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Review Article

Medication safety in the operating room: literature and expert-based recommendations

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Abstract

Human error poses significant risk for hospitalized patients causing an estimated 100,000 to 400,000 deaths in the USA annually. Medication errors contribute, with error occurring in 5.3% of medication administrations during surgery. In this study 70.3% of medication errors were deemed preventable. Given the paucity of randomized controlled studies, we undertook a rigorous review of the literature to identify recommendations supported by expert opinions. An extensive literature search pertaining to medication error, medication safety, operating room, and anaesthesia was performed. The National Guidelines Clearinghouse was searched for any anaesthesia or operating room medication safety guidelines.
A total of 74 articles were included. Recommendations were tabulated and assigned points based on a scale revised from a prior study. A total of 138 unique recommendations were identified, with point tallies ranging from 4 to 190. An in-person focus meeting occurred, where the 138 recommendations were reviewed, combined and condensed. A modified Delphi process was used to eliminate items found to be unimportant or those unable to be quantified (e.g. "minimize fatigue"). A total of 35 specific recommendations remained. Adverse events as a result of medication errors occur frequently in the operative setting. There are few rigorous studies to direct medication safety strategies, but this should not lead us to do nothing. The overwhelming consensus regarding best practices should be accepted, and the recommendations implemented. Our list of recommended strategies can hopefully be used to assess local vulnerabilities and institute system solutions.

Key words: anaesthesiology; medication safety; operating room

Human error poses significant risk for hospitalized patients, leading to patient harm and death. Preventable adverse events are estimated to result in between 100,000 to 400,000 deaths in the USA each yr.[1–5] Medication errors contribute to preventable adverse events,[6] and the errors that occur in the operating room are especially problematic, as the anaesthesia provider is typically the only practitioner involved in the entire process, prescribing, formulating, dispensing, and administering the medication, thus removing the protection of double checks that exist in other hospital areas.[7] In one of the only prospective,

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observational studies of medication errors in the operating room, Nanji and colleagues[8] reported that 193 of 3671 (5.3%) medication administrations during 277 operations involved a medication error and/or an adverse drug error, and found that 79.3% were preventable. This rate confirms that of previous retrospective studies. In a survey of South African anaesthetists, 94% reported that they had made at least one error; 22.6% reported at least four errors.[9] A recent study involving self-reported medication errors found an error or near miss in 52/10,574 cases, for an incidence of 0.49%, or one in every 203 cases,[10] echoing the rate reported from New Zealand, (1:133 anaesthetics);[11] South Africa, 0.37% (1:274 anaesthetics);[12] and Japan, 0.22% (1:450 anaesthetics).[13] Common errors include wrong dose as a result of either miscalculation of dose, concentration, or infusion rate; substitution (syringe or ampule/vial swap); repetition (extra dose) and omission (missed dose).[11 14] In all studies, the majority of reported errors were associated with minimal or no harm; however, there are a distressing number of case reports of less common, but lethal or potentially lethal errors, including wrong route,[15–17] miscalculation of dilution or failure to dilute,[18] misprogramming of infusion pumps,[19] administering known allergic drug, and failure to flush a line after a drug.[20 21]

Various techniques to reduce medication errors have been proposed since John Snow advocated the use of a specific chloroform mask to reduce concentration errors with inhaled anaesthesia.[22] Unfortunately, there are few randomized controlled trials that demonstrate the ability of a specific technique to reduce the rate of medication error. Jensen and co-workers[23] recognized this issue in 2004, and undertook a systematic review to identify the evidence available at the time, and to provide recommendations that were at least supported by the Canadian Task Force on Preventive Health Care Level III evidence (i.e. "opinions of respected authorities, based on clinical experience, descriptive studies or reports of expert committees").[24] In the 12 yr since that publication, numerous consensus statements have been released and a set of recommendations from the Anesthesia Patient Safety Foundation.[7] In the absence of sufficient prospective, randomized trials with evidence on which to base practice, we undertook a rigorous literature review to update Jensen and colleagues, by identifying those recommendations that at least are based on "the opinions of respected authorities"[23 24].

Methods

We performed an extensive literature search to identify publications pertaining to medication error and medication safety in the operating room. Searches included PubMed, Google Scholar, and an internet search for national recommendations (Joint Commission [JC], Center for Disease Control [CDC], Association of periOperative Registered Nurses [AORN], Institute for Safe Medication Practices [ISMP]) as detailed below. The National Guidelines Clearinghouse was searched for any medication safety guidelines for anaesthesia or the operating room.

A PubMed search using the MeSH terms 'Drug/Medication Error, Drug/Medication Safety, Operating Room, Anaesthesia' was conducted. In addition, the references of all articles reviewed were checked for additional pertinent articles. Only peer-reviewed articles were included; we assumed all case reports and editorials were peer reviewed. A review of the retrieved titles was performed by two of the authors for inclusion. We excluded foreign language articles unless the abstract was in English and provided enough detail to be included. If neither the abstract nor article could be retrieved through our academic institutions, the article was excluded. As anaesthesia systems, drugs and equipment have changed significantly over the past decades, we limited the search to articles published between 1/1/1994 and 1/1/2014, a 20-yr span.

Inclusion and exclusion criteria were pre-determined, and revised after the first 10 articles had been reviewed. For inclusion, articles had to contain either recommendations regarding medication safety, or cite contributing factors for errors. Errors or recommendations involving physical mistakes such as a needle tip entering the artery during a regional block, an inadvertent spinal puncture during epidural placement, an adverse drug event not as a result of error or violation (de novo anaphylaxis), or awareness under anaesthesia because of equipment failure were excluded. In addition, drug decision errors were excluded unless it involved preventable harm (giving a drug where the patient was known to be allergic). Single case reports were excluded except in rare occasions, for example, a unique error occurred that was not addressed in other articles, or where it provided the background for a detailed review of the literature and expert opinion.

A search of the National Guideline Clearinghouse was performed using the search terms as listed above. In addition, a guideline or consensus statement mentioned in any reviewed publication was retrieved. We included international standards for medication safety (ISO), but did not include country specific standards.

Data extraction and collection

Each included article was reviewed by the first author (JAW) and by one other author. A specific data extraction form was completed for each article, noting the type of publication (guideline *vs* journal article), whether it was peer reviewed or not, and the method of compiling the recommendations or errors (scientific design, expert consensus, case series or report, literature review of published recommendations). A summary list of all recommendations was created in an iterative fashion.

Recommendations were graded according to the type of publication, using a point scale adapted from Jensen and colleagues[23] and modified by human factors engineers: recommendations based on studies with a scientific design were given a score of 8; recommendations based on a formal consensus of experts (e.g. the recommendations made by the Anesthesia Patient Safety Foundation) or a rigorous review of the literature were given a score of 6; recommendations by a group of experts (not reaching formal consensus or guideline level, but where the experts were widely published in the field of medication safety) were given a score of 4, recommendations based on a case series, such as surveys to collect recollections of errors, were given a score of 4, and individual case reports and editorials by a single individual was given a score of 2. Given the dearth of randomized controlled trials (RCTs), any publication that utilized a scientific design was awarded 8 points. These publications included randomized controlled studies, defined retrospective review of prospectively collected databases (national incident reporting systems such as the National Learning and Reporting System, or the Australian Incident Monitoring System, or local registries specifically created to monitor medication errors), observational studies, and an internet survey that invited anaesthetists to perform drug dilution calculations.

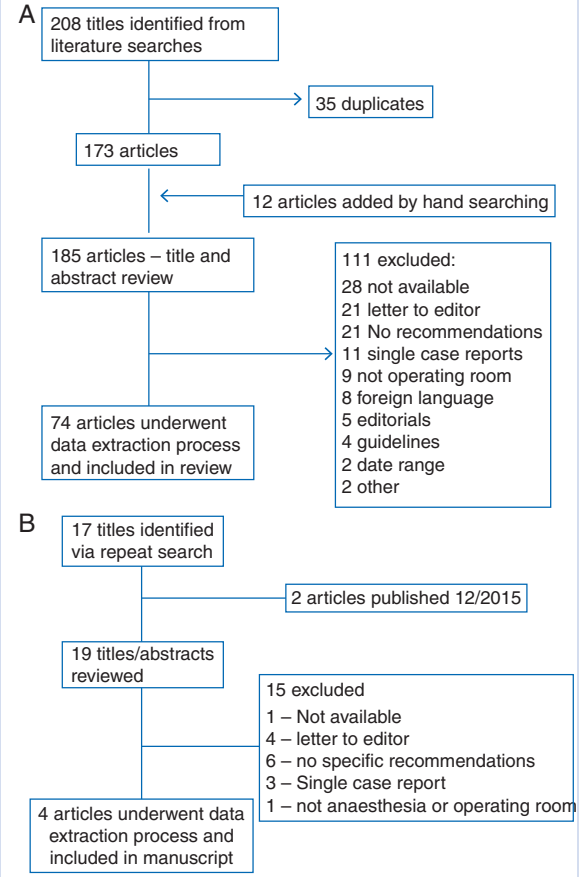

Fig 1 Identification of pertinent articles.
A. Included in Initial Process (Search 1.21.2014)
B. Updated Search (12.7.2015)

Results

A total of 208 articles were identified from the initial literature searches of which 35 were duplicates. An additional 12 articles were identified by hand searches; a total of 185 articles entered the abstract review process. Of these, 111 were excluded, and a total of 74 articles were included (Fig. 1a, Table 1).[10–15 18 20 21 23 25–88] The guidelines search identified six guidelines or sets of recommendations regarding medication safety in the operating room: Association of periOperative Registered Nurses (AORN),[89] Anesthesia Patient Safety Foundation (APSF),[7] Institute for Healthcare Improvement (IHI),[90]American Society of Healthcare (formerly Hospital) Pharmacists (ASHP),[91] the Center for Disease Control (CDC),[92] and the Institute for Safe Medication Practices (ISMP Canada).[62]

A total of 138 specific, unique recommendations were made among the publications and guidelines and the total number of points given to any recommendation were tallied (available as Appendix 1 online supplemental information). The summary of recommendations by category, where italics represent subcategories of the category above, is presented in Table 2, and by point tally in Table 3. Among the 138 recommendations, the points accumulated ranged from 4 points (easy access to drug reference libraries, in only one citation) to 190 (establish an incident reporting system, recommended by 30 publications). The top 50 recommendations based on number of points accrued are shown in Table 3, together with the number of publications that made that recommendation.

The authors, consisting of six physician anaesthetists, one pharmacist with experience in an OR satellite pharmacy, and two human factors engineers, conducted an in-person focus meeting, where the 138 individual recommendations were discussed. Each of the 138 recommendations was left as is, combined with those closely related or, because of a low point score, deleted. After this iterative process, 44 elements remained. A modified Delphi process with 3 iterations was used to eliminate those items the group did not find important to safety (e.g. physician preference cards updated regularly) or those deemed impossible to measure or quantify (e.g. "minimize clutter", "minimize fatigue"). The 35 specific recommendations that remained following this process are shown in Table 4.

This detailed iterative process took 24 months, and a repeat search was therefore performed to identify any articles not included in the prior search. Among the17 new titles identified in the search and two articles identified by hand search, four new articles were identified as being pertinent to this study (two from title search,[93 94]two from hand search.[8 95]) In three articles, recommendations supported the 35 specific recommendations already stated (e.g. bar code use, compliant labeling, route specific administration methods and/or labeling and computer prompts re drug concentrations and dosing). In the fourth article, Nanji and colleagues[8] support barcode assisted documentation and administration, decision support re dose calculation and maximum dosing, and alerts for next scheduled administration, but also made four process based recommendations that were new. These were: 1) changing the time of medication documentation (i.e. scan the syringe before injection to allow for alerts and warnings); 2) reducing opportunities for work-arounds; 3) connecting infusions to the most proximal port, and 4) rigorous vender selection and training. After discussion, we concluded that #2 would be difficult to define or measure; and that #3 and #4 were intriguing, but would have had few points or citations in our original process, and therefore were not included in the final list of 35 recommendations. Recommendation #1 appears to be captured in bar code use, in that it is seemingly obvious that syringes would be scanned before injection, but Merry and colleagues[66] found multiple instances where barcode scanning was simply not done. The recommendation regarding barcode use includes scanning the syringe barcode before administration with visual and auditory alerts.[66] In addition, barcode use should be developed to permit scanning of a drug vial or ampule before drawing up, with a printer system that provides a barcode label for the syringe.[94]

Discussion

The compiled list of recommended strategies to improve intraoperative medication safety presented in Table 3 is based on a rigorous evaluation of the literature, together with significant input from human factors engineers and practitioners. Our list is more comprehensive than that of either Jensen and colleagues,[23] who identified 12 specific recommendations that were then condensed into one general and five specific strategies, or the APSF consensus.[7] Both Jensen and APSF recommendations sought to identify those recommendations that were felt to be the "most important" strategies likely to have the greatest impact on the error rate, while we sought to provide a

Table 1 Included references

Author	Yr	Study type	Points Awarded	Number of Recommendations
Abeysekera [14]	2005	Scientific design	8	5
Amor M [25]	2012	Scientific design	8	2
Arnot-Smith [26]	2010	Scientific design	8	10
Baker [27]	2007	Scientific design	8	2
Beyea [28]	2002	Editorial	2	3
Beyea [15]	2003	Case report	2	16
Beyea [29]	2003	Scientific design	8	14
Bowman [20]	2013	Case series	4	1
Broussard [30]	2009	Case report	2	7
Brown-Brumfield[31]	2010	Review of literature	6	9
Cartwright [32]	2012	Review of literature	6	7
Cassidy[33]	2011	Scientific design	8	2
Cheeseman [34]	2011	Scientific design	8	1
Cohen [35]	2001	Case report	2	5
Cook[36]	2009	Scientific design	8	0
Cooper[37]	2013	Review of literature	6	32
Cooper[10]	2012	Scientific design	8	2
Currie[38]	1993	Scientific design	8	8
Erbe[39]	2011	Scientific design	8	4
Evley[40]	2012	Scientific design	8	2
Fasting[41]	2000	Scientific design	8	11
Froese[42]	2010	Case report	2	4
Gargiulo[43]	2012	Scientific design	8	2
Glavin[44]	2010	Review of literature	6	9
Hanna[45]	2011	Review of literature	6	17
Haslam[46]	2006	Scientific design	8	3
Hendricksen[47]	2007	Editorial	2	2
Hicks[49]	2011	Review of literature	6	15
Hicks[48]	2004	Case series	8	15
Hintong[50]	2005	Scientific design	8	3
Hove[55]	2007	Case series	4	4
Irita[51]	2004	Scientific design	8	2
James[52]	2003	Scientific design	8	9
Jensen[23]	2004	Scientific design	8	17*
Jones[53]	2008	Case series	6	6
Khan[54]	2005	Scientific design	8	6
Koczmara[56]	2007	Case report	2	14
Lessard[57]	1993	Case report	2	6
Llewellyn[12]	2000	Scientific design	8	17
Loughnan[58]	2008	Scientific design	8	0
Majahan[59]	2011	Editorial	2	17
McDonnell[60]	2009	Case report	2	13
Meadows[61]	2009	Review of literature	6	20
Merali[62]	2008	Scientific design	8	14
Merry[65]	2007	Scientific design	8	6
Merry[67]	2001	Scientific design	8	15
Merry[66]	2011	Scientific design	8	9
Merry[64]	2011	Editorial	2	4
Merry[63]	2011	Review of literature	6	24
Meyer[18]	2008	Case series	2	3
Ogelsby[21]	2013	Case report	2	3
Orser[71]	1994	Survey of expert opinion	6	12
Orser[69]	2001	Survey of expert opinion	6	6
Orser[68]	2004	Editorial	2	10
Orser[70]	2013	Review of literature	6	15
Paix[72]	2005	Scientific design	8	2
Sakaguchiaga[73]	2008	Case series	4	3
Shannon[74]	2009	Scientific design	8	5
Shridhar[87]	2011	Case series	4	7
Shultz[75]	2010	Scientific design	8	12
Smetzer[76]	2010	Case report	2	11
Stratman[77]	2013	Scientific design	8	33

(continued)

Table 1. (continued)

Author	Yr	Study type	Points Awarded	Number of Recommendations
Tan[78]	2013	Scientific design	8	2
Thompson[79]	2007	Editorial	2	9
Tienfenthale[80]	2006	Case report	2	2
Walker[81]	2010	Editorial	2	3
Webster[11]	2001	Scientific design	8	1
Webster[83]	2004	Scientific design	8	10
Webster[82]	2010	Scientific design	8	8
Weller[84]	2009	Scientific design	8	0
Wheeler[85]	2004	Scientific design	8	1
Wheeler[88]	2005	Review of literature	6	16
Wildsmith[86]	2002	Editorial	2	1
Yamamoto[13]	2008	Case series	4	7
AORN [89]	2006	Guidelines	6	43
APSF[7]	2010	Consensus	6	32
AHSP	1999	Guidelines	6	20
CDC	2007	Guidelines	6	11
IHI	2012	Consensus	6	25
ISMP	2010?	Consensus	6	80

*Jensen and colleaguesstate they have 12 recommendations, but had combined several into a single recommendation.

Table 2 Outline of types of recommendations

RECOMMENDATION THEME	Number of recommendations
Patient Information	**12**
Medication Reconciliation	*5*
Patient Data	*7*
Drug Information	**8**
Provider	**4**
Bulk Inventory	**7**
Look alike	*3*
Segregate bulk stock	*4*
Cart Inventory	**34**
Organize, standardize drug drawers	*12*
Manage high risk drugs	*13*
Organize cart (not drawer related)	*6*
Regional medications	*3*
Case Medications	**59**
Labeling of medications	*10*
Preparation of medications	*20*
Administration of medications	*14*
Sterile field medications	*7*
Communication	*6*
Pharmacy	**5**
Culture	**9**
TOTAL	**138**

comprehensive set of recommendations to prevent both common and uncommon errors.

Medication error, although it likely has occurred since the dawn of medicine, does not appear in a literature search until the mid 1960s (unit based dosing reduces errors in hospital wards).[96 97] Anaesthesia-related medication error reporting appears even later; our literature search uncovered no references to medication error during anaesthesia, or in the operating room before being mentioned as one of the preventable anaesthesia mishaps reported by Cooper and colleagues.[98] Multiple articles since that time, using voluntarily reported medication errors, have estimated that a medication error occurs in one out of every 130-300 surgeries; a recent direct observational study has put that number much higher, at one in every 2.2 surgeries (of 277 surgeries, 127 had at least one error or adverse drug event) with 79.3% considered to be preventable.[8] Despite the pervasive nature of medication error in anaesthesia, there continues to be a paucity of randomized, controlled trials of interventions to improve medication safety. The only controlled trial of a medication safety strategy that we are aware of is that of Merry and colleagues,[66] who demonstrated that a comprehensive organization, labeling and administration system (SAFERsleep™) that incorporates bar coding at preparation, provides visual and auditory identification at administration, and electronic recording, reduces medication error. Although proved to reduce intraoperative medication errors, uptake of this system has been slow, possibly as a result of its stand-alone nature (anaesthetic record not incorporated into a comprehensive electronic medical record).

Given the lack of randomized controlled studies to direct intraoperative medication safety strategies, definition of best practices must rely on expert opinion. Consensus statements regarding medication safety strategies have been published by multiple entities (ISMP, APSF, AORN) over the past two decades.[7 89] However, as evidenced by Nanji and colleagues[8], these strategies appear to not have been effectively implemented, or these strategies when implemented are not effective, as error rates have not decreased over several decades.[10–12] Only a few studies report on efforts to implement strategies such as those proposed by APSF, either to present effective implementation strategies, or to point to improvements in outcomes.[62] Although most studies of intraoperative medication error find that most errors are associated with little or no harm, a few are devastating, with mortality directly related to the error.[68 71] Clearly, medication error can have significant consequences, and failure to implement safety strategies perpetuates this risk.

Kitson and colleagues[99] have presented a conceptual framework regarding implementation of evidence based practices, which can shed light on why implementation often falters, and inform our efforts to increase implementation of the recommendations so widely supported in our review. This framework

Table 3 Top recommendations by points and number of citations

Topic	Sub-topic	Recommendation	Points	Citations*
Culture	Culture	Incident or error reporting system	190	30
Case Medications	Labeling	Every medication labeled with drug name, date, concentration	178	29
Case Medications	Administration	Read and verify every vial, ampule, syringe label before administration	170	28
Case Medications	Labeling	Colour code labels by drug class	152	25
Cart Inventory	Organize/Standardize drug drawers	Standardize drug trays across all locations	136	21
Culture	Culture	Adequate teaching and in-service training	134	23
Case Medications	Labeling	Bar code and scanner	114	17
Case Medications	Preparation	Use prefilled whenever possible	104	17
Culture	Culture	Written policies for medication safety	100	20
Patient Information		Single location for recording medications	98	15
Patient Information		Automated alerts for dose, allergy, interactions	96	15
Pharmacy	Pharmacy	Pharmacist assigned to support OR	90	15
Case Medications	Preparation	Verify high risk med doses with 2 people	88	13
Cart Inventory	High Risk Meds on Cart	Standardize concentrations across units	84	14
Case Medications	Administration	Bar code scan with audible and visual alert	84	12
Bulk Inventory	Look-alikes	Avoid buying look-alikes	82	14
Patient Information		Verify allergies	74	14
Cart Inventory	High Risk Meds on Cart	Only one concentration of drug on cart	74	12
Case Medications	Administration	Smart pump used for all infusions	68	13
Case Medications	Administration	Retain all vials, ampoules, syringes until end of case	66	10
Case Medications	Administration	Smart pumps have libraries that are standardized across units	66	11
Case Medications	Labeling	Preprinted labels with room for concentration, date, time	64	10
Cart Inventory	High Risk Meds on Cart	Dangerous drugs not stored on cart	62	10
Cart Inventory	Organize/Standardize drug drawers	Drug trays have modular system	62	9
Case Medications	Administration	Colour coded infusions sets for epidural *vs* i.v.	62	12
Culture	Culture	Establish a just culture	62	10
Case Medications	Preparation	Compounded and diluted drugs are prepared by the pharmacy	60	10
Cart Inventory	High Risk Meds on Cart	No concentrated drugs on cart	58	11
Culture	Culture	Adequate supervision	56	10
Case Medications	Administration	2 person verification of all medications administered	52	9
Case Medications	Communication	At handover, review drugs given and all drugs on cart, field	52	10
Case Medications	Communication	Verbal orders are verified by speak back using protocol	52	12
Patient Information	Medication Reconciliation	Complete med reconciliation; meds in standard format in chart	50	8
Provider		Minimize distractions	46	9
Case Medications	Administration	Route specific administration sets (epidural, i.v., etc.)	46	10
Patient Information		Verify weight	44	9
Drug information		Drug info immediately available, maximum doses specified	44	8
Cart Inventory	Organize/Standardize drug drawers	Arrange drugs by drug class	42	6
Cart Inventory	Organize/Standardize drug drawers	Eliminate unusual drugs from usual locations	42	7
Cart Inventory	Organize/Standardize drug drawers	Pharmacy prepares, delivers, tracks all drug trays	40	6
Case Medications	Preparation	Compounded drugs are prepared by pharmacy	40	6
Case Medications	End of case	Discard all syringes, containers, multi-dose vials at end of case	40	6
Drug information		Cognitive aids, checklists, rescue protocols	38	7
Provider		Minimize fatigue	38	7
Bulk Inventory	Segregate bulk stock	Unique i.v. solutions stored in separated area from regular i.v. solutions	38	7
Pharmacy	Pharmacy	Pharmacy policy for identifying, removing outdated drugs	38	6
Case medications	Labeling	Generic terms	36	5
Case Medications	Sterile Field	Verify all meds as passed to field (2 person). Verify against vial	36	7

(continued)

Table 3. (continued)

Topic	Sub-topic	Recommendation	Points	Citations*
Case Medications	Preparation	Pharmacy prepares standardized solutions for OR	34	6
Case Medications	Preparation	Tallman lettering	34	7
Case Medications	Sterile Field	All solutions and meds on sterile field are labeled with drug name, date, concentration	34	7
Case Medications	Administration	All ports clearly labeled as IV, epidural	32	9
Case Medications	Preparation	Medications drawn up by the person who will use them	32	7

*For identification of each article citing a specific recommendation, see Appendix 1, supplemental online information.

consists of the *evidence* that underpins the recommendations, the *context* in which the recommendations are implemented, and how implementation is *facilitated*. In our case, intraoperative medication strategies are hampered by the lack of actual research, and must rely on clinical experience, leading many to ignore the subject altogether. Our qualitative review, like that of Jensen and colleagues,[23] found that the level of consensus among published expert opinions is high, with a strong consistency of view. Although our review found a few recommendations made only once (utilize trained anaesthesia assistants), most recommendations were made by multiple expert groups, and were highly concordant. We found only one recommendation, that of colour-coded labels, to have seemingly contradicting recommendations.[34 46] While Cheeseman and colleagues[34] found that the addition of colour to labels increased the speed of recognition, Haslam and colleagues[46] found that the process of implementing the International Colour Coding System increased the rate of medication errors. This contradiction was weak, as the errors in the Haslam study occurred primarily as a result of a change in the system of colour coding (e.g. blue now indicated narcotic whereas it formerly indicated neuromuscular blocking agent).

The second pillar of implementation in Kitson's framework is the context in which recommendations are made, namely the culture of the organization. It is striking that the recommendation with the strongest support was the establishment of a voluntary and blame free incident reporting system. There was a strong emphasis on establishing a just culture that encourages reporting of errors with the understanding that individual errors typically require a system solution, but yet with accountability for willful violations. Once again, there is a paucity of literature that specifically addresses how safety culture impacts implementation of medication safety strategies.

The final pillar of implementation is facilitation, that is, "the type of support required to help people change their attitudes, habits, skills, ways of thinking and working".[99] Critical to any change implementation is helping teams believe that change is needed. Nanji and colleagues[8] have furthered this cause by demonstrating that medication errors are much more common than believed, that many result in adverse events, and that many are preventable. However, a given institution or individual may believe that their practice is "safer" than that presented, and may believe that they have already instituted necessary strategies. To date, there has not been a tool to assist in identifying hazards; we believe that our list may be most valuable when used as a tool to assess vulnerability within an institution. Like Jensen and the APSF task force, we set out to collate recommended strategies to prevent medication error, but we have kept our list comprehensive, rather than focus on the "most important" as some items not on prior lists (label/identify every catheter with route) might have prevented errors with devastating outcomes (epidural bupivacaine given intravenously; i.v. chemotherapeutic agent given intrathecal).

Each item in our list offers opportunities for error reduction (cognitive aids on crash cart or malignant hyperthermia cart); our expert panel felt that failure to use the strategy represents vulnerability in the system. Once identified, an institution can determine which vulnerabilities can be ameliorated; reassessment of vulnerability can be conducted on a recurring basis.

Limitations

As already recognized, our study is limited by the dearth of high quality, prospective medication safety studies, obviating a rigorous, systematic review that could follow either a Cochrane or PRISMA format. Like the APSF consensus,[7] and the review by Jensen and team,[23] this list of recommendations is based nearly entirely on expert opinion, whether in the context of a review of voluntarily reported errors, solicited expert opinions, or formal consensus statements or guidelines. However, this review was conducted with a defined search strategy, specific inclusion and exclusion criteria, a systematic review process, and a clear process for weighting the recommendations. We utilized validated methods such as focus group review and a modified Delphi technique to refine our recommendations.

The only true RCT in medication safety with an outcome of error reduction we identified was that of Merry and colleagues,[66] which tested the ability of a computer-based bar code system to provide visual and auditory identification before administration. This system included several other strategies such as standardized cart drawers and surfaces, with prescribed placement of each type of drug (e.g. unusual drugs not typically used placed in unique colour coded bin on the cart top), and a method for clearing all unusual drugs after each case. This integrated system was shown to be effective in reducing drug errors, but which of the specific components of the system contributed to the reduction cannot be determined. Each of the components in this system has been included in our list as a recommended strategy, but there are also many recommended strategies that have never been rigorously tested. However, the rate of error, the wide variety of types of errors and contributing events, and the cost of randomized, controlled trials makes the investigation of each individual recommendation nearly impossible.

Finally, we did not include a step used in the Jensen study, that of rating recommendations based on the authors' belief that it would have prevented a specific error reported in the literature. While we recognize the potential value of this step, the history of medicine offers many instances where a change in process was believed to offer improved care, but did not. The most obvious of these is the step of marking the operative site to prevent wrong site surgeries. Recommended by the Joint

Table 4 Medication safety strategies

THEME	RECOMMENDED STRATEGY
Patient Information	Complete medication reconciliation
	Medications in standard format in chart
	Single location for recording medications across surgery (pre, intra, PACU)
	Time out includes: (note number of timeouts observed)
	Patient identification
	Weight
	Allergies
	Medication information such as antibiotic given
	Automated alerts within anaesthesia information system for:
	Dose
	Allergy
	Drug-drug interactions
	Establish weight-based dose limits*
	Infusion device has prompts re limits
	Computer prompted
	Paper sheet to consult
Drug Info	Cognitive aids, checklists, rescue protocols; Infusion rate charts
	Specialized carts have protocols (malignant hyperthermia, cardiac arrest)
Cart Inventory	Drug trays in anaesthesia carts:
	Standardized across all locations
	Tray divisions labeled clearly
	Drugs placed to minimize confusion
	Modular system
	Pharmacy manages drug trays
	Eliminate unusual drugs from usual locations
	Unique location or tray
	Remove at end of case
	Single use vials preferable;
	If multi-dose vial required, discard at end of case
	Management of high risk/dangerous drugs
	No concentrated drugs
	Only one standard concentration on cart
	Pharmacy provides diluted, high risk drugs (insulin, heparin)
	Alert label on concentrated or high risk drugs
	No large volume epinephrine
	Separate regional cart for regional drugs
	Only preservative free local anaesthetics
	SQ or topical local anaesthetics clearly labeled
	Pharmacy prepares all compounded drugs
	Regional anaesthetic solutions clearly segregated from i.v. meds
Administration	Every medication labeled with name, date, concentration*
	3 if Barcode system used
	2 if Preprinted, colour coded per ISO standards
	Avoid abbreviations and zero issues
	Unlabeled syringe immediately discarded
	Minimize provider prepared syringes
	Prefilled whenever possible
	Compounded and diluted drugs prepared by pharmacy
	Provider prepares dilutions of high risk meds, 2 person check or careful double check
	Verify high risk med and weight based doses with 2 people
	Asepsis
	Cap syringes
	Sterile technique for spinal/epidural placement, injection
	Read and verify every vial, ampoule, syringe label before administration*:
	Barcode system in use with audible and visual cues
	Use a 2 person check
	Single person check
	Smart pump used for all infusions
	Smart pumps are standardized across units
	Pumps have libraries with guardrails and alerts
	Clearly identify route of administration:

(continued)

Table 4. (continued)

THEME	RECOMMENDED STRATEGY
	Route specific administration sets (epidural, i.v., etc.); Colour coding (yellow epidural, red arterial); Labels on every infusion line and port No ports on epidural/intrathecal lines Sterile field meds: Only 1 med passed to field at a time, Checked and verified aloud by 2 persons Labeled with drug name, date, concentration Any unlabeled discarded Segregation of topical or irrigation fluids (not in parenteral syringe) Handovers (shift changes, relief, PACU/ICU, nurse, MD) have protocol driven review of drugs given and all drugs on cart, field Verbal medication orders verified by speak back, announced when given, entered into chart (preferable recorded in AIM) Discard all syringes, containers, MDV at end of case unless connected to patient - clean sweep
Culture	Non-punitive QA system for incident reporting, analysis, and intervention Written policies for medication safety; adequate teaching of new staff on policies Establish a culture of respect and collaboration that endorses patient safety and establishes compliance (just culture/compliance) Adequate supervision, teaching and in-service training
Pharmacy	Formulary designed to avoid purchase of lookalike meds; when unable to avoid, do not store in proximity; add alert labels to lookalike medications Pharmacist assigned to support OR; Pharmacists available 24/7 for questions; Pharmacists participate in educational, M&M; OR pharmacists receive specialized education re OR Pharmacy responsible for medication flow (ordering to discard) Pharmacy stocks, tracks, delivers drug trays; Pharmacy prepares all compounded or diluted high risk drugs Pharmacy prepares infusions Policy for return of unused or unusual drugs - clean sweep Changes in drugs supplied (new labels, new concentrations) require alerts to staff and possibly alert labels on new drugs Unique i.v. solutions (glucose, heparin, hypertonic, sterile water, epidural solutions) stored separate from regular i.v. solutions

*Recommendations represent the various options, moving from least vulnerable system to more vulnerable.

Commission in 1998, this single process change did not have the desired effect, despite being seemingly such an obvious solution to preventing wrong site surgery.[100 101] Our approach therefore has been to simply present the recommendations that are most strongly advocated by experts in the field; whether or not implementation of these recommendations will change the rate of medication errors remains to be seen.

Conclusions

Adverse events related to medication errors occur frequently in the operative setting and most are preventable. Although many are readily caught and corrected, some result in tragic outcomes. To date we have only a single randomized controlled trial of interventions to prevent such errors. The dearth of evidence from randomized controlled trials, however, is not permission for us to do nothing, or to view the current state as acceptable. The number of patients who have died as a result of operative medication error requires that vigorous attempts be made to assess vulnerabilities in medication safety that exist in our operating rooms, and to put system level processes in place to prevent harm. Institutions hopefully can use our list of recommended strategies as a tool to assess vulnerabilities and institute system solutions.

Authors' contributions

Study design/planning: J.A.W., J.H.A., E.H.L., J.R.K., M.H.W., I.L. , R.W., R.L.C. Study conduct: J.A.W., J.H.A., E.H.L., J.R.K., M.H.W., I.L. , R.W., R.L.C. Data analysis: J.A.W., J.H.A., E.H.L., J.R.K., M.H.W., I.L. , R.W., R.L.C. Writing paper: J.A.W., J.H.A., E.H.L., J.R.K., M.H.W., I.L. , R.W., R.L.C. Revising paper: all authors

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

Declaration of interest

JAW serves as a member of the ASA Anesthesia Incident Reporting System Committee and as deputy editor for the anaesthesia safety section of UptoDate. Her department has received support in exchange for her participation in the

Medtronic Team Training in Patient Safety for Cardiovascular Teams. She has no personal or family financial conflict.

JHA serves as chair of the Society of Cardiovascular Anesthesiologists Quality, Safety, and Leadership Committee; he has received an unrestricted educational grant from PharMEDium Services.

MHW serves as chair of the ASA Critical Care Committee and as a member of the ASA Deep Sedation Committee; he has no financial conflict of interest.

RLC serves as a reviewer for ISMP Newsletter and has received an honorarium from Bectin Dickinson for presenting a webinar on medication safety.

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