OREGON HEALTH & SCIENCE UNIVERSITY

SCHOOL OF MEDICINE – GRADUATE STUDIES

A SYSTEMATIC REVIEW OF NEAR REAL-TIME AND POINT-OF-CARE CLINICAL DECISION SUPPORT IN ANESTHESIA INFORMATION MANAGEMENT SYSTEMS

By

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CERTIFICATE OF APPROVAL

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Has been approved

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Abstract

Background

Anesthesia information management systems (AIMS) are sophisticated hardware and software technology solutions that can provide real-time, point-of care feedback to anesthesia providers. This feedback can be tailored to provide clinical decision support (CDS) to aid clinicians with processes of care, compliance with documentation, and adjusting resource utilization. I conducted a systematic review of near real-time and point-of-care CDS within AIMS within the framework of the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) to evaluate and categorize peer-reviewed reports of the benefits of CDS in AIMS.

Methods

Studies were identified using searches of the electronic databases Medline and EMBASE. One reviewer analyzed the search results and screened studies based on title, abstract, and full text. Studies of sufficient homogeneity in terms of design, intervention, and desired outcome were allocated into one group

Results

The analysis included 23 articles (Table 1). The Medline search query returned 1,063 articles and the EMBASE search query returned 162 articles for a combined total of 1,125 articles in the initial sample (Figure 1). The review of article titles eliminated 1,064 articles, leaving 61 articles. During the review of article abstracts, 28 articles were removed, while 5 articles were eliminated after review of the full article text.

Conclusion

There is strong evidence for the inclusion of near real-time and point-of-care CDS in AIMS to enhance perioperative antibiotic prophylaxis compliance as well as documentation compliance and completeness. Additional research is needed in many other areas of AIMS-based CDS.

Introduction

Anesthesia information management systems (AIMS) began in the 1980s as simple, computer-based intraoperative record keepers to complement or replace paper documentation of a patient's anesthetic course.[1] The core function of AIMS continues to be the generation of an automated, continuous electronic record of the patient's physiological data that allows for manual notation of intraoperative events such as medication administration.[2]

AIMS have since evolved into sophisticated hardware and software systems that are available as either a stand-alone product or as a component of a hospital's electronic health record (EHR) system. Both types offer features that expand their capabilities beyond intraoperative record keeping and enable anesthesia providers to record, view, and share patient information across the entire perioperative continuum. For instance, many AIMS allow users to view patients' prior anesthetic records and preoperative assessment forms. Most AIMS that are integrated within a hospital's EHR can retrieve relevant patient information (e.g. age, weight, allergies, medication lists) from the EHR and then load that information automatically into the preoperative assessment and the intraoperative record.[3] In fact, some AIMS are modules of EHRs, share the same underlying database as the EHR, and are designed to present specialty-specific view of the data relevant to perioperative requirements.

AIMS have been shown to enhance the quality and safety of patient care,[4] and clinical decision support (CDS) is one of the factors that has contributed to these benefits.[5] CDS systems provide clinicians with patient-specific assessments or recommendations to assist with clinical decision-making.[6] CDS is an active area of anesthesia research and development largely due to its potential to improve patient care and outcomes. CDS has become increasingly integrated into AIMS, and CDS can typically be categorized into one or more types: process of care (e.g.

improving adherence to clinical protocols and guidelines[7]) and administrative and resource management (e.g. documentation and billing[8]).

Systematic reviews have shown how CDS that is embedded within hospitals' EHRs can improve clinical performance, resource utilization and patient care.[9,10] Most of the recent reviews on CDS and AIMS have been narrative rather than systematic in nature.[11,12,13,14] One recently published systematic review of CDS in AIMS did not state the search queries that were used, did not refer to any systematic review guidelines, lacked articles from 2015, included post hoc pager alerts and emails, and included an article on a non-AIMS CDS.[15,16] Thus, I conducted a systematic review of near real-time and point-of-care CDS within AIMS within the framework of the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P).[17,18] The goal of this PRISMA-P-compliant systematic review was to evaluate and categorize peer-reviewed reports of the benefits of CDS in AIMS.

Methods

Eligibility Criteria

The selection criteria included studies of CDS specifically built within AIMS (not EHRs) that were published in English in peer-reviewed journals between January 1, 2000 and December 1, 2015. The interventions sought included any implementations of CDS resulting in an improvement in process of care, finance and resource management, and outcomes-based decision support.[7,8,9] In the process of care category, the outcome measures sought included adherence to established clinical protocols and guidelines. In the category of administrative and resource management, the outcome measures sought included billing, medication and procedure documentation. Review articles and case reports were excluded from analysis.

Information Sources

Studies were identified using searches of the electronic databases Medline and EMBASE.

Search Strategy

The Medline and EMBASE search strategies were created by a Health Sciences Librarian with expertise in systematic review searching. The full Medline and EMBASE search queries are listed in the Appendix.

The Medical Subject Heading (MeSH) keywords used for the Medline search included the following: “integrated advanced information management systems”, “information management”, “hospital information systems”, “decision support systems, clinical”, electronic health records”, “decision support techniques”, “anesthesia”, and “medical record systems, computerized”. Non-MeSH keywords and phrases included “anesthesia information

management" as well as wildcard phrases such as "post-anesthes*" and "anaesthes*". Inclusion filters were applied for human subjects, the English language, presence of an abstract, and publication dates between January 1, 2000 and December 31, 2015. Exclusion filters included case reports and reviews.

The EMBASE search query consisted of the keywords "information system", "information management", "anesthesia information management system", "electronic medical record", "electronic health record", "ehr", "emr", decision support system" and "clinical decision support". Inclusion filters were applied for the English language and publication dates between January 1, 2000 and December 31, 2015. An exclusion filter for Medline results was applied.

The Medline and EMBASE results were combined into a Microsoft Excel spreadsheet that included each study's title, authors, date of publication, and journal information. Duplicates were removed. One reviewer (AFS) screened the article titles for relevance to CDS in AIMS and used each article's title to decide whether to accept, reject, or mark for further review. The reviewer then screened the abstracts of all articles that were marked "accept" or "further review" in order to either accept or reject each remaining article. The full electronic versions of the articles marked "accept" were then obtained via institutional library access or directly contacting the article's contact author. The full articles were reviewed for inclusion of AIMS CDS with near-real-time alerts delivered to anesthesia providers at the point of care or through pages or text messaging to supervising anesthesiologists; review articles, articles describing the use of checklists and other decision aids, and articles on utilizing AIMS data to drive post-hoc emails and pages were removed at this step.[19,20]

The data items extracted included the type of CDS alert, the behavior category, the message modality, and the outcome of the intervention. The measured outcomes in the reviewed

studies included compliance rate with a care process or clinical protocol, vital sign monitoring and alert utilization rates, postoperative nausea and vomiting, and documentation completeness and compliance.

If studies were sufficiently homogeneous in terms of design, intervention, and desired outcome, then the studies were allocated into one group (e.g. perioperative antibiotic prophylaxis). The quality of evidence for all outcomes was judged using the Grading of Recommendations Assessment, Development and Evaluation working group methodology.[21] For each category, the evidence was graded as "weak" or "strong" based on the following: quality of evidence, study design (prospective versus retrospective), and number of participating study centers (3 or more would be considered as "strong" evidence). One reviewer [AFS] graded the studies.

Results

Study selection

The analysis included 23 articles (Table 1). The Medline search query returned 1,063 articles and the EMBASE search query returned 162 articles for a combined total of 1,225 articles in the initial sample (Figure 1). The review of article titles eliminated 1,164 articles, leaving 61 articles. During the review of article abstracts, 33 articles were removed, while 5 articles were eliminated after review of the full article text.

Perioperative antibiotic prophylaxis – Initial dosing and re-dosing

Prophylactic antibiotic (PA) administration 1 to 2 hours before surgical incision has been shown to reduce the risk of wound infection.[22] Five studies showed that CDS in AIMS was associated with significant improvements in the administration and/or re-dosing of perioperative antibiotic prophylaxis. Schwann et al. prospectively examined the effects of PA administration CDS point-of-care electronic prompts over 2 consecutive 6-month periods; the alerts increased PA administration compliance by 32% and were associated with a 0.4% absolute risk reduction in the incidence of surgical site infections (SSIs).[23] Nair et al. showed that real-time CDS reminders improved PA rates to >99% (compared to a baseline of 90% with paper records) over a 6-month period.[24] Wax et al. described the impact of a visual interactive electronic CDS reminder on documented PA administration within 60 min before surgical procedure starting time (82.9% during 8 months before CDS vs 89.1% during 10 months after, $p < 0.01$).[25]

Antibiotics must be re-dosed at regular intervals during lengthy surgical cases in order to maintain efficacy.[26] St. Jacques et al. reported that the use of a basic AIMS reminder system increased the appropriate PA re-dosing rate from 20% to 58% ($p < 0.001$),[27] while Nair et al.

described similar PA re-dosing rates with basic AIMS reminders (62.5% ± 1.6%) that were improved with real-time CDS (83.9% ± 3.4%) ($p < 0.001$).[28]

Thus, there are five studies from a variety of settings that have demonstrated strong evidence to support including AIMS CDS for PA administration and re-dosing in order to achieve significantly higher rates of PA compliance.

Postoperative nausea and vomiting prophylaxis

Postoperative nausea and vomiting (PONV) is one of the most common complaints following surgery and a considerable cause of dissatisfaction with recovery from anesthesia; thus, anesthesiologists will often administer prophylactic antiemetic medications to patients to reduce the likelihood of PONV.[29] Kappen et al. randomized anesthesiologists to exposure to a CDS tool—automated risk calculations for PONV—and found that the anesthesiologists exposed to the PONV prediction model administered more prophylactic antiemetics (rate ratio, 2.0; 95% CI, 1.6-2.4); however, a significant reduction in PONV incidence was not observed.[30] In contrast, Kooij et al. implemented AIMS-based CDS reminders using a simplified PONV risk score that increased PONV guideline adherence from 38% of high risk patients to 73%;[31] this change in practice was associated with a decrease in PONV from 32% to 23% ($p = 0.01$) in a general surgical population.[32] The same group showed that withdrawal of the PONV CDS support resulted in a decrease in adherence to PONV prophylaxis recommendations 6 weeks after discontinuation of CDS (79% vs 41%, $p < 0.001$).[33]

There is weak evidence to support a recommendation for PONV CDS in AIMS. The available research is limited to two research groups, and only one group showed a positive patient outcome (reduction in PONV) after that practice change.

Management of vital sign monitors and alarms

The American Society of Anesthesiology has set standards and guidelines for monitoring vital signs that includes standard basic anesthetic monitors and alarms.[34] Vital sign monitor alarms are disabled routinely during cardiopulmonary bypass (CPB), as the lack of pulsatile flow would cause the pulse oximeter alarm and other alarms to fire continuously. Eden et al. developed an algorithm to identify separation from CPB by the return of pulsatile flow and implemented an AIMS-based CDS reminder to remind the user to reactivate the vital sign monitor alarms.[35] The rate of alarm reactivation increased significantly in the post-implementation phase (from 22% to 63%).[35] Nair et al. implemented an AIMS CDS alert to notify the anesthesia provider if non-invasive blood pressure (NIBP) measurements had not been taken in the last 7 min. There was a significant reduction in the occurrence of extended NIBP gaps (>15 min) and the mean gap duration declined from 23.1 ± 2.0 to 18.6 ± 1.1 min ($p < 0.001$).[36] Ehrenfeld et al. conducted a prospective multicenter study where automated AIMS CDS tools were installed at 2 of the 3 centers to provide near real-time alerts to anesthesia providers of NIBP gaps; the incidence of gaps was reduced significantly (2.72% ± 0.60% vs 1.54% ± 0.19%, $p < 0.0001$).[37] In contrast, Epstein and Dexter described an AIMS CDS hypoxemia alert to send text pages to supervising anesthesiologists, but found that the system had low utility as nearly all hypoxemic episodes were resolved before arrival of the anesthesiologist to the operating room.[38]

There is relatively weak evidence to support AIMS CDS to remind anesthesia providers to enable vital sign monitor alarms after CPB. There is strong evidence (two studies, one of which was prospective multicenter) to support AIMS CDS to remind anesthesia providers to obtain NIBP readings. There is weak evidence (one retrospective study) against implementing AIMS CDS to alert anesthesiologists of intraoperative hypoxemic episodes.

Intraoperative glucose management

Perioperative glycemic management is important to avoid complications from hyperglycemia and hypoglycemia, especially in diabetic patients.[39] Nair et al. implemented an AIMS-based real-time CDS reminder to anesthesia providers to follow an institutional glucose management protocol. While compliance with the protocol (i.e. hourly glucose measurement and correct insulin doses) improved significantly, the AIMS CDS reminder did not improve mean glucose levels or other glycemic management parameters.[40] The authors postulated that this discrepancy existed because of a tendency for providers to adopt permissive hyperglycemia for fear of hypoglycemia under anesthesia, and an overall poor rate of compliance (24.2%) with correct insulin doses even with the use of the CDS tool.

There is weak evidence (one study) to support AIMS CDS for intraoperative blood glucose management for improved protocol compliance, and weak evidence that patient outcome measures are unaffected.

Intraoperative blood pressure management

Intraoperative hypertension and hypotension are associated with an increase in morbidity and mortality.[41] Nair et al. implemented AIMS-based near real-time notification of scenarios contributing to hypotension and hypertension.[42] The CDS alert was associated with a reduction in the duration and frequency of hypotension with high concentrations of inhaled anesthetic (δ = -0.26% [confidence interval, -0.38% to -0.11%], $P < 0.001$); the effect of the alert on anesthesia providers' management of hypertension was significant but less than the management of hypotension.[42]

There is weak evidence to support the use of CDS in AIMS to manage intraoperative hypotension and hypertension.

Intraoperative ventilator management

Low tidal volume (Vt) ventilation has been shown to reduce mortality in acute lung injury (ALI) patients in the intensive care unit; however, anesthesiologists do not routinely use low tidal volume ventilation in the operating room.[43] Blum et al. conducted a randomized controlled trial using an AIMS CDS alert that notified anesthesiologists via hospital pager that a patient had lab values that were associated with ALI and showed a clinically significant reduction in mean Vt from 508 to 458 mL ($p=0.033$).[44]

There is weak evidence to support the use of CDS in AIMS to notify anesthesiologists of lab values that are associated with ALI to decrease tidal volumes.

Documentation Compliance

The core function of AIMS remains recordkeeping, and many researchers have built AIMS CDS to enhance anesthesia providers' compliance with documentation requirements. Choi et al. showed a significant improvement in documentation compliance over a four-year period after implementing an AIMS with a custom-made anesthesia script for a specific or common surgical procedure.[45] McCarty et al. described a significant increase in complete airway management documentation using real-time airway documentation guide CDS in the AIMS as part of a process improvement methodology.[46] Freundlich et al. conducted a 3-year randomized trial and found that alerting anesthesia providers to documentation errors via automated page resulted in improved documentation (baseline 33%, post-intervention 87%, $p < 0.001$).[47] Nair et al. used an AIMS CDS alert to notify anesthesia providers to document beta-blocker drug administration and improved documentation compliance from 60.5% to 94.6% ($p < 0.001$).[48] Sandberg et al. implemented an automated AIMS-based paging system to remind providers to document patient allergy data and saw a compliance improvement from 70% to 92% after initiating the alerts.[49] Kheterpal. et al showed an increase in arterial catheter documentation from 75% to 88% after implementing an AIMS-based pager reminder.[50]

There is strong evidence (multiple centers and prospective studies) that implementing AIMS CDS alerts can improve documentation completeness and compliance.

Resource conservation and utilization

High fresh gas flows (FGFs) can cause the wastage of expensive inhalational anesthetic to the scavenging system of an anesthesia machine.[51] Nair et al. implemented real-time AIMS-based notification of high FGFs to anesthesia providers and saw the mean (± standard deviation)

FGFs reduced from 2.10 ± 1.12 L/min during baseline to 1.60 ± 1.01 L/min when the CDS intervention was instituted ($p < 0.001$).[52]

There is weak evidence (one study) supporting the use of AIMS CDS to manage FGFs during anesthesia.

Discussion

This is the first PRISMA-P compliant systematic review of near real-time, point-of-care CDS in AIMS. There is strong evidence for the inclusion of near real-time and point-of-care CDS in AIMS to enhance perioperative antibiotic prophylaxis compliance as well as documentation compliance and completeness. While the other categories of AIMS CDS consisted of only weak evidence, in most cases the grade was due to a paucity of studies and not the quality of the data.

In a few studies, reminders were associated with a more significant effect on desired provider behavior when the reminders were based on real-time CDS instead of predetermined time intervals. This may be due to better integration of CDS into the clinical workflow[53] as well as improving the relevance and timeliness of the clinical messages.[54] This observation reinforces the importance of remembering the five "rights" of CDS, which consist of delivering the right information, to the right person, in the right intervention format, through the right channel, at the right time in workflow.[55]

This study had several limitations. Because a solo reviewer performed the analysis, some arbitrariness was associated with assessing categories as "strong" and "weak", and there was no adjudication process. While the search queries were designed to be broadly inclusive, relevant studies within the time period of interest were missed that might have changed some assessments from weak to strong.[56]

The published evidence for near real-time, point-of-care CDS in AIMS is promising yet limited despite the proliferation of AIMS in U.S. academic anesthesia departments (approximately 75% by the end of 2014).[57] In fact, the 23 articles analyzed in this review originated from only 9 medical centers. This paucity of near real-time, point-of-care AIMS CDS

articles may be due to the challenges associated with conducting and publishing these studies, which are often based on quasi-experimental pre- and post-intervention design. Two concerns about this study design include the absence of randomization and unknown interceding events that might affect providers' behavior during the study period, as well as the possibility of clustering events as a function of time.[15]

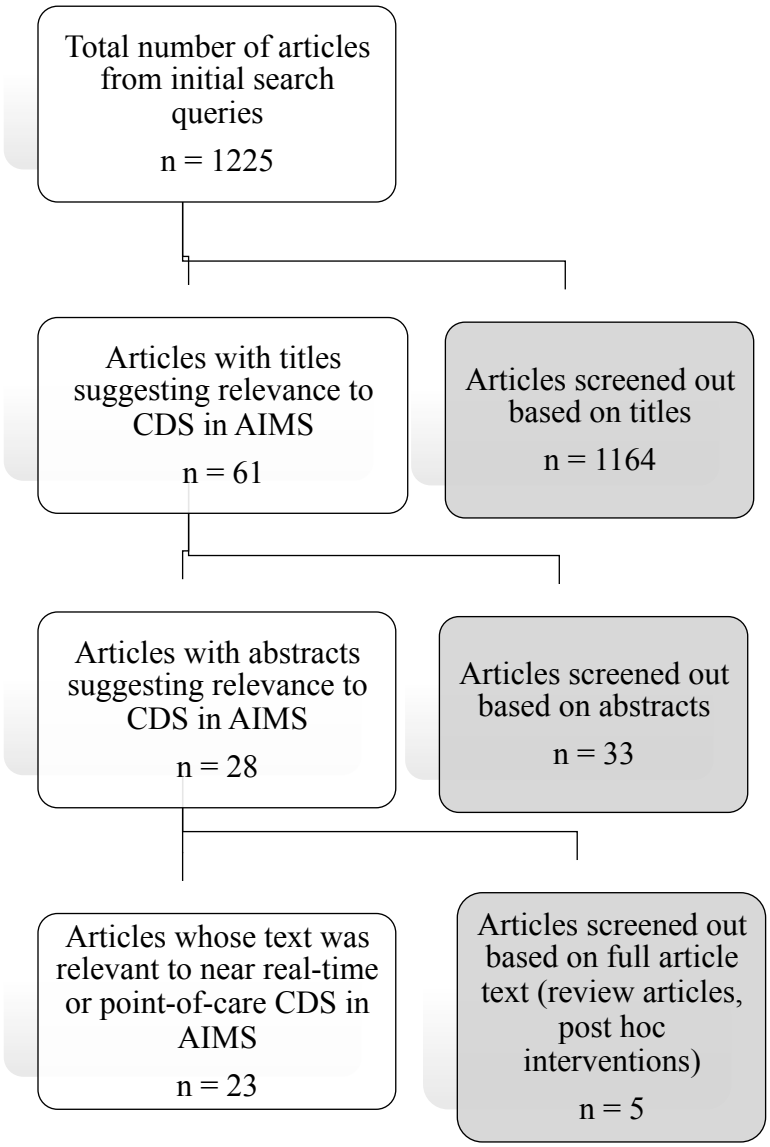
Lastly, when implementing CDS in AIMS, one must also weigh concerns about alert fatigue, which can occur when interruptive alerts distract the AIMS user from more relevant alerts; this "signal-to-noise" concern has been studied in EHR CDS.[58] It is interesting to note that none of the studies in this review addressed the risk of alert fatigue.[59] Future studies of AIMS CDS should consider the impact that new alerts may have on attention to established alerts.

Summary and Conclusions

This is the first PRISMA-P compliant systematic review of near real-time, point-of-care CDS in AIMS. Strong evidence exists for the inclusion of CDS in AIMS to enhance compliance with perioperative antibiotic prophylaxis protocols and documentation requirements. There is limited evidence supporting other applications of AIMS CDS, mainly due to a paucity of studies and not the quality of the data. Despite the challenges that are associated with conducting studies of AIMS-based CDS, additional research is warranted to ensure that future AIMS development and meaningful use criteria are based on high-quality evidence from multiple centers.

Figures

Figure 1. Enrollment flow diagram of articles published between January 1, 2000 and December 31, 2015 on clinical decision support (CDS) in anesthesia information management systems (AIMS) retrieved from Medline and EMBASE.



Tables

Table 1. Peer-Reviewed, Published Articles Related to Near Real-Time and Point-of-Care Clinical Decision Support in Anesthesia Information Management Systems.

Category	First author's last name	Year of publication	Reference	Summary
Perioperative antibiotics	Schwann	2011	[23]	Increased antibiotic compliance and decreased surgical site infections
	Nair	2010	[25]	Increased antibiotic compliance
	Wax	2007	[24]	Increased antibiotic compliance
	Nair	2011	[28]	Increased antibiotic redosing rate
	St. Jacques	2006	[27]	Increased antibiotic redosing rate
PONV prophylaxis	Kappen	2014	[30]	Increased antiemetic admin
	Kooij	2012	[32]	Decreased patient postoperative nausea and vomiting
	Kooij	2010	[33]	Compliance returned to baseline rates after
	Kooij	2008	[31]	Increased adherence to clinical guidelines
Vital sign monitors and alarms	Eden	2009	[35]	Increased alarm reactivation rates after cardiopulmonary bypass
	Nair	2013	[36]	Decreased blood pressure recording gaps
	Ehrenfeld	2011	[37]	Decreased blood pressure recording gaps
	Epstein	2012	[38]	No effect on incidence or duration of hypoxemic events
Glucose management	Nair	2015	[40]	Higher compliance rates with clinical protocol
Blood pressure management	Nair	2014	[42]	Higher compliance rates with clinical protocol
Ventilator management	Blum	2013	[44]	Decreased tidal volumes administered to patients
Documentation	Choi	2014	[45]	Improved overall documentation compliance
	McCarty	2014	[46]	Improved airway documentation
	Freundlich	2013	[47]	Improved anesthesia start time documentation
	Nair	2012	[48]	Improved beta-blocker documentation
	Sandberg	2008	[49]	Improved allergy documentation
	Kheterpal	2007	[50]	Improved arterial catheter documentation
Resource utilization	Nair	2013	[52]	Fresh gas flow management

Appendix

Medline Search Query

Search ((((((anaesthesia OR anesthesia OR anesthesiology OR anesthesiologist* OR anaesthesiologist* OR anaesthesiology OR periop* OR PACU OR post-anesthes* OR post-anaesthes* OR postanaesthes* OR postanesthes* AND (information AND manag*) AND decision*))) AND ("2000/01/01"[PDat] : "2015/12/31"[PDat]) AND English[lang])))) OR ((((((((((((((((((((integrated advanced information management systems[MeSH Terms]) OR Information Management[MeSH Terms]) OR "anesthesia information management") OR "electronic health records") OR Medical Records Systems, Computerized[MeSH Terms]) OR Hospital Information Systems[MeSH Terms]) OR decision support systems, clinical[MeSH Terms]) OR decision support techniques[MeSH Terms])))) AND (((anaesthesia* OR anesthesia* OR anesthesiologist* OR anaesthesiologist* OR anesthesia[MeSH Terms])))))) AND ("2000/01/01"[PDat] : "2015/12/31"[PDat]))) NOT "case reports"[Publication Type]) NOT "review"[Publication Type]) AND hasabstract[text] AND Humans[Mesh] AND English[lang])))))))

EMBASE Search Query

No.	Query	Results
#13	**#9** OR **#10** AND [embase]/lim NOT [medline]/lim AND [english]/lim	162
#12	**#9** OR **#10** AND [embase]/lim NOT [medline]/lim	162
#11	**#9** OR **#10**	506
#10	**#1** AND **#3** AND **#4** AND (**anesthes***:ti OR **anesthes***:ab) AND **decision***:ti AND [embase]/lim	6
#9	**#1** AND **#3** AND **#4** AND **decision***:ti AND [english]/lim AND [2000-2015]/py	506
#8	**#1** AND **#3** AND **#4** AND (**anesthes***:ti OR **anesthes***:ab) AND **decision***:ti	6
#7	**#1** AND **#3** AND **#4** AND [english]/lim AND [2000-2015]/py	1,747
#6	**#1** AND **#3** AND **#4** AND [english]/lim	1,768
#5	**#1** AND **#3** AND **#4**	1,790
#4	**'decision support system'**/exp OR **'clinical decision support'**	15,751
#3	**'electronic medical record'**/exp OR **'electronic medical record'** OR **'electronic health record'** OR **ehr*** OR **emr***	108,258
#2	**'electronic medical record'**/exp OR **'electronic medical record'** OR **'electronic health record'** OR **ehr*** OR **emr***	108,258
#1	**'information system'**/exp OR **'information management'** OR **'anesthesia information management system'**	120,669

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