Published in final edited form as:
Anesthesiol Clin. 2011 September ; 29(3): 389–396. doi:10.1016/j.anclin.2011.05.003.

Real-Time Alerts and Reminders Using Information Systems

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Synopsis

Adoption of information systems throughout the hospital environment has enabled the development of real-time physiologic alerts and clinician reminder systems. Within the operating room environment, these clinical tools can be made available through the deployment of anesthesia information management systems (AIMS). Creating usable alert systems requires understanding technical considerations including system latency, workflow integration and the availability of appropriate alerting technology. A variety of successful implementations are reviewed, encompass cost reduction, improved revenue capture, timely antibiotic administration and post-op nausea and vomiting prophylaxis. Challenges to the widespread use of real-time alerts and reminders include AIMS adoption rates and the difficulty in appropriately choosing areas and approaches for information systems support.

Keywords

anesthesia information management systems; aims; real-time alerts; reminders; clinical decision support

Introduction to Real-Time Alerts and Reminders

Real-Time Alerts in Healthcare

One of the hallmarks of modern medicine is the availability of large volumes of patient information including both physiologic measurements and laboratory data. Systems that analyze these data and report unexpected or abnormal conditions back to a clinician at or

Correspondence to: Jonathan P Wanderer.

Conflicts: Jonathan P Wanderer reported no conflicts of interest
Conflicts: Warren S Sandberg reported no conflicts of interest
Conflicts: Jesse M Ehrenfeld reported no conflicts of interest

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near the moment that these data are available are known as real-time alert systems. Real-time alert systems are found throughout healthcare and can be classified as simple or complex. Simple alerts include high/low threshold alerts on parameters such as blood pressure and heart rate. Most modern patient monitors incorporate these alerts as audible alarms that trigger when out-of-bounds parameters are detected. Complex alerts permit the detection of data trends, the incorporation of multiple parameters and transmission of alert conditions by means other than audible proximity. Reminders, on the other hand, serve to cue clinicians to clinical events that should occur but have not. This review will focus on real-time alerts and reminders both in and out of the operating room (OR).

Real-time alerts would be expected to be most useful in clinical situations where patient conditions are anticipated to change on a second-to-second or minute-to-minute basis. Outside of the OR, the intensive care unit and emergency room are other acute care settings where physiologic conditions change on this short timeline. One of the first real-time alert systems described was a wireless PDA-based system triggered by critical laboratory or vital sign data using thresholds. Parameters were set such that approximately one alert per day was generated.[1] Interestingly, and perhaps not unexpectedly, the PDA user was almost always the first clinician to become aware of the abnormality. This observation demonstrates both the effectiveness of and impetus for the further development of this technology.

Anesthesia Information Management Systems

Anesthesia information management systems (AIMS) store patient demographic information and continuously record physiologic data into a database during anesthesia care. Periodic querying of these databases and/or monitoring of incoming data allow for the implementation of real-time alerts with both simple and complex alert conditions. In addition to patient data, case details and surgical events are stored. Checking of the AIMS-generated anesthesia record allows for quality control measures to ensure completeness of documentation for billing and clinical purposes, and facilitates notification of anesthetists when records are inconsistent or incomplete.

AIMS have benefits beyond enabling real-time alerts and reminders. The automated recording of patient physiologic data, for instance, has been demonstrated to be more reliable than human recorded data. During critical situations, irrespective of provider experience and training, manual charting frequently is incomplete. [2] Automated systems are capable of keeping accurate records throughout these events and are recommended by the Anesthesia Patient Safety Foundation. [3]

The adoption of AIMS has not yet become widespread despite having this set of compelling features. According to one recent survey, only 44% of academic anesthesia departments have implemented or are committed to implementing AIMS. [4] Substantial funding is required to set up as well as maintain AIMS which can be a prime barrier to adoption. Anesthesia departments that have AIMS have usually benefited from substantial financial support for both implementation and maintenance. While AIMS can add value to a healthcare organization, they require significant customization to do so. [5] When well supported, however, AIMS can facilitate billing, research and critical patient care functionality.

Clinical Decision Support

Overview

Information systems designed to improve clinical decision making are known as computerized clinical decision support systems (CDSS). The construction of these systems is motivated by the acknowledgement that human beings are imperfect implementers of clinical protocols and best practices with a finite ability to memorize important lists such as drug-drug interactions. The overall goal of CDSS is to improve patient care by leveraging the benefits of information technology. The use of CDSS began with the availability of computers within the clinical environment and its effectiveness utilizing computer-based reminders was first evaluated in 1976. [6] Not unsurprisingly, this early report notes that "it appears that the prospective reminders do reduce errors, and that many of these errors are probably due to man's limitations as a data processor rather than to correctable human deficiencies."

A recent review of CDSS found one hundred published articles examining the impact of CDSS on provider performance and patient outcomes. [7] CDSS were found that support a diverse variety of medical fields including psychiatry, medicine, surgery and pediatrics. Decision support was provided via numerous mechanisms including reminders or protocol presentations at time of order entry, printed reminders that were placed into patient charts, reminder pages and automated emails. Performance and patient outcomes were improved in 76% of the 21 reminder-based studies, though of note no study showed improvements in major patient outcomes such as mortality. The majority of systems were designed and built by study authors (72%), and almost all were targeted at physician users (92%).

Different Types of Decision Support

AIMS based decision support in the operating room can be grouped into three distinct categories: (1) managerial, (2) process of care, and (3) outcomes based decision support. Each category of decision support brings with it a varying degree of benefits, consequences, and difficulty in terms of implementation.

Managerial decision support focuses on helping providers interpret real-time data to more efficiently utilize the global set of resources made available to them at any particular point in time. This includes efforts to maximize OR efficiency & throughput, decrease costs, and optimize deployment of OR personnel. Examples include the prediction of when a surgical case is likely to end through the utilization of live inputs, historical models, and Bayesian analysis in order to obtain operational efficiencies, or the re-assignment of PACU bed request priorities when there either is an actual or impending PACU wait list or delay in order to facilitate overall OR throughput. Both examples, have as a goal facilitation of distinct managerial tasks – maximizing case completion rates and minimizing off-hours OR utilization and overtime.

Process of care decision support focuses on allowing providers to improve adherence to clinical protocols, guidelines, and standards of care. Process of care issues are typically more time more-urgent than managerial decision support concerns, and examples include efforts to ensure prophylactic antibiotics are received within one hour of surgical incision, maintenance of normothemia, and glucose monitoring in patients who are at risk for hyper- or hypoglycemia.

Outcome based decision support focuses on rewarding, incentivizing, and facilitating care that leads to better patient outcomes downstream. Because the data sources that allow measurement of meaningful patient outcomes are downstream from the perioperative environment, efforts at implementing this type of decision support have been quite limited to date.

Technical Considerations

One of the primary concerns of CDSS end-users--and one of the important factors in determining the success of a CDSS intervention--is ergonomic management. Successful integration of CDSS into clinical workflow can result in a seamless implementation with a high impact on provider performance and/or patient outcomes, while poor integration can lead to frustrated clinicians and little impact. The most successful CDSS will blend into the workflow rather than interrupt it; they will “present the right information, in the right format, at the right time, without requiring special effort.” [8]

Additional strategies for altering clinician behavior include education and individualized feedback, and these approaches can easily be used together. As an example, an anesthesia group set out to improve completion of quality assurance documentation which started at a baseline completion rate of 48%. [9] Education, workflow integration and individual performance feedback were incorporated and resulted in a stepwise improvement of completion rates (55%, 68% and 78%, respectively). The impact of education and feedback tended to fade with time, while further improvement in the workflow via user interface optimization ultimately resulted in a completion rate of 94%. Studies that rely on reminders alone have also noted their impact fading with time. [10]

As noted above, the practice of anesthesia involves making time-critical decisions and thus alerts and reminders function most effectively when operating at the temporal resolution of seconds to minutes, rather than hours to days. Unfortunately, latency becomes noticeable and problematic when designing real-time interventions. Physiologic monitors obtain data at variable or clinician-specified intervals, which are then transmitted to AIMS at a pre-defined interval, which are in term analyzed by decision support functions that operate on an intervention-specific interval. CDSS that depend on events documented by the user, such as case start time, are subject to additional documentation latency as well as incompleteness. The cumulative effect of these intervals needs to be carefully considered when designing CDSS. [11] AIMS typically are able to provide granularity for data on a one minute basis. By contrast, reliable and timely detection of critical events such as hypotension and hypoxia requires maximum sampling intervals of 36 seconds and 13 seconds respectively. [12] Until a technical solution to the problem of latency is at hand, real-time alerts and reminders in anesthesia will be able to address only a subset of clinical issues.

In addition to the problem of data latency, data reliability remains an issue. Sources of artifacts within the operating room environment abound, such as misplaced pulse oximeter probes, poorly sized blood pressure cuffs, improperly aligned pressure transducers, temporarily artifact in transducer signal due to blood draws or calibration, etc. Ideally, erroneous signals would be marked as such via AIMS by the end-user before CDSS analyzed these data but in practice the effort required to mark every data point affected by artifact in real-time is unrealistic. As a consequence, CDSS-triggered alerts and reminders must be interpreted by the clinician within the context of what is known about the reliability of the information on which the intervention is based.

Alerting Functions

A number of modalities of alerting or reminding clinicians have already been mentioned, specifically email, pages, printed messages placed in patient charts and on-screen reminders. On-screen reminders can be further classified as hard-stop interruptions that require management before additional work can be performed, soft-stop interrupts that can be acknowledged or delayed, as well as non-modal notifications that do not block software interaction at all. Additionally, investigative work has been performed on optimizing audible alerts although the sheer number of operating room devices utilizing this alert functionality somewhat limits enthusiasm for introducing more sources of noise. [13] Tactile alerting functions have also been explored though so far are not in widespread use. [14] The final frontier in anesthesia alerting technology seems to be the use of heads up display, in which bionic anesthetists view messages beamed directly to their field of view. [15]

Proof of Concepts in the Peer Reviewed Literature

Drug Dosing Reminders

The implementation of antibiotic dosing reminders has proven popular as a CDSS task, as pre-operative antibiotic administration has a firm clinical basis, is frequently analyzed as a quality measure, does not require a low-latency system and should occur within a narrow, specific time-frame within an anesthetic. Improvement after implementation of antibiotic reminders depends in part on pre-intervention compliance rates and appropriate workflow integration. Simple computer prompting, for instance, increased adherence from 20% to 58%. [16] Incorporation of antibiotic reminders within an anesthetic text task list, along with reminder emails stating the provider's performance relative to peers, improved timely administration from 69% to 92%. [17] The use of a visual reminder, rather than a text reminder, has also been demonstrated to improve administration practices. [18]

Drug-drug interactions

As much as 19% of medical errors can be attributed to complications of drug administration such as allergic reactions and drug-drug interactions. [19] In the outpatient and inpatient setting numerous CDSS have been deployed aimed at reducing medication errors, and in some settings this has resulted in a 55% reduction in error rate compared to pre-CDSS adoption. Typically these CDSS are implemented within a computerized physician order entry system. This approach makes these safety efforts difficult to translate to the operating room environment, as medication administration is most often documented retrospectively, rendering drug-drug interaction detection moot in the typical perioperative workflow. However, the use of simple barcode readers and software which can facilitate recording drug doses just before administration have been shown to reduce errors. (Merry, Webster, et al. 2002)

Revenue Capture

One of the key areas for the realization of the value proposition for AIMS is the facilitation of billing via automated monitoring of documentation completeness. Ensuring reimbursement for arterial line placement, for instance, is a task well suited to CDSS as it is straightforward to detect the presence of arterial line data and the absence of arterial line documentation and/or compliance. Documentation reminders delivered via email and paging for one group resulted in an increase in compliance from 80% to 98%, with an estimated increase of $40,500 in annual revenue. [20] Similarly, entire anesthesia records can be checked for essential elements. Our group utilized paging reminders to reduce rates of incomplete charting from 1.31% to 0.04%, reduce time for correcting anesthesia records and increased revenue an estimated $400,000 per year. (Spring, Sandberg et al. 2007)

Cost Reduction

In addition to improving revenue capture, CDSS can also be utilized to reduce costs. Choosing a low cost inhalational agent, for instance, and using low fresh gas flows (FGF) are two simple methods for decreasing the cost of providing an anesthetic. An individual feedback intervention performed with AIMS data but implemented with a departmental chair letter resulted in an initial 26% decrease in FGF, which decreased over time to 19%. [21] The same study paradoxically demonstrated an unexplained and statistically significant increase in high cost inhalational agent use, though small in effect (isoflurane use decreased from 76% to 73%).

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Postoperative Nausea and Vomiting

Addressing adherence to institutional treatment guidelines for postoperative nausea and vomiting (PONV) has been another area of interest. By mandating entry of PONV risk factor data and providing an on-screen alert when PONV prophylaxis is indicated but not given, one group was able increase compliance with guidelines from 38% to 73%. [22] After the reminder and risk factor data entry was disabled, compliance returned to pre-intervention baseline with an adherence rate of 37%.

Alarm Use After Cardiopulmonary Bypass

During cardiopulmonary bypass, lack of pulsatile blood flow can trigger physiologic monitor alarms, which in turn can result in practitioners turning off alarm functionality. After coming off bypass and prior to intervention the rate of monitor alarm reactivation at one institution was a dismal 22%. [23] An AIMS-based alert was developed capable of detecting post-bypass vital signs and notified the provider to reactivate monitor alarms if they were disabled. The alarm reactivation rate climbed to 63% after the functionality was enabled, and up to 83% after a one-time educational session regarding the reminder. Of note, this intervention required the recording of monitor alarm status into the AIMS record, which is not always transmitted.

Discussion and Future Directions

The above review of the literature reveals a diverse set of successful AIMS-based CDSS interventions that have positively impact anesthesia care in a variety of areas. The experience of AIMS-based CDSS mirrors the experiences of CDSS outside of the OR and is notable for three specific themes.

The first theme noted is that long-term success is achieved by designing an intervention that is seamlessly integrated into workflow and can be left permanently implemented without disruption. Ideally a reminder or alert will be set to trigger at an opportune time or be delivered by a mechanism that does not interrupt ongoing workflow. These mechanisms include but are not limited to paging and non-modal reminders.

The second theme is that most successful interventions are conceived of, implemented and tracked by clinicians who are addressing appropriately selected problems. At the moment due to latency limitations this restricts the problem domain to those amenable to reminders that may arrive within several minutes of a triggering event, rather than within seconds. Another consideration when selecting an area to address is that a greater intervention effect is achieved by tackling a problem where baseline behavior is far from ideal, rather than already close to it.

The third theme is that successful CDSS implementations usually include more than the simple activation of a reminder or alert. Instead, adjuvants are added such as an educational component or feedback via another communication channel. Both of these types of efforts have consistently demonstrated improvements in intervention effect, though of note some interventions worked without the use of feedback.

Looking forward, it is clear that we will continue to see the growth of AIMS-based interventions as additional institutions adopt AIMS technology and achieve some of the care improvements that the addition of real-time alerts and reminders can provide. Without question these projects will continue to require substantial resources in order to create effective implementations, as they necessitate a complete understanding of existing clinical workflow and appropriate design of interventions. Additional areas ripe for intervention will be explored, and it is likely that we will see at least a proof of concept solution for the latency issue. While AIMS databases and/or available storage may limit monitor recording resolution to one minute intervals, it is feasible to develop alert technology that continuously analyzes monitor data and is also integrated with AIMS. With this development, there will be no limitation in scope to clinical problems that AIMS with CDSS can address.

Conclusion

We have explored the adoption of real-time physiologic alerts and clinical reminder systems within the hospital environment, focused on perioperative care. As AIMS become more prevalent, use of these information systems to improve patient care, reduce costs and enable accurate billing will become more common. Existing alert systems already function across a variety of arenas within the perioperative environment and these systems will likely continue to diversity as healthcare information systems become more integrated. Successful deployment of clinical alerts and reminders requires thoughtful consideration of existing workflow and appropriately selected interventions.

Acknowledgments

Funding: Financial support for this review was provided by 5T32GM007592 from the National Institute of Health, as well as by department funds of the Department of Anesthesia, Critical Care, and Pain Medicine, Massachusetts General Hospital.

References

1. Shabot MLM. Real-time wireless decision support alerts on a palmtop PDA. Proc Annu Symp Comput Appl Med Care. 1995; (19):174–177. [PubMed: 8563261]
2. Devitt JH, Rapanos T, Kurrek M, Cohen MM, Shaw M. The anesthetic record: accuracy and completeness. Can J Anaesth. 1999 Feb; 46(2):122–128. [PubMed: 10083991]
3. Muravchick S, Caldwell JE, Epstein RH, et al. Anesthesia information management system implementation: a practical guide. Anesth Analg. 2008 Nov; 107(5):1598–1608. [PubMed: 18931218]
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. Egger Halbeis CB, Epstein RH. The value proposition of anesthesia information management systems. Anesthesiol Clin. 2008 Dec; 26(4):665–679. vi. [PubMed: 19041622]
6. McDonald CJ. Protocol-based computer reminders, the quality of care and the non-perfectability of man. N Engl J Med. 1976 Dec 9; 295(24):1351–1355. [PubMed: 988482]
7. Garg AX, Adhikari NK, McDonald H, et al. Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review. JAMA. 2005 Mar 9; 293(10):1223–1238. [PubMed: 15755945]
8. James BC. Making it easy to do it right. N Engl J Med. 2001 Sep 27; 345(13):991–993. [PubMed: 11575294]
9. 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):390–395. table of contents. [PubMed: 16861422]
10. Demakis JG, Beauchamp C, Cull WL, et al. Improving residents' compliance with standards of ambulatory care: results from the VA Cooperative Study on Computerized Reminders. JAMA. 2000 Sep 20; 284(11):1411–1416. [PubMed: 10989404]
11. Epstein RH, Dexter F, Ehrenfeld JM, Sandberg WS. Implications of event entry latency on anesthesia information management decision support systems. Anesth Analg. 2009 Mar; 108(3): 941–947. [PubMed: 19224807]
12. Derrick JL, Bassin DJ. Sampling intervals to record severe hypotensive and hypoxic episodes in anesthetised patients. J Clin Monit Comput. 1998 Jul; 14(5):347–351. [PubMed: 9951760]

13. McNeer RR, Bohorquez J, Ozdamar O, Varon AJ, Barach P. A new paradigm for the design of audible alarms that convey urgency information. J Clin Monit Comput. 2007 Dec; 21(6):353–363. [PubMed: 17973195]
14. Ng JY, Man JC, Fels S, Dumont G, Ansermino JM. An evaluation of a vibro-tactile display prototype for physiological monitoring. Anesth Analg. 2005 Dec; 101(6):1719–1724. [PubMed: 16301248]
15. Liu D, Jenkins SA, Sanderson PM, et al. Monitoring with head-mounted displays: performance and safety in a full-scale simulator and part-task trainer. Anesth Analg. 2009 Oct; 109(4):1135–1146. [PubMed: 19762741]
16. St Jacques P, Sanders N, Patel N, Talbot TR, Deshpande JK, Higgins M. Improving timely surgical antibiotic prophylaxis redosing administration using computerized record prompts. Surg Infect (Larchmt). 2005; 6(2):215–221. [PubMed: 16128628]
17. 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. Anesth Analg. 2006 Oct; 103(4):908–912. [PubMed: 17000802]
18. 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. Anesth Analg. 2007 Jun; 104(6):1462–1466. table of contents. [PubMed: 17513642]
19. Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. J Am Med Inform Assoc. 2001 Jul–Aug; 8(4): 299–308. [PubMed: 11418536]
20. Kheterpal S, Gupta R, Blum JM, Tremper KK, O'Reilly M, Kazanjian PE. Electronic reminders improve procedure documentation compliance and professional fee reimbursement. Anesth Analg. 2007 Mar; 104(3):592–597. [PubMed: 17312215]
21. Body SC, Fanikos J, DePeiro D, Philip JH, Segal BS. Individualized feedback of volatile agent use reduces fresh gas flow rate, but fails to favorably affect agent choice. Anesthesiology. 1999 Apr; 90(4):1171–1175. [PubMed: 10201691]
22. 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):893–898. table of contents. [PubMed: 18292437]
23. 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]