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The impact of drug error reduction software on preventing harmful adverse drug events in England: a retrospective database study

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ABSTRACT

Introduction The use of intravenous administration systems with dose error reduction software (DERS) is advocated to mitigate avoidable medication harm. No large-scale analysis of UK data has been attempted. This retrospective descriptive study aimed to estimate the prevalence of hard limit events and to estimate the potential severity of DERS events.

Method Twelve months of DERS data was obtained from two NHS trusts in England. Definitions for drug categories and clinical areas were standardised and an algorithm developed to extract hard maximum (HMX) events. Subject matter experts (SMEs) were asked to rate severity of all HMX events on a scale of 0 (no harm) to 10 (death). These were analysed by clinical area and drug category, per 1000 administrations.

Results A total of 745 170 infusions were administered over 644 052 patient bed days (PBDs). 45% of these (338 263) were administered with DERS enabled. HMX event incidence across the whole dataset was 17.9/1000 administrations (95% CI 17.5 to 18.4); 9.4/1000 PBDs (95% CI 9.2 to 9.7). 6067 HMX events were identified. 4604 were <2-fold deviations and excluded. HMX were identified in all drug categories. The highest incidence was antibacterial drugs (2.21%; 95% CI 2.13 to 2.29). Of the 1415 HMX events reviewed by SMEs, 747 (52.6%) were low/no harm. Drugs with greatest potential harm were antiarrhythmics (21.8/1000 administrations; 95% CI 16.3 to 29.1), parenteral anticoagulants (24.16/1000 administrations; 95% CI 15.3 to 37.9) and antiepileptics (20.86/1000 administrations; 95% CI 16.4 to 26.5). DERS has prevented severe harm or death in 110 patients in these hospitals. Medical and paediatric areas had higher prevalence of potentially harmful HMX events, but these were probably related to profile design.

Conclusion Compliance with DERS in this study was 45%. DERS events are common, but potential harm is rare. DERS events are not related to specific clinical areas. There are some issues with definition and design of drug profiles that may cause DERS events, thus future work should focus on implementation and data standardisation for future large-scale analysis.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Intravenous medication error is common, but the severity of these errors is poorly evaluated and understood.
⇒ Dose error reduction software (DERS) are proposed as an important intervention to mitigate these errors.
⇒ However, their uptake in health systems outside of North America is low, because there is a lack of data about their effectiveness in different healthcare territories.

WHAT THIS STUDY ADDS

⇒ 'Smart' infusion devices suggest that the intravenous medication error rate may be less common than systematic reviews suggest (from 101 errors per 1000 administrations to 17.9 per 1000) but almost half of these errors (47.4%) could be harmful.
⇒ The prevalence of DERS events in acute medical and paediatric settings is twice as common as in other situations, which may be related to poor profile mapping to clinical practice.
⇒ However, across two large NHS institutions using DERS for 1 year, severe harm or death was avoided in as many as 110 patients.
⇒ DERS does have a role in intravenous medication safety, but further study is required to support adherence to DERS software in the clinical setting and ensuring that DERS parameters support clinical practice. Further, there is a need to standardise the definitions of DERS parameters and events. This study has demonstrated the potential utility of algorithmic analysis methods to bring databases together.

INTRODUCTION

Medication error is a persistent problem in all healthcare systems that despite best efforts continues to exert a burden on health economies, patients and their families. It is estimated that 1 in 20 patients worldwide experience iatrogenic harm. Twenty-five per cent of these harm events are thought to be attributed to medication. Furthermore, 6% of these harm events may lead to permanent disability or death.[1] While much medication-associated harm is unavoidable, it has been estimated that 6% of harms related to medicines are

caused by errors, costing up to $42 billion per year.[2] This global burden is felt as keenly in advanced healthcare systems like the UK, where there are estimated 237 million medication errors every year, contributing to almost 1700 deaths and £100 million of unnecessary expenditure.[3]

A considerable number of these avoidable medication events are related to intravenous medicines,[4] with evidence of a complex, multifactorial process that is prone to error at many stages.[5] For almost 20 years, the use of drug error reduction software (DERS)—intravenous administration devices that are preprogrammed with drug libraries, drug concentrations and dosing rates and limits to mitigate programming and delivery errors—have been recommended as an intervention to reduce administration errors, and these have been adopted in numerous care settings.[6–9] In a 2013 single-centre study in England,[6] 1.4% (3700/173 891 infusions) of infusion starts triggered a dosing alert, 0.3% (831/173 891 infusions) triggering a hard limit warning. Of all these 3700 alerts, 66.3% (2452/173 891) of these alerts were overridden with no change in infusion. Additionally, the bypass rate in this study (those infusions where DERS was not used for the infusion) was 34.6% (91 989/265 880) of infusions. The reasons for this bypass rate were not explored.

In a systematic review, Ohashi and colleagues identified only 1 randomised controlled trial (RCT) and 10 post-intervention studies that all used heterogeneous outcome measures.[10] None of these 11 studies were reported from the UK. This review highlighted that compliance with DERS systems was low, with an average bypass rate of 25% in one study.[11] However, in the UK study by Cousins *et al*, the bypass rate was 35%.[6] Also in Ohashi's review, the potential severity of the DERS alerts were reported as surrogate measures based on the degree of deviation from maximum limits. Most included studies considered potential severity of events using the factor of upper limit deviation. Using this method, there is an assumption that a 100-fold deviation from a hard limit is more harmful than a twofold deviation. The outcomes of medication administration errors are often more nuanced, and rooted in the nature of the drug, where it is used and the dose-response features of the drug.

Thus, there is a clear lack of data to enable the evaluation of the use of DERS in the UK healthcare setting. This is on the background of increasing regulatory and commissioner-led direction to incorporate DERS into day to day healthcare. Two major strategic papers in the last 6 months in the UK both extol the benefits and risks of DERS systems.[12 13] In the report by the Healthcare Safety Investigation Board,[13] three serious errors involving the misprogramming of fentanyl infusions using DERS systems were described. It was identified that intra-organisational variation in the way drugs are used (often at a departmental level) were a key contributory factor to these events. Furthermore, the lack of robust data review lead to delayed identification of the safety issues revealed by the DERS system.[13] Currently, DERS drug libraries are developed in a localised manner by individual clinical units, or at a single hospital level, resulting in substantial variation in the definition of drugs, their doses and their concentrations within a geographical area. Additionally, this localised approach to DERS implementation leads to only localised ad hoc reviews of data at variable time points. These serve only to inform local learning, but there is a potential opportunity from these data to provide system-wide learning opportunities and foster a culture of data sharing within the health system, enabling policymakers to have evidence-based insights into infusion practice and outcomes.

The single UK DERS study cited earlier is now more than 10 years old and focused on a single site. Other sites in the UK have taken up DERS since this study. There is thus a great repository of data available for secondary analysis to contribute to the evidence base of the impact of DERS over multiple sites, and to identify potential areas of concern to support the development of proactive interventions to support the implementation of intravenous medication systems in the future.

Therefore, this study aims to retrospectively analyse historical data from a large database formed of data from two DERS systems in operational use in England today:

- To determine the rate of DERS usage in clinical areas (as a proportion of total administered infusions).
- To ascertain the incidence and prevalence of potentially avoided adverse drug events (using DERS events as an indicator of these).
- And to assess the potential severity of these events if they were permitted to be administered to patients.

METHODS

Regulatory approvals and database access

Two independent and geographically distinct sites using a proprietary DERS system (Guardrails; Becton Dickinson, Oxford, UK) in England were identified and approached to collaborate on this study, along with the pump manufacturer (BD UK Limited) who funded the work through an unrestricted research grant. Both the University of Manchester Research Ethics Committee and the NHS Health Research Authority deemed this study to be non-ethics-bearing research as it involved the secondary analysis of anonymised routinely collected data. Each study site gave their explicit permission for researchers to access their data. Following discussions with clinicians and medical engineers at each site, a suitable time window was identified for data mining. This period needed to be at least a year where no significant changes to the structure or implementation of their DERS systems were undertaken. This was agreed to be the period between January 2016 and April 2017. Twelve-month database extracts from each site between January 2016 and April 2017 were obtained from the manufacturer and the data pooled into a single database to further anonymise the sites.

Proprietary analysis platforms are not designed or intended for retrospective interrogation and analysis of events across multiple sites so a novel Standard Query

Language (SQL) tool was developed and validated to enable the raw databases to be manipulated and interrogated.

Database interrogation

Data cleaning, manipulation and interrogation

An entity relationship diagram (ERD) was developed in order to understand the linkage of parameters and values in the database (online supplemental file 1). Databases were built around variable parameters: 'Drug Profiles' (clinical areas where medicines were used, reflecting local protocols) and 'Drug Names' (descriptors of medication for display on pump interfaces). There were then standard parameters such as dosing units (milligram, microgram, etc), volumes (mL) and definitions for soft limits and hard limits (minimum and maximum.) Hard limits are those doses above or below which the device would not permit an infusion to be programmed. This would result in an alert requiring programming to be reviewed. Soft limits are advisory alerts that an acceptable threshold has been passed, but no action is required.

In order to produce a database query that searched like-for-like across the different datasets, the profile libraries of both centres were reviewed by a researcher (AS) who mapped drug profile libraries to standard outputs (surgical, medical, paediatric, theatres, critical care, women's care) and mapped drug names to drug classes per British National Formulary classification. Drug library names were set at a local level and referred to ward names or numbers. Thus, the allocation of each profile to the standard outputs above was confirmed with clinicians at participating centres (AP, MR and EW). Those that were not intended for routine clinical use (training, test and obsolete libraries) were deleted from the database.

Furthermore, drug categories were reviewed by the research team. Lists of parameters were not the same between the participating centres, therefore it was necessary to define parameters (drug names, drug categories) into a unified output, and this was undertaken by the project lead (AS) (online supplemental file 2). Additionally, anticancer chemotherapy, simple intravenous fluids (defined as those not containing potassium), blood products and parenteral nutrition parameters were removed from the dataset for two reasons: (1) these drugs are subject to additional process controls around training, prescribing and preparing of these medicines to maintain safety; and (2) were only used in one of the two site's databases, thus analysis would not be balanced.

A database analyst (WSG) was employed to build a database enquiry using SQL Server 2019 (Microsoft, Redmond, Washington, USA) and Microsoft Azure Data Studio (Microsoft) on servers hosted within the European Economic Area. Queries were run to obtain the following data:

1. The overall number of infusion starts, and those infusions started using DERS.
2. The number of soft limit and hard limit events.

SQL enquiries were validated using random sample queries that were then compared with the same outputs from the proprietary analysis system (BD Continuous Quality Improvement (CQI) BD Infusion Analytics, Franklin Lakes, New Jersey, USA). Once validated, the enquiries were run over the entire dataset and exported to an excel spreadsheet for onward coding and analysis.

Data analysis

Output data were analysed using descriptive statistics to estimate the rate of events over the entire database, and those events with DERS enabled expressed as a raw incidence rate (in per cent), incidence per 1000 infusions, and per 1000 patient days. Data on patient bed occupancy were obtained from publicly available Hospital Episode Statistics data for participating organisations, using Finished Consultant Episode data (FCE) and pooled.

Data on events were then sorted by soft limit (minimum and maximum) alerts and hard limit (minimum and maximum) alerts. Soft limit alerts were then excluded from onward analysis as these are just advisory alerts and not intended to stop activity. Hard limit events were then analysed across the whole dataset, and then by clinical area and by drug category. Statistical analysis was undertaken using Microsoft Excel (V.2016) with CIs calculated for prevalence rates.

Severity rating

Subject matter expert panel

All hard maximum events (HMX) were then taken and presented to SMEs to assess the potential severity of the events recorded. The method of retrospective severity scoring developed by Dean and Barber was used.[14] A group of 12 SMEs was convened. All were pharmacists with at least 5 years of clinical experience, and experience of informatics or in an environment that used DERS systems. SMEs were purposively allocated to three groups of four. Given the close working relationships of some of the SMEs (same working environment, similar clinical backgrounds), SMEs were divided so that they were not in the same group as another colleague in their employing organisation, or working in the same clinical field as a colleague (eg, three paediatric specialist pharmacists were allocated to three separate groups). SMEs attended a short 30-minute training session outlining the scoring system. In recognition of the effort involved and time commitment to assess HMX, SMEs were offered an honorarium payable on completion of their severity ratings.

Severity scoring

All HMX were randomised and split evenly into three separate datasets. These were then provided to SMEs in an Excel spreadsheet with clear instructions on how to complete the form. SMEs were asked to review each HMX individually, using only the information available—drug, clinical area, programmed dose, hard limit parameter and degree of deviation from that hard limit. No other context was provided as that was not available (this reflects the on-site review process

where organisations can only review events retrospectively with no other contextual information.) They were then asked to rate the potential severity of that event if there had been no pump alert. SMEs were asked to rate these HMX on a scale of 0 to 10, where 0 represented no harm whatsoever and 10 represented probable death of the patient. An assumption was made that the infusion would be administered to the patient until the next anticipated opportunity for a pump review.

Analysis of severity events

The mean potential harm score was calculated for each event, and for statistical analysis, transformed into categorical variables—no/low harm (score 0–3), moderate harm (score 4–7) and severe harm (score 8–10). Validity of the harm scoring within the groups was taken as three out of four (75%) severity ratings being within the same category. All ratings met this criteria so no further resolution of disagreement was needed. Descriptive statistics were then used to assess the prevalence of different levels of harm across clinical areas and drug categories. The incidence of HMX events as a proportion of all infusions was considered too low to support any further statistical analysis (eg, tests of correlation).

Patient and public involvement

As a retrospective database study, patients and the public were not involved in the development or analysis of the data in this study.

RESULTS

Incidence and prevalence of DERS alerts

A total of 1 493 035 infusions were administered in these hospitals during the study period. DERS functionality was bypassed in 633 339 (42.4%). When excluded medications (cancer chemotherapy, intravenous fluids without potassium added, parenteral nutrition and blood products) were excluded from the dataset, 745 170 infusions were administered and 45.3% of these (338 263) were administered with DERS enabled.

Across the study periods, there were 644 052 patient bed days (PBDs) in these study sites. It was impossible to reliably segregate these PBDs into specialist areas using publicly available data. Thus, all onward calculations of prevalence of DERS events are undertaken using aggregate PBDs.

A total of 6067 hard limit (max) (HMX) events were identified in this sample. This represents a prevalence of HMX events in administered infusions of 17.9/1000 (95% CI 17.5 to 18.4) administrations.

The prevalence of HMX by clinical area is summarised in table 1.

When analysing the incidence of HMX events in DERS enabled infusions, it was observed that when ranking against the proportion of HMX events with DERS infusions as denominator, the top 10 drug categories accounted for only 3.13% of DERS infusions. When ranked according to the raw incidence of HMX events, the top 10 drug categories accounted for 75% of DERS infusions (table 2).

These differences across the whole dataset are presented in online supplemental files 3; 4. Given these weighting differences, table 3 summarises the top 10 drug categories of drugs associated with DERS alerts ranked by incidence of alerts, weighted by the raw incidence of DERS infusions.

Severity of intercepted events

Of 6067 HMX events, 4652 (77%) events were less than twofold deviation of the hard limit. Using a sample of these events (including all insulin events), these were judged by the research team to represent dose rounding, dosing discrepancies (eg, a deviation of an infusion to a child of less than 10% greater than the HMX, or an infusion of a maintenance fluid programmed at 185 mL/hour when the HMX limit is 150 mL/hour) or appropriate dose escalations that would not cause harm or adverse events (using the categorisation described by Lyons *et al* in their prospective observational study).[15] These were excluded

Table 1 Summarised prevalence of HMX alerts over all intravenous infusions, DERS infusions and bed days

Clinical area	HMX events	Total infusions	Total DERS infusions (% from total infusions)	HMX per 1000 DERS administration (95% CI)	HMX per 1000 administration (95% CI)	HMX per 1000 bed days
Paediatric	665	29 560	11 847 (40.1)	56.1 (52.1 to 60.4)	22.5 (20.9 to 24.3)	
Medical	2423	197 535	82 769 (41.9)	29.3 (28.1 to 30.4)	12.3 (11.8 to 12.8)	
Surgical	1303	137 095	67 916 (49.5)	19.2 (18.2 to 20.2)	9.5 (9 to 10)	
Women's care	89	15 161	5274 (34.8)	16.9 (13.7 to 20.7)	5.9 (4.8 to 7.2)	
Theatres	8	2712	979 (36.1)	8.2 (4.1 to 16)	2.9 (1.5 to 5.8)	
Critical care	1579	36 307	169 478 (46.7)	9.3 (8.9 to 9.8)	4.3 (4.1 to 4.6)	
Total	6067	745 170	338 263 (45.4)	17.9 (17.5 to 18.4)	8.1 (7.9 to 8.3)	9.4 (9.2 to 9.7)

Bed days are presented using total aggregate data only and not subdivided into specialities due to differences in hospital reporting and classification.
DERS, drug error reduction software; HMX, hard maximum.

Table 2 Weighting effect of proportional incidence and raw prevalence in the dataset

Ranking method	Infusions (n=745 170)	DERS infusions (n=338 263)	Top 10 HMX events (as a proportion of all infusions)
Proportional incidence	20 090	10 575	2.7% (all) 3.1% (DERS)
Raw incidence	555 182	255 279	74.5% (all) 75.5% (DERS)

DERS, drug error reduction software.

from SME analysis. 1415 HMX events were then passed to the SMEs. The average scores were categorised into harm levels as described. More than half of these (747) were of low/no harm. Table 4 presents the distribution of harm across the five clinical areas ranked by proportion of HMX events.

When considering moderate/severe harm events that have been intercepted by DERS, this equates to 0.9 events per 1000 administrations (668/745170) and 1.04 events per 1000 PBDs (668/644 052).

When examining HMX events by drug category, all but six drug categories were represented in the data. When all harm levels are taken into account, antibacterial drugs represented the highest frequency category with 563 (39.8%) HMX events. However, when low-no harm events are removed from the analysis, the nature of the drugs involved changes, with potassium chloride accounting for 28.1% of HMX associated with potential for moderate or severe harm. The top 10 drug categories account for 581 out of 668 (87%) of the potentially moderate and severe HMX events. Further, 110 out of 1415 (7.8%) HMX events had the potential to cause permanent disability or death. The top 10 categories ranked by incidence/1000 administrations are presented in table 5; however, the full tables ranked by both raw incidence and proportional incidence of harm are available in online supplemental files 4AB.

Relationships between harm events and clinical area or drug category

The incidence of moderate/severe events in each clinical area were compared (table 6). Paediatric and medical areas had rates two to three times higher than other areas.

In medical areas, 43 drug groups were represented in potential harm events, but three drugs were associated with almost half of all potential harm events: fluids containing potassium chloride (16.2%; 44/272), gentamicin (15.8%; 43/272) and amiodarone maintenance infusions (13.2%; 36/272). In paediatric areas, 15 drugs were represented in these alerts, and 3 drugs accounted for over half of all potential harm events: caffeine loading doses (24.5%; 13/53), teicoplanin maintenance doses (15.1%; 8/53) and calcium gluconate bolus doses (13.2; 7/53). Full data for paediatric and medical areas are presented in online supplemental file 7.

Table 3 Distribution of HMX events by drug category

Drug category	Infusions	DERS infusions	HMX events	HMX incidence (% from ALL infusions) (%; 95% CI)	HMX incidence (% from DERS infusions) (%, 95% CI)
Antiepileptics	5269	3068	177	3.36 (2.91 to 3.88)	5.77 (5.0 to 6.65)
Antiviral drugs	10 582	4882	235	2.22 (1.96 to 2.52)	4.81 (4.25 to 5.45)
Poisoning antidotes	6542	2325	98	1.5 (1.23 to 1.82)	4.22 (3.47 to 5.11)
Calcium and magnesium	29 243	16 897	535	1.83 (1.68 to 1.99)	3.17 (2.91 to 3.44)
Loop diuretics	11 711	5484	131	1.12 (0.94 to 1.33)	2.39 (2.02 to 2.83)
Potassium chloride	86 746	32 504	749	0.86 (0.8 to 0.93)	2.3 (2.15 to 2.47)
Antibacterial drugs	279 633	134 821	2979	1.06 (1.0 to 1.1)	2.21 (2.13 to 2.29)
Vitamins and minerals	20 160	9794	190	0.94 (0.82 to 1.09)	1.94 (1.69 to 2.23)
Insulin	33 177	6644	85	0.26 (0.21 to 0.32)	1.28 (1.04 to 1.58)
Non-opioid analgesics	72 119	38 860	179	0.25 (0.21 to 0.29)	0.46 (0.4 to 0.53)
All other drug categories	189 988	82 984	709	0.37 (0.35 to 0.4)	0.85 (0.79 to 0.92)
Total	745 170	338 263	6067	0.81 (0.79 to 0.83)	1.79 (1.75 to 1.84)

Top 10 by prevalence with aggregated figures for all others. See online supplemental file 3 for details of all drug categories.
DERS, drug error reduction software; HMX, hard maximum.

Table 4 Distribution of harm by severity and clinical setting

Clinical area	HMX events (%)	Events <2fold deviation (% of all HMX)	Low/no harm	Moderate	Severe	Total
Medical	2423 (39.9)	1771 (73%)	380	246	26	652
Critical care	1579 (26)	1184 (75%)	148	171	76	395
Surgical	1303 (21.5)	1012 (78%)	202	78	11	291
Paediatric	665 (11)	604 (91%)	8	43	10	61
Women's care	89 (1.5)	75 (84%)	8	6	0	14
Theatres	8 (0.1)	6 (75%)	1	1	0	2
Total	6067	4652 (77%)	747	545	123	1415

HMX, hard maximum.

DISCUSSION

This study is the first longitudinal multicentre prevalence study using retrospective DERS data in England. It is also the first such study that uses estimation of harm to complement the event data and provide more information on the effectiveness of DERS in a complex health system. We have adapted the methodology used by Cousins *et al*[6] and estimated the extent of DERS use, and characterised the drugs involved across two diverse organisations using the same DERS system. This study is novel in its use of reliable severity estimation for the events identified, and thus estimate that DERS may have saved as many as 110 lives over the study period.

This study has shown that compliance with DERS is low at around 45% (633 339/1 435 000 infusions). This stands in contrast to many previous studies where compliance is estimated between 65% and 80%.[6 11 16 17] These studies are all prospective experimental designs therefore the high compliance could be associated with the attention to protocol and data collection that goes with complex interventional studies. This study offers a retrospective analysis of DERS compliance 'in the wild' and may represent a more realistic estimate of DERS compliance.

From this dataset, we estimate that the incidence of hard limit events is 9.4/1000 PBDs and 17.9/1000 administrations. This reflects the findings of a 2018 systematic review of medication errors in English hospitals, which estimated that 1 in 10 intravenous administration errors were associated with a potential for harm.[18] What is reassuring is that this potential for error may not translate into actual patient harm. About 77% (4652/6067) of HMX events are related to small discrepancies in administration or dose rounding (particularly in paediatric practice). Furthermore, 52% (745/1415) of high-factor deviations from hard limits are associated with low or no harm.

The mean harmful HMX rate was 0.2% of DERS administrations (IQR 0.11–0.28). However, in medical and paediatric settings, this was two and three times higher, respectively (0.33% and 0.45%). This does not compare with the prevalence identified in other UK studies of medication error prevalence. Blandford and colleagues found no difference between all clinical areas in their multicentre study of 16 centres in England, with an error rate of 12%–13%.[19] The findings from that study also hold across national borders and practice contexts.[20] However,

Table 5 Potentially harmful DERS events by drug category (top 10, by incidence/1000 administrations)

Drug category	DERS infusions (%)	Moderate	Severe	Total	Incidence/1000 administrations (95% CI)
Parenteral anticoagulants	745 (0.3)	5	13	18	24.16 (15.3 to 37.9)
Antiarrhythmic drugs	2018 (0.9)	39	5	44	21.8 (16.3 to 29.1)
Antiepileptics	3068 (1.4)	21	43	64	20.86 (16.4 to 26.5)
Potassium chloride	32 504 (15)	166	22	188	5.78 (5.0 to 6.7)
Insulin	6644 (3.1)	16	20	36	5.4 (3.9 to 7.5)
Loop diuretics	5484 (2.5)	25	0	25	4.56 (3.1 to 6.7)
Antiviral drugs	4882 (2.3)	16	0	16	3.28 (2.0 to 5.3)
Vitamins and minerals	9794 (4.5)	20	0	20	2.04 (1.3 to 3.2)
Calcium and magnesium	16 897 (7.8)	29	4	33	1.95 (1.4 to 2.7)
Antibacterial drugs	134 821 (62.2)	134	3	137	1.01 (0.9 to 1.2)

DERS, drug error reduction software.

Table 6 Incidence of harmful DERS events by clinical area

Clinical area	DERS infusions	HMX events	Rate of HMX events in all DERS infusions (%)
Critical care	169 478	247	0.15
Medical	82 769	272	0.33
Paediatric	11 847	53	0.45
Surgical	67 916	89	0.13
Theatres	979	1	0.10
Women's care	5274	6	0.11
Mean rate			0.20 (IQR=0.12–0.28)

DERS, drug error reduction software; HMX, hard maximum.

these studies were observational, detecting errors and discrepancies prior to administration. This study has estimated a rate of those administration errors that may go undetected using traditional devices.

We have identified important system-wide considerations in these data. In medical and paediatric settings, there is a likelihood that a lack of standardised practice, the need to round doses for administration or previous use of conventional infusion devices contribute to HMX events. For example, 32 out of 64 administrations of phenytoin triggering a 'severe' HMX event were programmed as a rapid infusion of 1000 mg over 5 min where the DERS limits were set to administer phenytoin over 20 min per international guidelines. This case demonstrates how local practices often run counter to attempts at standardisation such as DERS and local learnt practice is often more prevalent than written guidelines.[21] Additionally, nursing rounding of dose rates is often unavoidable, especially in smaller patients and children. This is related more to the accuracy of the pump programming (in mL/hour) and the hyper-accurate calculations and measurements implied in paediatric and neonatal infusions.[22] This suggests that there are issues with the way DERS profiles are defined, which are only identified during routine use. Of note in Ohashi's findings[10] were the importance of implementation and education and training on the effectiveness of DERS systems as a safety intervention, and thus many studies' outcomes are potentially undermined by poor implementation.

Considerable work needs to be undertaken in understanding how work is done in the real world which may also improve compliance.[23 24]

DERS does not prevent wrong-drug selection or programming errors,[25] thus DERS should be considered as part of an intervention bundle to improve the safety of intravenous administration providing a 'hard' control against the most catastrophic of administration errors. However, the components of these 'bundles' are not yet clear. In the USA, an infusion safety intervention bundle including standardised labelling, documentation and discontinuation standards, and the implementation of standardised DERS across three hospital sites reduced intravenous administration errors from 146 to 123 per 100 administrations, but had no significant impact on potentially harmful errors (they increased slightly from 0.5 to 0.8 per 100 administrations).[25] This may be because potentially harmful medication administration errors are rare (as our study has identified) and there are already considerable resilience mechanism within the system. DERS is a tool to encourage and support safe administration of medicines according to established standards and not a replacement for other controls already in place. However, we must note that compliance with DERS can never be 100%—there will always be medicines that do not have a profile at the point of use because they are new, or there is an immediate adaptation required to meet patient needs thus it must be expected that bypassing of DERS will occur occasionally.[26–28] This must be considered when developing drug libraries on a national scale, to ensure that appropriate standards are laid down.[12 13] It is also important to consider the limitations of the software on the likelihood for bypassing. The system studied in this research has a limit of 100 drugs per profile that representatives from both sites have cited as a restriction on the development of their profiles, thus there are drugs that should have a DERS entry, but do not because there is insufficient capacity in the device for them.

This study has several important limitations. The lack of context around HMX (patient and response) will affect outcome and severity estimates. There is no validated definition of a DERS medication error, nor are entries in drug libraries standardised between organisations. Thus, assumptions are implicitly made about each HMX event based on the personal and professional opinions of the rater. Context is also important in gauging potential severity as patient comorbidities would impact on dose-related or dose–rate-related response and many DERS studies have examined pump operation around HMX alerts.[29 30] Furthermore, as a study covering 1 year of data, we have not allowed for any changes to the device programming parameters being made in response to pump data reviews at each site. It cannot be excluded that the incidence or nature of events may have changed over the study period. Finally, we must acknowledge the composition of our SME panels—all were pharmacists, chosen for their experience with DERS and a wide range

of clinical specialities. They represented an easily accessible pool of expertise in the constrained circumstances of the COVID-19 pandemic. It cannot be excluded that there is some bias in the evaluations of severity and other professions may have scored differently.

Because DERS data are analysed at a local level retrospectively, it is expected that profiles and architecture evolve with time, as improvements to process are made. Point-prevalence analysis such as this is useful in demonstrating DERS impact as a control for potential medication error. We recommend future studies of DERS that are longitudinal in nature with multiple points of data analysis to capture the impact of DERS on HMX alerts, DERS compliance, and the impact of localised responses to DERS data and revision of drug libraries. We also advocate for this data analysis to be undertaken on a large scale, at a national level, using standardised terminology and parameters[31] to support system-wide learning as part of the NHS Patient Safety Strategy.[32] The potential applications for artificial intelligence and machine learning in the analysis of this data should be explored.

CONCLUSIONS

This study has demonstrated that DERS, while being used, is bypassed in more than half of intravenous administrations. Thus, our estimates of potential harm events may be an underestimate because of this bypassing. Nevertheless, where DERS is used, the prevalence of potentially harmful medication adverse events is roughly the same as those estimates from systematic reviews where 1 in 10 intravenous medication errors may be associated with a potential for harm. However, this harm may not be manifested in real life as the data available from DERS databases do not include the context around alerts, nor data relating to patient comorbidities or the other controls in place to ensure safe medication administration. In spite of this, we can still conclude that DERS has potentially prevented serious harm or death to over 100 patients across these two hospitals.

This absence of context is also important when considering the aetiology of potentially harmful intravenous medication events, as DERS data only report what has happened, but cannot explain why that has happened. Indeed, this study has detected clear examples of where the drug profile has not correlated with practice resulting in an apparently high prevalence of HMX alerts as operators find themselves prevented from administering medications the way they are used to administering. We conclude that current approaches to DERS implementation are focused only on development of the drug libraries, without understanding real-world practice at the sharp end. This is an important finding given the drive to promote uptake of these technologies in the NHS, and manufacturers, commissioners and NHS organisations should consider this when considering the introduction of DERS.

Notwithstanding these limitations, this study has successfully merged two organisational databases and analysed the data from both using a simple SQL algorithm by identifying and standardising definitions for drug categories and clinical areas. What we have not been able to do is explore the actions around each potential harm event because of non-standard terminologies and definitions between organisations. The standardisation and harmonisation of all these data terms across organisations and manufacturers is vital for future large-scale analysis of DERS data to inform system-wide learning in the NHS.

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