Systemic Causes of In-Hospital Intravenous Medication Errors: A Systematic Review

Sini Kuitunen, MSc (Pharm), † Ilona Niittynen, MSc (Pharm), † Marja Airaksinen, PhD (Pharm), † and Anna-Riia Holmström, PhD (Pharm) ††

Objectives: Delivery of intravenous medications in hospitals is a complex process posing to systemic risks for errors. The aim of this study was to identify systemic causes of in-hospital intravenous medication errors.

Methods: A systematic review adhering to PRISMA guidelines was conducted. We searched MEDLINE (Ovid), Scopus, CINAHL, and EBM reviews for articles published between January 2005 and June 2016. Peer-reviewed journal articles published in English were included. Two reviewers independently selected articles according to a predetermined PICO tool. The quality of studies was assessed using the GRADE system and the evidence analyzed using qualitative content analysis.

Results: Eleven studies from six countries were included in the analysis. We identified systemic causes related to prescribing (n = 6 studies), preparation (n = 6), administration (n = 6), dispensing and storage (n = 5), and treatment monitoring (n = 2). Administration, prescribing, and preparation were the process phases most prone to systemic errors. Insufficient actions to secure safe use of high-alert medications, lack of knowledge of the drug, calculation tasks, failure in double-checking procedures, and confusion between look-alike, sound-alike medications were the leading causes of intravenous medication errors. The number of the included studies was limited, all of them being observational studies and graded as low quality.

Conclusions: Current intravenous medication systems remain vulnerable, which can result in patient harm. Our findings suggest further focus on medication safety activities related to administration, prescribing, and preparation of intravenous medications. This study provides healthcare organizations with preliminary knowledge about systemic causes of intravenous medication errors, but more rigorous evidence is needed.

Key Words: patient safety, medication safety, intravenous medications, medication errors, systemic cause, risk management, systematic review

Intravenously administered drugs are associated with the highest medication error frequencies and more serious consequences to the patient than any other administration route.1–3 The bioavailability of intravenously administered medication is high, therapeutic dose range is often narrow, and effects are hard to undo. Many intravenously administered drugs are high-alert medications, bearing a heightened risk of causing significant patient harm if used in error.4 For example, in intensive care, the most serious medication errors are associated with intravenously administered high-alert medications, such as catecholamines, insulin, electrolytes, opioids, and parenteral nutrition.5–6

Intravenous medication administration is a multistep process involving specific administration devices, information systems and many healthcare professionals with different work tasks and skills. This complex delivery process poses to safety risks if inappropriate systemic defenses are not in place.7–10 Identification of the systemic causes of medication errors (e.g., the possibility to make mistakes in infusion pump programming or confusion between similar drug names and packages) highlights the weaknesses of current intravenous medication practices. This enables the development of medication processes by implementation of effective systemic defenses to prevent medication errors (e.g., smart infusion pumps with error-reduction software or effective means to prevent confusion between similar drug names and packages).

However, the systemic causes of errors throughout the intravenous medication process have not been systematically reviewed. Previous systematic reviews have focused on types and incidence of intravenous medication errors5 or the effectiveness of smart infusion pumps as a systemic defense.11 These studies present important knowledge of the frequency of errors and effectiveness of a systemic defense, but they do not focus on medication safety issues throughout the in-hospital intravenous medication process. The aim of our study was to explore recent evidence of systemic causes of in-hospital intravenous medication errors to inform medication safety improvement activities.

METHODS

Study Design

A systematic review of recent evidence on systemic causes of in-hospital intravenous medication errors was carried out following the PRISMA guidelines for undertaking and presenting systematic reviews.12 The quality of included studies was assessed according to the GRADE system.13 The included articles were analyzed using qualitative content analysis.14,15

Search Strategy

A systematic literature search was performed in June 2016 on MEDLINE (Ovid), Scopus, CINAHL, and EBM reviews covering the period from January 2005 to June 2016. This period was chosen to focus on the most recent evidence published in peer-reviewed journals. An example of the search strategy is presented in Table 1.

We divided the search terms into two themes (“intravenous medication therapy” and “medication errors”), both of which needed to appear in the included articles. The theme “medication error” was chosen according to our study objectives to explore preventable adverse drug events, which occur as a consequence of errors in the medication process caused by omissions or commissions.5,16 The search strategy was completed with other terms.
Inclusion and Exclusion Criteria
We applied a predetermined PICO tool (participants, interventions, comparison, and outcomes) to select studies for inclusion.2 A study was included if participants were hospitalized patients or the study used a patient scenario in a simulated hospital environment, and patients received intravenous medication. We decided to exclude studies conducted in ambulatory settings, such as home infusion chemotherapy, because we wanted to focus on in-hospital intravenous medication process. We also excluded studies focusing on multiple administration routes, if the findings related to intravenous administration route could not be reliably identified and extracted from the results. Comparison was not required. Studies applying measures associated with systemic causes resulting in medication errors or assessment of a system defense to prevent medication errors were included. Studies exploring unpreventable adverse drug events or only incidence and types of medication errors were excluded. Only English language articles were included. Peer-reviewed journal articles using all methods and study designs were included.

Data Extraction and Analysis
Data extraction and analysis were carried out by one of the authors (S.K.), and the results were carefully reviewed by the other authors (I.N., A.R.H., M.A.). Study characteristics, country and setting, objectives, study design, materials and methods, key findings, and quality of evidence were extracted to a table (Supplementary File 1, http://links.lww.com/JPS/A243). We assessed the quality of evidence using the GRADE system, which has the following four levels of evidence: very low, low, moderate, and high.13 Evidence from randomized controlled trials (RCTs) was graded as high quality and evidence that included observational data was graded as low quality. Factors that decreased the quality of evidence (e.g., study limitations and inconsistency of results) or increased the quality of evidence (e.g., large magnitude of effect) were also taken into account. Measures used in the articles concerning systemic causes of in-hospital intravenous medication errors were extracted to Table 2.

We analyzed the contents of the included articles using qualitative content analysis to identify systemic causes, examples of errors, and suggested systemic defenses for error prevention (Table 3).10,14,15 We used Leape’s classic analysis of medication errors as a foundation of our taxonomy.14 Because of the fast development in medication safety research during the past decades and the most important medication safety issues arising from the studies included in our systematic review, we had to make some modifications to the categorizations (Table 3, Table 4). Because we wanted to identify the most crucial systemic risk factors causing errors in the intravenous medication process, we defined a systemic cause as a system failure or an iterative error-prone process step or task, which can be replaced with safer system modifications (e.g., calculation tasks related to preparation can be removed by using standard concentrations of prefilled syringes). The findings were extracted and classified according to the error type and medication process stage, in which the error happened or could have been prevented.

Similar to medication error (Table 1), as inconsistency in terminology and definitions related to medication errors is widely known.17 A combination of themes “adverse drug event” and “intravenous” was also considered. It was not included to the final search strategy, because the combination resulted to significantly wider amount of citations with the emphasis on drug safety and adverse drug reactions without the objective on medication safety.

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The systemic causes affecting more than one process stage were identified and presented in Table 4.

RESULTS

Characteristics of the Included Studies (n = 11)

This systematic review is based on 11 peer-reviewed original articles (Supplementary File 1, http://links.lww.com/JPS/A243). The studies were conducted in the United Kingdom (n = 4),18,25,27,28 United States (n = 3),19–21 Spain,26 France,22 Republic of Korea,23 and Canada.24 All studies were carried out in hospital setting. Three studies were conducted in neonatal intensive care units20,26,27 and three in adult oncology.22,24,25

All of the included studies applied an observational study design (Supplementary File 1, http://links.lww.com/JPS/A243). Four of the studies were retrospective analyses of medication error reports,19–21,25 three were observational studies involving analyses of infusion concentrations,26–28 two were interview studies,18,23 one was a prospective analysis of medication orders,22 and one was a direct observation study.24 The three studies investigating infusion concentrations to detect preparation errors26–28 used a controlled study design. More than one error detection method was used in two studies, of which one combined a video...
TABLE 2. Measures Used to Identify and Describe Errors in the Included Studies (N = 11)

| Measures used in more than one study | Systemic causes of errors (n = 8 studies) | Measures used in only one of the included studies | Measures related to characteristics of errors (n = 6) |
|--------------------------------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|                                      | Actual or potential causes of errors (n = 3) | Measures related to the time of the error: day of the week, time of error, year in which the incident occurred | Measures related to error consequences: actions taken after the error, level of care rendered as a result of the error |
|                                      | • The principal defense(s) that had been breached by each incident (n = 1) | • Severity of errors (n = 3): NCC MERP Index for Categorizing Medication Errors, validated scale at four levels, assessment of the degree of actual harm | • Error type (n = 5) |
|                                      | • Concentration accuracy of prepared infusion solution (n = 3) | • Process phase in which the error occurred (n = 2) | • Time of the error, level of care rendered as a result of the error |
|                                      | • Identification of calculation errors and accuracy errors based on the amount of concentration deviation | | • Day of the week, time of error, year in which the incident occurred |
|                                      | • Solution prepared in ward versus pharmacy | | • Time of error, year in which the incident occurred |
|                                      | • Individual concentrations of potassium and magnesium measured at regular intervals during infusions | | • Year in which the incident occurred |

NCC MERP, The National Coordinating Council for Medication Error Reporting and Prevention.

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**Systemic Causes of Medication Errors and Potential Systemic Defenses for Error Prevention**

The studies identified systemic causes of intravenous medication errors related to prescribing (n = 6 studies), preparation (n = 6), administration (n = 6), dispensing and storage (n = 5), and treatment monitoring (n = 2) (Table 3). The process stage with the most systemic error caused was administration.18-21,23,25 The manual adjustment of infusion rates for each patient is an especially high-risk task, which can lead to wrong dose errors.19,20,23 An infusion pump programming error can occur as a consequence of confusion between hours and minutes (e.g., 20 minutes instead of 20 hours),20 weight and volume (e.g., order 5 mg/10 minutes, programmed 5 mL/10 minutes), decimals (e.g., order 0.5 mL/h, programmed 5.0 mL/h),20,28 volume and time (e.g., 24 mL instead of 24 minutes),20 syringe sizes (e.g., 20 mL intended, 30 mL used and programmed),20 or two medications’ infusion rates.20

In all of the studies (n = 11), potential systemic defenses for intravenous medication error prevention were suggested (Table 3). Error prevention strategies were presented in discussion sections of the articles; thus, their effectiveness was not measured. Overall, activities related to process standardization, replacement of error-prone tasks with technological solutions and staff education were suggested to decrease possibilities of errors and improve error detection.18-28

Some systemic causes enabled medication errors in more than one process stage (Tables 3, 4). Insufficient actions to secure safe use of high-alert medications18,23,25 and lack of knowledge of the drug18,19,24,26-28 were identified as the two causes, which affected the most process stages, followed by calculation tasks18,19,21,26 and confusion between look-alike, sound-alike medications (LASAs).18,19,21,22 The studies also pointed out that absence of a systemic defense, or an existing defense breaking down, can enable errors. For example, failure to review orders after prescribing or to double-check during the preparation and administration stages can let errors actually reach the patient.18,22,24

**DISCUSSION**

To the best of our knowledge, this is the first systematic review to summarize systemic causes of intravenous medication errors in hospitals. We found a limited number of studies, all of them being observational studies not providing the most rigorous evidence. Current intravenous medication systems remain vulnerable, which can result in patient harm. According to the included studies, administration, prescribing, and preparation are the process phases most prone to systemic errors. We found insufficient actions to secure safe use of high-alert medications and lack of knowledge of the drug two leading error causes in multiple process stages, followed by calculation tasks, failure in double-checking procedures, and confusion between LASA medications.

Considering the issues related to high-alert medications, the Institute for Safe Medication Practices recommends standardizing the ordering, storage, preparation, and administration of high-alert medications and improving access to information about these drugs.1 Furthermore, healthcare organizations should use multidisciplinary teams to review more carefully and standardize the use processes of high-alert medications through risk management strategies, such as failure mode and effects analysis and root cause analysis of reported errors.19,20
| Error Type | Systemic Causes and Examples of Errors | Potential Systemic Defense for Error Prevention |
|------------|--------------------------------------|-----------------------------------------------|
| Prescribing (ordering, transcription and order verification) (n = 6)\(^{18,19,21-23,25}\) | **LASA medications; communication errors:** choosing a wrong drug (e.g., a sound-alike drug), confusion with drug name because of verbal prescription\(^{22,23}\) | Incorporating medical consultation and multidisciplinary reports to CPOE\(^{22}\) |
| **Wrong drug\(^{22,23}\)** | **CPOE and CDSS:** not taking CPOE alarms into account, “alarm fatigue,” inaccurate adaptation (e.g., 10 mg/kg instead of 15 mg/kg), weight (e.g., 64 kg instead of 74 kg), or unit (e.g., 3 mg instead of 3 g)\(^{22,23}\) | Standardized procedures for high-alert medications and emergencies\(^{23}\) |
| **Wrong dose\(^{19,21-23}\)** | **Communication errors:** confusion with dosage because of verbal prescription\(^{23}\) | Pharmacist’s analysis of prescriptions and duplication of previous order in CPOE\(^{22}\) |
| **Wrong route\(^{25}\)** | **Calculation tasks:** 10-fold errors, failure in dosage conversation\(^{19,21}\) | Standardized procedures for high-alert medications and emergencies\(^{23}\) |
| **Wrong choice\(^{19}\)** | **Extra dose\(^{22}\)** | Increasing vigilance and adapting alarms to the needs of prescribing physicians\(^{22}\) |
| **Wrong choice\(^{19}\)** | **Wrong route\(^{25}\)** | Using conversion charts to reduce the need for calculations\(^{19}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Documented independent double-checks for calculations\(^{19}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Not reported |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Standardization of schedules and utilization of CPOE\(^{22}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Full training of practitioners before they participate in high-risk processes (e.g., prescribing PCA)\(^{19}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Pharmacist’s analysis of prescriptions within the CPOE system\(^{22}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | System simplification\(^{2}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Equal responsibility and empowerment to challenge prescriber\(^{18}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | Education, training, and increased access to supportive resources\(^{18}\) |
| **Wrong choice\(^{19}\)** | **Wrong choice\(^{19}\)** | “Tall man” lettering to help practitioners visually distinguish between packages\(^{19}\) |
| **Multiple error types\(^{18,19,22}\)** | **Lack of knowledge of the drug:** failure to adjust dose to comorbidities (e.g., renal impairment, sleep apnea) or other drugs (e.g., opioid and multiple CNS drugs)\(^{19}\) | ADD directly linked to pharmacy information systems\(^{19}\) |
| **Multiple error types\(^{18,19,22}\)** | **Other systems:** CPOE and CDSS; failure in documentation (e.g., wrong patient identity or treatment setting identification, incomplete or illegible prescription, contradictory or duplicated orders, prescription forgotten, or documented in wrong place)\(^{18,19,22}\) | No not overriding prompts from ADD without consulting a pharmacist\(^{19}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Independent double-checks of products by two individuals\(^{19}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Separate storage of high-risk route drugs (e.g., IT doses in a locked fridge)\(^{25}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Maintaining adequate product inventory for patient care\(^{18}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Multiprofessional resolving of differences between products and original order\(^{21}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Documenting independent double-checks for calculations\(^{19}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Entering only one preparation to the biological safety cabinet at a time\(^{24}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Partnering and instructions with preparation supplies and final product\(^{24}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | An independent double-check of diluent volume during preparation\(^{24}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Documenting independent double-checks for calculations\(^{27}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Implementation of standard concentrations to eliminate calculation errors\(^{26,27}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Using bulk solutions prepared aseptically in pharmacy\(^{26,27}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Using right-sized syringe in volume measurements\(^{26,27}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Drug manufacturers’ and syringe providers’ compliance with current legislation\(^{26}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | An independent double-check of diluent volume during preparation\(^{24}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Educational interventions about correct preparation technique\(^{26}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Using electrolyte solutions prepared commercially or aseptically in pharmacy\(^{28}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Vigorous mixing and using bags rather than syringes for electrolyte solutions\(^{28}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Equal responsibility and empowerment to challenge prescriber\(^{18}\) |
| **Multiple error types\(^{18,19,22}\)** | **Failure to double-check:** overconfidence, casual attitudes or deciding not to question prescriber (e.g., respected physician, other person not available)\(^{18,22}\) | Education, training and increased access to supportive resources\(^{18}\) |

(Continued next page)
| Error Type | Systemic Causes and Examples of Errors | Potential Systemic Defense for Error Prevention |
|------------|---------------------------------------|-----------------------------------------------|
| Administration (n = 6)\(^{18-21,23,25}\) | LASA medications; similar looking equipment; several injection lines on a single fluid hanger, confusion between LASA medications\(^{19,23}\) | Barcode medication administration systems\(^{19,23}\) |
| Wrong drug\(^{19,23}\) | LASA medications; similar looking equipment; several injection lines on a single fluid hanger, confusion between LASA medications\(^{19,23}\) | Independent double-checks of products by two individuals\(^{19}\) |
| Wrong dose\(^{19-21,23}\) | Calculation tasks; products supplied in different concentrations (e.g., pump not reprogrammed when starting replacement infusion), 10-fold errors, confusion between weight and volume (e.g., 1 mg ordered, 10 mg/mL used, 1 mL given)\(^{19,21}\) | Smart pumps including a drug library and safety-alerts\(^{20}\) |
| Wrong route\(^{0,21,23,25}\) | LASA medications; similar looking equipment; confusion between two routes (e.g., oral syrup given IV), similar tubing or syringes (e.g., unlabelled tubing and syringes, confusing IV line with epidural line, connecting IV line to other lines)\(^{21,23}\) | Standardizing infusion pumps (e.g., pumps from a single manufacturer)\(^{20}\) |
| Extra dose\(^{18}\) | CPOE and CDSS; communication errors: failure to record medication administration, unauthorized drug (e.g., wrong patient or unordered drug)\(^{18}\) | Documented verification of orders, validation of infusion device settings and trace of infusion pump tubing at shift change\(^{20}\) |
| Missed dose\(^{19,20}\) | Infusion device problems: tubing disconnected or never connected to patient, pump not turned on, interrupted infusion not resumed\(^{19,20}\) | Not reported |
| Equipment failure\(^{20,23}\) | Infusion device problems: insufficient pump settings (e.g., not allowing infusion <1 mL/h), infusion device shortage, device malfunction\(^{20,23}\) | Not reported |
| Multiple error types\(^{18}\) | Failure to double-check: distractions, poor instructions of which things should be checked, not checking thoroughly (e.g., task carried out with a trusted colleague)\(^{18}\) | Education, training, and increased access to supportive resources\(^{18}\) |
| Treatment monitoring (n = 2)\(^{18,23}\) | Lack of knowledge of the drug; high-alert drugs: lack of knowledge (e.g., serious adverse effects, high-alert medications), no support resources, or choosing not using them\(^{18,23}\) | Education, training, and increased access to supportive resources\(^{18}\) |

Abbreviations: ADD, automated dispensing device; CDSS, clinical decision support system; CPOE, computerized physician order entry; IT, intrathecal; IV, intravenous; LASA, look-alike sound-alike; PCA, patient-controlled analgesia.
Calculation tasks were identified as a cause of wrong dose errors in multiple medication process stages. Pediatric and neonatal populations are at the highest risk for life-threatening calculation errors because of weight-based dosing and inadequate commercial products. Standard concentration procedures are an important way to improve intravenous medication safety. Calculation tasks can also be eliminated or secured by successful implementation of other systemic defenses, such as smart infusion pumps using error-reduction software, dose conversion charts, and decision support systems. In addition, smart infusion pumps can reduce errors related to manual pump programming, which we identified as a particular high-risk task. Manual independent double-checks are widely used in error identification, but the frequent poor quality of these procedures can enable medication errors. Safety of procedures relying on accuracy and awareness of an individual is easily jeopardized. Likewise, procedures that lack sensitivity to all potential error types are problematic. Some manual double-checks could relatively simply be replaced with more reliable technological solutions (e.g., barcode scanning) or even by eliminating error-prone process steps (e.g., reducing preparation errors by using pre-prepared syringes or sealed systems requiring minimal manipulation before use).

In our study, absence of a standardized order review protocol was identified as a risk factor for inheritance of prescribing errors in later process stages. To support safe prescribing, an order review by a clinical pharmacist combined with clinical decision support systems would be an optimal strategy for error reduction. In addition, confusion between LASA medications can be particularly significant when high-alert medications are involved. To decrease errors related to LASA medications, use of Tall Man lettering (e.g., morphine and HYDROMorphon), safe storage, auxiliary labels, and barcode medication administration systems should be considered.

Our study was conducted in accordance with the PRISMA checklist. We included only peer-reviewed articles in the analysis and assessed the quality of selected studies using the GRADE system. The literature search was restricted to articles published in English; thus, studies published in other languages were excluded. Although intravenous medications are widely used in hospitals and associated with frequent and particularly serious errors, the number of studies included in our systematic review was limited. Many excluded studies focused on incidence and types of intravenous medication errors, with no emphasis to examine why the errors happened. We also excluded some studies focusing on multiple administration routes, if the findings related to intravenous administration route could not be reliably identified and extracted from the results. We needed to make some modifications to the error categorizations presented in Leape’s classic analysis of medication errors, because we wanted to identify the most crucial systemic causes of intravenous errors to inform medication process development in hospitals.

PROBABILITY OF DETERMINING THE CAUSES OF INTRAVENOUS MEDICATION ERRORS

Calculation tasks were identified as a cause of wrong dose errors in multiple medication process stages. Pediatric and neonatal populations are at the highest risk for life-threatening calculation errors because of weight-based dosing and inadequate commercial products. Standard concentration procedures are an important way to improve intravenous medication safety. Calculation tasks can also be eliminated or secured by successful implementation of other systemic defenses, such as smart infusion pumps using error-reduction software, dose conversion charts, and decision support systems. In addition, smart infusion pumps can reduce errors related to manual pump programming, which we identified as a particular high-risk task. Manual independent double-checks are widely used in error identification, but the frequent poor quality of these procedures can enable medication errors. Safety of procedures relying on accuracy and awareness of an individual is easily jeopardized. Likewise, procedures that lack sensitivity to all potential error types are problematic. Some manual double-checks could relatively simply be replaced with more reliable technological solutions (e.g., barcode scanning) or even by eliminating error-prone process steps (e.g., reducing preparation errors by using pre-prepared syringes or sealed systems requiring minimal manipulation before use).

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Table 4: The Most Crucial Systemic Causes Resulting in Intravenous Medication Errors in More Than One Medication Process Stage

| Systemic Cause                                    | Prescribing | Dispensing and Storage | Preparation | Administration | Treatment Monitoring |
|---------------------------------------------------|-------------|------------------------|-------------|----------------|---------------------|
| Insufficient actions to secure safe use of high-alert medications | X           | X                      | X           | X              | X                   |
| Lack of knowledge of the drug                     | X           | X                      | X           | X              | X                   |
| Calculation tasks                                 | X           | X                      | X           | X              | X                   |
| Failure in double-checking procedures             | X           | X                      | X           | X              | X                   |
| Confusion between LASA medications                | X           | X                      | X           | X              | X                   |
| Lack of CPOE standardization and ineffectiveness of CDSS | X           | X                      |             | X              |                     |
| Confusion between similar looking equipment (e.g., syringes, infusion bags, tubing) | X           | X                      |             | X              |                     |
| Communication errors                              | X           | X                      |             |                 |                     |
| Problems related to drug product                  |             |                        |             |                 |                     |

Abbreviations: CDSS, clinical decision support system; CPOE, computerized physician order entry.

CONCLUSIONS

According to our study, insufficient actions to secure safe use of high-alert medications, lack of knowledge of the drug, calculation tasks, failure in double-checking procedures, and confusion between LASA medications are the leading systemic causes of intravenous medication errors. Current intravenous medication systems remain vulnerable. Our findings suggest further focus on medication safety activities related to administration, prescribing,
and preparation of intravenous medications. Process standardization and implementation of effective systemic defenses are essential to improve medication safety. Our study provides healthcare organizations with preliminary knowledge about systemic causes of intravenous medication errors, but more rigorous evidence is needed.

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