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Estimating the impact on patient safety of enabling the digital transfer of patients' prescription information in the English NHS

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ABSTRACT

Objectives To estimate the number and burden of medication errors associated with prescription information transfer within the National Health Service (NHS) in England and the impact of implementing an interoperable prescription information system (a single digital prescribing record shared across NHS settings) in reducing these errors.

Methods We constructed a probabilistic mathematical model. We estimated the number of transition medication errors that would be undetected by standard medicines reconciliation, based on published literature, and scaled this up based on the annual number of hospital admissions. We used published literature to estimate the proportion of errors that lead to harm and applied this to the number of errors to estimate the associated burden (healthcare resource use and deaths). Finally, we used reported effect sizes for electronic prescription information sharing interventions to estimate the impact of implementing an interoperable prescription information system on number of errors and resulting harm.

Results Annually, around 1.8 million (95% credibility interval (CrI) 1.3 to 2.6 million) medication errors were estimated to occur at hospital transitions in England, affecting approximately 380 000 (95% CrI 260 397 to 539 876) patient episodes. Harm from these errors affects around 31 500 (95% CrI 22 407 to 42 906) patients, with 36 500 (95% CrI 25 093 to 52 019) additional bed days of inpatient care (costing around £17.8 million (95% CrI £12.4 to £24.9 million)) and >40 (95% CrI 9 to 146) deaths. Assuming the implementation of an interoperable prescription information system could reduce errors by 10% and 50%, there could be 180 000–913 000 fewer errors, 3000–15 800 fewer people who experience harm and 4–22 lives saved annually.

Conclusions An interoperable prescription information system could provide major benefits for patient safety. Likely additional benefits include healthcare professional time saved, improved patient experience and care quality, quicker discharge and enhanced cross-organisational medicines optimisation. Our findings provide vital safety and economic evidence for the case to adopt interoperable prescription information systems.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Reducing medication errors at transitions of care is a complex challenge due in part to the leaky pipeline involved with the transmission of prescription information between settings.

⇒ A system in which a single record of information is accessible across different settings makes the requirement to transmit information redundant and thereby reduces the scope for medication errors.

WHAT THIS STUDY ADDS

⇒ This study adds a new estimation of the incidence and harm of medication errors at transitions of care in the English NHS and estimates the impact of an interoperable prescription information system on reducing errors.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Countries signed up to the WHO's Medication Without Harm Challenge can use our findings to inform local decision-making on the estimated benefits of implementing an interoperable prescription information transfer system.

⇒ Our findings could be used in business cases to support the investment in the infrastructure required to establish an effective interoperable system.

INTRODUCTION

An estimated 237 million medication errors occur during the medication

process in England annually, costing the National Health Service (NHS) £98 million per year, consuming over 180 000 bed days, and contributing to around 1700 deaths.[1] Medications are a key cause of preventable patient harm globally.[2] WHO's 'Third Global Patient Safety Challenge: Medication Without Harm' aimed to reduce the global level of severe, avoidable harm related to medications by 50% between 2017 and 2022.[3] One key area was medication safety in transitions of care, highlighting the need to improve medication safety through leadership, medicines reconciliation capacity and capability, patient partnership and improving information quality and availability.[4]

Access to accurate prescribing information is key to patient care, especially when they move from one care setting to another, such as admission to and discharge from hospital. However, there are often unintended discrepancies and deficiencies in prescribing information provision, leading to clinically important medicines being omitted or being given inappropriately.[5] Fragmented, inconsistent prescribing information transfer between settings jeopardises patient safety and complicates the provider's role of assessing and treating patients.[6] Over 60% of patients may have at least one unintended medication at hospital admission.[7] Over 40% of patients may experience postdischarge medication error(s) which can result in avoidable patient harm and healthcare costs.[1 8 9]

Across many sectors, there have been huge leaps in technology development to enable information systems to share data digitally, often referred to as system interoperability. Enabling the digital sharing of prescription information across care settings could reduce the prevalence of information transfer errors and the associated risk of avoidable harm to patients.[10–12] The development of interoperable systems to facilitate digital medicines reconciliation has shown promise in reducing time taken to complete the process and to further reduce unintentional discrepancies, mostly focused on hospital admission and discharge.[13 14] However, previous work is based on small-scale, qualitative or review studies, and/or relate to electronic prescribing interventions which are not fully interoperable. Furthermore, the impact on medication errors and associated harms has not been estimated in a way that can support decision making about the commissioning of these systems.

There is a nationwide initiative by the NHS in England to introduce interoperability into all NHS healthcare and social care settings including prescription information as part of the NHS Long Term Plan and digital transformation agenda and the government's Health and Social Care Committee's commitment to the digitisation of the NHS.[15] This has been operationalised as key components of 'ISN DAPB4013' which is an Information Standard introduced into the NHS in England in 2023, to contribute to the wider aim of the NHS 'to create fully interoperable, computable medication and prescription information across the NHS enabling seamless transfer of care and ultimately a patient-centred consolidated medication record'.[16 17] In simple terms, this means that the aim of the current initiative is to allow fully interoperable access to all sources of information about a patient's medication. In the future, the ultimate aim is to have one patient-centred consolidated medication record, to which there will be fully interoperable access. There is no evidence to support the patient safety impact of implementing a fully interoperable prescription information system across England, so NHS England commissioned us to estimate the potential patient safety impact. The evidence directly linking medication errors to patient harm and/or costs is also sparse. Our objectives were (1) to estimate the number and burden of medication errors associated with prescription information transfer within the NHS in England and (2) to estimate the patient safety benefits of implementing an interoperable prescription information system in reducing these errors.

METHODS

This study used published evidence and stakeholder/expert input to estimate the annual prevalence, patient harm and NHS costs of undetected transition medication errors in England in the absence of an interoperable prescription information system. Building on the methods used in our previous work to estimate medication errors in England,[1] we developed a probabilistic mathematical model. We used this model to estimate the effect of implementing an interoperable prescription information system on the rate of transition medication errors and associated harm and costs. The approach is described below, with additional details reported in online supplemental material. We presented our analysis to the NHS Digital Interoperable Medicine Standards working group as a source of expert opinion on the validity of our assumptions.

Transition medication errors and harm

A medication error may be defined as: 'Any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the healthcare professional, patient or consumer'.[18] The outcomes used in this study are medication errors occurring at transitions of care that involve the transfer of prescription information, referred to as *transition medication errors*. This excludes intentional medication changes during the medication reconciliation process. Types of transition medication errors include omissions, extra medicines, duplicated medicines, wrong dose, wrong frequency, wrong timing, wrong formulation and acute medicines prescribed for chronic use.[6]

There are multiple transitions that can involve information transfer. In this study, we focus on four information transfer settings: primary care to secondary

care (hospital admission); secondary care to primary care (hospital discharge); intrahospital transition (where there is transfer of information from one electronic prescribing system to another, including both inpatient and outpatient care); interhospital transition. Transitions excluded were ambulance/paramedic care; when patients change primary care practice; mental health and other specialist services such as sexual health, private hospitals (separate governance structures); devolved nations (Wales, Scotland, Northern Ireland); hospital prescribing to dispensing; outpatient/emergency care to community pharmacy.

Harm caused by medication is referred to as an adverse drug event (ADE).[6] ADEs can occur even when the medicine is prescribed appropriately (eg, due to unknown allergies), this is an adverse drug reaction and are not generally considered to be preventable. However, if there are questions about whether the prescription was appropriate this is a medication error. Some medication errors do not lead to harm, others can lead to serious harm.[19] Any resultant ADE following a medication error is considered 'preventable' or 'avoidable'. We use avoidable ADEs to capture harm caused by a medication error. For this analysis, we have measured the burden of harm from transition medication errors using hospitalisations, length of hospital stay and deaths. These were the only objective measures of the burden of harm that could be estimated from the available data. The cost perspective taken was that of NHS England, cost year 2020–21. Annual costs were estimated by attaching publicly available unit costs to hospital admissions.

Key assumptions

Most hospitals in England employ some form of medicines reconciliation which is effective in reducing transition medication errors.[5 13 14] Medicines reconciliation can be defined as 'the process of identifying the most accurate list of a patient's current medicines including the name, dosage, frequency and route and comparing them with the current list in use, recognising and documenting any discrepancies, thus resulting in a complete list of medications'.[20] Digitally enabled medicines reconciliation cannot take place in the absence of a healthcare professional already in situ to carry out some form of 'standard' medicines reconciliation. Therefore, our estimate of the error rate prior to implementation of an interoperable prescription information system includes transition medication errors that would be expected (and undetected) in the presence of standard medicines reconciliation (which may include access to non-interoperable digital prescription information). In addition, digitally enabled medicines reconciliation cannot take place in the absence of electronic prescribing systems. At the time of this work, not all English hospitals had electronic prescribing in place for inpatients, with varying patterns of electronic prescribing systems existing within one hospital setting. The NHS Long Term Plan has a commitment to eliminate paper prescribing in hospitals and introduce digital prescribing across the entire NHS by 2024,[21] so in consultation with service providers and policy makers, we have assumed that prior to introduction of the prescribing information system, all hospitals in England:

- have electronic prescribing for standard inpatient wards (therefore no discrepancies caused by manual chart rewrites are included in our estimates);
- did not have 100% interoperability between standard inpatient ward electronic prescribing systems and other electronic prescribing systems (such as emergency departments, intensive care, theatres);
- did not have 100% interoperability between electronic prescribing systems in different hospitals.

PICO framework

The analysis conducted is summarised in the following PICO framework:

- Population: people taking medicines at defined care transitions.
- Intervention: digitally enabled interoperable prescription information system (rolled out across NHS care settings in England and allowing access to a single, up-to-date, electronic prescribing record for each patient).
- Comparator: manual medicines information transfer (which can include use of systems that provide access to digital information, but requires manual transfer to another medicines information system).
- Outcomes: transition medication errors, hospitalisations, length of hospital stay, readmissions, deaths.

The intervention can be described as the ability to digitally migrate fully interoperable, computable medication and prescription information from the medication record for a patient in one setting (such as general practice) into another setting (such as secondary care). This is the key component of ISN DAPB4013 which is being introduced across the NHS in England.[16 17] It currently requires the intervention of a healthcare professional to carry out this migration, but does not require any manual re-keying of information. Therefore, we assume that this intervention will be carried out as an addition to, or adaptation of, standard medication reconciliation. It is planned that eventually all settings will have this functionality, but the present aim to ensure that this functionality exists in key transitions is detailed above. Currently only prescribed medications are included in the system, but future iterations may allow inclusion of over-the-counter medication. Currently, patient consent is not required for this transfer of information between settings as the data do not move outside NHS systems. The comparator can be described as standard medication reconciliation as defined above.

Rapid literature reviews

Three rapid literature reviews were conducted which are each described in more detail in online supplemental material. For each review, systematic searches for studies were undertaken from February to July 2022 via contact with experts in the field; searching of electronic databases; checking of bibliographies and citation searching of retrieved papers (including grey literature). We used a comprehensive pearl-growing and iterative approach to deal with the complexity of finding published work in this area, a challenge common to this type of public health topic.[22] We started with key reviews,[23 24] the WHO report[4] and other publications with which the team were familiar to allow development of an initial search strategy, along with extracting reviews from reviews of reviews. Databases searched were Medline, Embase, DARE, Cochrane, PsycINFO, CENTRAL, CINAHL, Web of Science from 2000 to June 2022. We carried out citation searches and chain searches of all sources found. Non-indexed journals publishing in this area were hand-searched (in June 2022): *Journal of Medicines Optimisation, International Journal of Pharmacy Practice, Research in Social and Administrative Pharmacy, International Journal of Clinical Pharmacy* and *European Journal of Hospital Pharmacy*. Conference abstracts were excluded. The review included full-text journal publications only and studies reported in English. Quality assessment of included studies was undertaken,[25] summary tables and narrative syntheses were produced. Authors were not routinely contacted.

Estimating the prevalence of transition medication errors

The parameters used to estimate the prevalence of transition medication errors are reported in table 1. To avoid overestimating the number of transition medication errors, we first excluded errors that would be detected by standard medicines reconciliation.[26 27] Transition medication error prevalence was then defined as the total number of items prescribed or dispensed with an undetected medication error divided by the total number of items prescribed.[26 27] The number of patients with an error was estimated by dividing the number of items with an error by the mean number of items prescribed per person at the respective transitions.[28–30]

Estimating the burden of transition medication errors

The parameters used to estimate the burden of transition medication errors are reported in table 1. The primary approach used was to identify available England-based case studies of estimates of burden from ADEs and extrapolate to estimate the impact for England per annum. Data from non-English case studies were used to supplement this evidence where necessary. We estimated increased length of hospitalisations and deaths associated with transition errors at admission, intrahospital and interhospital transition errors,[31] and the number of hospitalisations (readmissions) and deaths associated with errors at discharge.[32 33] The key assumption is that definitely avoidable ADEs approximate the harm from medication errors; hence these studies were considered acceptable. Due to lack of primary data, it was necessary to assume that the proportion of errors resulting in harm at admission[31] was the same at intrahospital or interhospital transitions.

Probability distributions

To incorporate uncertainty associated with model parameters, we used Monte Carlo simulation. Model parameters were selected 1000 times at random from a specified probability distribution. The 1000 simulations provided a point estimate (the mean of the simulated values) and measure of uncertainty (the 95% credibility interval (CrI) of the simulated values). There is a 95% probability that the true value lies within the range of the CrI. We did this for parameters where the necessary data (eg, SE, 95% CI or numerator and denominator) were provided in the source publication. A beta distribution was used for parameters which were probabilities of events occurring (error detection, ADE, avoidability of ADE, ADE leading to harm). A log-normal distribution was used for effect sizes (OR of detecting errors through medicines reconciliation). The specific distributions used are reported alongside the model parameters in table 1.

Estimating the impact of implementing interoperable prescription information systems on transition medication errors

We were unable to identify any literature relevant to the English health service that could be used to estimate the impact of implementing an interoperable prescription information system. We identified a meta-analysis of various 'electronic medication reconciliation' interventions which reported a pooled effect size (a relative risk of 0.55).[14] However, the interventions in some of the studies used to generate this estimate were not necessarily interoperable, so we looked for further evidence around effect size. We found two studies of interventions relevant to a UK setting, with clear reporting of a relevant primary outcome measure. A quasi-experimental study from a public hospital in Spain compared medication discrepancies on admission prescription orders when the lead physician did or did not have access to an electronic list of preadmission medications. It reported a relative risk for medications at admission being prescribed with an unintended discrepancy of 0.53 (postimplementation vs preimplementation).[34] A quasi-experimental study from a single hospital in the USA reported the effect of implementing an interoperable system on medication errors at discharge was a relative risk of 0.69.[35] Both studies counted errors before and after implementation

Table 1 Parameters used to estimate the number of medication errors per year at hospital transitions and associated harm

Description	Parameter	Source
Annual hospital activity in England		
Number of FAEs	17 127 498 episodes	NHS Digital[28]
Number of overnight admissions: total number of FAEs minus number of day case finished consultant episodes (7 386 255)	9 741 243 admissions	NHS Digital[28]
Number of intrahospital transitions: 71.7% of patients in an observational study of elderly (median age: 79 years) patients had at least one intrahospital transfer during their overnight admission. Intrahospital transfers in general population was assumed to be one-quarter of this rate (ie, 17.9% of overnight admissions) supported by expert opinion.	1 746 118 transitions	Boncea *et al*[30]; expert opinion
Number of interhospital transitions: estimated from ambulance activity data (category 1–4 interfacility transfer incidents)	222 794 transitions	Ambulance System Indicators for England (2021–22)[29]
Number of FAEs discharged: same as total number of FAEs	17 127 498 discharges	NHS Digital[28]
Annual prescribing activity in England		
Mean number of items prescribed at inpatient admission, also assumed to be number of items prescribed at intrahospital and interhospital transitions	4.78 items	Ashcroft *et al*[26]
Mean number of items per discharge prescription	4.9 items	Lloyd *et al*[27]
Number of items prescribed at overnight hospital admission	46 521 652 items	Calculated from number of event and items prescribed
Number of items prescribed at intrahospital transitions	8 339 006 items	
Number of items prescribed at interhospital transitions	1 064 006 items	
Number of items prescribed at discharge	83 518 624 items	
Prevalence of errors		
RRR in medication errors at transfer following medicines reconciliation (vs no medicines reconciliation)	RRR 0.13 (log-normal dist; alpha: −2.04; beta: 0.163)	Redmond *et al*[5]
Medication error rate at admission and interhospital transition Detected by meds rec: 13.28% (beta dist; alpha: 5910; beta: 38 586) Total: 15.30%	Undetected by meds rec 1.99%	Ashcroft *et al*[26]; calculated using Redmond *et al*[5]
Medication error rate at intrahospital transition Detected by meds rec: 3.94% (beta dist; alpha: 598; beta: 14 591) Total: 4.50%	Undetected by meds rec 0.58%	Ashcroft *et al*[26]; calculated using Redmond *et al*[5]
Medication error rate at discharge Detected by meds rec: 6.31% (beta dist; alpha: 1989; beta: 29 513) Total: 7.20%	Undetected by meds rec 0.94%	Ashcroft *et al*[26]; calculated using Redmond *et al*[5]
Harm from errors		
Errors at inpatient admission, intrahospital and interhospital transition leading to harm: Proportion of inpatient episodes where an ADE occurs Proportion of ADEs that are definitely avoidable (ie, harm from an error) Proportion of inpatient episodes with an ADE (ie, definitely avoidable ADE) (14.7%×6.4%) Proportion of ADEs related to drugs that were initiated prior to hospitalisation (131 out of 733 ADEs)	14.7% (beta dist; alpha: 535; beta: 3107) 6.4% (beta dist; alpha: 45; beta: 665) 0.9% 17.9%	Davies *et al*[31]

Continued

Table 1 Continued

Description	Parameter	Source
Burden of harm from errors at inpatient admission, intrahospital and interhospital transition: proportion of people with extended admission due to harm mean additional length of stay	26.8% (beta dist; alpha: 147; beta: 398) 4 days	Davies *et al*[31]
Burden of harm from errors at inpatient admission, intrahospital and interhospital transition: proportion of people who have an ADR that die as a result	0.18% (beta dist; alpha: 1; beta: 544)	Davies *et al*[31]
Errors at discharge leading to harm: proportion of people with medication-related harm following hospital discharge who were readmitted to hospital	21.1% (beta dist; alpha: 87; beta: 326)	Parekh *et al*[32]
Burden of harm from errors at discharge: median duration of admissions due to ADE	6 days	Osanlou *et al*[33]
Burden of harm from errors at discharge: proportion of people admitted to hospital due to an ADE who died as a result	0.42%	Osanlou *et al*[33]
Unit costs		
Cost per excess bed day in hospital (weighted mean of elective and non-elective)	£372	NHS schedule of reference costs[43] NHSCII pay and prices index for inflation[44]
Cost of a non-elective inpatient admission	£3626	NHS schedule of reference costs[45] NHSCII pay and prices index for inflation[44]

ADE, adverse drug event; ADR, adverse drug reaction; Dist, distribution; FAEs, finished admission episodes; meds rec, medication reconciliation; NHS, National Health Service; RRR, relative risk reduction.

of a new system and so any new errors would be included. While both studies were from high-income settings, they only included complex patients (those prescribed ≥3 or ≥5 drugs, respectively) and so may not be generalisable to the health service in England. Also, both are single centre before and after studies, with high risk of confounding.

Due to the poor quality of evidence around effect size, we used an iterative analysis approach to estimate the impact of a range of potential effect sizes. We simulated the impact of reducing the number of transition medication errors (the mean number of errors at each transition across the 1000 simulations) by 10%, 20%, 30%, 40%, 50% and 60%. We calculated the impact of reducing the number of errors on the number of patients experiencing harm from an error, bed days of inpatient care due to an error (and associated cost) and deaths due to an error.

RESULTS

Table 1 summarises the model parameters used to estimate the number of transition medication errors and associated harm and costs.

The estimated annual number and burden of medication errors at hospital transition are summarised in table 2. The total annual number of undetected transition medication errors (in the presence of standard medicines reconciliation but without an interoperable prescription information system) was estimated to affect 1826 113 (95% CrI 1 255 039 to 2 602 101) items prescribed per year. The relative contribution of each care transition was admission to hospital (52% of all transition medication errors); discharge from hospital (44% of all transition medication errors); intrahospital transitions (3% of all transition medication errors) and interhospital transitions (1% of all transition medication errors).

Over a year, the total number of patient episodes estimated to experience harm from a transition medication error is 31 604 (95% CrI 22 407 to 42 906). Per year, these errors are estimated to result in 36 704 (95% CrI 25 093 to 52 019) additional bed days of inpatient care, costing around £17.8 million (95% CrI £12.4 to £24.9 million), and causing 45 deaths (95% CrI 9 to 146). There is particular uncertainty around the estimated number of deaths (as demonstrated by the wide CI). This is because this is a relatively rare outcome.

Figure 1 shows the estimated number of medication transition errors per 100 000 hospital admissions (panel A) and the total cost of excess bed days due to harm from errors, also per 100 000 hospital admissions (panel B) per year. The shorter height of the bars for intrahospital and interhospital transfers reflects that a small proportion of admitted patients are transferred during their stay.

Estimated impact of implementing an interoperable prescription information system

Table 3 shows the estimated annual impact of reducing the number of transition medication errors by 10%–30%, and 50% (results for all scenarios modelled are presented in online supplemental material table S1). For each 10% reduction in the number of transition medication errors, there would be an estimated 3160 fewer patient episodes where harm from

Table 2 Estimated annual number of transition medication errors and number of patient episodes experiencing at least one medication error at a point of transition (in the presence of standard medicines reconciliation) and associated harm

	Admission	Intrahospital transition	Interhospital transition	Discharge	Total
	Number per year (95% CI)				
Number of transition medication errors	946 487 (649 887 to 1 344 608)	50 285 (34 881 to 72 905)	21 647 (14 864 to 30 753)	807 694 (555 407 to 1 153 835)	1 826 113 (1 255 039 to 2 602 101)
Number of patient episodes with at least one transition medication error	198 186 (136 081 to 281 550)	10 529 (7304 to 15 266)	4533 (3112 to 6439)	165 637 (113 900 to 236 621)	378 885 (260 397 to 539 876)
Number of patients with harm from transition medication error	16 348 (11 869 to 21 254)	869 (631 to 1147)	374 (271 to 486)	14 013 (9636 to 20 019)	31 604 (22 407 to 42 906)
Excess bed days due to harm	17 653 (12 518 to 23 877)	938 (659 to 1308)	404 (286 to 546)	17 709 (11 630 to 26 287)	36 704 (25 093 to 52 019)
Cost of excess bed days	£6 560 165 (£4 651 996 to £8 873 304)	£348 717 (£244 836 to £486 158)	£150 039 (£106 397 to £202 943)	£10 704 318 (£7 360 779 to £15 291 696)	£17 763 238 (£12 364 008 to £24 854 101)
Deaths due to harm	30 (1 to 119)	2 (0 to 6)	1 (0 to 3)	12 (8 to 18)	45 (9 to 146)

Numbers in the 'Total' column are calculated from non-rounded values therefore cannot be directly calculated from values in the table which are reported to the nearest whole number.

an error occurs, 3670 bed days prevented (at a cost saving of £1 755 088), and 4 deaths prevented over a year. A more effective interoperable prescription information system has the potential to save more lives and resources.

DISCUSSION

The total number of undetected transition medication errors (in the presence of standard medicines reconciliation) was estimated to be 1 826 113 in England per year, with at least one transition medication error occurring in 378 885 patient episodes. The total number of patient episodes where harm from a transition medication error occurs is estimated to be 31 604, with the majority (52%) resulting from errors at hospital admission. Transition medication errors are estimated to result in 36 704 additional bed days of inpatient care annually, costing around £17.8 million, with 45 people estimated to die. Per 10% reduction in the number of errors, there would be over 3160 fewer patient episodes where harm from errors is experienced and over £1.8m saved in-hospital admission and readmission costs. Based on the international literature identified, the relative risks of medication errors following implementation of an interoperable prescription information system could reduce transition medication errors by around 30%–50%,[14 34 35] although generalisability of these estimates to the UK setting is unclear. Annually, this would result in between 9 481 and 15 802 fewer patient episodes where harm from a transition medication error is experienced, 11 011 and 18 352 fewer bed days of inpatient care and around £5.3 and 8.8 million and 13 and 22 lives saved.

Comparison with published estimates of medication error prevalence and burden

We are not aware of another published estimate of numbers and burden of transition medication errors specifically. However in 2007, the National Patient Safety Agency (NPSA) estimated NHS costs of preventable medication errors (not restricted to transition errors) to be £774 million, at 2005–6 prices (£1.1 billion at 2020–21 prices).[36 37] They included definitely or probably preventable ADEs in their estimates. In our subsequent work, we only included definitely preventable ADEs which gave estimated NHS costs of preventable medication errors of £98 million, at 2015–16 prices (£109 million at 2020–21 prices).[1] In the current analysis, we have restricted our primary estimate to include only definitely avoidable ADEs. A broader definition of avoidability could increase our estimates up to 10-fold. However, if this broader definition of avoidability is used, then it should be noted that widespread adoption of an interoperable prescription information system would only prevent a subset of these transition medication errors (ie, the avoidable ones).

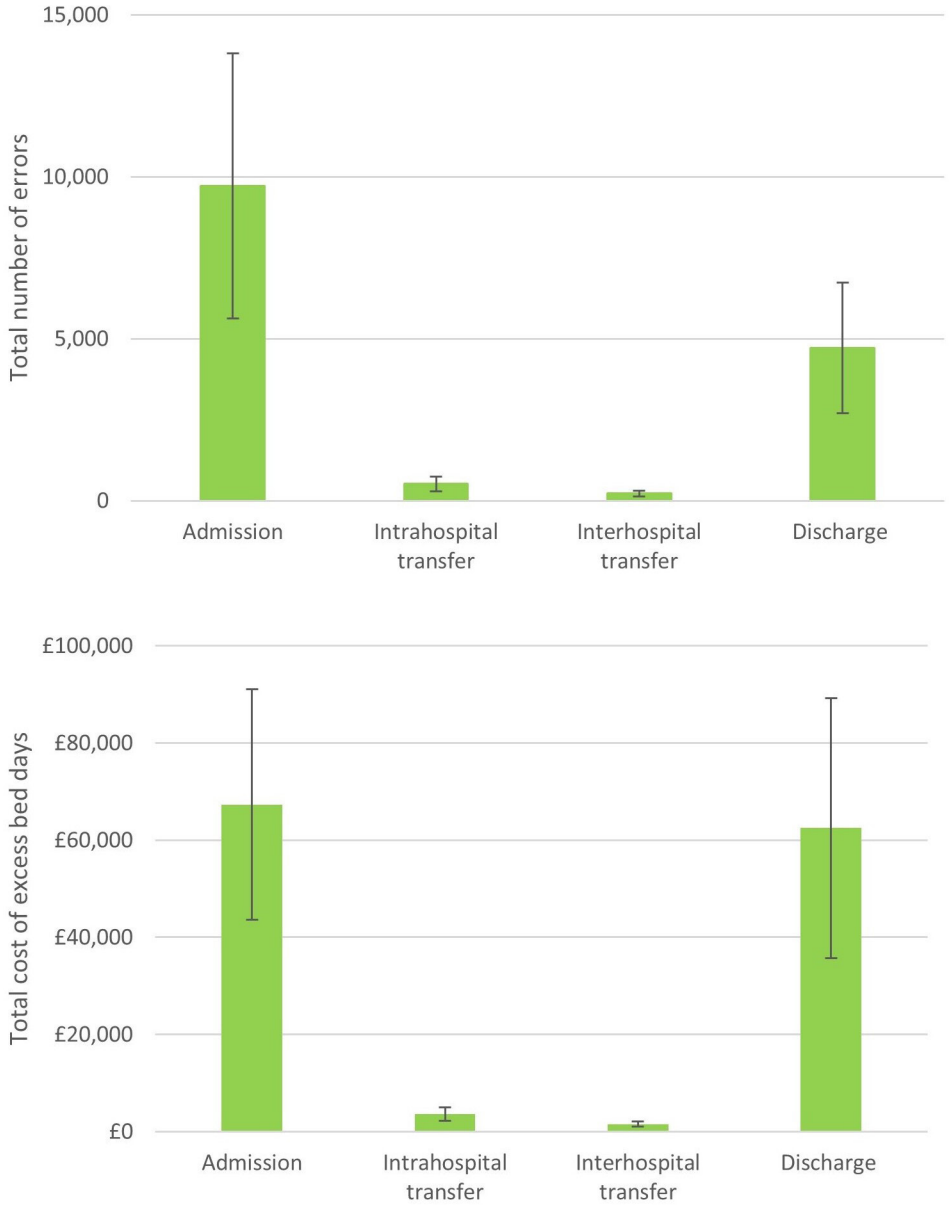

Figure 1 Estimated total number of transition medication errors (A) and total cost of excess bed days due to harm from errors (B) per 100 000 hospital stays, with 95% credibility interval.

Strengths and limitations

The limitations of this work stem largely from lack of data on medication errors and their sequalae. We had to make a number of assumptions, as detailed in the 'Methods' section. The estimates presented here are likely to be indicative rather than definitive because of this. Where assumptions have been made, we have used conservative estimates. To illustrate uncertainties in the underlying data, we have conducted a probabilistic estimation of the number of transition medication errors and associated harm and costs and reported CIs around mean estimates. We have explored the impact of implementing an interoperable prescription information system at a range of plausible effectiveness levels. As more robust primary data emerge on the effectiveness of these systems, our estimates can be further refined. Due to a lack of data, we have had to exclude many transitions (such as to and from nursing homes and mental health settings). Similarly, we have only measured the harm and costs associated with transition medication errors using objective outcomes reported robustly in published literature (hospital (re)admissions and death). This does not incorporate psychological harm or long-term sequalae associated with medication errors or costs from a societal perspective (eg, inability to work or loss of income).

There will also be some patients who experience harm from transition medication errors who are treated in emergency departments, by paramedics or in primary care services. The impact of excluding care transitions and other harms associated with medication errors will be an underestimate of the benefit of

Table 3 Number and burden of transition medication errors and estimated reduction for different effect sizes following implementation of an interoperable prescription information system

	Admission	Intrahospital transition	Interhospital transition	Discharge	Total
Number of transition medication errors					
Preimplementation	946 487	50 285	21 647	807 694	1 826 113
10% fewer errors	94 649	5029	2165	80 769	182 611
30% fewer errors	283 946	15 086	6494	242 308	547 834
50% fewer errors	473 243	25 143	10 824	403 847	913 057
Number of patients episodes with harm from a transition medication error					
Preimplementation	16 348	869	374	14 013	31 604
10% fewer errors	1635	87	37	1401	3160
30% fewer errors	4904	261	112	4204	9481
50% fewer errors	8174	434	187	7007	15 802
Excess bed days due to transition medication errors					
Preimplementation	17 653	938	404	17 709	36 704
10% fewer errors	1765	94	40	1771	3670
30% fewer errors	5296	282	121	5313	11 011
50% fewer errors	8826	469	202	8855	18 352
NHS cost of excess bed days due to transition medication errors					
Preimplementation	£6 560 165	£348 717	£150 039	£10 704 318	£17 763 238
10% fewer errors	£656 016	£34 872	£15 004	£1 049 196	£1 755 088
30% fewer errors	£1 968 049	£104 615	£45 012	£3 147 589	£5 265 265
50% fewer errors	£3 280 082	£174 358	£75 019	£5 245 981	£8 775 442
Deaths due to transition medication errors					
Preimplementation	30	2	1	12	45
10% fewer errors	3	0	0	1	4
30% fewer errors	9	0	0	4	13
50% fewer errors	15	1	0	6	22

NHS, National Health Service.

implementing an interoperable prescription information system in the NHS in England.

A key limitation is the assumption that definitely avoidable ADEs correspond to medication errors. There was minimal data directly linking transition medication errors to outcomes and costs. Therefore, we based our estimates on English observational data of healthcare resources used to treat ADEs that used published criteria to identify what proportion of all ADEs observed were avoidable. It was necessary to assume that the occurrence of avoidable ADEs and their associated burden and cost can be used to approximate the burden and cost of harm from transition medication errors. This generates a conservative estimate of the number of transition medication errors, which may be interpreted by some commentators as underestimating the total. We could have included 'possibly' avoidable ADEs, which according to the source paper by Davies *et al*,[31] was an additional 46.9% of events, however this would have markedly increased the uncertainty.

The real picture in English hospitals is also more complex than it was necessary to assume for this analysis. It is anticipated that all English hospitals will have electronic prescribing systems in place for inpatients by the end of 2023, which will allow a degree of linkage, between hospitals and primary care. However, within a single hospital there may be more than one electronic prescribing system in use. It is unclear to what extent these systems are currently interoperable, and this is likely to be different across different hospitals. In addition, provision of standard medicines reconciliation is variable across English hospitals, so the baseline transition medication error rates in individual trusts may be higher or lower than the measure used in our work. Further investigation into the effectiveness of applying interoperability standards compared with standard medicines reconciliation without interoperability in the NHS context would be valuable.

We have not considered the cost of setting up interoperable prescription information systems in our analysis. The cost of doing so is likely to be highly heterogeneous between settings and within an organisation dependent on the reality of current systems, the size and complexity of services provided and the patient population and other infrastructure factors. Our findings can be used by commissioners to inform decision-making on their approach to operationalising an interoperable prescription information system in their own context. We have provided estimates for how much benefit would need to be realised in order to offset implementation costs which can be used in

local financial planning. We have also provided estimates of the prevalence of transition medication errors (and associated costs) per 100 000 hospital admissions so that our findings can be used similarly by commissioners internationally.

The results may underestimate the benefits on an interoperable prescription information system accrued in primary care. The impact of transition medication errors postdischarge will often be managed in primary care leading to increased general practitioner, pharmacist and administrative staff workload. Therefore, reduced transition medication errors from secondary care to primary care will potentially free up time for staff in these groups. Future research should be performed to identify the impact of reducing transition medication errors on primary care provider resources. Another consideration for implementing an interoperable prescription information system is that while transcription errors may be reduced, other prescribing errors may not be. It is important that prescribers do not assume that technology will detect errors and must remain vigilant.

Policy implications/recommendations

A recent report by the King's Fund describes the steps needed to help interoperability improve patient care.[38] Fundamental to this is the need for positive working relationships between staff and care leaders, and an enabling environment which aligns capacity for change, skills development (including digital literacy) for the NHS workforce and information governance. The existence of interoperable prescription information systems alone is not sufficient to deliver benefits to patients. The success of implementing interoperable systems will also be promoted where there is good staff buy-in and a culture of agreement about how useful it is by stakeholders.[39] These systems do not operate in a vacuum and require a healthcare professional to be already undertaking medicines reconciliation so that they can realise the added benefit of interoperability. The widespread adoption and active use of interoperable systems across the NHS will be pivotal to realising the benefits of interoperability and a key step towards the ultimate aim of having one patient-centred consolidated medication record, to which there will be fully interoperable access.

It is likely that the introduction of interoperability solutions will allow more, and better, medicines reconciliation episodes to be done overall. This further impact on the reduction of transition medication errors has not been taken into account in our estimates. The ability of interoperability solutions to support more responsive and timely medicines reconciliation during care transfers requires service expansion and reconfiguration. Development and resourcing of hybrid digital/clinical roles to inform technology solution design and implementation is required to realise these benefits.

A more explicit role for patients, carers and families is essential to improve medication safety in transitions of care.[4] There have been attempts to include patients in electronic discharge,[40–42] and WHO has developed a free 'Medsafe' app (https://www.iapo.org.uk/news/2019/jul/18/who-medsafe-app) to support patients holding an up-to-date medicines record. In their report on medication safety at care transitions, WHO identified information technology systems and electronic health records as a key strategy for improving safety.[4] They also acknowledged that a key challenge was information sharing between and within healthcare settings and that cost-benefit modelling could be used to gain the support of healthcare leaders and other stakeholders in creating change. Interoperable prescription information systems offer a solution to the information sharing challenge and our analysis provides an estimate of the potential benefits of implementing this type of system. Our findings can be used to inform decision making on the implementation of strategies to improve medication safety at care transitions, which is especially relevant for countries participating in the WHO's Medication Without Harm Challenge.

Audits need to be carried out to measure the number of transition medication errors, including at interhospital and intrahospital transfer. These data are needed both prior to and after interoperability is introduced across the NHS in England to be able to assess the impact on transition medication errors.

CONCLUSIONS

Transition medication errors persist despite standard medicines reconciliation, and an interoperable prescription information system has the potential to substantially reduce transition medication error prevalence, associated harm and healthcare costs. Additional potential benefits include healthcare professional time saved, improved patient experience and care quality, quicker discharge and enhanced cross-organisational medicines optimisation. We have presented a range of plausible effect sizes for the impact of implementing an interoperable prescription information system on the prevalence of medication errors. This is vital safety and economic evidence which can inform evidence-based commissioning.

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