objective data to assess individual provider practice patterns. This data can then be used by quality managers to detect outliers and drive performance improvement efforts.(12)

Improving Quality of Information Transfer

Accurate and complete documentation is important for a variety reasons, including ensuring the highest quality care (16,18), transfer of information (39,40), and facilitating provider reimbursement. (22) While a patient may in some circumstances receive “perfect” medical care, if the corresponding documentation is flawed or insufficient may, the provider’s efforts may not be recognized or financially reimbursed. (41) It is estimated that the average physician loses approximately 10% of potential revenue due to billing mistakes made at the point of care.(42) Furthermore, when an anesthesiologist hands over a case to another anesthesiologist, continuity of the care is critically important and complete intraoperative records are essential for full information transfer.(43) Because AIMS can facilitate complete and accurate electronic charting, they have the capacity to improve information transfer and reduce the rate of missing information. (44)

Cost-Effectiveness

To date, there have been no studies of the overall cost-effectiveness of AIMS published in the peer-reviewed literature. While it is difficult to calculate the overall benefit to patients in terms of more traditional measures (i.e. lives saved per dollar spent), the benefits of these systems to patients have been proven in several areas.(3) AIMS have clearly been shown to enable clinicians to provide patients with appropriate care, a higher percentage of the time, through their decision support tools – and AIMS may ultimately be shown to have cost-saving potentials.

The Duke University Medical Center Department of Anesthesia used their AIMS to compute costs of each anesthetic administered. They were able to use this information to reduce the cost of an average anesthetic from \$56.00 to \$32.00 per case. This is estimated to have saved \$938,000 in the first year of their cost containment program. (41)

Limitation of AIMS

One of the potential and important downfalls of AIMS that affects quality control is the inability of the system to discern what data represents artifact in a particular clinical setting. (21) For example, the transducer for an arterial line may momentarily be dropped onto the ground and thus the AIMS would falsely record an abnormal value. (45) This may subsequently be interpreted as a clinically significant event. In another instance, a patient may experience transient desaturation from sedation but quickly return to full saturation within a minute. With an electronic record, this may be misinterpreted as a critical incident should there be a bad outcome, even if the event was unrelated to the momentary desaturation. (45–46) In order to address this problem, some AIMS require the user to validate physiologic values and others generate a confirmation button that allows user to agree or disagree when a value is detected that is grossly outside of the normal ranges. For example, the Vanderbilt Perioperative Information Management System (VPIMS) is one such system that requires users to validate vital signs before placing them into the electronic record.

As the anesthesia record is a primary piece of evidence used in court during a malpractice proceeding, artifactual or transient data have significant medicolegal implications. (45) Feldman et. al. sent surveys to anesthesia departments in North America that were users of AIMS. The survey was designed to investigate whether the use of AIMS increase malpractice exposure. Contrary to the concern that AIMS may increase liability, results showed that AIMS is actually a useful risk-management tool. (45) In fact, some feel that AIMS could be used to prevent litigations by helping to identify unsafe practices before the lawsuit occurs. (45)

One final criticism of AIMS, and all clinical decision support systems in general, is the degree to which providers become dependent on them. This dependence is problematic when systems fail, or providers change institutions or clinical environments and no longer have access to the systems upon which they have become reliant.(47)

Future of AIMS and Quality Process Measures

While the utility and place of AIMS in the perioperative environment is wide ranging and fast-growing, the current literature is still relatively limited. Studies on AIMS have only been done in a few institutions as widespread adoption of these technologies has not yet occurred worldwide. Trends from the past decade suggest that penetration of AIMS will increase in the near future. AIMS have been demonstrated to be able to increase quality of care and improve operating room efficiency.(3,8,10,15,16) In addition, they have the capacity to alter anesthesia providers behavior and change clinical practice.(19) Enhancing the accuracy of intraoperative charting systems and easing information retrieval has the potential to have enormous research and legal implications.

The most exciting and fastest area of AIMS product development is around real-time clinical decision support. This feature has the potential to revolutionize the delivery of patient care by assisting clinician in making the best clinical decision possible while following the recommended practices. For example, one proposed system upon detection of a chaotic ECG and disappearance of a pulse oximeter waveform, could prompt the end-user to consider ventricular fibrillation as a diagnostic possibility and then make available on-screen

the appropriate ACLS algorithm. (3) As these systems become more robust, eventually they will enable providers across a wide-variety of scenarios to provide care in more effective and efficient ways.

References

1. Bloomfield EL, Feinglass NG. The anesthesia information management system for electronic documentation: what are we waiting for? *J Anesth*. 2008; 22(4):404–411. [PubMed: 19011780]
2. Benson M, Junger A, Quinzio L, Fuchs C, Sciuk G, Michel A, et al. Clinical and practical requirements of online software for anesthesia documentation an experience report. *Int J Med Inform*. 2000 Jul; 57(2–3):155–164. [PubMed: 10961571]
3. Ehrenfeld JM, Rehman MA. Anesthesia information management systems: a review of functionality and installation considerations. *J Clin Monit Comput*. 2010 Aug 24.
4. Egger Halbeis CB, Epstein RH, Macario A, Pearl RG, Grunwald Z. Adoption of anesthesia information management systems by academic departments in the United States. *Anesth Analg*. 2008 Oct; 107(4):1323–1329. [PubMed: 18806048]
5. Ehrenfeld JM. Anesthesia Information Management Systems - A Guide to Their Successful Installation and Use. *Anesthesiology News*. 2009 September.:1–7.
6. Balust J, Egger Halbeis CB, Macario A. Prevalence of anaesthesia information management systems in university-affiliated hospitals in Europe. *Eur J Anaesthesiol*. 2010 Feb; 27(2):202–208. [PubMed: 19918183]
7. Boersma E, Kertai MD, Schouten O, Bax JJ, Noordzij P, Steyerberg EW, et al. Perioperative cardiovascular mortality in noncardiac surgery: validation of the Lee cardiac risk index. *Am J Med*. 2005 Oct; 118(10):1134–1141. [PubMed: 16194645]
8. Edsall DW, Deshane P, Giles C, Dick D, Sloan B, Farrow J. Computerized patient anesthesia records: less time and better quality than manually produced anesthesia records. *J Clin Anesth*. 1993 Jul-Aug; 5(4):275–283. [PubMed: 8373603]
9. Rohrig R, Junger A, Hartmann B, Klasen J, Quinzio L, Jost A, et al. The incidence and prediction of automatically detected intraoperative cardiovascular events in noncardiac surgery. *Anesth Analg*. 2004 Mar; 98(3):569–77. [PubMed: 14980900]
10. Bates DW, Gawande AA. Improving safety with information technology. *N Engl J Med*. 2003 Jun 19; 348(25):2526–2534. [PubMed: 12815139]
11. Sandberg WS, Sandberg EH, Seim AR, Anupama S, Ehrenfeld JM, Spring SF, et al. Real-time checking of electronic anesthesia records for documentation errors and automatically text messaging clinicians improves quality of documentation. *Anesth Analg*. 2008 Jan; 106(1):192–201. [PubMed: 18165578]
12. Muravchick S, Caldwell JE, Epstein RH, Galati M, Levy WJ, O'Reilly M, et al. Anesthesia information management system implementation: a practical guide. *Anesth Analg*. 2008 Nov; 107(5):1598–1608. [PubMed: 18931218]
13. Benson M, Junger A, Fuchs C, Quinzio L, Bottger S, Jost A, et al. Using an anesthesia information management system to prove a deficit in voluntary reporting of adverse events in a quality assurance program. *J Clin Monit Comput*. 2000; 16(3):211–217. [PubMed: 12578105]
14. Lerou JG, Dirksen R, van Daele M, Nijhuis GM, Crul JF. Automated charting of physiological variables in anesthesia: a quantitative comparison of automated versus handwritten anesthesia records. *J Clin Monit*. 1988 Jan; 4(1):37–47. [PubMed: 3339390]
15. Balust J, Macario A. Can anesthesia information management systems improve quality in the surgical suite? *Curr Opin Anaesthesiol*. 2009 Apr; 22(2):215–222. [PubMed: 19390248]
16. O'Reilly M, Talsma A, VanRiper S, et al. An anesthesia information system designed to provide physician-specific feedback improves timely administration of prophylactic antibiotics. *Anesth Analg*. 2006; 103(4):908–12. [PubMed: 17000802]
17. Driscoll WD, Columbia MA, Peterfreund RA. An observational study of anesthesia record completeness using an anesthesia information management system. *Anesth Analg*. 2007 Jun; 104(6):1454–61. [PubMed: 17513641]

18. Hollenberg JP, Pirraglia PA, Williams-Russo P, Hartman GS, Gold JP, Yao FS, et al. Computerized data collection in the operating room during coronary artery bypass surgery: a comparison to the hand-written anesthesia record. *J Cardiothorac Vasc Anesth*. 1997 Aug; 11(5): 545–551. [PubMed: 9263082]
19. Ehrenfeld JM, Sandberg WS. Incidence of Intraoperative Gaps in Patient Monitoring during Anesthesia. *Anesthesiology*. 2006 October.:A974.
20. Benson M, Junger A, Quinzio L, Fuchs C, Michel A, Sciuk G, et al. Influence of the method of data collection on the documentation of blood-pressure readings with an Anesthesia Information Management System (AIMS). *Methods Inf Med*. 2001 Jul; 40(3):190–195. [PubMed: 11501631]
21. Cook RI, McDonald JS, Nunziata E. Differences between handwritten and automatic blood pressure records. *Anesthesiology*. 1989 Sep; 71(3):385–390. [PubMed: 2774266]
22. Reich DL, Wood RK Jr, Mattar R, Krol M, Adams DC, Hossain S, et al. Arterial blood pressure and heart rate discrepancies between handwritten and computerized anesthesia records. *Anesth Analg*. 2000 Sep; 91(3):612–616. [PubMed: 10960387]
23. Ouchterlony J, Arvidsson S, Sjostedt L, Svardsudd K. Perioperative and immediate postoperative adverse events in patients undergoing elective general and orthopaedic surgery. The Gothenburg study of perioperative risk (PROPER). Part II. *Acta Anaesthesiol Scand*. 1995 Jul; 39(5):643–652. [PubMed: 7572015]
24. Cohen MM, Duncan PG, Pope WD, Biehl D, Tweed WA, MacWilliam L, et al. The Canadian four-centre study of anaesthetic outcomes: II. Can outcomes be used to assess the quality of anaesthesia care? *Can J Anaesth*. 1992 May; 39(5 Pt 1):430–439. [PubMed: 1596966]
25. Cohen MM, Duncan PG, Pope WD, Wolkenstein C. A survey of 112,000 anaesthetics at one teaching hospital (1975–83). *Can Anaesth Soc J*. 1986 Jan; 33(1):22–31. [PubMed: 3948043]
26. Cooper JB, Cullen DJ, Nemeskal R, Hoaglin DC, Gevirtz CC, Csete M, et al. Effects of information feedback and pulse oximetry on the incidence of anesthesia complications. *Anesthesiology*. 1987 Nov; 67(5):686–694. [PubMed: 3674468]
27. Forrest JB, Rehder K, Cahalan MK, Goldsmith CH. Multicenter study of general anesthesia. III. Predictors of severe perioperative adverse outcomes. *Anesthesiology*. 1992 Jan; 76(1):3–15. [PubMed: 1729933]
28. Beilin Y, Wax D, Torrillo T, Mungall D, Guinn N, Henriquez J, et al. A survey of anesthesiologists' and nurses' attitudes toward the implementation of an Anesthesia Information Management System on a labor and delivery floor. *Int J Obstet Anesth*. 2009 Jan; 18(1):22–27. [PubMed: 18848442]
29. Vigoda MM, Gencorelli F, Lubarsky DA. Changing medical group behaviors: increasing the rate of documentation of quality assurance events using an anesthesia information system. *Anesth Analg*. 2006 Aug; 103(2):390–5. [PubMed: 16861422]
30. Sanborn KV, Castro J, Kuroda M, Thys DM. Detection of intraoperative incidents by electronic scanning of computerized anesthesia records. Comparison with voluntary reporting. *Anesthesiology*. 1996 Nov; 85(5):977–987. [PubMed: 8916813]
31. Costanza ME, Stoddard AM, Zapka JG, Gaw VP, Barth R. Physician compliance with mammography guidelines: barriers and enhancers. *J Am Board Fam Pract*. 1992 Mar-Apr; 5(2): 143–152. [PubMed: 1575066]
32. Headrick LA, Speroff T, Pelecanos HI, Cebul RD. Efforts to improve compliance with the National Cholesterol Education Program guidelines. Results of a randomized controlled trial. *Arch Intern Med*. 1992 Dec; 152(12):2490–2496. [PubMed: 1456861]
33. Browner WS, Baron RB, Solkowitz S, Adler LJ, Gullion DS. Physician management of hypercholesterolemia. A randomized trial of continuing medical education. *West J Med*. 1994 Dec; 161(6):572–578. [PubMed: 7856157]
34. Studnicki J, Schapira DV, Bradham DD, Clark RA, Jarrett A. Response to the National Cancer Institute Alert. The effect of practice guidelines on two hospitals in the same medical community. *Cancer*. 1993 Nov 15; 72(10):2986–2992. [PubMed: 8221566]
35. Cohen MM, Rose DK, Yee DA. Changing anesthesiologists' practice patterns. Can it be done? *Anesthesiology*. 1996 Aug; 85(2):260–269. [PubMed: 8712440]

36. Kooij FO, Klok T, Hollmann MW, Kal JE. Decision support increases guideline adherence for prescribing postoperative nausea and vomiting prophylaxis. *Anesth Analg*. 2008 Mar; 106(3):893–8. [PubMed: 18292437]
37. Gillerman RG, Browning RA. Drug use inefficiency: a hidden source of wasted health care dollars. *Anesth Analg*. 2000 Oct; 91(4):921–924. [PubMed: 11004049]
38. 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. *Anesth Analg*. 2009 Apr; 108(4):1203–1208. [PubMed: 19299787]
39. Fuchs C, Quinzio L, Benson M, Michel A, Rohrig R, Quinzio B, et al. Integration of a handheld based anaesthesia rounding system into an anaesthesia information management system. *Int J Med Inform*. 2006 Jul; 75(7):553–563. [PubMed: 16263327]
40. 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. *Anesth Analg*. 2010 Mar 1; 110(3): 871–878. [PubMed: 20185663]
41. Girbes AR, Zijlstra JG. Spend time on patients and families or on documentation? *Anesth Analg*. 2009 Sep; 109(3):691–692. [PubMed: 19690232]
42. Terry K. How the device in your hand can put more money in your pocket. *Med Econ*. 2001 Dec 17; 78(24):44–6. 49–50. [PubMed: 11808471]
43. O'Byrne WT 3rd, Weavind L, Selby J. The science and economics of improving clinical communication. *Anesthesiol Clin*. 2008 Dec; 26(4):729–44. vii. [PubMed: 19041626]
44. Meyer-Bender A, Spitz R, Pollwein B. The anaesthetic report: custom-made printouts from anaesthesia-information-management-systems using extensible stylesheet language transformation. *J Clin Monit Comput*. 2010 Feb; 24(1):51–60. [PubMed: 19898945]
45. Feldman JM. Do anesthesia information systems increase malpractice exposure? Results of a survey. *Anesth Analg*. 2004 Sep; 99(3):840–3. [PubMed: 15333420]
46. Ehrenfeld JM, Funk LM, Van Schalkwyk J, Merry AF, Sandberg WS, Gawande A. The incidence of hypoxemia during surgery: evidence from two institutions. *Can J Anaesth*. 2010 Jul 31.
47. Chambers CV, Balaban DJ, Carlson BL, Grasberger DM. The effect of microcomputer-generated reminders on influenza vaccination rates in a university based family practice center. *J Am Board Fam Pract*. 1991; 4:19–26. [PubMed: 1996510]

Figure 1. Overview of an AIMS clinical decision support system showing the relationship between OR physiologic monitors, AIMS workstations, AIMS servers, hospital enterprise wide clinical systems, and hospital paging functions

Figure 2.
AIMS-based notification regarding avoidance of hypothermia

Figure 3.
AIMS-based drug redosing alert

Figure 4.
Anesthesia workroom display showing individual operating room status

Table 1

Bias, Reliability, Accuracy

• Bias	
–	<i>Recorder bias</i> is the discrepancy between the expectation of a recorder and the actual (true) value of the parameter being recorded.
• Reliability	
–	<i>Reliability</i> is the degree to which a set of measurements are consistent; related inversely to random error
• Accuracy	
–	<i>Accuracy</i> is the degree of closeness of a set of measurements to their actual (true) value