Electronic Health Record Competency and Medication Safety Among Critical Care Nurses: A Protocol for a Systematic Review

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ABSTRACT

Background: Electronic health records (EHRs) and integrated electronic medication systems are increasingly embedded in critical care practice, yet medication-related harm persists. The safety benefits of these technologies depend partly on nurses' ability to use EHR functions accurately, interpret electronic information, and integrate digital safeguards with clinical judgment. Evidence directly linking EHR competency with medication safety among critical care nurses remains fragmented. Objective: This protocol describes a systematic review that will synthesize evidence on the relationship between EHR competency and medication safety among critical care nurses. Methods: The review will follow the Population–Exposure–Outcome framework. PubMed/MEDLINE, CINAHL, Scopus, Embase, Web of Science, and the Cochrane Library will be searched for English-language studies published from January 2015 to the final search date. Eligible designs will include randomized and quasi-experimental studies, cohort, case-control and analytical cross-sectional studies, qualitative studies, and mixed-methods studies that assess EHR-related competency and medication-safety outcomes in critical care nurses. Two reviewers will independently screen studies, extract data, and assess methodological quality using design-specific Joanna Briggs Institute critical appraisal tools; disagreements will be resolved by consensus or a third reviewer. This protocol has been registered in PROSPERO with a registration CRD420261473721. Findings will be synthesized narratively, with meta-analysis undertaken when methodological and clinical homogeneity permits. Where appropriate, certainty of evidence will be assessed using GRADE. Conclusion: The review is intended to clarify how EHR competency is defined and measured, identify medication-safety outcomes associated with competency, and determine individual, organizational, and technological factors that shape this relationship. The findings may inform nursing education, competency assessment, digital-health implementation, and medication-safety policy in critical care.

Keywords: electronic health records; nursing informatics; digital competency; medication safety; medication errors; critical care nursing; patient safety; barcode medication administration

INTRODUCTION

Medication safety is a central component of patient safety and quality healthcare. Preventable medication-related harm remains a global concern, prompting the World Health Organization to launch the Medication Without Harm challenge in 2017 with the goal of reducing severe and avoidable medication-related harm by 50% (Donaldson et al., 2021). Medication errors are among the most common causes of preventable healthcare harm and are associated with substantial clinical and economic consequences, including increased

morbidity, mortality, hospitalization, and healthcare costs (Sheikh et al., 2019). Because of this continuing burden, medication safety has become a priority for healthcare organizations, policymakers, and healthcare professionals, with technology-enabled medication safety identified as an important area for strengthening patient safety systems (Sheikh et al., 2019).

The burden of medication-related harm is particularly pronounced in critical care settings, where patients have severe and complex illnesses, experience high medication exposure, frequently receive high-risk medications, and require care within a fast-paced and dynamic clinical environment (Puxty et al., 2025). Critically ill patients have been reported to experience an average of 1.7 medical errors per day, with medication errors accounting for about 78% of serious adverse events in intensive care units (Gracia et al., 2019).

Reported medication-error rates vary widely across intensive care units, reflecting differences in study designs, surveillance and detection methods, medication-use systems, staffing conditions, communication, and clinical workflows. Factors such as staff inexperience, role overload, interruptions, transfers of care, and the use of high-risk medications further increase the demands placed on critical care professionals and reinforce the need for stronger technological and organizational safeguards in medication management (Puxty et al., 2025). Although Philippine evidence specific to intensive care remains limited, a hospital-wide study at a major Philippine tertiary hospital found that incorrect-dose administration accounted for 42% of serious errors, while medication-administration errors were also documented among sentinel events (Habana et al., 2025).

Critical care nurses play a central role in medication safety because they administer and monitor complex therapies at the bedside. Gracia et al. (2019) found that gaps in critical care nurses' medication knowledge were associated with errors involving antibiotic administration intervals, medications administered through nasogastric tubes, and the dilution, concentration, and infusion rates of high-risk medications. Gregory et al. (2022) added that electronic medication administration records can support patient safety while also contributing to computer fatigue, workaround practices, and reduced bedside time. These findings suggest that medication safety in technology-intensive ICUs depends on nurses' ability to combine pharmacologic knowledge, clinical judgment, and competent use of electronic medication systems while preserving patient-focused care (Gracia et al., 2019; Gregory et al., 2022).

The adoption of Electronic Health Records and integrated electronic medication systems has transformed medication management by linking electronic prescribing, medication administration, clinical documentation, and decision support within a shared digital environment. Gates et al. (2021) found that electronic medication systems can reduce certain prescribing and medication-error rates, although effects on actual patient harm remain inconsistent and new error types may emerge. Cahill et al. (2025) further showed that EHR design and usability, including medication-information display, clinical alerts, and interoperability, influence clinicians' ability to recognize and respond to medication-related risks. These studies indicate that EHR-integrated medication technologies can strengthen medication verification and clinical decision-making when system design, usability, implementation, and clinical use are aligned (Cahill et al., 2025; Gates et al., 2021).

Despite their benefits, electronic health records do not automatically ensure medication safety. Cahill et al. (2025) found that EHR design can either strengthen or undermine medication safety depending on how effectively the system supports data entry, automation, user guidance, clinical workflows, searchability, customization, and interoperability. In intensive care settings, Kizzier-Carnahan et al. (2019) further showed that clinicians may be exposed to a high volume of passive EHR alerts, many of which are low priority, increasing the risk of alert fatigue and making it more difficult to identify clinically significant information. Complementing these findings, Weinschreider et al. (2024) emphasized that insufficient EHR knowledge, skills, and attitudes among nurses may contribute to unsafe practices and patient harm. Taken together, these studies indicate that medication safety depends not only on the technical design and usability of the EHR but also on a manageable alert burden and healthcare professionals' competency in using the system accurately and consistently (Cahill et al., 2025; Kizzier-Carnahan et al., 2019; Weinschreider et al., 2024).

Among frontline healthcare professionals, critical care nurses are intensive users of electronic health records because medication management requires continuous documentation, rapid retrieval and interpretation of patient information, and appropriate use of electronic medication-safety functions. Forman et al. (2020) described nursing informatics competency as extending beyond basic computer literacy to include the knowledge and skills needed to manage digital information and support evidence-based patient care. Complementing this view, Kleib et al. (2021) demonstrated that structured experience with electronic health records can strengthen nurses' documentation and critical-thinking abilities. McGonigle and Mastrian (2025) further emphasized that nursing informatics involves transforming electronic data into meaningful information and knowledge that can guide clinical decisions. Taken together, these sources indicate that EHR competency integrates technical proficiency, information management, clinical reasoning, communication, and professional accountability. In critical care practice, these capabilities enable nurses to interpret electronic patient data, recognize medication-related risks, and use digital safeguards without allowing technology to replace nursing judgment (Forman et al., 2020; Kleib et al., 2021; McGonigle & Mastrian, 2025).

In the Philippines, healthcare digitalization has been strengthened by the Universal Health Care Act and national eHealth initiatives that promote interoperable health information systems across healthcare institutions (Republic Act No. 11223, 2019). The Act requires healthcare providers and insurers to maintain electronic health records and electronic prescription logs that comply with national standards and can be uploaded through interoperable systems. Britiller et al. (2023) found that EHR implementation in Philippine healthcare facilities may support quality care, teamwork, workload management, and data accessibility, although implementation challenges remain. Philippine eHealth adoption is also influenced by infrastructure, stable internet and power supply, workforce training, organizational commitment, leadership engagement, and readiness for change. These conditions suggest that uneven implementation may affect how consistently nurses use EHR systems and apply digital information to medication-safety practices.

Although research on electronic health records, nursing informatics, and medication safety has expanded, these areas are often examined separately. Nursing informatics studies tend to emphasize competency domains and nurses' EHR knowledge, skills, and attitudes, while medication-safety studies more often focus on electronic medication systems, usability, documentation, and safety outcomes (Cahill et al., 2025; Forman et al., 2020; Gates et al., 2021; Weinschreider et al., 2022). A recent systematic review reported that nursing informatics interventions in critical care were associated with improved patient safety outcomes, including fewer medication errors, but it did not focus on the specific pathway linking nurses' EHR competency to medication management (Shi et al., 2025). Direct evidence connecting critical care nurses' EHR competency, their use of electronic medication-safety functions, and medication-safety outcomes therefore remains limited. Comparisons across studies are also difficult because digital and informatics competency are defined and measured differently, and medication-safety outcomes vary across studies. D'Agostino et al. (2026), for example, identified 27 instruments representing overlapping constructs of nursing informatics, digital health, and information and communication technology competency (D'Agostino et al., 2026; Gates et al., 2021).

A recent systematic review found that health information technologies can support evidence-based practice and improve patient safety in critical care settings (Britiller et al., 2023). However, no published systematic review has comprehensively examined the relationship between Electronic Health Record competency and medication safety among critical care nurses. Addressing this gap is important because understanding how nurses' competency affects medication safety can guide competency-based education, workforce development, hospital policies, and future digital health initiatives.

The rapid digital transformation of healthcare has fundamentally changed the way healthcare professionals deliver patient care, document clinical information, and communicate across multidisciplinary teams. Central to this transformation is the widespread implementation of Electronic Health Records (EHRs), which have replaced traditional paper-based records with integrated digital systems designed to improve the accessibility, accuracy, and continuity of patient information. Over the past two decades, governments and healthcare organizations worldwide have invested substantially in EHR technologies as part of broader initiatives to improve healthcare quality, patient safety, and operational efficiency (World Health

Organization [WHO], 2021). However, while EHR systems provide sophisticated technological capabilities, their effectiveness ultimately depends on the competency of healthcare professionals who use them. Among nurses, particularly those working in high-acuity environments such as intensive care units (ICUs), competency in using EHR systems has become an essential professional requirement rather than merely a technical skill.

Electronic Health Record competency refers to the knowledge, technical skills, cognitive abilities, and professional attitudes required to effectively utilize electronic health information systems in delivering safe and high-quality patient care. Unlike basic computer literacy, EHR competency encompasses a broad range of capabilities, including navigating electronic records, documenting patient assessments accurately, retrieving clinical information efficiently, utilizing clinical decision support tools, managing electronic medication records, ensuring data privacy and security, and integrating electronic information into clinical decision-making (McGonigle & Mastrian, 2025). Consequently, EHR competency is increasingly recognized as a critical dimension of nursing informatics competency and digital health readiness.

The evolution of EHR competency parallels the advancement of healthcare informatics. Earlier implementations of electronic records primarily focused on replacing paper documentation. However, contemporary EHR systems have evolved into comprehensive clinical information systems that integrate computerized physician order entry (CPOE), barcode medication administration (BCMA), clinical decision support systems (CDSS), laboratory reporting, radiologic imaging, medication reconciliation, and quality monitoring dashboards (Healthcare Information and Management Systems Society [HIMSS], 2023). As these systems become increasingly sophisticated, nurses are expected not only to document patient information but also to interpret electronic alerts, identify potential medication interactions, coordinate multidisciplinary communication, and support evidence-based clinical decision-making. Consequently, EHR competency now encompasses both technical proficiency and clinical reasoning.

The importance of EHR competency is particularly evident in nursing practice because nurses constitute the largest group of healthcare professionals interacting with electronic records throughout the continuum of patient care. Nurses routinely access EHR systems during patient admission, assessment, medication administration, clinical documentation, shift handovers, discharge planning, and interdisciplinary collaboration. Given this extensive interaction, deficiencies in EHR competency may have direct consequences on patient safety. Inaccurate documentation, incomplete medication records, delayed recognition of electronic alerts, incorrect patient identification, and inefficient information retrieval have all been associated with increased risks of clinical errors and compromised patient outcomes (Agency for Healthcare Research and Quality [AHRQ], 2023).

Contemporary literature emphasizes that EHR competency should not be viewed solely as technological proficiency but rather as an integration of informatics knowledge, clinical judgment, communication skills, and professional accountability. McGonigle and Mastrian (2025) argue that competent nurses must demonstrate the ability to transform electronic health information into meaningful clinical knowledge that supports evidence-based decision-making. This perspective aligns with the Data-Information-Knowledge-Wisdom (DIKW) framework, which underpins nursing informatics by emphasizing the progression from data collection to informed clinical action. Under this framework, EHR competency enables nurses to convert raw patient data into actionable clinical insights, thereby facilitating timely interventions and reducing the likelihood of adverse events.

Professional organizations have likewise acknowledged the importance of EHR competency within nursing practice. The American Nurses Association (ANA) recognizes informatics as a core nursing competency that integrates nursing science, information science, and computer science to improve patient outcomes (American Nurses Association, 2022). Similarly, HIMSS (2023) emphasizes that digital competency among nurses extends beyond documentation to include data governance, interoperability, cybersecurity awareness, analytics, and technology-enabled patient care. These competencies have become increasingly important as healthcare organizations continue to adopt digital health innovations, including artificial intelligence, predictive analytics, telehealth platforms, and mobile health technologies.

Several competency frameworks have been developed to guide nursing education and workforce development. One of the most influential is the TIGER (Technology Informatics Guiding Education Reform) Initiative, which identifies three foundational domains of nursing informatics competency: basic computer competencies, information literacy, and information management (Sensmeier et al., 2019). Although originally developed to facilitate EHR adoption, the TIGER competencies remain relevant because they emphasize the integration of technology into clinical practice rather than mastery of specific software applications. More recently, international competency frameworks have expanded these domains to include digital professionalism, cybersecurity, ethical use of health information, data analytics, and digital communication, reflecting the increasingly complex technological landscape of healthcare (HIMSS, 2023).

Research consistently demonstrates that nurses with higher levels of EHR competency report greater confidence in clinical documentation, improved workflow efficiency, enhanced communication, and increased adherence to patient safety protocols. Conversely, inadequate competency has been associated with documentation omissions, workflow interruptions, user frustration, alert fatigue, and increased cognitive workload (AHRQ, 2023). Alert fatigue, in particular, has emerged as a significant concern in contemporary healthcare. Nurses frequently encounter numerous electronic alerts during medication administration and clinical documentation. When these alerts become excessive or poorly designed, clinicians may override important warnings, potentially increasing the risk of medication-related adverse events. Therefore, EHR competency involves not only recognizing alerts but also critically evaluating their clinical significance within the broader context of patient care.

Education and continuous professional development play pivotal roles in enhancing EHR competency. Studies have demonstrated that structured EHR training programs, simulation-based education, competency assessments, and ongoing technical support significantly improve nurses' confidence and performance in electronic documentation (McBride & Tietze, 2023). Furthermore, competency development should not be considered a one-time educational intervention but rather a continuous process that evolves alongside technological advancements. Healthcare organizations increasingly recognize that successful implementation of EHR systems depends not only on system design but also on sustained investments in workforce education, mentorship, and competency evaluation.

The relationship between EHR competency and medication safety has gained considerable research attention. Medication administration represents one of the most technologically integrated aspects of nursing practice, requiring nurses to navigate electronic medication administration records, barcode scanning systems, clinical decision support alerts, and electronic physician orders. Deficiencies in EHR competency may contribute to medication documentation errors, incorrect medication verification, delayed medication administration, and failures to recognize contraindications or allergy alerts (WHO, 2021). Conversely, nurses who demonstrate higher EHR competency are more likely to use electronic safety features effectively, thereby reducing the risk of medication errors and improving patient outcomes. Despite this theoretical relationship, existing studies vary considerably in their definitions of competency, measurement instruments, and outcome indicators, making it difficult to draw definitive conclusions regarding the magnitude of this association.

Medication Safety

Medication safety is recognized globally as one of the most fundamental dimensions of healthcare quality and patient safety. It encompasses the prevention of avoidable harm associated with medication use while ensuring that patients receive the most appropriate pharmacological therapy to achieve optimal health outcomes. The World Health Organization (WHO) defines medication safety as the processes and systems designed to minimize medication-related risks throughout the medication use continuum, including prescribing, transcribing, dispensing, administering, monitoring, and documentation (World Health Organization [WHO], 2021). Medication safety extends beyond preventing medication errors; it also involves creating healthcare environments where safe medication practices are embedded in organizational culture, supported by effective technology, evidence-based policies, and competent healthcare professionals.

Medication-related harm remains a major global public health concern despite remarkable advances in healthcare technology. According to the WHO (2017), medication errors account for approximately US$42 billion in preventable healthcare costs annually and affect millions of patients worldwide. These errors contribute to increased morbidity, mortality, prolonged hospitalization, reduced patient trust, and significant economic burdens on healthcare systems. Consequently, medication safety has become one of the WHO's Global Patient Safety Challenges under the initiative "Medication Without Harm," which aims to reduce severe avoidable medication-related harm by 50% globally through improved healthcare systems, professional education, and patient engagement (WHO, 2017).

Medication safety is a multidisciplinary responsibility involving physicians, pharmacists, nurses, healthcare administrators, and patients. However, among these professionals, nurses play a particularly critical role because they represent the final safeguard before medications reach patients. Nurses are responsible not only for administering medications but also for verifying physician orders, assessing patient readiness, identifying contraindications, monitoring therapeutic responses, recognizing adverse drug reactions, documenting medication administration, and educating patients regarding medication use (Institute of Medicine [IOM], 2000). As the healthcare professional who spends the most time with patients, nurses occupy a unique position in preventing medication errors and ensuring safe medication practices.

The medication use process consists of several interconnected stages, each presenting opportunities for potential error. These stages include medication prescribing, order transcription, medication dispensing, preparation, administration, documentation, monitoring, and evaluation. Errors occurring at any point within this continuum may compromise patient safety. Studies have consistently shown that medication administration is among the most vulnerable phases because it requires nurses to integrate clinical knowledge, patient assessment, technological proficiency, communication, and critical thinking under conditions that are often characterized by heavy workloads, interruptions, and time constraints (Agency for Healthcare Research and Quality [AHRQ], 2023). Consequently, medication safety depends not only on individual competence but also on the effectiveness of healthcare systems designed to support safe medication practices.

Historically, medication safety initiatives focused primarily on identifying and correcting individual healthcare professionals responsible for errors. This person-centered approach often resulted in a culture of blame, discouraging incident reporting and limiting opportunities for organizational learning. However, contemporary patient safety theories advocate a systems-based perspective, recognizing that medication errors typically arise from multiple interacting factors rather than isolated individual negligence. James Reason's Swiss Cheese Model illustrates how organizational weaknesses, system failures, communication breakdowns, technological limitations, and human factors align to permit medication errors to reach patients (Reason, 2000). This systems approach has significantly influenced medication safety policies worldwide by emphasizing risk management, organizational learning, and continuous quality improvement.

Technology has become one of the principal strategies employed to enhance medication safety. Electronic Health Records (EHRs), Computerized Physician Order Entry (CPOE), Clinical Decision Support Systems (CDSS), Barcode Medication Administration (BCMA), electronic Medication Administration Records (eMAR), and automated dispensing cabinets have collectively transformed medication management processes. These technologies aim to reduce transcription errors, improve communication among healthcare providers, facilitate medication verification, identify drug interactions, and support evidence-based clinical decision-making (McGonigle & Mastrian, 2025). Nevertheless, technological solutions alone cannot eliminate medication errors. Their effectiveness depends heavily on healthcare professionals' competency, appropriate system implementation, organizational support, and continuous training.

The increasing integration of health information technology has also shifted attention toward nurses' competency in utilizing digital systems during medication administration. Electronic medication systems require nurses to accurately retrieve patient information, verify medication orders, interpret electronic alerts, document medication administration, and respond appropriately to clinical decision support recommendations. Deficiencies in Electronic Health Record competency may compromise medication safety by increasing documentation inaccuracies, alert overrides, medication omissions, or failures to

recognize contraindications (Healthcare Information and Management Systems Society [HIMSS], 2023). Thus, medication safety has become closely associated with nursing informatics competency and digital literacy in contemporary healthcare environments.

The complexity of medication safety is particularly evident in critical care settings. Patients admitted to intensive care units often receive multiple high-alert medications, continuous intravenous infusions, vasoactive agents, sedatives, anticoagulants, insulin, antibiotics, and electrolyte replacements that require precise dosing and continuous monitoring. These patients frequently experience rapid physiological changes that necessitate frequent medication adjustments and interdisciplinary communication. Consequently, medication administration in critical care is inherently more complex than in general hospital wards (World Federation of Societies of Intensive and Critical Care Medicine, 2023). Even minor documentation inaccuracies or delays in recognizing medication alerts may result in significant adverse outcomes.

Medication safety is influenced by numerous human, technological, organizational, and environmental factors. Human factors include clinical knowledge, pharmacological competence, critical thinking, communication skills, fatigue, stress, cognitive workload, and years of professional experience. Organizational factors encompass staffing adequacy, leadership support, patient safety culture, continuing education, availability of standardized protocols, and interdisciplinary collaboration. Technological factors involve system usability, interoperability, interface design, alert functionality, barcode scanning reliability, and integration among healthcare information systems (AHRQ, 2023). The interaction among these variables determines the effectiveness of medication safety initiatives and influences healthcare outcomes.

Research consistently demonstrates that healthcare organizations with strong medication safety cultures experience lower rates of medication errors and improved patient outcomes. Safety culture encourages transparent reporting of near misses, multidisciplinary collaboration, continuous learning, and non-punitive responses to errors. The Institute of Medicine (2000) emphasized that healthcare organizations should focus on identifying system vulnerabilities rather than assigning blame to individual healthcare professionals. This philosophy has become foundational to modern medication safety programs and has influenced accreditation standards, quality improvement initiatives, and nursing education globally.

An important component of medication safety involves adherence to standardized medication administration principles, commonly referred to as the "Rights" of medication administration. Traditionally, nurses have been educated to verify the right patient, right medication, right dose, right route, right time, and right documentation before medication administration. Contemporary literature has expanded these principles to include additional rights such as the right reason, right response, right assessment, right education, and the patient's right to refuse treatment (Potter et al., 2025). While these principles remain fundamental, digital healthcare technologies increasingly support their implementation through electronic verification systems, barcode scanning, automated alerts, and electronic documentation.

Despite technological advancements, medication errors continue to occur because healthcare technologies themselves may introduce new forms of risk. One example is alert fatigue, a phenomenon in which healthcare professionals become desensitized to frequent electronic alerts, resulting in inappropriate dismissal of clinically significant warnings. Similarly, poor interface design, duplicate documentation requirements, workflow disruptions, and interoperability problems may contribute to user frustration and increase cognitive workload during medication administration (Topaz et al., 2023). These findings suggest that medication safety depends not only on technological availability but also on user competency and human-centered system design.

Another emerging issue involves the increasing use of artificial intelligence (AI) in medication management. AI-powered Clinical Decision Support Systems are now capable of identifying potential adverse drug events, predicting medication-related risks, and recommending evidence-based therapeutic interventions. Although these technologies have the potential to substantially improve medication safety, they also require nurses to possess advanced digital competencies, data interpretation skills, and professional judgment to appropriately evaluate AI-generated recommendations (Topaz et al., 2023). Consequently, medication safety

in modern healthcare increasingly depends on the integration of nursing expertise with intelligent technological systems.

Barcode Medication Administration (BCMA)

Barcode Medication Administration (BCMA) has emerged as one of the most significant technological innovations for improving medication safety and reducing medication administration errors in modern healthcare systems. As medication administration remains one of the most error-prone stages of the medication use process, healthcare organizations have increasingly adopted BCMA technology to enhance patient identification, verify medication accuracy, and promote adherence to the principles of safe medication administration. The integration of BCMA into Electronic Health Record (EHR) systems has transformed medication administration from a largely manual process into a technology-assisted workflow that strengthens patient safety while improving documentation accuracy (Agency for Healthcare Research and Quality [AHRQ], 2023).

BCMA is an electronic verification system that utilizes barcode technology to ensure that medications are administered to the correct patient before administration. In a typical BCMA workflow, nurses scan the barcode on the patient's identification wristband followed by the barcode on the prescribed medication. The system then compares the scanned information with the electronic medication order stored within the Electronic Health Record (EHR). If the medication corresponds to the physician's order, the system confirms the administration and automatically documents the event in the electronic Medication Administration Record (eMAR). Conversely, if discrepancies are detected, such as an incorrect medication, patient, dosage, route, or timing, the system generates an alert that requires further verification before medication administration proceeds (McGonigle & Mastrian, 2025).

The conceptual foundation of BCMA is rooted in the long-established principles of the "Rights" of medication administration. Traditionally, nurses have been trained to verify the right patient, right medication, right dose, right route, right time, and right documentation before administering medications. Contemporary nursing practice has expanded these principles to include additional rights, such as the right assessment, right evaluation, right patient education, and the patient's right to refuse medication (Potter et al., 2025). BCMA operationalizes many of these rights by electronically verifying patient identity and medication information while simultaneously documenting the medication administration process. Thus, BCMA functions not as a replacement for clinical judgment but as an additional safety mechanism that complements nurses' professional responsibilities.

The widespread implementation of BCMA has been driven by increasing concerns regarding medication errors, which remain among the most common preventable causes of patient harm worldwide. The World Health Organization (WHO, 2017) estimates that medication-related harm imposes billions of dollars in healthcare costs annually and contributes significantly to patient morbidity and mortality. Medication administration errors frequently occur because of patient misidentification, incorrect medication selection, dosage miscalculations, interruptions during medication preparation, communication failures, or documentation inaccuracies. BCMA addresses several of these vulnerabilities by introducing automated electronic verification before medications reach patients, thereby reducing dependence on manual checking procedures alone.

Numerous studies have demonstrated that BCMA implementation significantly reduces medication administration errors. A systematic review by Mulac et al. (2021) reported that BCMA systems are associated with meaningful reductions in wrong-patient errors, wrong-medication errors, and documentation omissions, particularly when integrated with Computerized Physician Order Entry (CPOE) and electronic Medication Administration Records (eMAR). Similarly, Truong et al. (2022) found that hospitals implementing BCMA experienced improvements in medication administration accuracy, documentation completeness, and compliance with medication safety protocols. These findings suggest that BCMA serves as an effective technological intervention for strengthening medication safety across diverse healthcare settings.

The effectiveness of BCMA, however, extends beyond its technological capabilities. Successful implementation depends heavily on healthcare professionals' competency in using the system appropriately. Nurses must understand the rationale behind barcode verification, follow standardized scanning procedures, interpret electronic alerts correctly, troubleshoot scanning failures, and avoid unsafe workarounds that bypass the intended safety mechanisms. Consequently, BCMA competency has become an important component of Electronic Health Record competency and nursing informatics competency (Healthcare Information and Management Systems Society [HIMSS], 2023). Without adequate education and continuous competency assessment, even advanced barcode systems may fail to achieve their intended patient safety benefits.

Critical Care Nursing and Intensive Care Unit (ICU) Practice

Critical care nursing is a highly specialized field of nursing practice that focuses on the comprehensive care of patients with life-threatening illnesses or injuries requiring continuous monitoring, advanced therapeutic interventions, and complex clinical decision-making. Nurses working in Intensive Care Units (ICUs) provide care for patients experiencing severe physiological instability, multi-organ dysfunction, traumatic injuries, postoperative complications, sepsis, respiratory failure, cardiac emergencies, and other critical conditions that demand rapid assessment and timely interventions. Due to the complexity of patient conditions and the extensive use of sophisticated healthcare technologies, critical care nursing has evolved into one of the most technologically intensive specialties within modern healthcare (American Association of Critical-Care Nurses [AACN], 2021).

The Intensive Care Unit represents one of the most challenging healthcare environments because patient conditions are characterized by rapid deterioration, unpredictable clinical changes, and high dependency on advanced medical technologies. Patients admitted to ICUs frequently require mechanical ventilation, continuous cardiac monitoring, invasive hemodynamic monitoring, renal replacement therapy, extracorporeal life support, multiple intravenous infusions, and continuous administration of high-alert medications such as vasopressors, sedatives, insulin, anticoagulants, and analgesics (World Federation of Societies of Intensive and Critical Care Medicine [WFSICCM], 2023). These complex clinical situations require nurses to possess advanced knowledge, technical expertise, critical thinking abilities, and rapid clinical judgment to ensure optimal patient outcomes.

Critical care nurses are uniquely positioned at the center of patient management because they maintain continuous bedside presence throughout patients' hospitalization. Unlike many healthcare professionals whose interactions with patients occur intermittently, ICU nurses provide continuous surveillance, frequently reassess physiological parameters, detect subtle clinical changes, administer medications, coordinate multidisciplinary care, communicate with families, and initiate emergency interventions when patient deterioration occurs (AACN, 2021). This constant patient interaction positions critical care nurses as the primary coordinators of patient safety within intensive care settings.

Medication administration represents one of the most demanding responsibilities of critical care nurses. ICU patients commonly receive multiple medications simultaneously through continuous intravenous infusions that require frequent titration based on changing physiological responses. Medications such as norepinephrine, epinephrine, dopamine, vasopressin, insulin, anticoagulants, sedatives, neuromuscular blocking agents, and antibiotics require precise dosage calculations, careful monitoring, and immediate adjustments according to patients' clinical status (World Health Organization [WHO], 2021). Consequently, medication management in intensive care is considerably more complex than in general medical or surgical wards, increasing the potential for medication errors and adverse drug events.

The complexity of critical care nursing has increased substantially with the rapid digitalization of healthcare systems. Contemporary ICUs rely extensively on Electronic Health Records (EHRs), Computerized Physician Order Entry (CPOE), Clinical Decision Support Systems (CDSS), Barcode Medication Administration (BCMA), electronic Medication Administration Records (eMAR), smart infusion pumps, and physiologic monitoring systems that continuously generate large volumes of patient data (McGonigle & Mastrian, 2025). Nurses are expected not only to operate these technologies competently but also to

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synthesize information from multiple digital sources into timely and accurate clinical decisions. Therefore, digital competency has become an essential component of professional competence in critical care nursing.

Electronic Health Records have fundamentally transformed workflow within intensive care units. Traditionally, patient documentation relied on handwritten records that were often fragmented, delayed, and difficult to access. Modern EHR systems provide real-time documentation, integrated laboratory results, radiological findings, medication administration records, clinical alerts, and interdisciplinary communication platforms that support continuity of care (Healthcare Information and Management Systems Society [HIMSS], 2023). For critical care nurses, EHRs facilitate continuous monitoring of patients' physiological status, rapid retrieval of historical clinical information, documentation of nursing interventions, medication verification, and communication among multidisciplinary healthcare teams.

Despite these technological advancements, the intensive care environment presents unique challenges that increase nurses' cognitive workload. ICU nurses must continuously interpret physiological monitoring data, evaluate laboratory results, administer multiple medications, respond to electronic alerts, coordinate with physicians and pharmacists, communicate with patients' families, and simultaneously document patient care within Electronic Health Record systems. This combination of clinical complexity and technological demands contributes to cognitive overload, increasing the likelihood of human error if nurses lack sufficient informatics competency or if technological systems are poorly designed (AHRQ, 2023).

One of the defining characteristics of intensive care nursing is the need for continuous clinical surveillance. Continuous surveillance refers to the ongoing observation, interpretation, and anticipation of patients' physiological responses to therapeutic interventions. According to AACN (2021), critical care nurses function as the first line of defense against patient deterioration because they are responsible for recognizing subtle changes before significant adverse events occur. This responsibility requires nurses to integrate information obtained from bedside assessments, physiological monitors, laboratory reports, medication records, and Electronic Health Records into comprehensive clinical decision-making. Consequently, competency in using digital health technologies directly influences nurses' ability to provide safe and effective patient care.

Medication safety is a central component of patient safety, and the risk of medication-related harm is particularly important in critical care. Intensive care patients commonly receive multiple high-alert medications, continuous infusions, frequent dose adjustments, and complex therapies within rapidly changing clinical conditions. These characteristics increase the need for accurate medication verification, timely documentation, continuous monitoring, and effective communication. Critical care nurses are central to this process because they administer medications, monitor therapeutic and adverse responses, document administration, and respond to medication-related risks at the bedside.

Electronic health records (EHRs) and integrated electronic medication systems have transformed these activities by linking prescribing, medication administration, clinical documentation, laboratory information, and clinical decision support. Technologies such as computerized physician order entry, electronic medication administration records, barcode medication administration (BCMA), and clinical decision support systems (CDSS) can strengthen medication-safety processes. However, technology does not independently guarantee safety. System usability, alert burden, workflow integration, organizational support, and the knowledge and skills of nurses using the technology may influence whether digital safeguards function as intended.

For this review, EHR competency is treated as a multidimensional construct rather than simple computer literacy. It refers to the demonstrated knowledge, skills, and proficiency required to navigate and document in an EHR, retrieve and interpret electronic clinical information, use electronic medication-management functions, respond appropriately to clinical decision support, and integrate electronic information with nursing judgment. This definition is consistent with contemporary nursing informatics literature emphasizing technical, information-management, cognitive, and professional dimensions of digital practice.

The relationship between EHR competency and medication safety is clinically plausible but not yet sufficiently synthesized among critical care nurses. Existing studies use different competency constructs and instruments, ranging from nursing informatics competency and digital-health measures to EHR-specific proficiency assessments and evaluations of training. Medication-safety outcomes also vary, including medication errors, adverse drug events, near misses, administration accuracy, BCMA compliance, CDSS-related behaviors, and documentation accuracy. These differences limit direct comparison across studies and justify a systematic review with prespecified operational definitions and synthesis rules.

The review is further justified by the sociotechnical nature of medication safety. The SEIPS 3.0 model provides a systems perspective in which people, tasks, technologies, organizational conditions, and care processes interact to produce safety outcomes. The DIKW framework complements this perspective by describing how nurses transform electronic data into information, knowledge, and clinically appropriate action. Together, these frameworks guide interpretation of how individual competency interacts with EHR design, workflow, organizational support, and clinical decision-making.

The review therefore focuses specifically on critical care nurses and studies that directly assess EHR-related competency or proficiency and report medication-safety outcomes. Studies concerned only with EHR implementation, software usability, or user satisfaction without a competency or medication-safety component will not be eligible. The review will distinguish medication-safety process outcomes from downstream clinical outcomes and will synthesize qualitative and quantitative evidence through separate but complementary analytical pathways.

THEORETICAL AND CONCEPTUAL FRAMEWORK

The theoretical foundation of this systematic review is anchored in the integration of the Systems Engineering Initiative for Patient Safety (SEIPS) 3.0 model and the Data, Information, Knowledge, and Wisdom (DIKW) framework. Together, these frameworks provide a dual-level lens for examining the relationship between EHR competency and medication safety among critical care nurses.

SEIPS 3.0 model

Sociotechnical Perspective: The SEIPS 3.0 Model

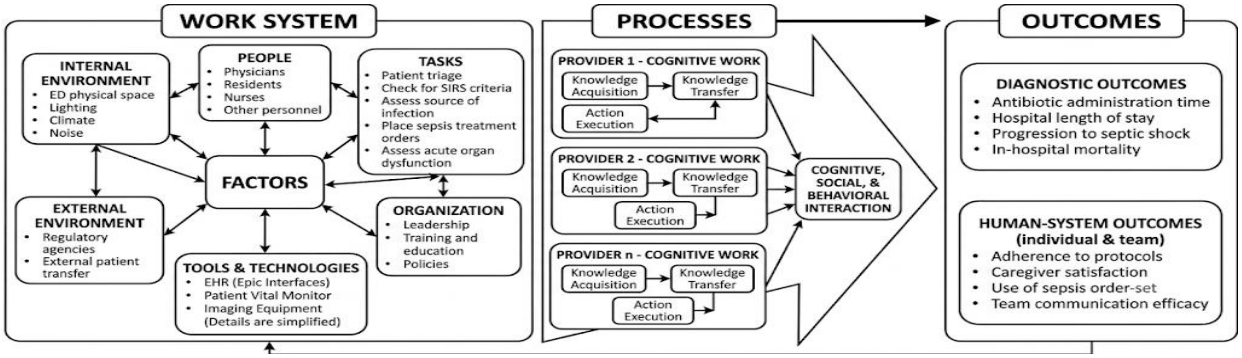


Figure 1. The SEIPS 3.0 Model. Source: Barbieri, et al. (2025).

Figure 1 shows the SEIPS 3.0 model which provides the overarching systems framework, positing that patient safety outcomes are non-linear, emergent properties derived from dynamic interactions within a complex sociotechnical system (Carayon et al., 2020). Within the high-acuity environment of the Intensive Care Unit (ICU), this model organizes healthcare delivery into three interdependent structural components:

The Work System: Represents the structural context comprising critical care nurses (the Person), who operate under specific organizational parameters (e.g., nurse-to-patient staffing ratios, administrative support, continuous informatics training, and unit safety culture) across physical ICU layouts. These clinicians utilize healthcare technologies—specifically EHR interfaces, Barcode Medication Administration

(BCMA) devices, and Clinical Decision Support Systems (CDSS)—to carry out complex tasks such as high-alert drug calculation, administration, and digital documentation (Holden et al., 2013; Carayon et al., 2020).

Care Processes: Refers to the physical, organizational, and cognitive activities executed by nurses during medication delivery. These include patient identification verification, multi-step electronic medication reconciliation, real-time charting, and the appraisal of automated clinical warnings (Carayon et al., 2014; Carayon et al., 2020).

Outcomes: Refers to the downstream clinical efficacy of the work system and care processes, operationalized as quantifiable patient safety indicators including medication administration error (MAE) rates, adverse drug events (ADEs), near-miss occurrences, and electronic chart documentation accuracy (Carayon et al., 2014).

DIKW framework

Cognitive Processing Perspective: The DIKW Framework

COGNITIVE PROCESSING PERSPECTIVE: THE DIKW FRAMEWORK

Complements SEIPS 3.0's structural orientation and shows on an internal, cognitive continuum for nurses making safe clinical decisions.

INCREASING COGNITIVE CONTINUUM

DIKW STAGE & CONTINUUM	DEFINITION	CLINICAL EXAMPLES & NURSING EXPERTISE	COGNITIVE IMPLICATIONS & REFERENCES
4. WISDOM	Operationalize EHR and real alerts and actions under extreme cognitive load. Highest stage of nursing informatics competency; advanced clinical judgment and discernment	Critically evaluates ambiguous CDSS alerts, recognizes latent technology-mediated errors, overrides non-applicable systemic prompts, judicious medication administration decisions	Decisions under extreme cognitive load; (Topaz, 2013; Nelson, 2018)
3. KNOWLEDGE	Cognitive integration of structured EHR information with foundational nursing expertise	Pharmacology, Organ-System Pathophysiology, Patient History	Comprehend subtle trajectories of Clinical Deterioration or Drug-Drug Interactions; (Nelson, 2018)
2. INFORMATION	Synthesized, contextualized data streams; meaningful clinical information by identifying trends	Patient Flowsheets, Electronic Telemetry Logs	(Matney et al., 2011; Nelson, 2018)
1. DATA	Unorganized, objective facts displayed within the EHR interface	Raw Vital Signs, Laboratory Values, Discrete Medication Orders	Basic inputs; (Nelson, 2018)

DIKW CONTINUUM

Figure 2. Cognitive Processing Perspective: The DIKW Framework.

To complement SEIPS 3.0's structural orientation, the DIKW framework (as shown in Figure 2) operationalizes EHR competency as an internal, cognitive continuum through which nurses process digital health data to make safe clinical decisions (Nelson, 2018). In critical care settings, EHR fluency requires continuous progression across four hierarchical tiers:

Data: Unorganized, objective facts displayed within the EHR interface, such as raw vital signs, laboratory values, and discrete medication orders (Nelson, 2018).

Information: Synthesized, contextualized data streams. A digitally competent nurse synthesizes discrete EHR data points into meaningful clinical information by identifying trends in patient flowsheets and electronic telemetry logs (Matney et al., 2011; Nelson, 2018).

Knowledge: The cognitive integration of structured EHR information with foundational nursing expertise, including pharmacology, organ-system pathophysiology, and patient history, enabling the nurse to comprehend subtle trajectories of clinical deterioration or drug-drug interactions (Nelson, 2018).

Wisdom: The highest stage of nursing informatics competency, characterized by advanced clinical judgment and discernment. Wisdom manifests when a nurse critically evaluates ambiguous CDSS alerts, recognizes

latent technology-mediated errors, overrides non-applicable systemic prompts appropriately, and makes judicious medication administration decisions under extreme cognitive load (Topaz, 2013; Nelson, 2018).

CONCEPTUAL FRAMEWORK

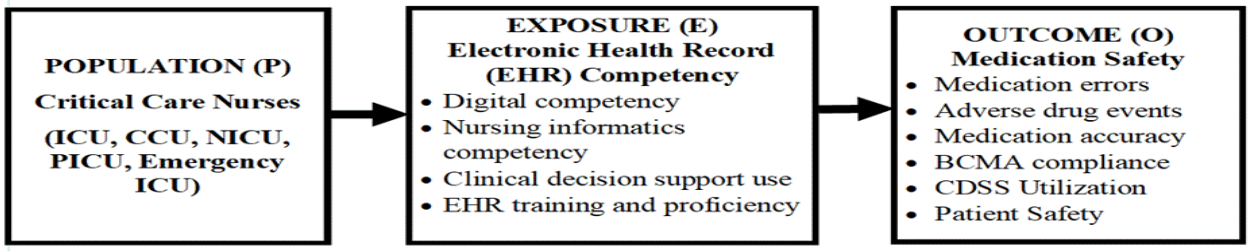


Figure 3. Conceptual Framework using the P-E-O format.

The figure above illustrates the conceptual framework that translates the protocol's eligibility criteria and analytical boundaries into a PEO (Population, Exposure, Outcome) structural model. Rather than employing a traditional clinical intervention model (PICO), the framework adopts a PEO architecture because the review primarily evaluates an exposure/competency construct and its relationship with outcomes (Munn et al., 2018). The framework hypothesizes the relationship between electronic health record (EHR) competency and medication safety among critical care nurses. The review focuses on critical care nurses working in intensive and specialized critical care settings as the target population.

(P) Target Population: High-Acuity Critical Care Environments

The population domain delineates frontline critical care nurses operating across specialized high-acuity units such as: Intensive Care Units (ICU), Coronary Care Units (CCU), Neonatal ICUs (NICU), Pediatric ICUs (PICU), and Emergency ICUs.

(E) Exposure Construct: Multidimensional EHR Competency

The exposure construct operationalizes nurse interaction with healthcare technologies, moving beyond binary classifications (e.g., "trained" vs. "untrained") into a four-part competency matrix:

Digital Competency: The foundational capability to operate digital hardware, navigate complex screen interfaces, and execute basic computer literacy tasks within the clinical workstation (Nagle et al., 2017).

Nursing Informatics Competency: The higher-order ability to integrate nursing science with information science, enabling nurses to synthesize disparate electronic data points (e.g., lab trends, fluid balances, telemetry outputs) into meaningful clinical decision-making (Formond et al., 2021).

Clinical Decision Support (CDS) Use: The behavioral fluency required to interpret, validate, and respond appropriately to automated system alerts, drug-drug interaction warnings, and clinical practice algorithms built into the EHR (Zheng et al., 2021).

EHR Training and Proficiency: The institutional exposure to structured informatics education and subsequent mastery of workflow-specific electronic charting tasks (Borycki, 2019).

Moreover, EHR competency is conceptualized as nurses' knowledge, skills, and proficiency in using electronic health record systems, including digital competency, nursing informatics competency, accurate electronic documentation, effective navigation of EHR systems, and appropriate use of clinical decision support technologies. These competencies are expected to facilitate safer medication management processes by improving documentation accuracy, supporting medication verification, promoting compliance with Barcode Medication Administration (BCMA), enhancing the use of Clinical Decision Support Systems (CDSS), and improving communication among healthcare professionals.

(O) Outcome Domain: Behavioral and Clinical Safety Metrics

The framework conceptualizes medication safety through dual-vector metrics, measuring both process-oriented behavioral metrics and downstream clinical outcomes:

Process Metrics (Mediating Safety Behaviors): Captures frontline operational compliance, including Barcode Medication Administration (BCMA) scan rates and Clinical Decision Support System (CDSS) utilization. High EHR competency directly reduces "workaround" behaviors—such as overriding barcode scans or ignoring critical warnings due to alert fatigue—thereby maintaining systemic guardrails (Koppel et al., 2008).

Clinical Outcomes (Downstream Patient Safety): Represents the ultimate measure of clinical efficacy, operationalized as reductions in Medication Administration Errors (MAEs), decreases in Adverse Drug Events (ADEs), improvements in medication dosage accuracy, and overall enhancements in patient safety and care quality (Institute of Medicine, 2007).

Improved medication management processes are, in turn, expected to contribute to better medication safety outcomes, including fewer medication errors, reduced adverse drug events, greater medication administration accuracy, enhanced patient safety, and improved quality of care. Through a systematic synthesis of the available evidence, this review seeks to determine the extent to which existing research supports these proposed relationships.

Review Question and Objectives

The primary review question is: What is the relationship between Electronic Health Record competency and medication safety outcomes among critical care nurses?

Secondary questions are: (1) How is EHR competency conceptualized, defined, and measured among critical care nurses? (2) What medication-safety outcomes have been examined? (3) Which dimensions of EHR competency are most strongly associated with medication-safety outcomes? (4) What individual, organizational, and technological factors influence the relationship? and (5) What methodological limitations and evidence gaps are present?

The primary objective is to comprehensively synthesize existing evidence regarding the relationship between EHR competency and medication safety among critical care nurses. Specifically, the review will identify and describe methods used to assess EHR competency, summarize medication-safety outcomes, determine the nature of the relationship, evaluate methodological quality, and identify research gaps.

METHODS

This protocol is reported in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P). The completed systematic review will be reported according to PRISMA 2020. The protocol has been developed before formal study screening and has been registered in PROSPERO.

Eligibility Criteria

Eligibility will be structured using the Population–Exposure–Outcome (PEO) framework. Eligible studies will include registered nurses, licensed practical/vocational nurses, nurse practitioners, or advanced practice nurses who are actively providing patient care in critical-care settings, including adult, pediatric, or neonatal intensive care units, coronary care units, high-dependency units, and emergency critical-care units. Studies involving students, nurse educators without clinical responsibilities, or non-nursing professionals will be excluded unless critical-care nurse data are separately extractable.

The exposure of interest is operationalized as EHR-related competency or proficiency demonstrated or measured at the individual nurse level. A study will qualify when it assesses at least one defined competency

domain, such as EHR navigation and information retrieval, electronic documentation, electronic medication-management functions/eMAR, BCMA use, CDSS or alert interpretation, digital information management, or a structured EHR/informatics competency assessment. Validated instruments, established competency frameworks, structured performance assessments, objective task-performance measures, or clearly described study-specific competency measures will be eligible. Formal EHR training alone will not be treated as equivalent to competency unless the study evaluates resulting competency/proficiency or directly links the training exposure to a medication-safety outcome. Studies focused only on system implementation, software usability, satisfaction, or organizational readiness without an assessable nurse-competency component will be excluded.

Medication-safety outcomes will be prespecified in two levels. Primary downstream clinical or event outcomes will include medication errors, medication-administration errors, adverse drug events, preventable medication-related harm, near misses, and medication-dose/administration accuracy. Secondary medication-safety process outcomes will include BCMA scanning/compliance, appropriate CDSS use or alert response, medication-documentation accuracy, and adherence to medication-safety procedures. Nurse confidence, workflow efficiency, and general technology acceptance will be treated as contextual or secondary outcomes and will not substitute for a medication-safety outcome.

Eligible designs will include randomized controlled trials, quasi-experimental studies, cohort studies, case-control studies, analytical cross-sectional studies, qualitative studies, and mixed-methods studies. Systematic reviews will not contribute primary data to the synthesis but may be used for citation chasing. Editorials, commentaries, opinion papers, conference abstracts without full text, case reports, study protocols, and narrative reviews will be excluded. Dissertations and theses will be eligible only if the full text contains sufficient data and the review team can assess their methodological quality. The publication period will be January 2015 through the final search date. English-language restriction is imposed because the review team does not have a prespecified translation resource; the potential for language bias will be acknowledged and reported as a limitation. The 2015 start date was selected to emphasize contemporary EHR-integrated medication systems, BCMA/CDSS use, and modern nursing informatics competency constructs while retaining a sufficiently broad evidence window.

Table 1. PEO Framework and Operational Definitions

PEO element	Operational definition
Population	Critical care nurses working in ICU, CCU, HDU, emergency critical care, adult ICU, pediatric ICU, or neonatal ICU settings.
Exposure	EHR competency, nursing informatics competency, digital competency, EHR proficiency/training, or competency in EHR functions supporting medication management.
Outcome	Medication safety, medication errors, adverse drug events, near misses, medication-administration accuracy, BCMA compliance, CDSS utilization, documentation accuracy, and related patient-safety indicators.

Comparators

Where applicable, eligible studies may compare higher versus lower EHR competency, proficient versus less-proficient users, different levels or types of EHR training when competency is assessed, usual practice, or alternative documentation/medication systems. Observational and qualitative studies without a formal comparator remain eligible when they directly assess EHR competency/proficiency and report relevant

medication-safety outcomes. Comparator status will be extracted and considered when interpreting effect estimates and causal strength.

Information Sources and Search Strategy

The literature search will be conducted in PubMed/MEDLINE, CINAHL, Scopus, Embase, Web of Science Core Collection, and the Cochrane Library. ProQuest Dissertations & Theses and Google Scholar will be searched for supplementary grey-literature identification using predefined procedures. Reference lists of included studies and relevant systematic reviews will be screened, and forward citation searching will be performed where feasible. Each database strategy will combine controlled vocabulary and free-text terms for three core concepts: EHR/digital competency, critical-care nurses, and medication safety. The complete database-specific strategies, field restrictions, limits, and search documentation are provided in Supplementary Appendix A and will be reported in accordance with PRISMA-S. The strategies below are prespecified for protocol purposes. Database-specific syntax will be retained exactly as executed, including the final search date and any documented platform-generated changes required for database compatibility. No unplanned search-term changes will be made after screening begins unless recorded as a protocol amendment.

PubMed/MEDLINE core strategy: ("Electronic Health Records"[Mesh] OR "electronic health record*"[tiab] OR "electronic medical record*"[tiab] OR EHR[tiab] OR EMR[tiab]) AND ("Clinical Competence"[Mesh] OR competenc*[tiab] OR proficien*[tiab] OR skill*[tiab] OR "digital competenc*"[tiab] OR "nursing informatics"[tiab] OR "informatics competenc*"[tiab]) AND ("Critical Care Nursing"[Mesh] OR "critical care nurse*"[tiab] OR "intensive care nurse*"[tiab] OR "ICU nurse*"[tiab] OR "critical care"[tiab]) AND ("Medication Errors"[Mesh] OR "medication safety"[tiab] OR "medication error*"[tiab] OR "medication administration error*"[tiab] OR "adverse drug event*"[tiab] OR "near miss*"[tiab] OR BCMA[tiab] OR "barcode medication administration"[tiab] OR CDSS[tiab] OR "clinical decision support"[tiab] OR eMAR[tiab]). Limits: English; humans; publication date 2015 through the final search date.

Table 2. Database-Specific Search Concepts and Limits

Database	Key search concepts / limits
PubMed/MEDLINE	EHR/EMR + competency/informatics + critical care nurses + medication safety/errors/BCMA/CDSS/eMAR; English; humans; 2015–final search.
CINAHL	EHR/EMR + clinical/informatics/digital competence + critical care nursing + medication safety/errors/BCMA/CDSS/eMAR; English; peer-reviewed; 2015–final search.
Scopus	EHR/EMR + competency/informatics + critical care nursing + medication safety/errors/BCMA/CDSS/eMAR; English; 2015–final search.
Embase	EHR/EMR + competence/informatics + critical care nursing + medication safety/errors/BCMA/CDSS/eMAR; English; humans; 2015–final search.
Web of Science	EHR/EMR + competency/informatics + critical care + medication safety/errors/BCMA/CDSS/eMAR; English; 2015–final search.
Cochrane Library	EHR/EMR + competency/informatics + critical care nurses + medication safety/errors/BCMA/CDSS/eMAR; English; 2015–final search.

Study Selection and Data Management

All retrieved citations will be exported with database name, search date, search strategy/version, and record count retained in the search log. Records will be imported into Zotero or EndNote for duplicate identification and removal and then uploaded to Rayyan for screening. Five reviewers will work in pairs. Two reviewers will independently screen each title/abstract and each full text against the predefined criteria.

Disagreements will be resolved through discussion and consensus, with adjudication by a third reviewer when necessary. Reasons for full-text exclusion will be recorded using standardized categories, and the final selection process will be reported in a PRISMA 2020 flow diagram. Search files, deduplication logs, screening decisions, and extraction versions will be retained as an audit trail.

Data Extraction

A standardized and pilot-tested data-extraction form will be used. Two reviewers will independently extract data from each included study and compare entries; discrepancies will be resolved through discussion and third-reviewer adjudication when necessary. In addition to bibliographic, participant, exposure, comparator, and outcome information, the form will capture the name and type of each EHR/informatics competency instrument, competency domains, scoring method, evidence of validity/reliability when reported, training characteristics, EHR functions assessed, outcome definitions and ascertainment methods, effect estimates, confidence intervals, adjustment variables, funding, conflicts of interest, and author conclusions. For qualitative evidence, reviewers will extract participant characteristics, data-collection method, analytic approach, themes/categories, supporting findings, and authors' interpretations relevant to competency and medication safety.

Table 3. Standardized Data-Extraction Domains and Variables

Data domain	Variables to be extracted
Study characteristics	Author, year, country, journal, title, objective, design, setting.
Participants	Sample size, age/sex where reported, nursing role, years of experience, critical-care unit.
Exposure/intervention	EHR competency, digital competency, nursing informatics competency, EHR training/proficiency.
Measurement	Competency instrument and outcome measurement tool/method.
Medication safety	Medication errors, ADEs, near misses, administration accuracy, BCMA, CDSS, documentation accuracy, patient-safety indicators.
Quantitative results	OR, RR, MD, SMD, correlation coefficient, p-values, 95% CIs, when available.
Qualitative results	Themes, categories, and authors' interpretations relevant to EHR competency and medication safety.
Other	Funding, conflicts of interest, authors' conclusions, and reviewer notes.

Quality Assessment and Risk of Bias

Two reviewers will independently assess methodological quality and risk of bias using the design-specific Joanna Briggs Institute (JBI) critical appraisal checklists. Applicable tools will include those for randomized controlled trials, quasi-experimental studies, cohort studies, case-control studies, analytical cross-sectional studies, and qualitative research. Mixed-methods studies will be appraised separately for their quantitative and qualitative components using the corresponding JBI tools. Reviewers will pilot the appraisal process on a small sample of studies. Each item will be recorded as Yes, No, Unclear, or Not Applicable, with an evidence note where appropriate. No universal numerical cutoff will be used to exclude studies solely on the

basis of the JBI score; instead, item-level limitations will inform interpretation, sensitivity analyses, and certainty assessment. Disagreements will be resolved by consensus or a third reviewer.

Table 4. JBI Critical Appraisal Tools by Study Design

Study design	JBI appraisal tool	Items
Randomized controlled trial	JBI Critical Appraisal Checklist for Randomized Controlled Trials	13
Quasi-experimental	JBI Critical Appraisal Checklist for Quasi-Experimental Studies	9
Cohort	JBI Critical Appraisal Checklist for Cohort Studies	11
Case-control	JBI Critical Appraisal Checklist for Case-Control Studies	10
Analytical cross-sectional	JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies	8
Qualitative	JBI Critical Appraisal Checklist for Qualitative Research	10
Mixed methods	Quantitative and qualitative components appraised using appropriate JBI checklists	—

Data Synthesis and Statistical Analysis

Study characteristics and findings will first be summarized descriptively in structured tables. Quantitative evidence will be grouped according to study design, critical-care setting, EHR competency construct/instrument, competency domain, and medication-safety outcome. Outcomes will be classified as downstream clinical/event outcomes or medication-safety process outcomes. Qualitative evidence will be synthesized separately using a descriptive thematic approach focused on barriers, facilitators, workarounds, contextual factors, and nurses' experiences relevant to EHR competency and medication safety. Findings from mixed-methods studies will be extracted and appraised by component; qualitative findings will not be converted into quantitative effect estimates. The final interpretation will integrate the two evidence strands at the discussion level while preserving the distinction between evidence types.

Meta-analysis will be considered only when at least two studies have sufficiently comparable populations, EHR competency exposures/interventions, outcome definitions, measurement scales, and study designs to justify pooling. Effect measures will not be combined solely because they address the same broad outcome label. Odds ratios and risk ratios will be pooled separately unless a defensible transformation is possible; continuous outcomes will use mean differences when the same scale is used and standardized mean differences when conceptually equivalent constructs use different scales. Correlation coefficients will be transformed to Fisher's z when appropriate. Adjusted estimates will be preferred for observational studies when sufficiently comparable. Random-effects models will generally be used because clinical and methodological diversity is anticipated. Heterogeneity will be examined using I^2, tau^2, the Q statistic, confidence intervals where available, and clinical/methodological inspection rather than relying on a single threshold.

Prespecified subgroup or sensitivity analyses may examine adult versus pediatric/neonatal critical care, EHR competency domain or instrument type, formal training versus measured baseline competency, downstream clinical versus process outcomes, study design, geographical region, and studies judged to have important

methodological limitations. Sensitivity analyses will examine the influence of high-risk-of-bias studies where sufficient studies remain. If substantial heterogeneity or conceptual incompatibility prevents meaningful pooling, findings will be presented narratively with direction and consistency of effects described without implying a pooled magnitude. Small-study and publication bias will be explored using funnel plots and Egger's regression only when at least 10 studies contribute to the same meta-analysis, recognizing the limitations of these methods with smaller evidence bases. Where quantitative pooling is not possible, the review will report study-level estimates and a structured narrative synthesis.

Certainty of Evidence

Where appropriate, certainty of evidence for major quantitative outcomes will be assessed using GRADE, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. GRADE assessments will be applied to clinically meaningful outcomes for which a body of quantitative evidence permits an overall certainty judgment. Qualitative evidence will be interpreted separately and will not be assigned a quantitative GRADE rating unless an appropriate qualitative evidence-certainty approach is prespecified in the final review. A Summary of Findings table will present key outcomes, effect estimates where available, numbers of studies and participants, and certainty ratings.

Protocol Amendments

Any substantive amendment to the protocol after registration will be documented, justified, dated, and reported in the final systematic review. The amendment record will distinguish changes made before and after study selection or data extraction where relevant.

Ethical Considerations

This systematic review will synthesize data from previously published studies and will not involve collection of primary human-participant data or access to identifiable personal information. Institutional ethical approval is therefore not anticipated to be required. All included studies will be appropriately acknowledged and cited. The review will use predefined criteria, transparent search and selection procedures, standardized extraction, and critical appraisal to minimize bias.

Protocol Status, Funding, Conflicts of Interest, and Dissemination

The protocol was developed before commencement of formal study screening and was prospectively registered in PROSPERO (CRD420261473721). The anticipated review period is September 2026 to February 2027. Formal searching, screening, extraction, risk-of-bias assessment, and synthesis will proceed according to this protocol. The exact date of each database search, including the final search date, will be recorded in the search log and reported in the completed review.

No specific external financial funding is planned. The review will use resources and research facilities available to the authors and their affiliated institutions. The authors declare no known financial, professional, or other conflicts of interest that could influence the design, conduct, analysis, or reporting of the review.

The protocol will be submitted to a peer-reviewed international journal in nursing, healthcare, health informatics, patient safety, or a related field. The completed systematic review will also be submitted for peer-reviewed publication and may be disseminated through academic conferences, scholarly presentations, and institutional research activities.

Author Contributions

All five authors contributed to the conception and design of the systematic review protocol, development of the eligibility criteria and search strategy, critical appraisal planning, and drafting or substantive revision of the manuscript. All authors approved the final version and agree to be accountable for the work and for

resolving questions related to its accuracy or integrity. The corresponding author will coordinate protocol registration, manuscript submission, and communication with the journal.

Declaration of AI Assistance

During preparation of the manuscript, the authors used ChatGPT and Grammarly as writing and language-support tools. The authors reviewed and edited the generated or assisted content and retain full responsibility for the accuracy, rigor, interpretation, and integrity of the final manuscript.

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Suplementary Materials

The original working manuscript contains detailed database-specific search strings, the standardized data-extraction worksheet, title/abstract and full-text screening forms, the JBI appraisal worksheet, and the PRISMA-P checklist. The current protocol retains the core PubMed strategy and methodological specifications in the main article. The following materials are provided to address methodological reproducibility and can be submitted as supplementary files or retained as the review team's prespecified audit documents.

Supplementary Appendix A. Database-Specific Search Strategies

Database	Final search strategy
A1. PubMed/MEDLINE	("Electronic Health Records"[Mesh] OR "electronic health record*"[tiab] OR "electronic medical record*"[tiab] OR EHR[tiab] OR EMR[tiab]) AND ("Clinical Competence"[Mesh] OR competenc*[tiab] OR proficien*[tiab] OR skill*[tiab] OR "digital competenc*"[tiab] OR "nursing informatics"[tiab] OR "informatics competenc*"[tiab]) AND ("Critical Care Nursing"[Mesh] OR "critical care nurse*"[tiab] OR "intensive care nurse*"[tiab] OR "ICU nurse*"[tiab] OR "critical care"[tiab]) AND ("Medication Errors"[Mesh] OR "medication safety"[tiab] OR "medication error*"[tiab] OR "medication administration error*"[tiab] OR "adverse drug event*"[tiab] OR "near miss*"[tiab] OR BCMA[tiab] OR "barcode medication administration"[tiab] OR CDSS[tiab] OR "clinical decision support"[tiab] OR eMAR[tiab]). Limits: English; humans; 2015–final search date.
A2. CINAHL	(MH "Electronic Health Records+" OR "electronic health record*" OR "electronic medical record*" OR EHR OR EMR) AND (MH "Clinical Competence+" OR competenc* OR proficien* OR skill* OR "digital competenc*" OR "nursing

	informatics" OR "informatics competenc*") AND (MH "Critical Care Nursing+" OR "critical care nurse*" OR "intensive care nurse*" OR "ICU nurse*" OR "critical care") AND (MH "Medication Errors+" OR "medication safety" OR "medication error*" OR "medication administration error*" OR "adverse drug event*" OR "near miss*" OR BCMA OR "barcode medication administration" OR CDSS OR "clinical decision support" OR eMAR). Limits: English; peer-reviewed; 2015–final search date.
A3. Scopus	TITLE-ABS-KEY(("electronic health record*" OR "electronic medical record*" OR EHR OR EMR) AND (competenc* OR proficien* OR skill* OR "digital competenc*" OR "nursing informatics" OR "informatics competenc*") AND ("critical care nurse*" OR "intensive care nurse*" OR "ICU nurse*" OR "critical care") AND ("medication safety" OR "medication error*" OR "medication administration error*" OR "adverse drug event*" OR "near miss*" OR BCMA OR "barcode medication administration" OR CDSS OR "clinical decision support" OR eMAR)) AND PUBYEAR > 2014 AND PUBYEAR < 2027 AND LANGUAGE(English).

A4. Embase	('electronic health record'/exp OR 'electronic medical record':ti,ab,kw OR EHR:ti,ab,kw OR EMR:ti,ab,kw) AND ('clinical competence'/exp OR competenc*:ti,ab,kw OR proficien*:ti,ab,kw OR skill*:ti,ab,kw OR 'digital competence':ti,ab,kw OR 'nursing informatics':ti,ab,kw OR 'informatics competence':ti,ab,kw) AND ('critical care nursing'/exp OR 'critical care nurse*':ti,ab,kw OR 'intensive care nurse*':ti,ab,kw OR 'ICU nurse*':ti,ab,kw OR 'critical care':ti,ab,kw) AND ('medication error'/exp OR 'medication safety':ti,ab,kw OR 'medication error*':ti,ab,kw OR 'medication administration error*':ti,ab,kw OR 'adverse drug event*':ti,ab,kw OR 'near miss*':ti,ab,kw OR BCMA:ti,ab,kw OR 'barcode medication administration':ti,ab,kw OR CDSS:ti,ab,kw OR 'clinical decision support':ti,ab,kw OR eMAR:ti,ab,kw). Limits: English; humans; 2015–final search date.
A5. Web of Science Core Collection	TS=("electronic health record*" OR "electronic medical record*" OR EHR OR EMR) AND TS=(competenc* OR proficien* OR skill* OR "digital competenc*" OR "nursing informatics" OR "informatics competenc*") AND TS=("critical care nurse*" OR "intensive care nurse*" OR "ICU nurse*" OR "critical care") AND TS=("medication safety" OR "medication error*" OR "medication administration error*" OR "adverse drug event*" OR "near miss*" OR BCMA OR "barcode medication administration" OR CDSS OR "clinical decision support" OR eMAR). Refined by: English; publication years 2015–final search year.
A6. Cochrane Library	([mh "Electronic Health Records"] OR "electronic health record*" OR "electronic medical record*" OR EHR OR EMR) AND ([mh "Clinical Competence"] OR competenc* OR proficien* OR skill* OR "digital competenc*" OR "nursing informatics") AND ([mh "Critical Care Nursing"] OR "critical care nurse*" OR "intensive care nurse*" OR "ICU nurse*" OR "critical care") AND ([mh "Medication Errors"] OR "medication safety" OR "medication error*" OR "adverse drug event*" OR "near miss*" OR BCMA OR "barcode medication administration" OR CDSS OR "clinical decision support" OR eMAR). English; 2015–final search date.

Note: The final executed strings will be saved verbatim from each database platform. If a platform requires a syntax-only adjustment, the original strategy and the executable adaptation will both be retained in the search log. Google Scholar and ProQuest will be used for supplementary identification rather than as substitutes for the six principal bibliographic databases

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Supplementary Appendix B. Database Search Result

This appendix presents the database search results, including the databases searched, search dates, and number of records retrieved from each database.

Database	Platform	Search Date	Records Retrieved
PubMed/MEDLINE	PubMed		
CINAHL	EBSCOhost		
Scopus	Elsevier		
Embase	Elsevier		
Web of Science Core Collection	Clarivate Web of Science		
Cochrane Library	Wiley Online Library		

Supplementary Appendix C. Operational Definition and Eligibility Decision Rules

This appendix provides prespecified operational definitions and decision rules to guide consistent application of the inclusion and exclusion criteria during title/abstract and full-text screening.

Domain	Eligible evidence	Not sufficient by itself
Population	Registered nurses providing direct patient care in critical-care settings, including ICU, CCU, MICU, SICU, PICU, or equivalent critical-care units	Studies involving only nursing students, non-nursing personnel, physicians, allied health professionals, or general hospital staff without separable critical-care nurse data
Critical-care setting	Hospital-based critical-care environments where nurses routinely provide care to critically ill patients	Emergency departments, general medical-surgical wards, outpatient settings, community settings, or mixed settings when critical-care data cannot be separated
EHR competency	Direct assessment of nurses' knowledge, skills, proficiency, competence, performance, or demonstrated ability in using an EHR or its medication-related functions	General attitudes, satisfaction, acceptance, perceived usefulness, intention to use, or frequency of EHR use without a direct competency/proficiency assessment
EHR-related exposure/function	EHR systems or integrated functions directly relevant to nursing documentation, medication management, clinical decision support, electronic medication administration, or related safety functions	Stand-alone technologies with no meaningful EHR component or studies describing digital health generally without an identifiable EHR-related component
Medication safety	Directly measured medication errors, near misses, adverse drug events, medication-related incidents, unsafe medication processes, or validated medication-safety indicators	General patient safety, quality of care, clinical outcomes, satisfaction, or documentation outcomes without a medication-safety component
Relationship between EHR competency and medication safety	Studies reporting an association, comparison, effect, or other interpretable relationship between	Studies assessing EHR competency and medication safety as unrelated variables without an analyzable or interpretable

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	EHR competency/proficiency and medication-safety outcomes	relationship
Study design	Quantitative observational, analytical, quasi-experimental, experimental, or other empirical designs that provide relevant primary data	Editorials, commentaries, protocols, narrative reviews, systematic reviews, conference abstracts without sufficient data, and opinion pieces
Publication period	Studies published from January 2015 through the final search date	Studies published before January 2015 or after the final search date
Language	Studies with an available English-language full text	Non-English studies when an English full text is unavailable
Outcome reporting	Studies providing sufficient information to identify or interpret the relevant medication-safety outcome	Studies that merely mention medication safety without reporting a relevant outcome or usable finding
Multiple populations/settings	Mixed-population or mixed-setting studies are eligible when data for critical-care nurses can be separately identified or extracted	Mixed populations/settings in which critical-care nurse data cannot be distinguished from other participants
EHR competency measurement	Validated instrument, structured assessment, objective performance measure, competency framework, or clearly described researcher-developed assessment directly measuring EHR competency/proficiency	Self-reported EHR use or confidence alone when it does not constitute a direct or clearly defined competency/proficiency assessment

Decision rule: When eligibility cannot be determined from the title and abstract, the study will be retained for full-text assessment. At the full-text stage, exclusion will be based on the first prespecified criterion that is clearly not met, with the specific reason documented in the screening form.

Supplementary Appendix D . Prespecified Outcome and Synthesis Matrix

This matrix specifies the outcomes of interest, their operational definitions, preferred measures, and the planned approach for synthesizing findings across included studies.

Outcome Domain	Prespecified Outcome	Operational Definition / Examples	Preferred Measure	Planned Synthesis
Primary outcome	Medication safety	Medication errors, near misses, adverse drug events, medication-related incidents, or other validated indicators of medication safety	Error rate, incidence, proportion, odds ratio, risk ratio, mean/SD, or other reported effect measure	Narrative synthesis; quantitative pooling if sufficient clinical and methodological homogeneity exists
Primary exposure-related outcome	EHR competency/ proficiency	Nurses' knowledge, skills, confidence, proficiency, or demonstrated competence in using EHR functions relevant to medication management	Validated competency score, proficiency level, assessment score, or other standardized measure	Narrative synthesis; standardized effect measures may be considered when appropriate

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Primary exposure-related outcome	EHR competency/proficiency	Nurses' knowledge, skills, confidence, proficiency, or demonstrated competence in using EHR functions relevant to medication management	Validated competency score, proficiency level, assessment score, or other standardized measure	Narrative synthesis; standardized effect measures may be considered when appropriate
Medication administration safety	Safe medication administration	Accuracy and safety of electronic medication administration, including barcode medication administration and electronic verification processes	Medication administration error rate; compliance/adherence percentage; error proportion	Narrative synthesis; meta-analysis where sufficiently comparable
Clinical decision-support safety	Use of medication-related CDSS	Appropriate use or performance of computerized clinical decision-support features, including alerts for allergies, interactions, dosing, or contraindications	Alert adherence, appropriate response rate, override rate, or medication-related error rate	Narrative synthesis; quantitative synthesis where comparable
Documentation-related safety	Quality and completeness of electronic medication documentation	Accuracy, completeness, timeliness, and consistency of electronic medication records	Documentation completeness/error rate or validated documentation score	Narrative synthesis
Secondary outcome	Medication-related adverse events	Patient harm or adverse events attributable to medication-use processes	Incidence, rate, proportion, or effect estimate	Narrative synthesis; pooling if appropriate
Secondary outcome	Near misses / intercepted errors	Medication errors identified and prevented before reaching the patient	Frequency, rate, or proportion	Narrative synthesis
Secondary outcome	Safety-related process outcomes	Compliance with medication-safety procedures, verification practices, or EHR-supported safety protocols	Compliance percentage, adherence rate, or process score	Narrative synthesis
Contextual outcome	Factors influencing EHR competency and medication safety	Training, workload, usability, system characteristics, organizational support, staffing, or other contextual factors	Qualitative themes or reported associations	Thematic/narrative synthesis

Supplementary Appendix E. Prespecified Synthesis Rules

This appendix presents the prespecified rules for synthesizing and interpreting findings across the included studies, including criteria for narrative synthesis, quantitative pooling, and management of clinical and methodological heterogeneity.

Synthesis Domain	**Prespecified Rule**
Primary emphasis	The synthesis will focus on the relationship between EHR related competency/proficiency and medication-safety outcomes among critical-care nurses**.**
Outcome harmonization	Outcomes will be grouped according to conceptually similar domains. Different measurement instruments will not be treated

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	as equivalent unless their constructs and measurement approaches are sufficiently comparable.
Meta-analysis	Statistical pooling will be undertaken only when studies demonstrate sufficient similarity in population, EHR exposure/competency construct, medication-safety outcome, study design, and measurement approach**.**
Narrative synthesis	Where statistical pooling is inappropriate because of substantial heterogeneity, findings will be synthesized narratively, emphasizing direction, magnitude, consistency, and clinical relevance **o**f associations.
Direction of effect	Findings will be classified according to whether greater EHR competency/proficiency is associated with improved, worsened, or unchanged medication-safety outcomes**.**
Heterogeneity	Clinical, methodological, and measurement heterogeneity will be explicitly considered when interpreting cross-study findings.
Missing data	Unreported outcome data will not be estimated unless sufficient information is available for a defensible calculation. Authors may be contacted when clarification is necessary.
Subgroup considerations	Where data permit, findings may be examined according to critical-care specialty, EHR functionality, competency domain, type of medication-safety outcome, and study design.
Certainty and interpretation	Conclusions will consider methodological quality, consistency of findings, precision of estimates, and applicability to critical-care nursing practice.

Supplementary Appendix F. Prespecified Evidence Classification and Synthesis Framework

This appendix presents the prespecified framework for classifying eligible evidence and determining the appropriate approach to synthesis based on study design, outcome characteristics, and methodological comparability.

Evidence type	Outcome group	Primary synthesis	Pooling rule
Quantitative	Downstream clinical/event outcomes	Effect estimates and structured narrative synthesis	Pool only conceptually and statistically comparable outcomes.
Quantitative	Medication-safety process outcomes	Structured narrative synthesis; effect estimates where available	Pool BCMA/CDSS/documentation measures only when the construct and metric are sufficiently comparable.
Qualitative	Experiences, barriers, facilitators, workarounds	Descriptive thematic synthesis	No statistical pooling.
Mixed methods	Quantitative + qualitative components	Separate component synthesis followed by integrated interpretation	No conversion of qualitative findings into numerical effects.

Note: Quantitative pooling will be considered only when studies are sufficiently comparable in population, exposure/intervention, comparator, outcome definition, and effect measure. Where substantial clinical or methodological heterogeneity precludes meaningful pooling, findings will be synthesized narratively.

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Supplementary Appendix G. Standardized Data-Extraction Form

This form will be used by the reviewers to systematically extract and record relevant study characteristics, EHR competency measures, medication-safety outcomes, and methodological information from all included studies.

Data domain	Fields to capture
Bibliographic	Author; year; title; journal; country; DOI; funding; conflicts of interest.
Design and setting	Study design; ICU/CCU/HDU/emergency/PICU/NICU; institution type; sample size.
Participants	Nurse role; age/sex if reported; years of experience; critical-care experience; inclusion criteria.
EHR competency exposure	Construct name; operational definition; domains; instrument/framework; validated vs study-specific; scoring; reliability/validity; objective vs self-report.
Technology/function	EHR platform if reported; eMAR; BCMA; CDSS; CPOE; alert type; medication workflow.
Training	Type; duration; timing; delivery mode; competency assessment; comparator.
Medication-safety outcome	Outcome definition; event/process classification; ascertainment method; denominator; follow-up/time point.
Quantitative results	OR/RR/HR/MD/SMD/correlation; adjusted/unadjusted; 95% CI; p-value; covariates; missing data.
Qualitative results	Data-collection method; analytic method; themes/categories; participant quotations if needed for synthesis; author interpretation.
Appraisal and notes	JBI item-level judgments; rationale; key limitations; reviewer notes.
Reviewer 1: _____ Reviewer 2: _____ Date of extraction: _____ Independent verification required: **Yes / No** Discrepancy/adjudication required: **Yes / No** Final agreed entry: _____	

Supplementary Appendix H. Title/Abstract and Full-Text Screening Form

This form will be used by two independent reviewers to assess potentially eligible studies against the prespecified inclusion and exclusion criteria.

Screening criterion	Title/Abstract	Full Text
Study ID / Citation	_____	_____
Critical-care nurses are included	Yes / No / Unclear	Yes / No / Unclear
EHR-related competency or proficiency is directly assessed	Yes / No / Unclear	Yes / No / Unclear
Medication-safety outcome is reported	Yes / No / Unclear	Yes / No / Unclear
Eligible study design	Yes / No / Unclear	Yes / No / Unclear
Publication date within January 2015–final search date	Yes / No	Yes / No
English full text available	—	Yes / No

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Full-text decision	—	Include / Exclude / Unclear
Reason for exclusion	—	Population / Exposure / Outcome / Design / Date / Language / Full text unavailable / Other
Other reason/details	_____	_____
Reviewer 1: _____ Reviewer 2: _____ Adjudication required: **Yes / No** Final decision after adjudication: **Include / Exclude** Adjudicator: _____ Date screened: _____		

Note: At the title/abstract stage, studies will be retained for full-text assessment when eligibility is unclear. Reasons for exclusion will be recorded only after full-text review.

Supplementary Appendix I. JBI Critical-Appraisal Recording Sheet

The current JBI checklist appropriate to each study design will be used. This recording sheet standardizes documentation without reproducing the full proprietary checklist wording.

Study ID	JBI design-specific tool	Item no.	Judgment (Y/N/U/NA)	Evidence note

Supplementary Appendix J. PRISMA-P Protocol Compliance Checklist

This checklist summarizes the protocol's compliance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) reporting guidelines.

PRISMA-P domain	**Protocol item**	**Location / status**
Administrative information	Title identifies the report as a systematic review protocol; authors, affiliations, correspondence, and registration are stated.	Main manuscript / Supplementary Appendix A–G
Introduction—Rationale	Background and rationale identify the clinical and methodological gap linking EHR competency with medication safety in critical care.	Main manuscript / Supplementary Appendix A–G

Introduction—Objectives	Primary and secondary review questions/objectives are explicitly stated.	Main manuscript / Supplementary Appendix A–G
Methods—Eligibility	Population, exposure, outcomes, designs, publication period, language, and exclusions are prespecified.	Main manuscript / Supplementary Appendix A–G
Methods—Information sources	Six principal databases plus supplementary grey-literature and citation-search methods are identified.	Main manuscript / Supplementary Appendix A–G
Methods—Search strategy	A reproducible core strategy and database-specific strategies are provided; exact executed searches and dates will be logged.	Main manuscript / Supplementary Appendix A–G
Methods—Data collection	Pilot-tested independent extraction and discrepancy resolution are specified.	Main manuscript / Supplementary Appendix A–G
Methods—Data items	Participant, exposure, competency instrument, outcome, effect estimate, funding, and conflict variables are prespecified.	Main manuscript / Supplementary Appendix A–G
Methods—Outcomes and prioritization	Downstream clinical/event outcomes are distinguished from medication-safety process outcomes.	Main manuscript / Supplementary Appendix A–G
Methods—Risk of bias	Design-specific JBI tools and item-level judgments are prespecified.	Main manuscript / Supplementary Appendix A–G
Methods—Synthesis	Narrative synthesis, qualitative synthesis, meta-analysis eligibility, effect measures, heterogeneity, subgroup/sensitivity analyses, and publication-bias assessment are prespecified.	Main manuscript / Supplementary Appendix A–G
Methods—Certainty	GRADE approach and applicability to quantitative evidence are specified.	Main manuscript / Supplementary Appendix A–G
Methods—Protocol amendments	Substantive amendments will be dated, justified, and reported.	Main manuscript / Supplementary Appendix A–G
Registration	PROSPERO registration CRD420261473721 is stated consistently.	Main manuscript / Supplementary Appendix A–G

Supplementary Appendix K. Prespecified Limitations to Be Reported

The following limitations will be prespecified and reported in the final systematic review:

Limitation Domain	Limitation Domain
Language restriction	The English-language restriction may introduce language bias because potentially eligible studies published in other languages will not be translated.
Publication period	The January 2015 start date may omit earlier evidence on foundational EHR competency or medication-safety technologies. The rationale for this restriction is to emphasize evidence from the era of contemporary integrated digital medication systems.
Conceptual heterogeneity	EHR competency may be measured using different instruments, domains, and operational definitions. This heterogeneity will be addressed through explicit construct mapping and restricted quantitative pooling rather than treating all competency measures as interchangeable.
Outcome heterogeneity	Medication-safety outcomes may differ in their definitions,

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	ascertainment methods, and clinical significance. Process measures, such as BCMA, CDSS use, and documentation quality, will therefore be distinguished from downstream outcomes such as medication errors and adverse drug events.
Qualitative evidence	Qualitative studies will provide contextual and explanatory evidence rather than quantitative effect estimates. Qualitative findings will therefore be synthesized separately and will not be converted into quantitative estimates or pooled with quantitative evidence.