RESEARCH PAPER

Drug Information Services as Medication-Safety Infrastructure for Safer Drug Delivery: A Narrative Review of Medication Error Prevention

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Abstract
Medication errors remain a leading cause of preventable patient harm, and improved access to reliable drug information services (DIS) may support prevention. DIS bring together evidence appraisal, pharmacist expertise, clinical decision support, pharmacovigilance, and communication throughout the medication-use process. This narrative review examines the role of DIS in medication safety and care quality, including electronic prescribing, adverse drug reaction (ADR) surveillance, alert fatigue, benefit–risk assessment, and pharmacist-led safety interventions. A meta-analysis of electronic prescribing systems reported fewer adverse drug events (risk ratio 0.52; 95% confidence interval 0.40–0.68), although certainty and outcome assessment limit inference. Some drug–drug interaction alert overrides are appropriate, whereas others may expose patients to preventable harm. Interdisciplinary strategies should focus on medication processes while addressing inadequate interoperability, low-value alerts, unvalidated artificial intelligence/machine learning, and difficulties generating dependable evidence from routine data. As a sociotechnical service, DIS can support evidence-based clinical decisions and intercept potential medication errors, provided human oversight and local evaluation remain central. Safety systems should prioritize preventable harm, near misses, equitable access, and measurable performance. Owing to variation in study designs and possible biases, the findings of this narrative review should not be interpreted as pooled causal effects.

Keywords: medication safety; drug information services; medication errors; patient safety; clinical decision support; pharmacovigilance; near misses
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Introduction

Medication error refers to any preventable event that may cause or lead to inappropriate medication use or patient harm. Medication safety depends on the quality of information used to select, prescribe, dispense, administer, and monitor medicines [1]. Drug information services (DIS) assess the quality of information required to choose, prescribe, give and monitor medicines. DIS reflect the contemporary focus of clinical practice and tend to align with electronic prescribing, clinical decision support systems (CDSS), pharmacovigilance and individualized dosing [2]. The key question is whether these technological advancements allow the clinical judgment of pharmacists to improve and achieve greater patient outcomes.

A major factor adversely affecting patient safety is medication error. While different definitions of medication errors exist, the most critical aspect of any definition is the patient's exposure to the risk of potential harm. There are situations where it may be more appropriate to consider a prescription error in terms of a potential medication adverse event (ADE) than actual harm [3]. Furthermore, a prescription may lead to drug-related admission to hospital even if actual harm does not occur. Reconciling these may require careful examination and distinction between prescription errors, potential ADEs and actual harm [4].

The reach of DIS has expanded from responding to individual requests to promoting safer flow of information across the medication-use system. While electronic sources are easily updated and accessible, they can also result in responsibility being fragmented, due to unclear ownership of the response, quality of the source, and customization of the software [5]. The role of a clinical pharmacist is critical when a patient is taking multiple medications, the patient's condition or organ functions are changing, or the patient is being transferred between different services, as in these situations additional warnings may be required [6].

We propose two complementary conceptual safety models (Figures 1 and 2) to illustrate how drug information services may identify unsafe situations and help intercept near misses. These models depict plausible information pathways; evidence that any single service directly reduces patient injury remains limited.

Drug information services and opportunities to prevent harm

DICs respond to patient-specific questions on drug-related issues such as dosage, interactions, contraindications, adverse effects and alternatives; assist with formulary decisions; conduct medication-use evaluations and provide continuing education to healthcare professionals [1,6]. In a survey of 647 UK healthcare professionals who used 62 medicines information services, 85% reported improvement in patient care and outcome, 77% reported impact on medication safety and 15% reported a major risk was avoided [2]. Aids provided by DICs are useful in assessing the outcome of the service user, however, these are not evidence

of reduction in adverse event. Cost, the awareness of the workforce, and the quality of Internet resources affect access to reliable information [7].

The institutional benefits of DIS depend on timely access to and adequate resolution of DIC enquiries. Enquiries concerning renal dosing, adverse drug reactions and therapeutic substitution also depend on clinician awareness of the service. As illustrated by a tertiary hospital evaluation, mature services may observe changes in the professional groups requesting information, including physicians and nurses [6,8].

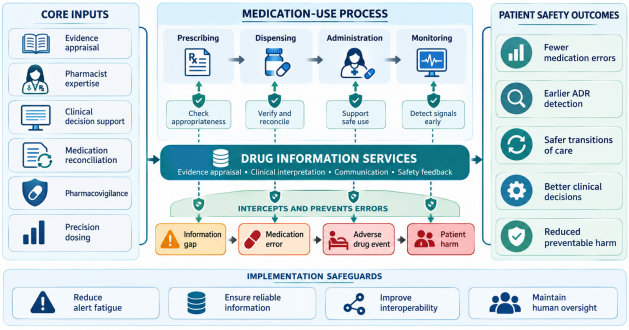

Figure 1. Integrated drug information services across the medication-use process. Diagram connecting evidence appraisal, pharmacist expertise, clinical decision support, reconciliation, pharmacovigilance and precision dosing with proposed patient-safety outcomes and implementation safeguards. The arrows are conceptual, not evidence of measured causal effects.

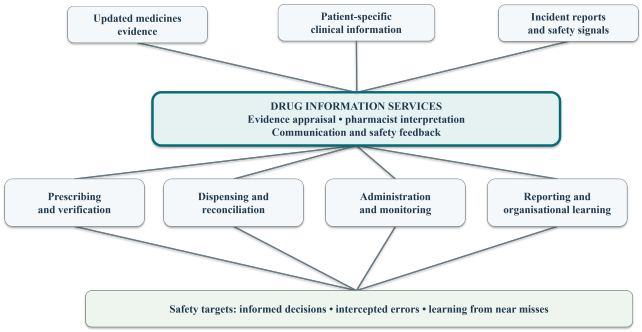

Figure 2. Drug information services as patient safety infrastructure. Conceptual model linking reliable evidence, patient context, and safety reporting to prescribing, dispensing, administration, monitoring, and organisational learning. Arrows represent proposed information pathways and safety targets, not measured causal effects.

Figure 3 illustrates a medication error pathway, beginning with incomplete or unreliable information, followed by an incorrect medication decision, an error and potential patient exposure. Drug information review, patient-specific decision support, pharmacist checks, medication reconciliation, and monitoring can interrupt this pathway. Actions taken before administration may avert exposure; once a medicine has been given, monitoring and follow-up become essential. An error can reach a patient without causing injury, and an adverse drug reaction during correct treatment is not automatically a preventable medication error.

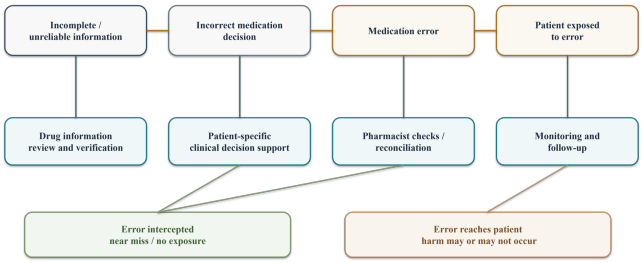

Figure 3. Medication error progression and opportunities for interception. Illustrative error pathway with preventive barriers. An error may be intercepted as a near miss, may reach a patient without causing injury, or may contribute to preventable harm. Adverse drug reactions can also occur during correct medication use and are not synonymous with medication errors.

Table 1. Differences in ADR definitions, case ascertainment, case-mix and preventability assessment limit comparison. The implied-ADR method used by Schechner and colleagues may identify possible drug-related admissions missed by diagnostic codes, but it does not establish that each admission was caused by a medication error [5]. This distinction is central when positioning DIS as an error-prevention intervention.

TABLE 1. Selected estimates of hospital admissions associated with adverse drug reactions

Study	Setting / method	Finding and interpretation
Kongkaew et al. [4]	Prospective observational studies	5.3% of admissions associated with ADRs
Hakkarainen et al. [9]	Meta-analysis of preventability studies	4.9% of admissions in source synthesis; 28.9% classified preventable
Bouvy et al. [3]	European observational literature	Approximately 3.6% of admissions attributed to ADRs
Schechner et al. [5]	Scottish polypharmacy cohort; administrative linkage	Approximately 13.7% implied ADR-associated admissions; not directly comparable

Prescribing systems, medication errors and patient outcomes

Computerized provider order entry (CPOE) and electronic prescribing can reduce dose, interaction, allergy, and transcription errors before drug administration. Studies reported significant reductions in medication errors, with study-specific relative reductions ranging from 13% to 99%, although risk of bias and outcome ascertainment varied [10]. A meta-analysis reported a relative risk (RR) of 0.52 (95% confidence interval [CI] 0.40–0.68) for adverse drug events and RR 0.55 (95% CI 0.30–1.01) for preventable adverse drug events; the certainty of evidence was considered very low [11]. Earlier evidence syntheses likewise identified heterogeneity in system design and observed effects [12].

Several reviews found very-low-certainty evidence for adverse drug event and medication error outcomes [13]. Therefore, although recorded medication error rates may decrease, consistent reductions in mortality or length of hospital stay have not been established.

It is important to consider the input of clinical pharmacists when setting alert thresholds and updating drug knowledge bases, and when resolving exceptions. At the time of administration, fully closed-loop safety systems cannot be assumed with smart infusion pumps that do not integrate with the electronic prescribing and medication systems [14].

The evidence on electronic prescribing varies across settings. Clinical decision support (CDS) modules integrated into computerized prescribing systems may reduce adverse drug events, but the relevant synthesis lacked randomized controlled trials [15]. Table 2 compares selected results and supports evaluating how clinicians respond to alerts and whether patient harm actually declines, rather than equating software installation with an effective safety intervention.

TABLE 2. Electronic prescribing and computerized order entry: selected outcomes

Evidence	Outcome	Finding / qualification
Ammenwerth et al. [10]	Medication errors, 25 studies	23 studies found significant reductions; magnitude differed substantially
Roumeliotis et al. [11]	Adverse drug events	RR 0.52 (95% CI 0.40–0.68); very-low-certainty evidence
Roumeliotis et al. [11]	Preventable adverse drug events	RR 0.55 (95% CI 0.30–1.01); effect uncertain
Ciapponi et al. [13]	Multiple hospital interventions	Important uncertainty from heterogeneous studies and outcomes

Alert fatigue, information reliability and human factors

Frequent electronic notifications may cause alert fatigue and clinician desensitization. A meta-analysis reported that approximately 90% of drug–drug interaction (DDI) alerts were overridden (95% CI 85–95%) [16]. An override does not itself indicate an unsafe decision: a systematic review found that the appropriateness of overrides varied across allergy, duplicate therapy, formulary and other alert types [17]. Evaluation should therefore distinguish clinically important alerts from low-value alerts rather than simply seeking a lower overall override rate (Table 3).

Several strategies may improve the efficiency of clinical alerting systems, including reducing unnecessary alert volume, grouping low-priority notifications, hiding selected low-value alerts and restricting unhelpful categories. Artificial intelligence (AI) may improve alert targeting, but unsafe or medically inappropriate generative-AI recommendations reinforce the need for clinical oversight. In one assessment of medication-related questions, only 26% (10/39) of ChatGPT responses were rated acceptable and fabricated references were observed [18]. AI outputs should therefore undergo professional verification before being used for medication decisions.

TABLE 3. Interpreting medication-alert override evidence

Evidence	Reported observation	Clinical implication
Felisberto et al. [16]	90% pooled physician DDI-alert override prevalence (95% CI 85–95%)	Large alert volume does not itself identify preventable harm
Poly et al. [17]	Override appropriateness varied substantially by alert class	Assess severity and appropriateness alongside override counts
Slight et al. [19]	High override proportions reported in primary-care alerting	Review alert specificity, thresholds and local workflow

The distinction between high override frequency and inappropriate override is important. Some drug-allergy alerts fire despite a documented patient tolerance or a clinically non-relevant reaction. However, a high-severity interaction warning may be overridden with monitoring or dose adjustment planned. Both situations may be appropriate, whereas overriding an alert for a high-risk combination may be unsafe. Usefulness and follow up are other important considerations when evaluating alerts [17,19].

As shown in Figure 4, improving the digital safety gains requires separating failure modes and identifying clinical and organizational safeguards. Improving relevance, auditing consequences and keeping human accountability are important aspects to prioritize rather than increasing the number of displayed alerts.

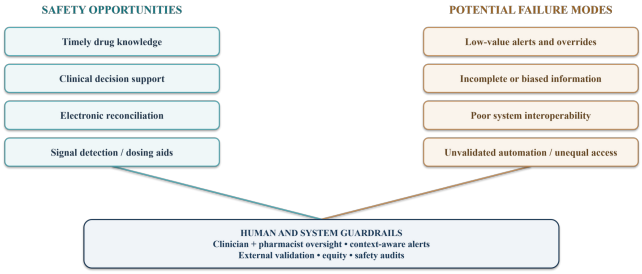

Figure 4. Digital medication safety opportunities, failure modes, and safeguards. Potential benefits of digital drug information depend on context-sensitive alerts, pharmacist and clinician oversight, external validation, audit, interoperability, and equitable access. The figure is conceptual; it does not indicate measured intervention effects.

Pharmacovigilance and organisational learning

Medication safety surveillance depends on feedback from case reports and clinical records, which can be used to update drug advice. By 31 December 2024, VigiBase contained more than 40 million individual case reports from over 160 countries [20]. Although its scale supports the recognition of rare signals, spontaneous reporting remains vulnerable to under-reporting and reporting bias. Fear of blame or litigation and cumbersome reporting processes can hinder learning from incidents [21].

Machine learning and AI can be used in pharmacovigilance to support earlier detection and prioritization of adverse drug reaction signals [22]. Before wider clinical adoption, transparency, subgroup fairness, workload, and false-positive signals require evaluation. Automated analyses of narrative patient records can assist with detection, but alerts

and possible signals still require pharmacist or clinician interpretation before changes to therapy are made [23].

Pharmacovigilance illustrates the value of clinical interpretation alongside large-scale safety data. In VigiBase, the proportion of reports classified as medication errors or related product-use issues increased from 2.5% before 2015 to 8.7% from 2015 onward [20]. This change in reporting frequency should not be mistaken for a threefold increase in population risk: the reporting numerator may be affected by surveillance intensity, reporting behaviour, or classification changes. Drug information professionals can help interpret safety signals, recommend formulary revisions and communicate safety bulletins [20,23].

Another approach is automated screening of discharge summaries and other free-text clinical narratives for possible adverse drug reactions. Natural-language-processing systems may identify relevant cases that are missed by coded diagnoses, although negation, incomplete medication histories, and differences in documentation limit accuracy. Careful patient-data governance is essential when developing and evaluating such tools [23].

Precision dosing and transitions of care

Model-informed precision dosing (MIPD) combines population pharmacokinetic models with individual clinical data and measured drug concentrations to guide therapeutic drug monitoring (TDM) [24]. At a paediatric hospital, a commercial Bayesian decision-support platform (InsightRX) was integrated into the electronic health record to assist vancomycin dosing. During more than two years of implementation, 853 patient-courses and 2,148 drug levels were evaluated using the tool; clinical pharmacists championed its adoption [25]. Such systems may improve dosing workflows, but external validation and evaluation of clinically meaningful outcomes remain necessary. Pharmacist review and the treating clinician's final decision remain essential when information is incomplete.

Medication reconciliation during discharge remains an important service gap. Systematic reviews and meta-analyses of pharmacist-led reconciliation at care transitions suggest possible improvements in selected clinical outcomes, but the evidence varies in quality and does not justify assuming prevention of every adverse event [26,27]. Medication information must be transferred accurately to patients and follow-up clinicians.

Implementation depends on end users as well as technical performance. A qualitative evaluation of bedside vancomycin model-informed dosing identified perceived benefits such as greater confidence in dose selection, along with constraints related to incomplete documentation, workflow, electronic health record integration and after-hours coverage [28]. This emphasizes the need to assess usability and staffing alongside pharmacokinetic performance.

Discharge errors may arise from missing or conflicting instructions, mismatched orders and inaccurate documentation of patients' actual medication use [29]. In a prospective cohort of older adults, 33% of 319 cardiometabolic medication changes made at discharge were subsequently modified within 90 days [29]. Medication counselling, communication with community prescribers, structured reconciliation and electronic discharge summaries should form a coordinated safety process. Clinical outcomes should be reported alongside the number of discrepancies corrected, because not all discrepancies would otherwise have caused patient harm.

Organisational interventions, costs and equity

A systematic review of 62 primary care studies found that, for medication-related admissions, the risk of organisation interventions was 0.81 (95% CI 0.70 to 0.95) and the risk for structural interventions was 0.90 (95% CI 0.83 to 0.97). The risk for professional interventions was not defined. Findings on reducing medication-related hospital admissions favour organisational and structural interventions [30]. Evidence also points to the benefit of hospital medication reviews in reducing readmissions, especially in the context of reconciliation and transitional care.

Beyond their clinical effects, medication errors can increase resource use through hospital admissions and prolonged monitoring. Estimates of their costs vary by perspective, data source and attribution method [31,32]. Evidence from hospital medication review and transitional-care syntheses also suggests possible reductions in selected readmission outcomes, subject to heterogeneous study methods [33,34]. Implementation costs should include recurring software subscriptions, interoperability work, staff training and pharmacist time. The concept of "techquity" in pharmacy education highlights how uneven access to digital technology may reproduce existing health inequalities [35]. Integrated services, reliable drug knowledge, responsive pharmacists and non-punitive incident learning may help reduce medication-related harm and strengthen safe transitions.

Economic findings support attention to medication safety, but they require a transparent costing perspective and denominator. A Finnish pilot study recorded 4,973 medication errors in a wellbeing services county in 2023 and estimated annual associated costs of €686,274, including staff time and service costs; national extrapolation was modelled rather than directly observed [36]. The OECD has likewise identified an important medication-safety burden for health systems [32]. These studies do not establish that purchasing a specific drug information platform will produce comparable savings. Economic evaluations should consider software, training, pharmacist time, avoided patient harm and local workflow effects.

Context is important when determining whether digital benefits are accessible. Resource-constrained health systems may struggle to afford frequently updated commercial resources, and connectivity or digital literacy may limit effective use [7,35]. Practical alternatives include locally maintained pharmacist-led reference systems, appropriate open-access evidence resources and professional support networks. Patient safety, not technological complexity alone, should remain the principal objective of system improvement [37].

Interpretation and evidence gaps

Drug information services may be understood as sociotechnical medication-safety services that bring together evidence appraisal, patient-specific decisions, clinical and pharmacist expertise, digital systems, and reporting feedback. The most consistently supported outcomes concern medication-use processes. Evidence for selected

service outcomes and hospital admissions is promising, whereas effects on mortality, preventable adverse drug events, and long-term patient-centred outcomes remain less certain. Future studies should use appropriate comparators and clinical end points to evaluate real-world DIS effects and assess equity, interoperability, alert quality and implementation context.

Conclusion

Drug information services connect evidence with prescribing, dispensing, administration, monitoring and communication. Electronic prescribing and selected pharmacist-led services can improve medication-safety processes, but frequent low-value alert overrides and limitations of AI-based tools show that technology alone is insufficient. Implementation should prioritize clinically relevant decision support, verified information, connected data, pharmacovigilance, independent evaluation and equitable access. Improving safety and reducing medication-related harm ultimately depend on how information is appraised, communicated and applied.

Statements and Declarations

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Author contributions. Writing and reviewing, supervision, methodology, and planning (specific contributions to be confirmed by the authors).

Ethics approval. Not applicable

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