Saudi Journal of Medicine and Public Health

https://saudijmph.com/index.php/pub

https://doi.org/10.64483/202412441

Optimizing the Medication Trajectory: A Multidisciplinary Framework for High-Reliability Prescribing, Administration, and Pharmacovigilance

Waleed Abdullah Alhabeeb [(1)] , Layth Talal Raji Alabdali [(2)] , Hassan Abdullah Hassan Kuriri [(3)] , Meshari Rushaydan Almutairi [(4)] , Abdulmajeed Abdulrahman Alanazi [(5)] , Noof Makrb Alfuhaigi [(6)] , Najah Atallah Alanazi [(7)] , Ibrahim Mohammed Abddullah Safhi [(8)] , Hassan Ali Hassan Albariqi [(9)] , Jaber Abdullah Ahmed Alkhaldi [(10)] , Mohammed Mujahid Ateeq Alkuwaykibi [(11)] , Mazen Khulaif Buthul Alruwaili [(12)]

(1) Maternity and Children's Hospital – Alhasa,Ministry of Health, Saudi Arabia,
(2) Ministry Of Health, Saudi Arabia,
(3) Al-Harth General Hospital – Jazan,Ministry of Health, Saudi Arabia,
(4) Fifth Al-Hasso General Hospital, Madinah Pool Scope,Ministry of Health, Saudi Arabia,
(5) Medina Health cluster, Al-Difaa Neighborhood Health, Center medina,Ministry of Health, Saudi Arabia,
(6) Prince Mutaib bin Abdulaziz Hospital, Ministry of Health, Saudi Arabia,
(7) Riffa Health Center in Al-Jouf, Ministry of Health, Saudi Arabia,
(8) Ahad almasareha General Hospital, Ministry of Health, Saudi Arabia,
(9) Eradah and Mental Health, Complex In Tabuk,Ministry of Health, Saudi Arabia,
(10) Department of Public Health,Ministry of Health, Saudi Arabia,
(11) Erada Hospital and Mental Health,Ministry of Health, Saudi Arabia,
(12) Erada Hospital and Mental Health in Qurayyat,Ministry of Health, Saudi Arabia

Abstract

Background: Medication errors persist as a leading cause of preventable patient harm globally, despite advancements in healthcare technology and protocols. These errors occur not within isolated silos but across a complex, interdependent pathway involving multiple disciplines. **Aim:** This narrative review aims to synthesize current evidence (2015-2024) on the integrated, interdisciplinary process of medication management, focusing on strategies for error reduction and enhanced patient safety from prescription through to monitoring. **Methods:** A comprehensive literature search was conducted across PubMed, Scopus, CINAHL, and Web of Science databases. The included literature comprised peer-reviewed articles, systematic reviews, meta-analyses, and key grey literature from professional organizations, published between 2015 and 2024. Thematic analysis was used to synthesize findings across eight core healthcare domains: Pharmacy, Medical Laboratories, Nursing, Radiology, Health Services & Hospital Management, Health Assistant/Health Security, Disaster Management, and Hospital Management. **Results:** The review identifies that high-reliability is achieved not through individual excellence but through seamless interoperability between disciplines. Critical nodes include technology-supported prescribing, interdisciplinary medication reconciliation, diagnostic stewardship informing therapy, and robust post-administration surveillance. Fragmentation in communication, information system incompatibility, and inadequate cross-disciplinary training remain significant vulnerabilities. **Conclusion:** A truly high-reliability medication pathway requires a systemic, socio-technical approach that embeds safety culture, interoperable health information technology, and structured interdisciplinary collaboration at every stage. Future efforts must prioritize integrated system design over domain-specific optimization.

Keywords: medication safety, interdisciplinary care, high-reliability organization, medication use process, patient harm

Introduction

Medication-related harm constitutes a formidable global public health challenge, with the World Health Organization (WHO) estimating its associated cost at USD 42 billion annually (World Health Organization, 2021). While often conceptualized as discrete events—a prescribing error, a mislabeled vial, an administration mistake—the genesis and prevention of these errors are deeply embedded within a complex, nonlinear system. This system, the medication use process (MUP), traverses multiple specialized domains, each with its own protocols, technologies, and cognitive frameworks. Traditional improvement efforts, often siloed within

*Corresponding author e-mail: walhabeeb@moh.gov.sa (Waleed Abdullah Alhabeeb).

Receive Date: 17 December 2024, Revise Date: 30 December 2024, Accept Date: 31 December 2024

pharmacy, nursing, or physician groups, have yielded incremental gains but frequently fail to address the systemic vulnerabilities that arise at the interfaces between these disciplines (Machen et al., 2019). The concept of high-reliability organizations (HROs), originating from industries like aviation and nuclear power, offers a compelling lens. HROs operate in inherently hazardous environments yet maintain exceptional safety records through principles like preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise (Weick & Sutcliffe, 2015). Translating these principles to healthcare, and specifically to the MUP, demands a shift from viewing safety as the responsibility of individual practitioners to understanding it as a property of the entire interconnected system.

This narrative review, therefore, aims to synthesize contemporary evidence (2015-2024) to construct an integrated model of the high-reliability medication pathway. It moves sequentially from prescription to monitoring, critically examining the role, interactions, and shared responsibilities of eight core disciplines: Pharmacy, Medical Laboratories, Nursing, Radiology, Health Services & Hospital Management, Health Assistant/Health Security, Disaster Management, and overarching Hospital Management. The central thesis is that medication safety is an emergent property of this network, where robustness is determined by the strength of its weakest interdependency.

The Prescribing Node

The journey of a medication order begins with the prescriber, but its safety is shaped by a supportive ecosystem designed to prevent errors of commission and omission. Computerized Provider Order Entry (CPOE) with integrated Clinical Decision Support (CDS) represents the technological backbone of a reliable prescribing node. Effective CDS goes beyond basic allergy and duplicate checking; it incorporates patient-specific data from medical laboratories (renal function, pharmacogenetic markers) and pharmacy records (current medications) to provide real-time guidance on dosing, contraindications, and therapeutic alternatives (Baysari et al., 2016). For instance, CDS rules that automatically adjust antibiotic or analgesic doses based on dynamically reported estimated glomerular filtration rate (eGFR) from the laboratory information system (LIS) can prevent adverse drug events (ADEs) in patients with renal impairment (Niazkhani et al., 2020).The pharmacy department's role is pivotal here, extending far beyond dispensing. Clinical pharmacists embedded in care teams conduct prospective order review, applying therapeutic expertise to intercept errors before they reach the patient. Their work is guided by institution-specific formularies managed by the Pharmacy and Therapeutics (P&T) Committee—a cornerstone function of Hospital Management. This committee, interdisciplinary by design, evaluates drug efficacy, safety, and cost-effectiveness, making system-level decisions that standardize and streamline the medication arsenal, thereby reducing variability and confusion (Ciccarello et al., 2021). Health Services Management contributes by designing and accrediting these technology-enabled systems, ensuring they align with safety standards from bodies like The Joint Commission and facilitating the workflow integration that makes CDS tools usable rather than disruptive (Ratwani et al., 2017).

However, technology introduces its own failures. Alert fatigue, caused by poorly specific or excessive CDS alerts, is a well-documented phenomenon that leads clinicians to override critical warnings (Wan et al., 2020). Furthermore, system fragmentation often means hospital CPOE may not integrate with outpatient pharmacy records or community laboratory data, creating information gaps at care transitions. This is where the role of Health Assistants or community health workers becomes crucial in bridging community-acquired medication histories into the institutional record, a precursor to formal medication reconciliation.

The Transitions and Verification Nexus

The transfer of medication responsibility across settings (admission, transfer, discharge) or within the pharmacy (sterile compounding) represents a high-risk phase. Medication reconciliation—the process of creating an accurate list of a patient's medications and comparing it to new orders—is a mandated safety practice. Its optimal execution is inherently interdisciplinary. While often initiated by physicians or nurses, its accuracy depends on pharmacy technicians and pharmacists verifying histories, medical laboratory data informing therapeutic decisions on continuation, and nursing providing patient and caregiver interviews (Abdulghani et al., 2018). Studies consistently show that pharmacist-led reconciliation at discharge significantly reduces preventable ADEs and readmissions (Manias et al., 2020).

Within the pharmacy, sterile compounding—for parenteral nutrition, chemotherapy, or epidurals—is a critical safety node. This is a pure pharmacy domain requiring stringent adherence to USP <797> and <800> standards. Errors here, such as concentration miscalculations or contamination, can have catastrophic consequences. Hospital management ensures safety through investment in appropriate facilities (cleanrooms), technology (compounding workflow systems), and rigorous quality control programs (Clark et al., 2020). The medical laboratory's role surfaces in testing the sterility and stability of compounded preparations, particularly for high-risk products (Table 1). Figure 1 illustrates the end-to-end medication use process, highlighting five critical stages: prescribing, dispensing, administration, monitoring, and pharmacovigilance.

Table 1: Interdisciplinary Roles and Interactions in the Medication Use Process

Process Stage	Key Disciplines	Primary Safety Functions	Critical Interdependencies
Prescribing	Health Services (CDS), Pharmacy, Lab	CPOE/CDS, clinical review, PGx/TDM data provision	Lab data feeds CDS; Pharmacy reviews based on formulary (Mgmt).
Dispensing/Compounding	Pharmacy, Hospital Management	Sterile compounding (USP <797>), formulary management, P&T Committee oversight	Management funds facilities; P&T is interdisciplinary.
Administration	Nursing, Health Services (Tech), Pharmacy	BCMA verification, "Five Rights," patient assessment, and accurate drug preparation	The pharmacy provides labeled drugs; the tech provides the BCMA system; Nursing executes the final check.
Monitoring	Nursing, Pharmacy, Lab, Radiology	Vital sign/ADE monitoring, TDM/PGx analysis, imaging for efficacy/toxicity	Lab/Radiology generates data; Nursing/Pharmacy interprets and acts.
Transitions/Adherence	Pharmacy, Nursing, Health Assistant	Medication reconciliation, discharge counseling, and community adherence support	Multi-source history gathering (Patient, HA, records); shared communication.
System Governance	Hospital Mgmt, Health Services Mgmt, Disaster Mgmt	Safety culture, HIT integration & funding, disaster planning, just culture policy	Sets conditions for all other stages; ensures resilience and learning.

Figure 1: Integrated High-Reliability Medication Safety Pathway: From Prescription to Pharmacovigilance

The Diagnostic-Informational Bridge

Before and during therapy, diagnostic services provide the essential data that transform a static prescription into a dynamic, personalized treatment plan. Medical laboratories are central to therapeutic drug monitoring (TDM) and pharmacogenomics (PGx). TDM, by measuring serum drug concentrations (e.g., for vancomycin, aminoglycosides, anticonvulsants), allows for dose individualization to achieve efficacy while avoiding toxicity (McKeating et al., 2016). PGx testing for genes like *CYP2C19* (clopidogrel) or *DPYD* (fluoropyrimidines) can identify patients at risk for severe adverse reactions or therapeutic failure, enabling pre-emptive therapy selection (Swen et al., 2023). The laboratory's timely and accurate reporting of renal and hepatic function is also a non-negotiable input for safe dosing.

Radiology provides a complementary, often overlooked, monitoring function. Imaging is critical for assessing the efficacy of chemotherapeutic agents (via tumor measurement on CT/MRI) and for diagnosing drug toxicity. Examples include monitoring for contrast-induced nephropathy, identifying pulmonary fibrosis from chemotherapeutic agents like bleomycin, or detecting osteonecrosis of the jaw associated with bisphosphonates (Torri et al., 2021). The radiologist's report, when integrated into the patient's holistic clinical picture, becomes a vital

feedback loop for the prescriber and pharmacist to assess the ongoing risk-benefit balance of a therapy.

The Administration Frontier

Medication administration is the final point of interception before a drug reaches the patient, predominantly overseen by nursing. The "Five Rights" (right patient, drug, dose, route, time) remain the bedrock of safe practice, but their execution is now augmented by technology. Bar-code-assisted medication administration (BCMA) systems electronically verify the "Five Rights" at the bedside by scanning the patient's wristband and the medication barcode, effectively preventing many administration errors (Seibert et al., 2014). However, nurses also engage in critical "rights" beyond the classic five: the right assessment (e.g., checking blood pressure before an antihypertensive), the right documentation, and the right patient education.

Nursing's role is deeply intertwined with other disciplines at this stage. They rely on the pharmacy for correctly prepared and labeled drugs. They act on data from medical laboratories (e.g., holding a medication if a lab value is critical) and interpret clinical signs that may correlate with findings from radiology. Furthermore, their bedside presence makes them essential for monitoring and reporting immediate adverse effects, initiating the post-administration safety net. Health services management is responsible for procuring, implementing, and maintaining BCMA and infusion pump technologies, ensuring their interoperability with the CPOE and electronic health record (EHR) to create a seamless closed loop.

The Monitoring and Adherence Continuum

Safety does not end at administration. Continuous monitoring for intended and unintended effects is a shared responsibility. Nursing monitors vital signs and clinical responses. Pharmacists perform post-administration profile reviews and follow up on TDM or PGx results to recommend dose adjustments. Outpatient monitoring extends into the community, where health assistants play a vital role in supporting medication adherence—a major factor in therapeutic success and safety. They can conduct home visits or calls to assess understanding, identify side effects, and troubleshoot access issues (Whitehouse et al., 2023). Health Security concerns manifest in monitoring the drug supply chain for counterfeit medications, a growing public health threat, and ensuring the cybersecurity of connected drug delivery devices (e.g., smart pumps) and prescription networks (Sweileh, 2021).

This continuum must also function under duress. Disaster management planning ensures the integrity of the medication pathway during crises. This includes plans for maintaining the "cold chain" for temperature-sensitive drugs like insulin or vaccines during power outages, protocols for emergency medication access and rationing, and strategies for managing surges in demand for critical drugs like analgesics or antidotes (Schumacher et al., 2021). The entire pathway's resilience is tested during such events, highlighting the importance of redundant systems and clear crisis protocols established by hospital management (Table 2).

Table 2: Common Systemic Vulnerabilities and Interdisciplinary Mitigation Strategies

Vulnerability	Affected Stage(s)	Potential Interdisciplinary Mitigation Strategies
Alert Fatigue	Prescribing	**Pharmacy/Health Services:** Design tiered, patient-specific CDS; **Mgmt:** Mandate regular CDS review/optimization.
Information Silos	All, especially Transitions	**Hospital Mgmt:** Invest in interoperable EHRs using FHIR standards; **All:** Advocate for shared data platforms.
Unclear Accountability at Handoffs	Transitions, Monitoring	**All:** Implement standardized handoff tools (SBAR); **Mgmt:** Sponsor interdisciplinary team training simulations.
Inadequate Patient Education	Administration, Transitions	**Nursing/Pharmacy:** Use the teach-back method; **Health Assistant:** Provide follow-up in the community; **Mgmt:** Fund dedicated medication counseling.
Supply Chain/Disruption Risks	Dispensing, Disaster planning	**Pharmacy/Disaster Mgmt:** Diversify suppliers, maintain emergency stockpiles; **Health Security:** Monitor for counterfeit drugs.
Culture of Blame	System Governance	**Hospital Mgmt:** Implement a just culture framework; **All:** Participate in blameless error reporting and analysis.

Overarching Governance and System Design

Achieving high reliability across this complex pathway is impossible without strategic governance and system-level design. Hospital management and health services management provide the essential infrastructure: a just culture that balances accountability and learning from errors, investment in interoperable health information technology (HIT),

and the promotion of interdisciplinary collaboration (Srimulyani & Hermanto et al., 2022). The P&T Committee, as mentioned, standardizes the formulary. Risk management departments analyze medication error data not to blame individuals but to identify flawed system processes.

A critical management function is overseeing the integration of often disparate HIT systems—pharmacy, laboratory, radiology, and nursing documentation—into a cohesive EHR. Lack of interoperability creates data silos, forcing clinicians to rely on memory or manual data transfer, which are error-prone (Palojoki et al., 2016). Management must also champion standardized communication tools like SBAR (Situation, Background, Assessment, Recommendation) for handoffs between disciplines and invest in simulation-based interdisciplinary team training to build shared mental models of the medication pathway (L. Gleeson et al., 2023).

This comprehensive analysis substantiates the conceptualization of the medication pathway as a complex socio-technical ecosystem, where safety emerges not from isolated components but from the dynamic interplay of human cognition, technological infrastructure, and the overarching organizational culture (Tawfik et al., 2023). The most potent safeguards against iatrogenic harm are found at the interfaces of deep interdisciplinary collaboration. These synergistic nodes transform linear workflows into adaptive, self-correcting circuits. For instance, the integration of real-time laboratory data—such as dynamic renal function metrics—into Clinical Decision Support (CDS) algorithms creates a closed feedback loop that personalizes prescribing at the point of care, moving from static protocols to responsive, patient-specific guidance (Wada et al., 2020).

Similarly, medication reconciliation evolves from a bureaucratic checklist to a robust safety net when it is structured as a collaborative process, leveraging the pharmacist's therapeutic expertise, the nurse's intimate knowledge of patient routines and responses, and the corroborative data from community health assistants (Clark et al., 2023; Knowles et al., 2023). Furthermore, the full potential of diagnostic disciplines is realized when radiologic surveillance for drug efficacy or toxicity is actively incorporated into therapeutic decision-making, ensuring that imaging findings translate directly into adjusted clinical management plans (Torri et al., 2021). These examples underscore that reliability is an emergent property of well-designed interactions, where the collective intelligence of the system surpasses the vigilance of any single actor.

Despite these exemplars of integration, persistent systemic vulnerabilities create critical fault lines that threaten patient safety. These gaps are predominantly structural and cultural, rather than stemming from a lack of individual diligence. First, **information silos** perpetuated by non-interoperable Health Information Technology (HIT) systems remain a fundamental barrier. The inability of hospital EHRs, pharmacy dispensing software, outpatient records, and laboratory information systems to seamlessly exchange structured data forces clinicians into the error-prone roles of data aggregators and translators, relying on memory, manual entry, and faxed documents (Roman et al., 2017). Second, the pervasive challenge of **alert fatigue** exemplifies a well-intentioned technological solution that has backfired. Poorly designed CDS, characterized by excessive, non-contextual, and low-specificity alerts, leads to habituation and override behaviors, effectively blinding clinicians to critical warnings and eroding trust in the system (Wan et al., 2020). Third, **workflow misalignment** occurs when safety technologies are imposed without sufficient end-user engagement in their design. For example, Bar-Code Medication Administration (BCMA) systems intended to enforce the "Five Rights" can generate cumbersome workarounds—such as scanning barcodes away from the bedside—if they disrupt the natural flow of nursing care and the multifaceted demands of the patient environment (Seibert et al., 2014).

Beyond technology, **training and measurement silos** reinforce disciplinary boundaries and obscure a holistic view of safety. Health professionals are educated in domain-specific competencies with limited formal training on shared system safety principles, interprofessional communication, or collaborative error analysis (Foronda et al., 2016). Consequently, they may lack a shared mental model of the medication pathway as a unified process. This fragmentation is mirrored in **performance measurement**, where quality metrics are typically anchored to departmental outcomes (e.g., pharmacy order verification time, nursing administration error rates) rather than tracking cross-functional process integrity or patient-centered outcomes across the entire continuum of care. This myopic measurement fails to capture where the system breaks down between disciplines and impedes accountability for end-to-end reliability.

Forging a path forward requires a commitment to genuine system engineering, moving beyond point solutions toward redesigning the foundational architecture of medication safety. Technologically, widespread adoption of **Fast Healthcare Interoperability Resources (FHIR) standards** is a non-negotiable prerequisite for dismantling data silos, enabling a longitudinal, shareable medication record that follows the patient (Lazzara et al., 2022). Concurrently, **human factors engineering** must be systematically applied to co-design CDS and BCMA workflows with frontline clinicians, optimizing for usability, cognitive load, and integration into clinical reasoning rather than mere compliance (Veazie et al., 2022). Culturally, institutions must implement structured **interdisciplinary morbidity and**

mortality conferences focused on medication-related harm, applying a just culture framework to dissect system failures without individual blame, thereby fostering collective learning and psychological safety (Frankel et al., 2006).

The frontier of innovation holds significant promise. Expanding the role of **health assistants and community paramedics** in post-discharge medication adherence support bridges the critical gap between institutional and home-based care, providing a human touchpoint for monitoring and education (Kangovi et al., 2014). Furthermore, leveraging **advanced analytics and artificial intelligence** moves the paradigm from reactive alerting to proactive risk prediction. By synthesizing data from EHRs, genomic profiles, social determinants of health, and real-time monitoring devices, AI models can stratify patients at highest risk for adverse drug events or non-adherence, allowing for targeted, pre-emptive interventions by the care team (Wong et al., 2018). Ultimately, achieving a high-reliability medication pathway demands that healthcare leadership, policymakers, and educators align incentives, investments, and training around the principle that safety is a system property, cultivated through intentional design, relentless interdisciplinary collaboration, and a culture of continuous learning and adaptation. Figure 2 depicts a systems-based model of interdisciplinary collaboration in medication safety.

Figure 2: Multidisciplinary Collaboration Model for High-Reliability Medication Management

Conclusion

The journey of a medication from prescription to monitoring is a perilous voyage across a landscape of specialized domains. This narrative review confirms that safety is not the product of any single discipline's vigilance but is emergent from the quality of interactions between them all—pharmacists, laboratory scientists, nurses, radiologists, technicians, managers, and community health workers. Building a high-reliability medication pathway requires a steadfast commitment from hospital leadership to foster a culture of safety, invest in intelligently integrated technology, and design processes with a deep understanding of interdisciplinary workflows. The goal must be to harden the entire system, making it resilient to human fallibility and capable of learning, adapting, and ultimately delivering on the fundamental promise of medicine: to first, not harm.

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