Original Article

An observational feasibility study of a new anaesthesia drug storage tray

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Summary

Drug errors in the anaesthetic domain remain a serious cause of iatrogenic harm. To help reduce this issue, we explored the potential safety impact of using a simple colour-coded tray for anaesthetic drug preparation and storage. Over a six-month period, three different trained researchers observed 30 cases at three NHS Trusts. Ten observations involved standard drug trays in 'normal' practice, and 20 observations, involved 'Rainbow trays' before and after their introduction. We conducted 20 semi-structured interviews immediately after completing the Rainbow tray observation with the anaesthetists involved. All discussions and detailed notes taken were transcribed, qualitatively analysed using line-by-line coding and then synthesised into narrative themes. We found that using standard, single compartment trays enabled quick, cheap, and portable drug preparation and storage, but was linked to potential or actual harmful errors, such as syringe swaps. Rainbow trays were perceived to be easy to use and effective at all three sites, aiding drug identification and separation, and hence likely to reduce drug error and increase patient safety. We have demonstrated that it is feasible to introduce a new colour-coded compartmentalised Rainbow drugs tray into clinical practice at three NHS hospitals in England. Further research is needed into their effect on the prevalence of drug error.

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Introduction

Drug preparation and administration in the operating theatre presents a particular challenge, distinct from other hospital settings [1]. Anaesthetists routinely choose, prepare, administer and record several potent intravenous drugs in a relatively short period, on their own, sometimes while stressed or fatigued [2]. Most developed countries have attempted to improve the prescription, preparation and administration of medications to help reduce the inherent difficulty of this process [3], but it remains a serious cause of iatrogenic harm [2, 4]. A recent prospective observational study examined the rate of medication errors and adverse drug events [1], finding that approximately one out of every 20 peri-operative drug administrations and every second operation resulted in drug errors or adverse drug events. More than one-third of these incidents led to observed patient harm; the other

two thirds had the possibility of patient harm. This is markedly higher than the rates observed in previous publications, wherein the incidence of drug errors ranged from 1:131 to 1:5475 'anaesthetic administrations' [5–8]. The lower incidence observed in the past is perhaps due to operators' unwillingness to self-report errors or the lack of awareness that an error occurred [1].

There are several practices employed within anaesthesia that help mitigate the risk of drug error. International colour coding of drug labels ensures that drug labels used by anaesthetists follow a standard colour design, reducing the risk of selecting the wrong class of drug. There are restrictions on the contents of the anaesthetic room drug cupboard to only those drugs that are frequently used or must be administered on an urgent basis. Pre-filled syringes help reduce the risk of the wrong drug being drawn up. Some hospitals use a double-checking system (either two-person double-check or machine-checking) during drug preparation [9, 10]. Nevertheless, several researchers have argued that the types of medication errors made, the most common drug errors and the main factors contributing to drug errors in anaesthesia have remained relatively unchanged for more than 20 years [1, 5, 11, 12]. However, novel solutions do not always work in practice. This may be due to a combination of lack of efficacy, unintended negative consequences or barriers to implementation. It is, therefore, appropriate to determine whether even apparently small or simple alterations in practice serve to reduce the risk of errors.

The original motivation for developing Rainbow trays resulted from anaesthetic (LS) and pharmacy (SG) dissatisfaction with current practice, in the context of serious drug errors and their consequences [13] and the frequency of clinical distractions [14]. Syringe swaps have consistently been cited as a major contributor to medication errors, with the potential and actual serious adverse consequences [7, 15].

The present study aimed to explore the potential impact of a simple adjunct to drug preparation and storage on safe drug administration during anaesthesia. The study aimed to investigate both the theory and process of introducing a Rainbow tray, and any perceived barriers and drivers to its use in daily practice.

Methods

We performed a multi-centre qualitative study, adopting an interpretive paradigm, utilising observation and semi-structured interviews. We used a pragmatic approach of convenience sampling within three NHS Trusts in England. Approval for this study was obtained from the NHS Research Ethics Committee, and local research governance approval was granted at all sites. Twenty different anaesthetists participated in the study. We sent each participant a letter of invitation and an information sheet and sought written consent from each before taking part.

Over a six-month period, three different trained researchers observed 30 drug preparations, 10 of which involved the standard trays in 'normal' practice and 20 of which involved new 'Rainbow trays'. The sample size of the observation was intended to achieve thematic saturation [16].

Standard practice at all three institutions is for anaesthetists to collect and transport their prepared drugs in one or more disposable, single-colour, unicompartmental paper trays.

In comparison, the Rainbow trays comprise three separate trays, one for non-emergency drugs, one for emergency drugs and another for local anaesthetic drugs (Fig. 1). Each compartment has a specific disposable insert with rounded edges to aid syringe retrieval and has a colour-coded base, matching ISO 26825:2008 [17].

We introduced the Rainbow trays to each anaesthetist after completing an initial observation with the standard trays. At least two weeks later, we carried out a second observation of drug preparation using the Rainbow trays.

We collected data using a standard, pre-tested observation schedule at all three sites, to promote reliability. We recorded any additional comments provided by anaesthetists, trainees or operating department practitioners (ODPs). We observed and recorded our observations in real time, focusing on the drug preparation, administration and use of the trays from throughout the case. All observations and detailed notes taken during the observation period were typed up immediately afterwards. The key themes of each observation are summarised in Fig. 2.

We conducted a total of 20 semi-structured interviews in order to reach theoretical saturation [18]. Each

Figure 1 The Rainbow tray.

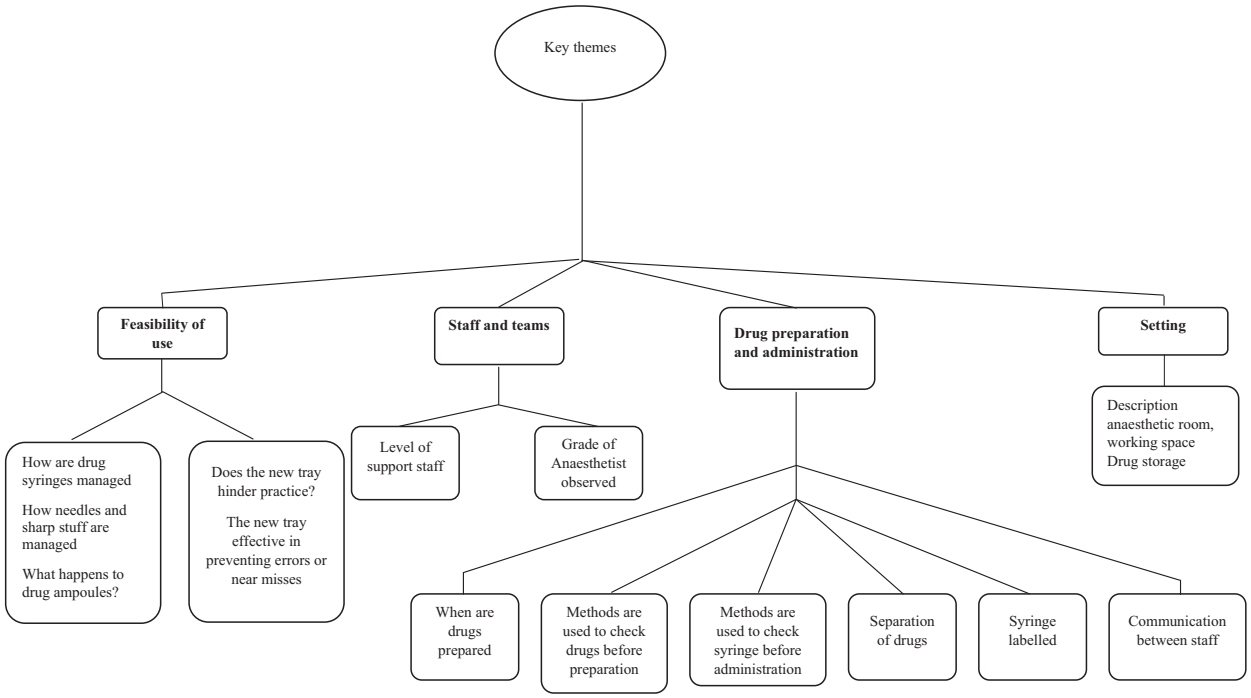

Figure 2 Key themes of the observations.

interview lasted 20–30 min commencing immediately after observing anaesthetists using the Rainbow tray. We used an interview guide as a prompt for each interview to ensure key questions were asked to all participants (Appendix 1). We digitally recorded and transcribed all discussions within one day of the interview.

During the interviews, we supplemented discussions using the observation notes to help elaborate topics that arose. Before beginning the interviews, we gave a brief outline of the format of the questions to participants to ensure that all questions were understandable and to mitigate any possible anxiety. The final transcripts were independently read through by DA and double-checked alongside the original records by the investigators (DA, RE, IM) for reliability and integrity. Any additional comments were included at this phase.

We analysed data from both the observations and interviews using thematic analysis to identify themes and subthemes. The interview and observation data were sufficiently in-depth to be coded line-by-line, as described by Charmaz [19]. Throughout the analysis, the transcripts were repeatedly revisited to compare categories and to look for 'negative' or contradictory themes, which could then be explored further during the study period both within the observations and the interviews. We used NVivo-11 (QSR International Pvt.

Ltd.; Melbourne, Australia) [20] to organise and manage the data. DA and RE carried out the initial analysis and coding, separately, and then met to discuss the coding and to agree or revise the thematic categories before discussing the results with the IM. Open coding generated 98 codes, which we synthesised into three thematic categories using focused coding, two of which we separated into three subcategories.

Results

Three thematic categories emerged from the data: standard practice (subcategorised into preparation, benefits and risks); Rainbow trays (subcategorised into preparation, benefits and disadvantages); and syringe labelling.

Standard practice

Anaesthetic induction was routinely carried out in an adjoined anaesthetic room at all three Trusts; we observed no cases of induction within the operating room. In Trust A and C we found that drugs were prepared sequentially before the patient arrived in the anaesthetic room, whereas at Trust B, drugs were prepared in advance for the whole operation list.

Standard practice in all three sites was to keep prepared syringes on a grey, disposable, compressed paper tray.

In all three NHS Trusts, the anaesthetist prepared drugs before the patient entered the anaesthetic room. Several reasons were given for this practice (Table 1).

In all three Trusts, 10 out of 20 anaesthetists read aloud the drug label, including the name of the drug, its concentration and expiry date, before the drug was drawn up. Once the drug was drawn up, we found that all anaesthetists labelled the syringe, but did not observe any occasions where the anaesthetist reconfirmed the drug in the syringe corresponded to the drug in the ampoule.

We observed that when drugs were checked by another individual after preparation, this was always by an anaesthetist, not an ODP or nurse. At Trust C, we did not observe any second-person double-check being performed, including when emergency drugs were prepared.

At Trust C, emergency drugs were prepared on an individual patient basis, whereas at Trusts A and B emergency drugs were prepared in advance for the whole theatre list. In Trusts A and C, empty ampoules were kept until the end of the operation; in Trust B they were discarded immediately after drawing up.

Table 1 Quotes about standard practice, by subcategory theme.

Subcategory	Quote
Preparation	'I like to draw up my drugs before the patient enters the anaesthetic room, so that I am not being distracted when I am doing it' [Trust C, anaesthetist 1] 'Normally I would like to prepare anticipate drugs before patient arrived because it takes reasons to avoid having wrong drug and to reduce risk of mistakes' [C, 4] 'I can give my undivided attention to the patient, and not delay the time before induction to minimise the anxiety levels of the patient.' [B, 2] 'I think once the patient is in the anaesthetic room, [making sure] the drugs [are] ready at that point means the patient is waiting for less time' [A, 9]
Benefit	'A very cheap method of drug trays' [C, 1; A, 5] 'They are simple, cheap, and ecological, and are quick and easy to use' [B, 2] 'It doesn't take up as much room on the anaesthetic machine work surface; the space is limited at the anaesthetic workstation' [B, 3] 'I can use a number of trays my practice uses a lot of local anaesthetic drugs to separate the local drugs from the other drugs I use' [A, 7] 'It is useful and just keeps drugs together, and if a couple of different types of drugs are used it is helpful, as I do not confuse my emergency drugs with other drugs' [A, 9] 'We use the grey tray to collect some other discarded ampules' [A, 9]
Risks	'Drug error is a risk and is not big enough, and all drugs are mixed up' [C, 1] 'It is easy to fail and choose the wrong drugs' [A, 4] 'Drugs may still fall out if tilted' [B, 3] 'Drug error is a risk' [B, 1] 'Obviously, in terms of the syringes all going together in the tray, we do have to be careful to pick up the right drug before we give it' [A, 7]

Across all three trusts, multiple drug syringes were held in the hand by the anaesthetist at the same time during induction; we did not observe any two-person double-check before their administration. We were not able to determine how precisely the anaesthetist checked each syringe before administration of its contents, for instance, whether the label colour and/or inscription was checked internally and explicitly against the anaesthetist's mental model of the correct drug.

Prepared drug syringes were placed in grey trays at all three Trusts. We observed that anaesthetists sometimes used more than one tray to separate the syringes containing 'emergency drugs' (typically metaraminol and/or ephedrine) from induction drugs. We found that the trays containing induction drug syringes were routinely placed on the anaesthetic machine during induction, whereas trays containing emergency drug syringes were left where they had been prepared.

On transfer to the operating room, the emergency drug tray (if used) was generally placed on top of the anaesthetic machine, whereas the induction drug tray was placed on the anaesthetic machine work surface. At Trust B, both drug trays were placed routinely on top of the anaesthetic machine, with an anaesthetic drug trolley moved to the operating room and placed behind the patient.

We found that there was no 'standard' practice for drug preparation, with considerable variation in the timing of drug preparation, the process of drug/syringe checking and the separation of emergency drugs.

Frequent, perceived benefits of the grey trays were ease of use, size and cost, together with the ability to separate the multiple drugs used during the anaesthetic pathway (Table 1). However, we observed that using a single tray made reading labels more difficult, the more syringes were used, and there was uniform acknowledgement that a crowded tray could lead to error, particularly when used ampoules were retained in the tray.

Rainbow trays

Introduction of the Rainbow trays did not appear to change the way drugs were prepared for anaesthesia. However, it did impact on the storage of syringes while in use, consistent with its intended purpose.

All anaesthetists cleaned the main body of the Rainbow tray with sanitising wipes before use, even though the tray includes a disposable insert as part of its design.

Once a drug was drawn up into a syringe and labelled, it was placed consistently into the correct colour-coded compartment within the Rainbow tray. This was observed for both the induction drugs and the emergency drugs.

Anaesthetists placed Rainbow trays in similar positions to grey trays in the anaesthetic room, but no longer held multiple syringes at the same time during induction, instead removing syringes from the tray individually and rechecking the label before administration.

Similarly, anaesthetists placed Rainbow trays on the anaesthetic machine work surface in the operating room. At the end of each operation, the Rainbow trays were taken back to the anaesthetic room, their inserts discarded and were cleaned in preparation for the next case.

Rainbow trays were considered easy to use (Table 2), and appeared to aid drug identification through colour-coded compartmentalisation, which reinforced individual syringe labelling.

We found that introducing the Rainbow trays appeared to increase anaesthetists' awareness of the potential for drug errors.

However, some anaesthetists commented on the Rainbow trays being too large (occupying too much anaesthetic machine worktop space) and/or their compartments being too small (Table 2).

Several anaesthetists identified a latent risk of syringe swap using the Rainbow tray, due to unrecognised, incorrect compartmentalisation.

Most of the participants were concerned about the cost effectiveness of Rainbow trays.

Fourteen out of 20 of the participants labelled syringes around the barrel at the neck of the syringe, predominantly to permit the accurate reading of syringe markings (Table 3) while enabling easy identification of the label colour no matter how the syringe was placed in whichever tray.

Discussion

We found that anaesthetists thought their current standard drug storage system was easy to use, low cost and portable, but had the potential for syringe swap errors, particularly when trays were crowded. They

Table 2 Quotes about Rainbow tray usage, by subcategory theme.

Subcategory	Quote
Preparation	'They do not change my practice, I prepare my drugs as I normally do with standard practice' [B, 4] 'They do not completely change my system of preparing the drug for the case. Except I have to separate and label the syringes'. [C, 1]
Benefit	'I did like it; it does not come with a lot of problems' [Trust A, anaesthetist 4; C, 5] 'I like it, it is straightforward; I like the colour code and how it's organised, and it is easy to use' [A, 8] 'I like using rainbow trays. I find it a good way of storing drugs; I think they are safer than the cardboard trays if used properly' [B, 4] 'I liked that they were tidy and they follow the normal order we use in the theatre' [A, 1] 'It is easy to find drugs and follow the normal sequences' [A, 2] 'I like the way that local anaesthetic drug are separate from the emergency drugs' [A, 1] 'I can see there is a benefit for [them] in [an] emergency' [A, 7] 'It is easy to identify syringes, especially in emergency situations' [B, 2] 'I like the way they ensure that you think about which drugs you might need and the way of separating drugs very carefully, although syringes in colour coded trays does not mean that the right syringe will get to the patient. Still, it is good and does add additional safety' [A, 4] 'It adds to the safety, as it is less likely to pick up the wrong syringe and the more likely to put the right drug in the syringe in the right compartment' [A, 8] 'I would think that the risk of administering the wrong drug is reduced' [B, 3]
Risks	'There are a number of drugs that go in the white compartment so I think that means you could potentially have a collection of drugs in that space that are potentially mixed up' [A, 9] 'In terms of layout of the tray, some compartments needed to be slightly larger, such as the other agents' compartment coloured white, as the variety of different drugs that would be placed in it' [C, 5] 'The size again was a drawback when regular drugs went to the patient, while the core trainee managed the airway' [B, 2] 'Once you have used most of the drugs in the tray, it takes up a lot of room on the anaesthetic machine table and made it more awkward to complete the anaesthetic chart' [B, 2]' 'It is a very bulky container that does not fit on the anaesthetic machine if everything is in the tray' [B, 1] 'There is potential for making the mistake of putting drugs in the wrong compartment' [A, 2] 'You might suddenly put drugs in the wrong compartment and pick them up without reading the label' [A, 8]

Table 3 Subcategories, key emerging themes and quotes for syringe labelling.

Subcategory	Quote
Reasons	'Around the barrel at the end does not cover any gradations' [Trust A, anaesthetist 4] 'I like be able to see the ml gradation and the labelling at the same time, and I think the advantage is that the colour is visible' [A, 8] 'By labelling around the syringes, you can obviously see the label whichever way the syringe lays' [A, 7] 'The biggest problem was that the labelling stickers did not stick very well along the barrel, so around it is the only way to make them stick' [A, 5]

readily accepted Rainbow trays into clinical practice, preferred them to standard trays and thought they had the potential to reduce drug errors.

We developed this ergonomic study to conceptualise how the Rainbow trays might work (or not), rather than to demonstrate any impact on the prevalence of drug errors per se. Ergonomics is concerned with the interaction between humans and their (working) environment. Understanding both how work is actually done (as opposed to how work is imagined to occur) and the impact of change on behaviour and attitude is the key to changing practice successfully [14].

We found no clear 'standard' practice for drug preparation and handling, despite this being a fundamental component of safe anaesthetic practice. This is perhaps more surprising to those outside anaesthesia than those within. Although there are legitimate debates about the balance between standardisation, clinical variation and professional autonomy, drug preparation and handling is a repeated, low-variability, high-risk task. Published literature describes drug preparation as a potentially high-risk clinical activity, and several factors could reduce the potential for error [2, 4, 21]. However, there is still

no definitive consensus on the best method for preparing drugs.

The Rainbow trays were designed according to Reason's recommendation for reducing complexity and in line with recommendations about the formal organisation of an anaesthetic workspace and the handling of drugs [21, 22]. Prototyping and informal user feedback improved various aspects of the design, including compartment sizes, incorporation of a reusable base and recyclable, disposable insert, and the separation of similar colours.

Study participants identified that current practice using relatively small, single compartment trays could facilitate drug error through misidentification, but noted that this could also be a problem using the colour-coded compartmentalised Rainbow tray. We do not suggest that any system which involves humans identifying labels will be error-free.

Introduction of the Rainbow tray appeared to have benefits beyond the design itself, with participants identifying an increased awareness of drug safety. Exhortations to vigilance in response to drug errors are perceived to be common practice within healthcare, with scant evidence of benefit [23]. In our study, the Rainbow tray appeared to act as an 'in the moment' reminder 'making it easy to do the right thing'. Cardboard trays remain freely available at the three Trusts and yet anaesthetists continue to choose to separate routine, emergency and local anaesthetic drugs with the Rainbow tray system. Similarly, changing induction behaviour, from holding drug syringes in one hand to selecting them individually, appears to be a response to introducing the Rainbow tray.

We found it interesting how anaesthetists also changed their practice in another, unpredicted way. The coloured Rainbow tray inserts are designed, and clearly labelled, as disposable. However, anaesthetists routinely cleaned them after use. Clearly, this suggests further design changes and/or education are necessary. Related to this, further life cycle analysis is required to clarify the environmental and cost consequences of using Rainbow rather than cardboard trays.

Similarly, feedback indicated concerns about size and workspace availability, due to the increased spatial footprint of the compartmentalised Rainbow tray. The relative size of the compartments themselves was also challenged by some anaesthetists, who found the white (miscellaneous) section too small in some cases to safely contain antibiotic syringes and saline flushes without overcrowding, suggesting that further, iterative redesign of the Rainbow tray is necessary.

Another unexpected finding was that some anaesthetists continued to 'cap' syringes with filler needles, despite this practice not being recommended [24, 25] and the Rainbow trays being deliberately designed not to accommodate a capped syringe. This represents a mismatch between 'work-as-imagined' and 'work-as-done' [26], and indicates an area for further education.

Participants correctly identified that the Rainbow trays themselves neither prevent incorrect syringe preparation, nor correct compartmentalisation (which could lead to drug error). These are legitimate concerns, and suggest that further education is needed about using the trays to aid drug selection rather than replace precise identification.

We identified considerable variation in how drugs were prepared and labelled, irrespective of which trays were used. Between Trusts and anaesthetists, syringes were variably prepared before lists or before each case, and/or the syringes labelled before or after preparation, and/or the label applied circumferentially to or longitudinally along the syringe barrel. We accept that there is little consensus in these areas [8, 27, 28] but suggest that there is a need to standardise these relatively basic tasks to prevent potential error.

Merry et al. have designed an integrated drug administration system in which anaesthetic drug trolleys are arranged to complement the process of anaesthesia. The bases of each drawer are divided into colour-coded sections that match the class of drug stored in each compartment [28]. However, they did not quantify the effect of the system's introduction on drug error rates. Evley et al. examined the feasibility of introducing either two-person or bar-coded drug confirmation in seven UK hospitals [9], but identified workarounds and other concerns that might limit the efficacy of each approach. The Rainbow trays may represent a pragmatic approach to introducing Merry's system into UK practice, where drugs are typically stored in locked cupboards rather than in trolleys. Pragmatic approaches to safety are common in

anaesthetic practice. Pin index systems on gas cylinders, colour coding and universal connectors, for example, have all been introduced after considered discussion between anaesthetists, manufacturers and regulators. This often requires an iterative process, to overcome design imperfections identified during development [29].

We have demonstrated that it is feasible to introduce a new colour-coded compartmentalised Rainbow tray into clinical practice at three NHS Trusts in England. The trays were readily accepted into practice and facilitated drug identification, as intended. Their introduction also appeared to remind anaesthetists of the potential for drug error and the need to check syringes before drug administration. There were few negative comments about the Rainbow tray. Further research is now needed to determine both the best strategies for ensuring continued use of the Rainbow trays, and their effect on the prevalence of drug error. Ultimately, introduction to other hospitals will inevitably depend on drivers such as national recommendations [30, 31], institutional policies, education [23] and cost, and we intend to report on how these challenges can be overcome in future papers.

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Appendix 1 – Interview questions

1 What is your current practice for drug preparation and storage?
2 Do you find any benefit of current practice?
3 Do you find any risks of current practice?
4 How do you feel about using a standardised/colour-coded drug tray?
5 Do you find any benefits of using the new rainbow tray?
6 Do you find any risk of using the new rainbow tray?
7 What do you feel should be best practice?

