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SPECIAL ARTICLE

Evidence-based strategies for preventing drug administration errors during anaesthesia

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Summary

We developed evidence-based recommendations for the minimisation of errors in intravenous drug administration in anaesthesia from a systematic review of the literature that identified 98 relevant references (14 with experimental designs or incident reports and 19 with reports of cases or case series). We validated the recommendations using reports of drug errors collected in a previous study. One general and five specific strong recommendations were generated: systematic countermeasures should be used to decrease the number of drug administration errors in anaesthesia; the label on any drug ampoule or syringe should be read carefully before a drug is drawn up or injected; the legibility and contents of labels on ampoules and syringes should be optimised according to agreed standards; syringes should (almost) always be labelled; formal organisation of drug drawers and workspaces should be used; labels should be checked with a second person or a device before a drug is drawn up or administered.

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Human error is an important problem in health care that causes harm to patients and increases costs [1–3]. Medication errors are particularly common [1,2]; in one estimate they accounted for 7000 deaths in the United States and increased hospital costs by more than $2 billion during 1993 alone [3]. Errors specifically related to drug administration are particularly troublesome in anaesthesia, where they may occasionally lead to devastating consequences for the patient, and at times for the anaesthetist as well. Furthermore, from lay and legal perspectives, error in something as apparently simple as drug administration carries powerful connotations of carelessness, albeit that this may be far from the truth [4].

The principle that medical practice should be 'evidence-based' has recently received great emphasis. 'Levels of evidence' have been identified [5,6]. Ideally, techniques used to administer drugs safely during anaesthesia should be evidence-based. In fact, practice in respect of this fundamental anaesthetic responsibility tends to be highly idiosyncratic [7–9]. Anecdotally, this is sometimes defended on the grounds that there is virtually no evidence at levels I or II, i.e. from randomised or controlled trials, to support any particular approach. However, a paucity of evidence at levels I and II does not justify such idiosyncrasy. On the contrary, Sackett *et al.* state that evidence-based medicine implies 'tracking down the best external evidence with which to answer our clinical questions' [10]. They go on to say that '…if no randomised trial has been carried out for our patient's predicament, we must follow the trail to the next best external evidence and work from there.' Such evidence would include the 'opinions of respected authorities, based on clinical experience, descriptive studies or reports of expert committees' [5], and could provide a basis for formulating agreed guidelines for safe drug administration [11]. In addition, evidence of this sort would provide a

well-informed starting point for trials designed to generate more evidence at levels I or II.

Therefore we have undertaken a systematic review of the literature to develop a list of recommendations for reducing error in intravenous drug administration in anaesthesia, based on the best evidence available. Because the majority of this evidence is at level IV, we developed our own operational ranking, which amalgamates levels I to III and provides a more fine-grained categorisation of level IV. Using this tool, we rated recommendations according to the number of authorities and the strength of evidence supporting them. In a second step, we validated these recommendations against reports of actual drug errors and pre-errors (near misses) collected in a previous study by our group [12]. In a third step, we identified additional recommendations from consideration of those reported incidents which would not have been prevented by any of the recommendations generated in step 1.

Methods

Step 1 – review of the literature and generation of the recommendations

We attempted to identify as many publications and reports (collectively termed the 'references') as possible from 1978 to 2002 inclusive (1978 being the date of Cooper *et al.*'s landmark study [13]), related in any way to error in the administration of drugs by intravenous bolus during anaesthesia. We first carried out a computerized search of the databases of PubMed, MEDLINE and EMBASE. The following key words were used: anaesthesia, medication error, error, medical errors, syringes, intravenous injections, i.v., pharmaceutical preparations, drug(truncated), adminst(truncated), dose, dosage (for searching MEDLINE and EMBASE), drug error and anaesthesia, violations and anaesthesia, drug errors and labels, drug error, drug error and colour coding, colour coding or labels and anaesthesia, prefilled syringes, colour coding and anaesthesia (for searching PubMed). In all cases, if a word had different British and American spellings, each was used in a separate search. All languages were included at this stage. In addition, we reviewed a substantial number of references related to drug error in anaesthesia that had already been collected over 7 years as part of ongoing research into this topic by our group. The Cochrane Library was checked for reviews of the topic. The reference section of each relevant publication was then examined to identify any further relevant publications, and these were obtained. The process of reference checking was repeated until no further relevant publications or reports could be identified. No attempt was made to identify unpublished material.

From these references, we then selected those with one or more recommendations (explicit or implicit) in relation to avoiding error in drug administration by intravenous bolus during anaesthesia (recommendations related to drug infusions were ignored). References in languages other than English that did not report randomised trials of specific strategies to prevent drug error were then excluded.

One investigator (L.S.J.) evaluated all the selected references for any evidence (including opinion) related to the causation or prevention of intravenous drug administration error in anaesthesia. Each publication or report included in the analysis was then allocated to a category (I to IV) of such evidence (Table 1) using the classification of Eccles *et al.* [6]. We then assigned these publications or reports to our own operational ranks of evidence (from A to D), which took into account the distribution of publications between these categories (Table 1). We amalgamated categories I to III of the Eccles' classification into rank A, and divided category IV into ranks B to D, depending on the extent to which the opinion expressed reflected any formal evaluation of data, and on the status of the publication in which such opinion was expressed. Opinion grounded in reports of cases was ranked as B. Rank C included surveys of the opinion of a number of 'experts', and publications whose standing provided some endorsement of the authority concerned, e.g. editorials, book chapters, narrative reviews, etc. Simple assertions of opinion published in the correspondence section of journals were ranked as D.

Two investigators (L.S.J. and A.F.M.) then reviewed the references together to identify strategies to prevent intravenous drug administration error in anaesthesia. These strategies were then categorised according to common themes, and each category was expressed as a recommendation for the reduction of intravenous drug administration error in anaesthesia. A list was made of all references containing evidence related to each recommendation. A distinction was made between evidence supporting the recommendation and that which opposed it.

A weighted evidence score was calculated for each recommendation. The aim of this score was to reflect the quantity of evidence at each rank for or against the recommendation, but also to mitigate the impact of multiple publications from the same authority. Points were allocated using the scheme shown in Table 2, first for supporting references and then for opposing references. For example, if an author 'Smith' had two publications in support of a particular safety recommendation, the first at rank B and the second at rank D, the evidence score for these would be 7. The number of authorities supporting each opinion was also counted, an authority being defined as the first author of each reference. In general, any given authority was counted only once in relation to any recommendation. However, if an authority appeared on

Table 1 Categories of evidence defined by Eccles *et al.* [6], definitions of the corresponding operational ranks of evidence used in the present study (with examples) and the number of publications identified at each rank.

Category of evidence	Definitions of the operational ranks of evidence, with references to example publications	Operational ranks of evidence and publications identified in each rank
Ia: evidence from meta-analysis of randomised controlled trials Ib: evidence from at least one randomised controlled trial IIa: evidence from at least one controlled study without randomisation IIb: evidence from at least one other type of quasi-experimental study III: evidence from non-experimental descriptive studies, such as comparative studies, correlation studies and case-control studies	Studies involving experimental designs [7] or prospectively collected incident reports [9].	A (n = 14) [7,9,12–15,25–32]:
IV: evidence from expert committee reports or opinions and/or clinical experience of respected authorities	Reports of series of cases [33]; reports of individual cases [48]; reports of cases or series in the form of a letter	B (n = 19) [33–51]:
	Surveys of opinion of specified 'experts' [53,57]; reports of expert committees [55]; book chapters [56]; narrative reviews [52]; editorials, or articles expressing the viewpoint of one or more acknowledged experts in the field [62]	C (n = 17) [8,17–19,52–64]:
	Correspondence not including case reports or other data relevant to the prevention of drug administration error [24]	D (n = 48) [16,20–24,65–106]

Table 2 Scheme for the allocation of points to each reference. Ranking was based on the operational ranks (A–D) identified in Table 1. An authority was defined as the first author of each publication or report.

	Highest ranking reference from each authority	Second highest ranking from that authority	Each additional reference from that authority
Rank A	8	4	2
Rank B	6	3	1
Rank C	4	2	0
Rank D	2	1	0

both sides of the balance, for instance if he or she supported a strategy under certain circumstances but not under others, this authority was counted on each side as if he or she had not appeared on the other.

If clear evidence at rank A or B in support of or against a theme was available, the recommendation was to be rated as clearly recommended (or clearly not recommended). Otherwise, recommendations were categorised as strongly recommended, recommended, possibly recommended or unclear (with equivalent not recommended categories). To do this, the quantity of evidence available was first considered, taking account of both the number of authorities and the total number of points (the sum of points for and points against) for each recommendation. Recommendations were divided into those with a substantial quantity of evidence (≥ 10 authorities and ≥ 40 points), those with an intermediate quantity of evidence (5–9 authorities and > 20 points) and those with a small quantity of evidence (< 5 authorities and < 20 points). Within the first two of these divisions, the balance of the evidence was then considered, reflected by the percentage of the points supporting (or not supporting) the recommendation. To achieve a given strength of recommendation required greater uniformity of opinion if the quantity of evidence was intermediate than if it was substantial. If the quantity was small, the recommendation was classified as unclear whatever the balance of points. This process is summarised in Table 3.

Step 2 – validation of the recommendations using incident data

A published audit [12] produced a set of reports in relation to 81 errors and 40 pre-errors in drug administration during 10 806 anaesthetics in two tertiary teaching hospitals in New Zealand. From these reports, we selected those that related to intravenous bolus administration. We then excluded those reports in which no information other than an affirmative response that an incident had occurred had been recorded.

Six volunteer anaesthetists and one investigator (L.S.J.) evaluated each of the remaining reports against each of the recommendations identified in step 1. For each error (including the errors narrowly avoided in the pre-error

Table 3 Scheme for determining the strength of a recommendation, based on the percentage of points for or against a given principle. The scheme for point allocation is shown in Table 2. In each case, a similarly worded finding of 'not recommended' would apply if the appropriate balance of points was opposed to the recommendation.

	Clear balance of evidence at ranks A and B	No clear balance of evidence at ranks A and B		
Strength of recommendation		≥ 10 authorities and ≥ 40 points	5–9 authorities and > 20 points	< 5 authorities or < 20 points
Clearly recommended	Achieved	Not achieved	Not achieved	Not achieved
Strongly recommended		Achieved if supported by ≥ 90% of points	Not achieved	Not achieved
Recommended		Achieved if supported by ≥ 75% of points	Achieved if supported by ≥ 90% of points	Not achieved
Possibly recommended		Achieved if supported by ≥ 66% of points	Achieved if supported by ≥ 75% of points	Not achieved
Unclear		Achieved if supported by < 66% of points	Achieved if supported by < 75% of points	Achieved

reports), they were asked to judge whether each particular recommendation, had it been in place at the time, would have been likely to prevent the error. The affirmative responses were then collated. Where a majority of reviewers answered 'yes', it was deemed that the recommendation would have been of value in preventing the event had it been used. An analysis was then undertaken using an EXCEL spreadsheet to identify the collective effect of different combinations of these recommendations on the total number of events that would have been prevented. This was done by removing recommendations in a stepwise manner until the grand total of preventable events was reduced. In this way, a core group of recommendations was identified, each of which was considered likely to have prevented incidents over and above the incidents that would have been prevented by all the other recommendations taken collectively. The strength of each of these recommendations was therefore upgraded by one step, unless it was already at the highest grade, in which case the recommendation was marked as 'endorsed'.

Step 3 – identification of additional recommendations from the incident data

Two study authors (L.S.J. and A.F.M.) then evaluated the incidents that would not have been prevented by any of the recommendations (in the opinion of the majority of the reviewers) in order to identify any further recommendations which might have been effective in these cases.

Results

Step 1 – review of the literature and generation of recommendations

Ninety-eight references related to drug administration error in anaesthesia by intravenous bolus, and containing at least one identifiable recommendation, were identified and categorised (Table 1). Only one involved a randomised clinical trial (conducted in a human-patient simulator) [7]; two could be considered experimental or quasi-experimental [14,15]; 11 others contained observational data, and 19 included information about cases or series of cases. Evidence from the remaining 65 (of which 48 were letters) was in the form of opinion unsupported by data.

All references acknowledged the importance of reducing drug administration error in anaesthesia, except one in which the author expressed the partially dissenting view that further communications on the subject of syringe swaps were no longer novel because of the number of publications already in print [16]. Opinion as to how a reduction in intravenous drug administration error should be achieved was divided into two main groups. There was no dissent from the theme that reading the label is important (Table 4). However, one group (weighted opinion score 20 points from seven authorities) appeared to hold that reading and checking labels should be the sole, or at least the central, strategy for avoiding drug administration error [16–24]. Members of this group did not necessarily eschew all systematic countermeasures to drug error. For example, Goresky advocates the separation of ampoules of similar appearance and emphasises the need for consultation before the introduction of new drugs into the operating room [20]. Nevertheless, this group is characterised by the view that supplementary means of identifying syringes and ampoules, particularly the use of colour coding, may detract from the primary technique of reading the label, and therefore be counterproductive. An extreme expression of this position suggests that it may be better for all ampoules to be of similar shape and size, with the objective of forcing

Table 4 Specific recommendations related to the avoidance of error in drug administration by intravenous bolus during anaesthesia, in order of strength.

Recommendation	Support in principle	Dissent in principle	Recommendations
(1) The label on any drug ampoule or syringe should be carefully read before a drug is drawn up or injected.	180 Points 38 Authorities A [7,9,14,26,28,31,32] B [33,34,38,40,44–46,48–51] C [8,17–19,55–59,61–63] D [16,20,22–24,47,65,67,69,71,81, 82,85,90,93,98,101,103–105]	None	**Strongly recommended** 100% by points from ≥ 10 authorities Endorsed by incident data analysis
(2) Legibility and contents of labels on ampoules and syringes should be optimised according to agreed standards in respect of some or all of font, size, colour and the information included (NB: there may be some disagreement on the detail of how this should be achieved).	76 Points 18 Authorities A [7,9] B [33,42,49] C [17,19,53,55,59,61–63] D [70,75,78,79,84,86,94,97]	None	**Strongly recommended** 100% by points from ≥ 10 authorities
(3) Syringes should be labelled (always or almost always).	76 points 16 authorities A [7,9,14,15,26] B [33,38,44] C [18,55,63] D [70,76,81,85,87,93,102]	None	**Strongly recommended** 100% by points from ≥ 10 authorities
(4) Formal organisation of drug drawers and workspace should be used with attention to: tidiness; position of ampoules and syringes; separation of similar or dangerous drugs; removal of dangerous drugs from the operating theatres.	89 points 15 authorities A [7,9,13,30]: B [33,36,38,39,48–50] C [55,61–63] D [20,88]	None	**Strongly recommended** 100% by points from ≥ 10 authorities
(5) Labels should be checked specifically with a second person or a device (such as a bar code reader linked to a computer) before a drug is drawn up or administered.	31 points 6 authorities A [7,9] B [33,38] C [8,52,56] D [90,92,104]	2 points 1 authority D [96]	**Recommended** 93.9% of points from ≥ 5 but < 10 authorities Upgraded by incident data analysis to: Strongly recommended
(6) Errors in intravenous drug administration during anaesthesia should be reported and reviewed.	42 points 7 authorities A [15,29] B [40,48,51] C [62,63] D [66]	None	**Recommended** 100% by points from ≥ 5 but < 10 authorities
(7) Management of inventory should focus on minimising the risk of drug error (e.g. a drug safety officer and/or a pharmacist should be appointed for the operating theatres and any changes in presentation should be notified ahead of time).	26 points 6 authorities A [9] B [43] C [55,63] D [88,99]	None	**Recommended** 100% by points from ≥ 5 but < 10 authorities
(8) Similar packaging and presentation of drugs contribute to error and should be avoided where possible.	95 points 22 authorities A [9,25] B [33,34,37,41,45,46,48,50,51] C [57,63] D [20,68,70,75,77,82,83,96,97,99–101]	11 points 4 authorities C [19] D [16,21,22,24]	**Recommended** 89.6% by points from ≥ 10 authorities
(9) Drugs should be presented in prefilled syringes (where possible) rather than ampoules (either for emergency drugs or in general).	29 points 7 authorities A [7,25] B [33,37] C [54] D [73,74,104,106]	8 points 2 authorities C [54,60]	**Possibly recommended** 78.4% by points from ≥ 5 but < 10 authorities Upgraded by incident data analysis to: Recommended
(10) Drugs should be drawn up and labelled by the anaesthetist who will administer them.	30 points 7 authorities A [9] B [38] C [54,61,64] D [88,93]	4 points 1 authority C [54]	**Possibly recommended** 82.2% by points from ≥ 5 but < 10 authorities

Table 4 (*Continued*).

Recommendation	Support in principle	Dissent in principle	Recommendations
(11) Colour coding by class of drug according to an agreed national or international standard should be used – of the syringe, part of the syringe, or of the syringe or ampoule labels.*	78 points 21 authorities A [7,9] B [33,35,41,47,48] C [53,56,58,59,63] D [16,65,69,72,75,81,90,92, 95–97,99,101,103–105]	30 points 7 authorities A [14] B [18] C [17,19,55] D [22,67,82,91]	**Possibly recommended** by 72.2% by points from ≥ 10 authorities
(12) Coding by syringe position or size or by the needle on the syringe should be used.	25 points 6 authorities A [9,14] B [44] C [8] D [67,71,85,88]	18 points 3 authorities A [9,26] D [88]	**Unclear** 58.1% by points from ≥ 5 but < 10 authorities

*One authority disapproves of colour coding in general but allows the possibility of red ampoule tips to warn of danger [18]; Fasting *et al.* concluded that colour coding was ineffective in eliminating syringe swaps, but this study was under-powered and, in a subsequent editorial, Orser [63] argued that one-tailed testing would have been appropriate, in which case the combination of colour coding and education would have resulted in a significant reduction in error.

anaesthetists to read the label [16]. Another group (weighted opinion score 314 points from 69 authorities), some of whom cite evidence from the disciplines of cognitive psychology and systems design, take the contrary view that reading and checking the label, while essential, are bound to fail some of the time unless supplemented by measures aimed at reducing error [7–9,12–15,20,25–106]. This group advocates a number of strategies to supplement reading and checking, or at least to identify errors if they do occur and facilitate an appropriate response (Table 4). Thus, 94% of opinion, by weighted points from a total of 76 authorities, supported the use of systematic countermeasures to drug administration error in anaesthesia, permitting us to make a strong recommendation to that effect (Table 4).

Twelve categories related to achieving a reduction in drug administration error were also identified that met the criteria for making a recommendation, i.e. they were supported (or opposed) by references from at least five authorities, and scored at least 20 points (see Table 3). From these themes, four strong recommendations, four recommendations and three possible recommendations were justified by the analysis of the references (Table 4); for the twelfth category the weight of opinion was unclear.

Step 2 – validation of the recommendations using incident data

Fifty two of the 81 error reports and 32 of the 40 pre-error reports were related to intravenous boluses. The information in four of the pre-error forms was minimal, i.e. only the 'Yes' and 'Pre-error' boxes were ticked. These were therefore excluded. In the opinion of the majority of the reviewers, each of 10 out of the 12 recommendations would have been likely to prevent at least one of the events, and 65% of the events would have been prevented by one or more of the recommendations had all of them been in place (Table 5 – the ineffective strategies numbered 6 and 12 are not shown). Removing recommendations from the analysis in a stepwise manner, starting from the least effective, made no difference to this total until only the three most effective (recommendations 1, 5 and 9) remained. Removing any of these three resulted in a reduction of the total number of incidents that would have been prevented by the remaining combination of recommendations. These three were therefore upgraded by one step if possible, or flagged as endorsed if already at the highest step.

Step 3 – identification of additional recommendations from the incident data

There were 22 errors and four pre-errors for which none of the strategies was thought likely to be effective by the reviewers. There was insufficient information to make a judgement in one error and one pre-error.

Failure in communication in one form or another was the most common contributing factor in the remainder. A lack of communication between the anaesthetist and the surgeon (leading, for example, to the administration of an incorrect or unwanted antibiotic) contributed to three errors; failure to read the notes or the anaesthetic record contributed to two errors and two pre-errors; failure to obtain pertinent or accurate pre-anaesthetic information, e.g. about allergy, from the patient contributed to two errors and one pre-error; other failures in communication resulted in two errors. We judged that

Table 5 Incidents which, in the judgement of the reviewers, would have been prevented had particular strategies, numbered across page, been followed. Totals for the 28 pre-errors and 52 errors (80 incidents) used for validation are shown under their respective error categories in column *n*. The column labelled *All* indicates the number of incidents that would have been prevented by at least one of the strategies had all the strategies been in place. Strategies 6 and 12 would not have directly prevented any of the incidents and are not shown. Strategies 1, 5 and 9 together were sufficient to prevent all incidents from this database.

Strategies	n	*All*	1	2	3	4	5	7	8	9	10	11
Incorrect dose – errors	16	12	8	7	0	0	9	0	1	8	7	0
Incorrect dose – pre-errors	3	3	0	0	0	0	3	0	0	1	0	0
Omission – errors	5	0	0	0	0	0	0	0	0	0	0	0
Repetition –errors	4	0	0	0	0	0	0	0	0	0	0	0
Substitution -errors	17	16	15	8	0	0	14	0	4	8	1	5
Substitution – pre-errors	16	16	16	13	3	2	16	0	8	11	0	10
Others – errors	10	1	0	0	1	0	0	0	0	1	1	0
Others – pre-errors	9	4	4	4	0	1	4	3	3	4	0	1
Incidents prevented by strategy; *n*		52	43	32	4	3	46	3	16	33	9	16
Incidents prevented by strategy; %		65%	54%	40%	5%	4%	58%	4%	20%	41%	11%	20%

two further recommendations could be made on the basis of this information: a clear drug history (including information on allergies) should be explicitly obtained from the patient and/or the patient's notes before any anaesthetic is administered (supplementary recommendation number 1); before any drug is administered on behalf of another health professional, explicit communication should take place (supplementary recommendation number 2).

Inattention, haste, distraction or fatigue contributed to six errors and one pre-error. The investigators judged that the strategies already identified in the study might have been helpful in preventing these had they been assiduously applied. Fatigue countermeasures might also have been helpful, but incident-based evidence for this is not compelling [12]. One error involved a technical problem with purging drug in the dead space of the intravenous line. One error involved administering vancomycin too quickly. The investigators judged that both of these errors reflected inexperience. In theory, they could have been countered by training. However, training of anaesthetists in pharmacology is already very extensive, so it was not clear what specific recommendation could be made that would have been both practical and effective in countering these incidents.

The remaining five errors were all omissions of intended drugs; no omission was thought preventable by any of the strategies identified in this study. It has been suggested that the use of a 'prompt' area in the workspace might be helpful in preventing these omissions [33], but only in one reference. The evidence was thought inadequate to justify a firm recommendation.

In summary, we are able to make six strong recommendations (one general and five specific), four recommendations and two possible recommendations on the basis of a synthesis of our analyses of the literature and of the error and pre-error reports (Table 4). In addition, we were able to make two supplementary recommendations (supplementary 1 and supplementary 2) on the basis of analysis of the incident data alone.

Discussion

This is the first systematic review of the literature on the reduction of intravenous drug administration error in anaesthesia. The results of this review have been refined by reference to reports of actual errors and near misses in 10 806 anaesthetics. We have produced a list of specific recommendations (Table 4) that reflect the best evidence available, and therefore provides the most authoritative guide so far published, on the minimisation of the important risk of intravenous drug administration error in anaesthesia. Within this list we have identified five specific strong recommendations.

Other comparable, relatively comprehensive lists of recommendations specifically targeting the reduction of intravenous drug administration error in anaesthesia have been published [9,48,63]. There is considerable overlap between these lists and ours. Orser & Oxorn [48,63], although strongly emphasising the need to check before administering a drug, stop short of specifying that the check should involve a second person or device, and Currie *et al.* [9] advocate a second person check whenever more than one person is involved. Our position on this point is stronger; the results of our study suggest that this form of double check could have prevented 58% of the errors reviewed, which made it the most effective single measure in our list. There is no recommendation in the lists from Currie *et al.* and Orser & Oxorn which runs contrary to our list. The main difference between our list and theirs is that ours has been weighted and ranked to reflect the available evidence, and has been tested against

reports of actual events. There are also a number of publications containing lists that address related problems. Our study differs from these in that it deals with a single clearly defined aspect of drug administration error and aims to do so comprehensively. The recommendations of this study endorse the list of concepts described in previous work from our own group [33]. This could reflect bias in the present process, but these concepts were formulated in part from a review of essentially the same body of literature, albeit by a less formal process than the present one, so it would be surprising if we had reached a substantially different endpoint.

Overarching our list of recommendations is the assumption that systematic countermeasures to reduce intravenous drug administration error are likely to be effective. This assumption is consistent with the teaching of several authorities on human psychology and the principles of safe design in general [107–109]. There are a number of authorities who appear to disagree with this position [16–19,21,23,24]. Our approach has demonstrated that they are in a substantial minority. This does not prove that they are incorrect, but it does perhaps place the onus on them to demonstrate that the majority view in this matter is misguided.

Our study has several limitations. Its greatest weakness arises from the fundamental problem that very little of the evidence evaluated in this study is experimental, and most is simply opinion. This weakness is compounded by the fact that some of this evidence is derived from the work of our own team, and our analysis might have been unduly influenced by our own viewpoint. In part, this is why we enlisted six independent anaesthetists for the validation of the recommendations using the incident reports, and included only one of the investigators in this process. Even this process was subject to potential bias: of necessity we took volunteers, and for convenience these came from our own department. The group may or may not have been representative of anaesthetists in general. Perhaps we should also have involved independent anaesthetists in other parts of the study, e.g. the selection of references and identification of recommendations, and perhaps sought to quantify interinvestigator reliability. However, the primary limitation in this study is its raw material, and repeated analyses of the data would not address this problem. Furthermore, we think that the process of reading the references, identifying common ideas, and then expressing them as practical recommendations, carried out by two of the study's investigators working together discursively, was fairly robust. In addition, a key difference between the present study and most qualitative research that involves the identification of themes or categories from textual data is that in our case these data are readily available to all readers. Thus it is possible for readers to test for themselves the results of our qualitative analysis against the original references. The main strength of any systematic review is that the description of its methods permits others to repeat it, presumably with the same results. This approach also decreases the risk of bias: if we have omitted any important references, it should be obvious that this does not reflect bias in selection, but instead has been the result of oversight or of a weakness in our search strategy.

We went to some lengths to ensure that those (including ourselves) who have published repeatedly on this topic were not unreasonably over-represented in the analysis. We also attempted to weight the evidence, so that those studies that are based on data, including observational data in the form of case reports, were given greater prominence than unsupported expressions of opinion. We set a threshold (five authorities and 20 points) to eliminate 'rogue' opinions expressed by only one or two authors. Our scoring system was evidently relatively arbitrary. Given the small number of references in evidence categories I, II and III, we found it necessary to devise a ranking system that subdivided category IV to allow a more detailed analysis. If we had not done this, most of the references would have been given equal weighting. We combined a simple count of the number of authorities involved with a more complicated scoring system for their individual publications. We think this approach was relatively balanced. The outcome in most instances was fairly clear and would probably not have changed much if no weighting had been used. We have taken a conservative approach in identifying recommendations and think that the key messages emerge fairly unequivocally from the data.

We were able to find little helpful precedence for our approach to this analysis of the evidence. In part, this difficulty reflects a heavy discounting of qualitative research methods by many who promote evidence-based medicine. This view has been challenged [110,111]. Randomised controlled trials do have limitations, and it may be very difficult to provide level I or II evidence for the effectiveness of any safety measure in an activity such as anaesthesia that has an inherently low risk. A recent Cochrane review of pulse oximetry in anaesthesia concluded that 'the value of peri-operative monitoring with pulse oximetry is questionable in relation to improved reliable outcomes, effectiveness and efficiency' [112], yet few anaesthetists would be persuaded that the lack of supportive evidence from randomised controlled trials justifies abandoning this technology. Most anaesthetists would endorse the value of expert opinion, notably their own opinion, based on clinical experience in relation to understanding this issue. Of course, there are examples in which widely held expert opinion eventually proved false

in the face of a definitive trial, but there are also examples of conflict in the outcomes of allegedly definitive trials. We concur with Sackett *et al.*'s [10] view of evidence-based medicine quoted in our introduction: we think it should involve a critical assessment of all the available evidence. We also think that the strengths and weaknesses of each different category of research should be recognised [111]. Having said this, there is clearly a need for more randomised trials to examine the effectiveness of countermeasures to drug administration error, and also a need for imaginative approaches to the design of randomised trials that will be capable of elucidating this issue. Simulation provides promising opportunities in this regard [7], and our list of recommendations provides a clear starting point for such studies.

In conclusion, this study strongly supports the use of systematic countermeasures to decrease the incidence of intravenous drug administration error in anaesthesia, and challenges the position of those anaesthetists who, on the grounds of limited evidence, decline to follow simple steps to decrease the likelihood of error in intravenous drug administration. We have identified a list of reasonable and sensible measures that are certainly supported on balance by the available evidence, and which, taken collectively, would probably have prevented more than half our previously reported intravenous drug administration errors. Obviously, some of these measures involve extra cost, but this cost would be offset by a decrease in the number (and therefore the cost, including the human cost) of intravenous drug administration errors. It will be particularly difficult to persuade pharmaceutical companies to improve their labelling, but our study demonstrates once again that the present disregard of patient safety in the presentation of drugs by many manufacturers is unacceptable. Several of our recommendations are inexpensive and straightforward (Table 4), and could be implemented immediately by any anaesthetist. More research is certainly needed to strengthen and refine our understanding of the challenging task of reducing intravenous drug administration error in anaesthesia, but clearly there is already enough evidence in relation to this endeavour to distinguish many aspects of safe from unsafe practice.

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