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ORIGINAL RESEARCH:
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Medication dose calculation errors and other numeracy mishaps in hospitals: Analysis of the nature and enablers of incident reports

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Abstract

Aims: To investigate medication dose calculation errors and other numeracy mishaps in hospitals and examine mechanisms and enablers which lead to such errors.

Design: A retrospective study using descriptive statistics and thematic analysis of the nature and enablers of reported incidents.

Methods: Medication dose calculation errors and other numeracy mishaps were identified from medication-related incidents reported to the Norwegian Incident Reporting System in 2016 and 2017. The main outcome measures were medications and medication classes involved, severity of harm, outcome, and error enablers.

Results: In total, we identified 100 numeracy errors, of which most involved intravenous administration route ($n = 70$). Analgesics were the most commonly reported drug class and morphine was the most common individual medication. Overall, 78 incidents described patient harm. Frequent mechanisms were 10- or 100-fold errors, mixing up units, and incorrect strength/rate entered into infusion pumps. The most frequent error enablers were: double check omitted or deviated ($n = 40$), lack of safety barriers to intercept prescribing errors ($n = 25$), and emergency/stress ($n = 21$).

Conclusion: Numeracy errors due to lack of or improper safeguards occurred during all medication management stages. Dose miscalculation after dilution of intravenous solutions, infusion pump programming, and double-checking were identified as unsafe practices. We discuss measures to prevent future calculation and numeracy errors.

Impact: Our analysis of medication dose calculation errors and other numeracy mishaps demonstrates the need for improving safety steps and increase standardization for medication management procedures. We discuss organizational, technological, and educational measures to prevent harm from numeracy errors.

KEYWORDS
drug dosage calculations, incident reporting system, intravenous administration, medication errors, morphine, numeracy, nurses, patient safety

1 | INTRODUCTION

Numeracy is a crucial skill for all healthcare professionals and is defined as “the ability to understand and use numbers in daily life” (Rothman et al., 2008, p. 585). For those involved in prescribing, dispensing, or administering medicines this includes the ability to perform tasks such as calculate the drug dose or infusion rate safely and accurately. However, as suggested in the literature, the numeracy skills of healthcare professionals are poor despite passing the required calculation tests (Warburton, 2010; Wright, 2010). Miscalculation of the medication doses, 10-fold errors, and other numeracy errors can result in wrong dose given with devastating consequences for the patient (Doherty & Mc Donnell, 2012). These types of errors have often been associated with individuals' poor arithmetic skills although there is insufficient evidence to connect calculation skills with medication errors (Wright, 2010).

2 | BACKGROUND

There is substantial evidence that nurses and nursing students perform badly when tested in medication calculations (Fleming et al., 2014; Grandell-Niemi et al., 2001; Simonsen et al., 2014; Wright, 2010). One study that measured numerical and drug calculation abilities found that 92% of nursing students and 89% of registered nurses failed the drug calculation test (McMullan et al., 2010). Another study in one nursing school showed no association between high school mathematics grade and the number of attempts required to pass the medication calculation test (Alteren & Nerdal, 2015). Wright concluded that written assessments are invalid measures of nurses' numeracy skills and that their skills were better in clinical practice than suggested by these formal tests (Wright, 2007).

Numeracy errors are also made by other health care professionals, such as miscalculating drug doses during prescribing (Bonadio, 2019). A scoping review of prescribing errors in children found that miscalculating drug doses was one of the main causes of prescribing errors (Conn et al., 2019).

Our previous study using data from medication errors from the Norwegian Incident Reporting System demonstrated that dosage errors are the most frequently reported medication errors, accounting for 38% of all errors (Mulac et al., 2020). Several studies have documented that dosage errors are common and have explored medication dose calculation errors as a subtype of dosage errors (Aronson, 2009; Gariel et al., 2018; Keers et al., 2013). Previous publications that have explored calculation errors specifically have used classroom-based calculation tests or surveys (Williams & Davis, 2016; Wright, 2010), or have focused on specific patient population and type of calculation errors, for example, 10-fold errors in children (Doherty & Mc Donnell, 2012; Tse & Tuthill, 2021), or errors with dosage equations (Lesar, 1998).

To our knowledge medication dose calculation errors in clinical practice have neither been defined nor analysed in previous studies despite this gap being highlighted more than a decade ago (Wright, 2010). Improved understanding of the nature and causal factors to calculation errors would be useful to identify and develop error-prevention strategies. Thus, we conducted a retrospective in-depth analysis of nationally reported medication-related incidents.

3 | THE STUDY

3.1 | Aims

The study aimed to investigate medication dose calculation errors and other numeracy mishaps and examine sources, mechanisms, and enablers that lead to such errors.

3.2 | Design and setting

A retrospective incident reports review was undertaken from medication-related incidents reported to the Norwegian Incident Reporting System in 2016 and 2017.

The reporting system was a mandatory, anonymous, electronic reporting and learning system of incident reports from all hospitals across Norway. Health professionals were legally obliged to report incidents that could have or had caused patient harm. In the 2-year study period, health care professionals from 64 hospitals in 2016 and 55 hospitals in 2017 reported approximately 20,000 incident reports of which about 17% were medication-related reports.

During the study period, both paper-based prescribing and electronic prescribing were used in Norwegian hospitals. Electronic Medication Administration Record (eMAR) was, at this point, implemented in a few hospitals and most of the medication administration described in the incident reports were documented on paper.

The dispensing process in the reporting hospitals comprised ward-based medication rooms where the medications were stocked and required dispensing, dilution, and further preparation by nursing staff before administering to the patient. Only chemotherapeutics, opioid cassettes for pain pumps, and parenteral nutrition were compounded and dispensed by hospital pharmacy staff.

3.3 | Definitions

We defined a medication error according to the National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) as “any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer” (NCC MERP, 2001). Causal factors to medication errors included error sources, error mechanisms and error enablers. Error source was defined as the initiating factor that precipitated the error (Tse & Tuthill, 2021, p. 2) e.g., writing slips, dose calculation, or misinterpretation of the written order. Error mechanisms were defined as the act or practice that led to the error source (Tse & Tuthill, 2021, p. 2) e.g., 10-fold errors, omitted calculations, mixed up units, or mental dose calculations. Error enablers were those factors that made it more likely for errors to occur (Tse & Tuthill, 2021, p. 2) e.g., double check omitted or deviated, small volume or quantity of the drug, or paper-based prescribing.

3.4 | Sample

Incident reports consisted of categorical data (e.g., patient age, incident date, day of the week) and free-text data (incident description, description of the cause, patient consequences, suggested prevention measures, and caseworker's comments). In total, 3372 medication errors were reported during the 2-year study period. These were classified into error types in a previously published study (Mulac et al., 2020): omission, wrong drug, wrong route, wrong formulation, adverse drug reaction, wrong dispensing label, wrong storage and dosage errors. To identify medication calculation errors or numeracy mishaps, we have thoroughly read and evaluated reports involving dosage errors. In the current study, we included dosage errors that resulted from a miscalculation of the medication dose or a numerical misconception of the medication dosage or its unit. Only actual events that reached the patient were included. Of the 116 incident reports which were classified under miscalculations or numeracy mishaps, we excluded three reports due to errors that were prevented from reaching the patient, five reports due to either insufficient and indistinct information, seven reports due to a non-dosage-related calculation or numerical error, and one calculation error did not occur in a hospital setting. Medication calculation errors and numeracy mishaps are hereafter collectively referred to as numeracy errors.

3.5 | Ethical considerations

Access to anonymized incident reports was granted by the Norwegian Directorate of Health where the Norwegian Incident Reporting System was based. Ethical approval was not required for this study.

3.6 | Data analysis

We conducted a quantitative analysis of the characteristics of numeracy errors and a qualitative thematic analysis of their causal factors. Data were analysed using IBM SPSS V25. First, frequency analysis and descriptive statistics were used to analyse the general characteristics of medication errors. Each report was categorized according to the patient age, stage in the medication process, route and formulation, overdosage or underdosage, medication name, and drug class. Second, free text descriptions from the reports were used for the qualitative analysis of the causal factors and harm.

3.7 | Rigour

We adapted the method reported in previous studies (Doherty & Mc Donnell, 2012; Tse & Tuthill, 2021) to analyse the nature and causal factors of numeracy errors. We thoroughly read all the reports to identify themes as they emerged from the data. The first and second authors independently categorized the themes of the error sources, mechanisms and enablers, and graded the severity of medication errors using the adapted NCCMERP classification system (NCC MERP, 2001). Each reported incident was then discussed until consensus was reached on classification. The classifications were thereafter presented to the last author and accordingly adjusted to the final categories.

4 | RESULTS

4.1 | Error characteristics

Over the 2 years, 100 numeracy errors met the inclusion criteria, as presented in Table 1. Patient age ranged from 0 to 96 years. One-third of all errors ($n = 28$) affected individuals under 18 years, half of whom were infants (<1 year). Most errors ($n = 85$) involved overdoses and 14 involved underdoses. The route of administration for numeracy errors was unevenly split: 77% were associated with

TABLE 1 Demographics and summary characteristics of medication dose calculation errors and other numeracy mishaps

	N	Percentage
Total number reports	100	100
Age		
<1	12	12
1–17	16	16
18–65	37	37
65+	35	35
Medication overdosage or underdosage		
Overdoses	85	85
Underdoses	14	14
Missing	1	1
Route and Formulation		
Intravenous infusion	52	52
Intravenous bolus injection	18	18
Oral tablets/capsules	11	11
Oral liquid	9	9
Subcutaneous injection	7	7
Missing	3	3%
Outcome of error		
No harm	22	22%
Harm	75	75%
Death	3	3%

the parenteral route, and 20% were associated with the oral route (Table 1).

Most errors (70%) involved intravenous administration route, of which 52% were intravenous infusions and 18% were intravenous injections. Errors associated with oral administration route involved tablet/capsule (11%) and liquid oral formulations (9%) and were commonly associated with small dosages or small volumes (Table 1).

The 100 errors involved 47 individual medications and 20 drug classes (Table 2). Analgesics were the most commonly reported drug class (23%) and morphine was the most common individual medication (9%). Most analgesic errors had an intravenous administration route (21/23). Half of the morphine errors involved an intravenous bolus injection ($n = 5$). The second most reported individual medication was insulin, followed by parenteral nutrition, oxycodone, and digoxin.

4.2 | Patient outcome and stage in the medication management process

The majority of errors (78%) caused patient harm (classified as NCC MERP Index Categories E-I, Table 3). These errors contributed to or resulted in three patients' deaths, the need for interventions to sustain life for 15 patients, and permanent harm with 10 patients.

Over half of reported incidents originated in the administration stage (57%), 25% in the prescribing stage, and 18% in the

TABLE 2 The 10 most frequent drug classes and individual medications identified from medication dose calculation errors and other numeracy mishaps

Drug class	Drug class number reports (%)	Medication name (*n*)
Analgesics	23 (23%)	Morphine (9)
		Oxycodone (6)
		Other opioid analgesics (6)
		Paracetamol (2)
Parenteral nutrition and intravenous fluids	12 (12%)	Lipid/total parenteral nutrition (7) [a]
		Fluids and electrolytes (5) [a]
Cardiac therapy	13 (13%)	Digoxin (6)
		Norepinephrine (3)
		Epinephrine (3)
		Levosimendan (1)
Antibacterials	9 (9%)	Vancomycin (2)
		Gentamicin (2)
		Sulfamethoxazole, trimethoprim (2)
		Clindamycin (1)
		Others (2)
Chemotherapy	8 (8%)	Methotrexate (1)
		Carboplatin (1)
		Others (6)
Drugs used in diabetes	7 (7%)	Insulin (7)
Anesthetics	6 (6%)	Ketamine (3)
		Lidocaine (2)
		Propofol (1)
Antithrombotic agents	3 (3%)	Warfarin (1)
		Dalteparin (1)
		Alteplase (1)
Other nervous system drugs	3 (3%)	Methadone (2)
		Buprenorphine (1)
Others[b]	17 (17%)	
Total number reports	100 (100%)	

[a]Lipid/total parenteral nutrition, and fluids and electrolytes include more than one single medication.

[b]Others include psycholeptics, diagnostic agents, diuretics, antiviral drugs, antihypertensives and beta blocking agents, corticosteroids, naloxone, immunoglobulins, diuretics, antiepileptics, and proton pump inhibitors.

preparation/dispensing stage. More harmful errors ($n = 78$) occurred during medication administration ($n = 46$) than during medication prescribing ($n = 17$) and dispensing ($n = 15$). Analgesics were the most harmful drug class: opiate overdoses were involved in half of the errors that lead to permanent harm, interventions to sustain life, and death.

4.3 | Error sources, mechanisms, and enablers

We identified causal factors that contributed to numeracy errors by identifying error sources, mechanisms (Table 4), and enablers (Table 5). The most common error source was *error of calculation*, which were incidents caused by dose miscalculation. Other common error sources were error *of incorrect administration*, *incorrect equipment programming*, and *writing slips during prescribing*.

The most common error mechanism was *10-fold errors* and occurred when a decimal point or zero was misplaced, omitted, and/or added. The availability of medication in *multiple strengths* or *mixing up units* were common mechanisms resulting in errors.

Some error enablers led to errors at all stages of the medication management process including *emergency/stress*, *inexperienced staff/lack of knowledge*, *and suboptimal technology design*. Other error enablers were linked to a specific stage in the medication process such as *lack of safety barriers to intercept prescribing errors and paper-based prescribing* during the prescribing stage. The most common error enabler, identified in 40 incidents, was *double check omitted or deviated* which was specific for the dispensing/preparation and administration stage. However, we found that although double check was adhered to it did not intercept the error in 28 incidents. Numeracy errors occurred with small medication dosages, more specifically when the dosage was below 1 unit, 1 ml or 1 mg, which was identified in 18 incidents. The requirement to dilute solutions intended for intravenous bolus injection resulted in 14 errors, which involved dilution of morphine, oxycodone, adrenalin, and noradrenalin.

4.4 | Error characteristics with the paediatric population

Half of all incidents which involved children (<18 years) were due to dose miscalculation. The paediatric incidents also arose due to failure to double check ($n = 20$), emergency/stress ($n = 6$), small volume <1 ml or small quantity <1 mg or units <1 unit ($n = 6$), and lack of safety barriers to intercept prescribing errors ($n = 6$). Four children were permanently harmed due to errors involving paracetamol ($n = 2$), gentamicin ($n = 1$), and tobramycin ($n = 1$). Interventions were required to sustain life for five paediatric patients due to errors involving morphine ($n = 3$) and insulin ($n = 2$) overdoses. We did not find any characteristic differences among errors occurring in adult versus paediatric patients, and thus errors are discussed collectively.

5 | DISCUSSION

This study identified several risk factors which caused numeracy errors and ranged from ineffective or lacked safeguards to unsafe procedures in the medication management process. While the cause of numeracy errors was often multifactorial, they highlighted the need for resilience within the medication management processes to avoid errors. Though sparse, we have also identified human factors of an individual's numeracy skills that contributed to errors. Our focus remained however on addressing the systems' defects engrained in the process of handling medications. Accordingly, while health professionals as individuals make mistakes, organizations allow for them to be serious. It is the latter situation that this study sought to explore.

There is a lack of consistency in medication errors causation research. Although various models for understanding errors exist, they have also been criticized for being too simplistic (Seshia et al., 2018), failing to prevent errors (Peerally et al., 2017), or not appropriately used to identify impactful interventions (Franklin et al., 2012). In this study, we wanted to understand the errors by leveraging on the rich descriptions in the incident reports. We therefore applied a relatively novel and more specific model of identifying error sources, mechanisms, and enablers (Doherty & Mc Donnell, 2012). By discussing error enablers, this method eventually allowed us to identify measures at a systems level with the potential to result in sustained improvements to patient safety.

Table 5 presents an exhaustive list of all error enablers from our data, followed by proposed measures that are supported by international recommendations, the research literature, and our analysis of the error enablers (American Hospital Association. Health Research & Educational Trust & Institute for Safe Medication Practices, 2002; Cohen et al., 2007; Fleming et al., 2014; Fox et al., 2019; Grissinger, 2010; Hedlund et al., 2017; Institute for Safe Medication Practices, 2015; Ohashi et al., 2014; Westbrook et al., 2021; Wright, 2007). These proposed measures will reduce or eliminate the impact of error enablers on the medication management process in clinical practice. Below we discuss areas, which, according to our analysis, require the greatest attention to reduce harm from numeracy errors.

5.1 | Intravenous preparation process

Intravenous medications were used in over half of the serious incidents in our study. Previous research has identified handling intravenous medications as a high-risk practice prone to deviations from procedures (Taxis & Barber, 2003). In our study, the intravenous preparation process was specifically exposed to risks when performing tasks with cognitive loads, such as dilution and bedside dose calculation while at the same time providing patient care. Some dilution errors occurred due to the lack of understanding of the exact concentration after dilution, which resulted in one infant receiving 7 mg of morphine instead of 0.7 mg. Administering from a syringe that contains more than the prescribed dose was found as a

TABLE 3 The outcome of medication dose calculation errors and other numeracy mishaps according to an adapted NCC MERP classification, the affiliated stages during medication management, and the most frequent drug classes

		Stage in medication process			Drug class							
	Total (*n*)	Prescribing	Preparation/ dispensing	Administration	Analgesics	Cardiac therapy	Parenteral nutrition and intravenous fluids	Antibacterials	Chemotherapy	Insulin	Anesthetics	Antithrombotics agents
Error, no harm												
C - An error occurred that reached the patient, but did not cause patient harm	14	5	3	6	2	3	3	1	2	1	0	0
D - An error occurred that reached the patient and required monitoring to confirm that it resulted in no harm to the patient and/or required intervention to preclude harm	8	3	0	5	1	2	0	1	2	0	0	0
Error, harm												
E - An error occurred that may have contributed to or resulted in temporary harm to the patient and required intervention	28	4	9	16	4	3	6	4	2	2	2	0
F - An error occurred that may have contributed to or resulted in temporary harm to the patient and required transfer to an intensive care unit, continuous monitoring, initial or prolonged hospitalization	22	6	1	14	5	3	2	1	1	1	1	1

(Continues)

TABLE 3 (Continued)

		Stage in medication process			Drug class							
	Total (*n*)	Prescribing	Preparation/ dispensing	Administration	Analgesics	Cardiac therapy	Parenteral nutrition and intravenous fluids	Antibacterials	Chemotherapy	Insulin	Anesthetics	Antithrombotics agents
G - An error occurred that may have contributed to or resulted in permanent patient harm	10	5	2	3	3	0	0	2	1	0	1	2
H - An error occurred that required intervention necessary to sustain life	15	1	3	11	6	1	1	0	0	3	2	0
Error, death												
I - An error occurred that may have contributed to or resulted in the patient's death	3	1	0	2	2	1	0	0	0	0	0	0
Total	100	25	18	57	23	13	12	9	8	7	6	3

Note: Index categories A - Circumstances or events that have the capacity to cause error; B - error occurred but did not reach the patient; are not included in our data because we only included medication errors that have reached the patient.

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

TABLE 4 Error sources and error mechanisms identified from medication dose calculation errors and other numeracy mishaps

	n	Selected examples
Error source		
Dose calculation	36	Dosage of 0.3 mg/kg propranolol for an infant of 1.5 kg was calculated to 4.5 mg
Drug administration	14	100 mg propofol injected instead of 10 mg
Writing slips during prescribing	12	Prescribed digoxin in mg instead of µg
Infusion pump programming	11	Entered 160 ml into the infusion pump for paracetamol infusion instead of 16 ml
Misinterpreted written order, units, decimal points	9	Patient received 1 tablet of 0.25 mg digoxin instead of ¼ tablet of 0.25 mg
Incorrect prescribing	8	Prescribed 25 mg prednisolone instead of 2.5 mg
Incorrect strength	5	An infant received glucose 500 mg/ml instead of Glucose 50 mg/ml that was prescribed
Incorrect preparation/compounding of drug	5	1 g vancomycin compounded in 100 ml sodium chloride instead of 250 ml
Misinterpreted verbal order or miscommunication	4	Administered intraosseous 1 mg/ml adrenalin injection instead of 0.1 mg/ml during cardiac arrest
Incorrect equipment	4	60 units insulin administered instead of 6 units (used regular 1 ml syringe to draw up insulin instead of insulin syringe)
Unknown	5	
Error mechanism		
10- or 100-fold errors	27	10 mg morphine injected instead of 1 mg
Multiple strength of drug available	11	Received one 8 mg tablet instead of one 2 mg tablet due to a storage error
Incorrect strength/rate entered to infusion pump	10	A fentanyl 50 µg/ml infusion was plotted as 10 µg/ml into the infusion pump
Mixed up units (e.g., mg with ml, or mixing g, mg, and µg), and incorrect conversion of units	10	The infusion pump with morphine was set to µg/ml instead of mg/ml
Typing or reading error (calculator, eMAR)	8	Patient height and weight was switched in the formula when calculating the body surface for chemotherapy dosage
Incorrect use of patient history (bodyweight, blood tests)	7	The carboplatin dose calculated based on a past creatinine value
Incorrect use of hospital procedures	6	The ketamine infusion was administered undiluted (10 mg/ml), resulting in a 5-fold overdosage
Omitted calculations	6	Calculated heparin dose without considering patient's weight
Administering from a syringe that contains more than the prescribed dose	6	10 mg/ml oxycodone ampoule was diluted to 2 mg/ml concentration into a 5 ml syringe, the nurse used the whole syringe content when administering and accidentally gave 4 ml (8 mg) instead of 2 ml (4 mg)
Proportion dose calculation error	4	An infant should have received 10 µg naloxone from a 40 µg/ml oral solution (10/40 = 0.25 ml), the equation was turned upside down and the nurse calculated 40/10 = 4 ml
Multiple complex calculations	3	Calculated the insulin dose with the correction factor instead of carbohydrate factor
Mental dose calculations	2	Mentally calculated 0.3 mmol/kg × 100 kg calcium chloride to be 130 mmol
Unknown	18	

Note: Each incident may have multiple factors.
Abbreviation: eMAR, electronic Medication Administration Record.

high-risk practice in the current study. This practice occurred when diluting opiates or withdrawing the entire content of an ampoule or vial into the syringe. We used one example from the data to illustrate (Figure 1) how this practice together with a minor distraction may lead to injecting the whole syringe content, or more than initially intended. A systematic review of intravenous medication preparation errors elaborated that error rates appeared to be lower when the preparation took place in the central pharmacy settings compared with nursing wards (Hedlund et al., 2017). Another measure shown to reduce dilution and labelling errors is prefilled syringes (Grissinger, 2010), which besides the safety aspect also offer advantages of their convenience, accuracy, sterility, and medication waste reduction (Makwana et al., 2011). Prefilled syringes are, however, employed only infrequently in a routine hospital setting because of

TABLE 5 Error enablers identified from medication dose calculation errors and other numeracy mishaps with proposed safety measures

Stage	Error enablers	*n*	Selected examples	Proposed safety measures
Prescribing	Lack of safety barriers to intercept prescribing errors	25	Prescribed prednisolone 25 mg instead of 2.5 mg.	• Electronic prescribing with proper dose-checking decision support and improved layout design • Pharmacist order verification
	Paper based prescribing	6	The insulin dose in multidose drug dispensing prescription stated Insulatard® 100 U followed by 8 U, which was overlooked (The erroneously written *100 U* was referred to the strength of insulin which is 100 U/ml, but was misinterpreted to be the dosage).	
Dispensing/preparation and administration	Double check omitted or deviated	40	The noradrenalin pump was set to 0.7 μg/kg/min instead of 0.07 μg/kg/min.	*Intravenous medications:* • Smart pumps linked with eMAR and BCMA • Limit bedside intravenous compounding of high-alert medications (dilution, syringe overage, calculation) • Prefilled ready-to-use injectables for high-risk medications and in emergency care • Proper description of risk-prone steps in injectables compounding procedure • Establish standardized concentrations and offer only one concentration per IV medication to avoid confusion • Use medication calculators in eMAR when handling withdrawal, dilution or dosage calculation*Double checks:* • Specific and clear description of double-checking procedure • Decrease the number of procedures that require double checks • Prioritize critical procedures for independent double checks e.g. dose calculation and pump programming • *Education should allow to*: • Visualize and estimate the dose mentally before calculating exact numbers • Develop the mathematical and conceptual skills of student nurses
	Small volume <1ml or small quantity <1 mg or units <1 U	18	The nurse attempted to administer 1.2 units (=0.012 ml) of insulin (100 IU/ml) using improper insulin syringe. Mistakenly, 12 units (=0.12 ml), a 10-fold higher dose, was drawn into a syringe and administered.	
	Dilution required	14	Oxycodone 10 mg/ml was diluted to 2 mg/ml (instead of the recommended 1 mg/ml), which led to a 2-fold overdosage as the volume for injection was not reduced accordingly.	
	Distraction during task	3	The physician ordered 1 mg morphine and the nurse drew 10 mg into a syringe which was handed to the physician while verbalizing the content of the syringe. As the physician simultaneously spoke with patient`s relatives while administrating, they accidentally injected the whole syringe 10 mg) instead of only 1 mg.	
	Multiple zeroes in order or dose amount	2	Patient received a heparin dose of 150,00 IE, instead of 1500 IE. 3 ml of the 5000 IE heparin was injected, instead of 0.3 ml. The dose was calculated mentally, and verbally confirmed by another nurse and seemed correct as it was a simple calculation.	

(Continues)

TABLE 5 (Continued)

Stage	Error enablers	*n*	Selected examples	Proposed safety measures
All stages	Emergency/stress	21	A severely hypotensive patient arrived at the ER and was subjected to multiple procedures simultaneously. Then, 50 µg of "emergency adrenaline" was injected, instead of the ordered 5 µg.	• Identify risks in communication during emergencies and establish best practices • Avoid calculations in emergency care using standardized concentrations
	Inexperienced staff/lack of knowledge	12	A nurse who was back from an extended sick leave wasn't familiar with handling oxycodone. The dilution was double-checked by another nurse but not the dosage resulting in an overdose.	• Establish supervision for new employees and part-time workers. • Evaluate the resilience of procedures to human factors, e.g., lack of knowledge and conceptual calculation skills
	Suboptimal technology design or new technology	7	The prescription for sulfamethoxazole/trimethoprim in eMAR stated only "sulfamethoxazole 400 mg × 3" which contributed the nurse to misinterpret the dose. The trimethoprim dosage was written in a separate note "trimethoprim 5 mg/kg with fivefold sulfa component".	• Periodical assessment/monitoring the electronic prescribing, eMAR and BCMA use to identify potentially unsafe practices

Note: Each incident may have multiple factors.

Abbreviations: BCMA, Barcode Medication Administration; CPOE, Computerized provider order entry; eMAR, electronic Medication Administration Record; IV, intravenous.

the additional cost they present to the hospital (Grissinger, 2010; Makwana et al., 2011). Although general hospital recommendations advise that intravenous drugs should be offered in only one concentration by the hospital pharmacy (Institute for Safe Medication Practices, 2015), including those for Norwegian hospitals, several medication errors in our study occurred because multiple strengths of intravenous medications were available, e.g., confusion between the low- and high-concentrated noradrenalin infusion. Barcode medication administration—scanning medications during dispensing and administration—could mitigate such mix-up errors of several available strengths (Poon et al., 2010). Our findings highlight the risks associated with intravenous preparation at the site of care and suggest standardizing the intravenous preparation process.

5.2 | Infusion pump-programming errors

Errors commonly occurred when programming intravenous pumps, e.g., 40 mmol/h instead of 40 ml/h. The programming of infusion pumps was usually not double-checked by other health professionals which enabled errors in 11 cases, most of which led to patient harm. Entering incorrect strength into the infusion pump, which was a frequent mechanism behind pump-programming errors in our study, could be avoided using standardized concentrations which are stored in the electronic library in infusion pumps sometimes referred to as "smart pumps". Smart pumps, connected to the electronic health record, have been shown to reduce programming errors (Ohashi et al., 2014). While most errors associated with intravenous infusion in our study were pump-programming errors, smart pumps per se could not have prevented all of these errors because, they have not been shown to reduce the risk of errors when used without barcode medication administration and rarely with electronic prescribing (Lyons et al., 2018). Since the costs and benefits of implementing smart pumps have not yet been established (Schnock et al., 2017), other interventions, which can be implemented immediately and at low cost should be prioritized, such as a specific description of procedures and safety steps when handling and programming infusion pumps, and standardizing protocols for infusion rate calculation.

5.3 | The double checks paradox

Instead of functioning as a safety net, double checks seemed to enable errors in our study. All numeracy errors in this study, which occurred during medication administration or dispensing ($n = 75$) required double checks e.g., high-alert medications and handling injections and infusions. Yet, double checks seemed to provide false safeguard and in 53% of these (40 out of 75 administrations) double checks were omitted or deviated, and 37% (28 out of 75 administrations) described that even when adhered to, double-checking did not prevent the error. The remaining errors ($n = 7$) did not provide information about the double-checking procedure. Alsulami et al. evaluated paediatric nurses' adherence to double checks and found that the step with the

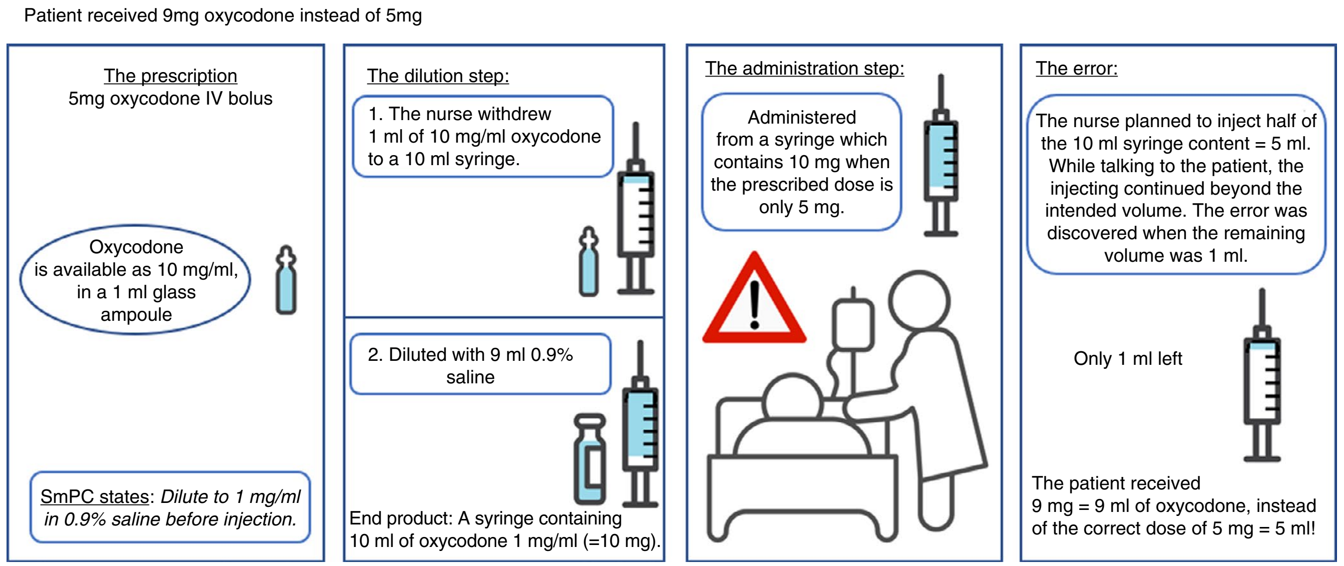

FIGURE 1 Administering from a syringe that contains more than the prescribed dose

lowest adherence was independent checks of the drug dose calculation, conducted only in 30% of administrations (Alsulami et al., 2014). It is however difficult to discuss the value of double checks in our study without a clear procedure for double-checking. The national medication management policy (The Norwegian Directorate of Health, 2015) requires independent double-checking, while the description of what an independent check is and the specific procedure to be performed in a double check is not described. This issue is especially important when the intravenous compounding comprises multiple stages and involves dilution, dose calculation, withdrawal, and administration of the correct dose (Figure 1). It is unclear which of these steps require a double check, and if all do, whether this is likely to be achievable in clinical practice with the current staffing levels. The concern with unprecise descriptions of the specific steps during double checks is also raised in a recent paper (Pfeiffer et al., 2020), which questioned the effect of double checks when the intervention itself is not clearly defined.

We did not differentiate the value of adhered double checks in the current study merely because the details of how these were performed were usually not described in the incident reports. However, our strict data inclusion provided incident descriptions with sufficient information to exclude an independent check and suggest double-checking was primed, i.e., usually described as: "a second nurse double-checked the calculation made by a first nurse" - the second nurse was "primed" with information about the dose or calculation rather than undertaking the calculation themselves. Moreover, double-checking procedures should be designed to avoid the likelihood of confirmation bias (Dickinson et al., 2010) i.e. instead of telling someone to check if a calculation is correct, one should ask the other person to calculate the dosage again. Others have advised against using the primed checks (Pfeiffer et al., 2020), as they require considerable resources for nurses but have shown not to reduce error rates (Westbrook et al., 2021). Additionally, requiring independent checks, which are infrequently performed in practice (Westbrook et al., 2021), often due to challenges with staffing, is likely to result in deviating from or omitting the double-checking. This is confirmed in the current study, where nurses described in several cases that it was difficult to find an available nurse for the double check, so they omitted it.

In addition to clearly stating which specific steps must be double-checked, we propose to reduce the number of double checks. This can be done, for example, by limiting the number of intravenous medications compounded at the bedside or on the ward. Thus, resources would be released for independent double checks for tasks that must be done at the bedside, such as when programming infusion pumps.

5.4 | High-alert medications

High-alert medications, which pose a higher risk of medication errors compared with other types of medications (Grissinger, 2016), were associated with almost 50% of the numeracy errors in our study and included digoxin, opiates, insulin, methotrexate, gentamycin, intravenous electrolytes, and antithrombotics. All digoxin errors occurred due to discrepancies between dosage units i.e., mg and μg. There appeared to be a mismatch between the unit on the prescription and the formulary oral digoxin which often caused confusion leading to the error. Insulin errors were primarily caused by dose miscalculation but also occurred when the nurse withdrew insulin in a non-insulin syringe or insulin syringe not scaled for small volume. Such practices were also found to cause errors in a review involving insulin-related patient safety incidents and were referred to as error-prone practice (Cousins et al., 2011). Insulin errors have also been caused by knowledge deficit, such as not spotting that the calculated dosage was significantly higher or lower than the standard dose range, such as administering 250 units of insulin in a single dose.

Opiate errors in this study involved specifically intravenous bolus injections of morphine and oxycodone. Moreover, the formulary oxycodone and morphine for intravenous bolus required dilution in each reported event from 10 mg/ml to 1 mg/ml, which increases risk especially in combination with bedside preparation because of unexpected distractions or interruptions (Institute for Safe Medication Practices, 2015). Opiate overdoses are relatively frequent, cause severe consequences for patients (Mulac et al., 2020), and led to life-threatening events for seven patients in the current study.

Numeracy errors involving high-alert medications arose because the bedside conditions were not appropriate for their compounding and dose calculation, which require a distraction-free environment, adequate knowledge, and proper quality checks in place. Although most hospitals in Norway have developed guidelines for managing high-alert medications, our findings imply that more specific instructions on the storage, dispensing, preparation, and formulary for each high-alert medication are needed. These efforts should include but are not limited to establishing maximum safe doses and severe alerts for potentially toxic doses, storage constraints, availability on the ward in unit doses or unit of use, and 24-h pharmacy-operated compounding service available seven days per week (American Hospital Association. Health Research & Educational Trust & Institute for Safe Medication Practices, 2002; Cohen et al., 2007).

5.5 | Safety during prescribing

All prescribing errors in this study occurred because there was no step to act as a safety barrier between the prescribing and administration stage. The physician orders in the current study proceeded without being verified, yet half of all prescribing errors were writing or typing slips. Inclusion of an additional step after prescribing, for example, pharmacist order verification, has shown to reduce the frequency of medication errors (Bond et al., 2002) and reduce potential harm from medication orders (Lustig, 2000). Bearing in mind that the eMAR deployment in Norwegian hospitals is ongoing, pharmacist verification is vital to consider since this intervention frequently follows eMAR implementation (Naidu & Alicia, 2019).

However, technology improvements could also engender a false sense of security, since the decision support features during electronic prescribing failed to detect erroneous inputs of dosage in the reported errors. This was also found in a recent study on prescribing errors in paediatric care in the UK which showed that dosage errors were least likely to be prevented by decision support contrary to for example errors involving allergies which were most likely to be prevented (Fox et al., 2019). Furthermore, decision support systems should be improved to guide prescribers to the correct dose by virtue of a patient's body weight and to trigger alerts to out-of-range dosages (Fox et al., 2019). Such efforts may have prevented seven prescribing errors in our study which were due to incorrect or outdated patient body weight or laboratory results, all of which caused patient harm.

Irrespective of the various technologies that have been widely applied to address errors, the main cause of numeracy errors was associated with institutional failures in high-risk processes, and these will not be solved by technological improvements. The procedures should facilitate the right personnel for the right task in appropriate conditions, which would allow health professionals to perform their tasks effectively and safely and therefore can successfully use technologies to additionally increase safety.

5.6 | Numeracy skills

Despite the above-addressed causes of numeracy errors at a systems level, we have also identified human factors that contributed to errors in the dispensing and preparation stage. These errors involved errors during proportional dose calculations, unsatisfactory conceptual understanding of units, volumes, and formulas to ensure handling medications safely and, which have also been highlighted by others when evaluating drug calculation skills of registered nurses (Fleming et al., 2014; Simonsen et al., 2014). Consequently, we suggest that nursing education strategies should be aligned with meaning and context i.e., allow students to visualize and estimate the dose mentally before calculating the exact numbers, which could be facilitated in clinical practice or simulated conditions.

5.7 | Strengths and limitations

The main limitation of this study is that numeracy errors were retrospectively identified from incident reports which are known for their underreporting (Franklin et al., 2009). With this in mind, we focused on the qualitative descriptions to identify patterns in error sources, mechanisms, and enablers. However, the information available to identify causes and contributing factors is dependent on what is reported and thus limits the transferability to broader healthcare. Numeracy mishaps were not as easily recognizable as pure calculation errors, and some numeracy mishaps may have gone unidentified within other dosage errors. We achieved methodological rigour by excluding all calculation errors and numeracy mishaps that had insufficient event descriptions needed to classify for error enablers. Therefore, this study is a thorough analysis of the nature and causes of the selected cases and does not reflect the frequency of all numeracy errors reported in the 2-year period. Including only definite cases allowed us to identify the failure, or in some cases, the absence of a safety net to prevent the error from reaching the patient. The data in this study are extracted from a national reporting system and individual hospitals are likely to have different practices, although we did not see any apparent differences in practice from the reported incidents.

6 | CONCLUSION

This study analysed how and why numeracy errors occurred and progressed undetected in hospitals. In all stages of medicines management, numeracy errors were enabled due to the lack of or improper safeguards. Dose miscalculation after dilution of intravenous solutions, programming infusion pumps, and double-checking were identified as unsafe practices. In addition to suboptimal safety environments, health professionals demonstrated poor numeracy skills and therefore struggled with dosage calculations and metric conversions. We recommend several organizational, technological, and educational measures to empower health personnel and prevent future calculation and numeracy errors.

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CONFLICT OF INTEREST

No conflict of interest has been declared by the authors.

AUTHOR CONTRIBUTIONS

AM and EH: Made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; AM, EH, AGG: Involved in drafting the manuscript or revising it critically for important intellectual content; AM, EH, AGG: Given final approval of the version to be published. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content; AM, EH, AGG: Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data is not publicly available.

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