Medication errors in hospitals

Exploring medication safety through incident reports and observation of practice

Alma Mulac

Thesis submitted for the degree of Philosophiae Doctor

Pharmacoepidemiology and Drug Safety (PharmaSafe) Research Group

Department of Pharmacy

Faculty of Mathematics and Natural Sciences

University of Oslo, Norway

2021

© Alma Mulac, 2022

Series of dissertations submitted to the
Faculty of Mathematics and Natural Sciences, University of Oslo
No. 2498

ISSN 1501-7710

All rights reserved. No part of this publication may be
reproduced or transmitted, in any form or by any means, without permission.

Cover: Hanne Baadsgaard Utigard.
Print production: Reprosentralen, University of Oslo.

To Reyna, Tara, and Omar for sharing simple wisdom

Acknowledgements

First and foremost, I would like to show my deepest gratitude to my main supervisor, Anne Gerd Granås. Thank you for influencing my decision of even starting a PhD. It has been such an intellectual ride having you by my side. I have been challenged with the whole specter of tests a PhD candidate meets on the way, from a research stay with my family during Covid-19 lock-down in California, a media storm and all it involved, to challenging article revisions. You have recognized my strengths and weaknesses and helped me remain my stamina. I appreciate your invaluable feedback throughout the years and acknowledge your part in my professional growth. Thank you for first being a genuine and understanding human being, and then my supervisor - I believe I learned from the best.

Ellen Hagesæther, my co-supervisor, thank you for always having time to discuss whatever I needed, at times that were challenging for you as well. Your attention to detail uncovered many discrepancies in my drafts. We make such a complimentary team!

Thank you to Katja Taxis, my co-supervisor, for your feedback and sharing your incredible knowledge and experience. Specially, thank you for not being easy on me during the writing of my first paper - that underpinned my writing skills in the work that followed.

Thank you, Liv Mathiesen, my co-supervisor for your guidance, enthusiasm and for providing the missing viewpoint when needed.

Thank you to all my colleagues from Pharmasafe for creating a wonderful scientific environment. In particular to Eirin Guldsten Robinson for introducing me into how things work at the University, Elin Ngo for brightening the days at the office, and Anette Vik Jøsendal for our weekly writing sessions and lively discussions.

Thank you to all my collaborators. To the employees at the former *Meldeordningen,* (Norwegian Incident Reporting System) at *Helsedirektoratet* for providing necessary support and guidance for the research process. Thank you to the collaborating team at the hospital and hospital pharmacy: *Sykehuset Østfold Kalnes, Sykehusapotekene HF, and Sykehusapoteket Østfold Kalnes.* Thanks to all the wonderful nurses who participated in the study! To pharmacy student Synne Nielsen, for collecting data for the observational study during our many days and nights at the hospital. Particularly, thank you to Rune Kristiansen for believing in our project and being always positive and enabling formalities at the hospital.

To Sally Rafie, the *Digitalization of Medicines Management* lecture you held in Oslo in 2019 was an aha moment for my PhD career and has without doubt influenced forming this thesis. Thank you for sharing your world of safety with me during my research stay at the University of California San Diego Health – I have learned so much from you!

Thank you to my friends for listening to me whine over wine, understanding and supporting me! Special thanks to Kirsti, for your selflessness and generosity from the first day of this challenging path! To Mija, Dalila, Aida, and Sabina for cheering for me during challenging times and for appreciating my ambitions. To my mother-in-law, for all the support and childcare you provided at busy times.

Thank you to my grandmother Saja, the wisest individual I know. You taught me that greatness lies in being persistent, patient, and humble. Your common saying (translated from Bosnian): '*Silent water cuts through hills*'- should be encompassed in a PhD survival manual.

My kind parents, Fadila and Zijad, thank you for always being present no matter how far apart we are. Mom, for making sure I always have a plan B! Dad, for teaching me that hard work betrays none. My gratitude to you is beyond words as is your goodness and support.

My sister Selma, thank you for being my energy booster! All time in the world is not enough for our talks. Thank you for being interested in every detail of my work and being perhaps the only one in my personal life to understand from firsthand experience what it takes to pursue a PhD.

My core strength, my daughters, Reyna and Tara, thank you for balancing me and bringing focus on the small things. What a relief it is to pursue intellectually demanding work and having you as my closest buddies with your simple wisdom. Your joy has turned my frowns into smiles many times. The whole world is yours to conquer, my beautiful creatures!

My dear husband, Omar, your unconditional support has made it possible for me to take this journey. Thank you for keeping me grounded but then again empowering me to chase my dreams. And for your endless patience. I dedicate this doctoral thesis to you and our kind daughters.

Fredrikstad, December 2021

Alma Mulac

Reason's cat and the teapot

'One afternoon in the early 1970s, I was boiling a kettle for tea. The teapot (those were the days when tea leaves went into the pot rather than teabags) was waiting open-topped on the kitchen surface. At that moment, the cat- a very noisy Burmese- turned up at the nearby kitchen door, howling to be fed. I have to confess I was slightly nervous of this cat and his needs tended to get priority. I opened a tin of cat food, dug in a spoon and dolloped a large spoonful of cat food into the teapot. I did not put tea leaves in the cat's bowl. It was an asymmetrical behavioural spoonerism.'

Anecdote by James Reason, renowned expert on human error, where he refers to the *bizarre slip* that changed his professional life (A life in Error, Reason J).

Abstract

Background: Medication errors are one of the most common incidents in healthcare and are associated with considerable patient harm. Improving knowledge about medication errors and analyzing their causes allows healthcare organizations to learn about flaws in their processes and can aid in designing preventive measures. One such measure is barcode medication administration, using scanning of barcodes on medicines and patients' wristband to verify the correct medication administration. Despite implementing measures to improve safety, it is difficult to know if anticipated improvements are occurring, since their use is not routinely measured.

Aims: The overall aim of this thesis was to explore the error-producing conditions across the medication management process in Norwegian hospitals. Specific focus was given to the most harmful events and understanding the role of technological interventions to improve the safety of medication administration.

Methods: The aims were explored with descriptive statistics and thematic analysis of the incident reports, and a mixed method observation of medication administration. We developed an observational tool to explore nurses' use of barcode technology during medication administration.

Results: Paper I explored medication errors reported to the Norwegian Incident Reporting System and described the errors with emphasis to the most severe errors. We analyzed 3372 medication errors reported in 2016 and 2017. Most errors occurred during medication administration stage (68%) and most frequent error type was dosage errors (38%) and omissions (23%). Errors most commonly involved analgesics, antibacterials and antithrombotics. A considerable number of incidents were harmful of which 5.2% (n =177) caused severe harm and 0.8% (n =27) were fatal.

Medication dose calculation errors and other numeracy mishaps were assessed and examined for causal factors in Paper II. We found that numeracy errors occurred due to lacked or poor safeguards during all medication management stages. Errors occurred because double checks were enabled or omitted, lack of safety barriers to intercept prescribing errors, and due to unsafe handling of intravenous and high-risk medications.

In Paper III we observed 44 nurses administering medications to 213 patients. Deviations from the hospital policies, such as not scanning the medication or the patient wristband, were registered with 6 of 10 patients during medication dispensing and 7 of 10 patients during medication administration. Deviations occurred due to a complex dispensing process, slow or cumbersome barcoding process, suboptimal technology design and non-specific policy description. The human factors approach allowed for a process-oriented analysis of how the technology altered nurses work by analyzing deviations from policies and their causes.

Conclusion: The medication management process lacked safeguards to intercept errors in all stages and raised the need for sustainable and structural improvement to reduce harm from medication errors. In this thesis, we discuss technological, organizational and procedural implications to improve safety in hospitals for the entire medication management process yet focus specifically on medication administration where errors most commonly occurred. The findings from the studies illustrate that a substantial number of patients were harmed due to preventable medication errors. Errors were caused by the lack of or improper safeguards during all stages in the medication management process. Writing slips during prescribing resulted in errors because there was no safeguard to intercept these errors. Specific tasks during medication preparation were error-prone, such as calculating medication doses, programming infusion pumps, mixing-up bolus injections and handling high-risk medications. The barcode medication administration prevented medication errors even in suboptimal working conditions. However, without systematic monitoring of the technology use, hospitals will fail to achieve the full benefits of barcode medication administration technology to patient safety. Improvement interventions should focus on increasing knowledge around medication safety, measuring errors and adverse drug events, analyzing incident data, and strengthening a safety culture within organizations.

Contents

List of Papers

Paper I **Mulac Alma,** Taxis Katja, Hagesæther Ellen, Granås Anne Gerd

Severe and fatal medication errors in hospitals: findings from the Norwegian Incident Reporting System

Eur J Hosp Pharm. 2020; 0:1-6. doi: 10.1136/ejhpharm-2020-002298.

Paper II **Mulac Alma,** Hagesæther Ellen, Granås Anne Gerd

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

J Adv Nurs, 2021; Oct 10. doi: 10.1111/jan.15072. Epub ahead of print.

Paper III **Mulac Alma**, Mathiesen Liv, Taxis Katja, Granås Anne Gerd

Barcode medication administration technology use in hospital practice:

a mixed-methods observational study of policy deviations

BMJ Qual Saf 2021; 0:1–10. doi:10.1136/bmjqs-2021-013223

List of Figures

List of Tables

Definitions of the key concepts

Adverse drug reaction
A response to a medicinal product which is noxious and unintended, and which occurs at doses normally used in man for the prophylaxis, diagnosis, or therapy of disease or for the restoration, correction or modification of physiological function (Council of Europe 2006a).

Adverse drug event
An injury or patient harm resulting from medication use (Bates, 1995).

Incident
An event or circumstance that could have resulted, or did result, in unnecessary harm to a patient (World Health Organization, 2009).

Medication error
Any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is under the control of a health care professional, patient, or consumer (National Coordinating Council for Medication Error Reporting and Prevention, 2021).

Medication safety
The freedom from preventable harm with medication use (Institute for Safe Medication Practices Canada, 2022). Medication safety can be viewed as the tools, resources, and required actions in medication management to reduce and prevent medication errors and patient harm.

Medication management process
A process used by health organizations to ensure safe use of medicines. The process starts with prescribing the medication, follows by preparing/ dispensing, administering, and monitoring of the patient for medication effects and side effects (Awami et al., 2009).

Patient safety
The freedom, for a patient, from unnecessary harm or potential harm associated with healthcare (Council of the European Union, 2009). Patient safety can be viewed as prevention of errors and adverse effects to patients associated with health care (World Health Organization, 2021).

Policy deviation
In this thesis, a policy deviation is defined as the act of dispensing or administering a medicine that is not in accordance with the specific medication management policy within the health care organization.

Safety culture
An integrated pattern of individual and organizational behavior, based upon shared beliefs and values, that continuously seeks to minimize patient harm which may result from the processes of care delivery (Council of Europe 2006a).

Systems approach
Systems approach focuses on improving the processes, systems, and environment in which people work rather than attempting only to improve individual skills and performance. An

approach to safety stating that errors may be seen as consequences of systemic failures, e.g., weaknesses in organizational processes (Reason, 2000).

Workarounds
Deviations from the standard operating procedures that do not follow implicit rules, assumptions, workflow regulations or intentions of system designers. Typically used because of deficiencies in system or workflow design (Reason et al., 1990).

Abbreviations

ADC	Automated Dispensing Cabinets
ADE	Adverse Drug Events
ADR	Adverse Drug Reaction
ATC	Anatomical Therapeutic Chemical
BCMA	Barcode Medication Administration
eMAR	electronic Medication Administration Record
EU	European Union
FMEA	Failure Mode and Effect Analysis
GTT	Global Trigger Tool
HCP	Health Care Professionals
ICD	International Classification of Diseases
IV	Intravenous
NCCMERP	National Coordinating Council for Medication Error Reduction and Prevention
RCA	Root Cause Analysis
SEIPS	System Engineering Initiative for Patient Safety
SPSS	Statistical Package for the Social Sciences
WHO	World Health Organization

1 Introduction

'Patient received a tenfold overdose with chemotherapy while in hospital' was a recent headline in a Norwegian national newspaper [1], unfortunately not an isolated event. The procedure, treatment or medication that is supposed to make a patient feel better, can at times cause patient harm. Among the EU member states, it is estimated that adverse events occur during one in ten hospitalizations [2]. The landmark report "To Err Is Human" has suggested that tens of thousands of patients die, and over a million are harmed, as a result of adverse events in hospitals [3]. Although these numbers and the validity of the methodologies used to estimate death rates have been debated at some length [4, 5], a substantial number of patients are harmed as a result of direct patient care [6]. Publication of the report "To Err is Human" has accelerated efforts to prevent medical errors, focusing specifically on medication-related events.

Medication-related events are among the most common types of adverse events in hospitals [7] and account for approximately 20% of all adverse events in hospitals [8, 9]. The increased focus on medication safety has resulted in global, national and local campaigns and programs to reduce harm from adverse events. The World Health Organization (WHO) aims to reduce severe, avoidable medication-related harm by 50% over five years in their global campaign from 2017 "Medication without harm" [10]. Health-care organizations world-wide are increasingly mandated by regulatory bodies to document patient safety initiatives and demonstrate reduction in patient harm caused by medication-related events [11-13].

Medication errors are preventable events that may cause or lead to inappropriate medication use or patient harm [14]. Such errors include for example prescribing or dispensing a wrong medication, administering a wrong dose or route, or giving the medication to the wrong patient. The incidence rate of medication errors ranges from 3%-10% [9, 15-18]. Medication error incidence rates found in the literature vary considerably because definitions and methods utilized to measure medication errors differ. After analyzing comprehensive literature on medication error incidence rates, the Institute of Medicine suggested that about one medication error occurs per patient per day in hospital care in the US [19]. In the UK, it is estimated that medication errors have contributed to 12, 000 deaths per year [20].

The acknowledgement of patients being harmed in hospitals due to medication errors has accelerated improvement strategies worldwide. However, in Norway, the attention to safety in the medication management process is primarily at the local or regional level, however we lack a national strategy. Preventing medication errors was for instance not prioritized in the National

Patient Safety Campaign (2011-2013) and the National Patient Safety Program (2014-2018) [21]. Fortunately for medication safety, the national focus on medication errors has been sharpened with the publishing of the latest and ongoing national patient safety effort, the National Action Plan for Patient Safety and Quality (2019-2023), that addresses medications as one of three target areas in need of special attention [22]. In parallel to a national focus on medication errors, the digitalization of health records and other technologies are presently implemented in hospitals across Norway. The aim with most technologies in health care is to lead to standardization, traceability, and increased safety. However, information technology can be especially error-prone in the early stage of implementation, due to suboptimal design and can at times lead to new errors. Considerable resources have in the last decade been dedicated to digitalizing health care systems, while little efforts are made to evaluate postimplementation benefits and challenges that can jeopardize safety [23]. Measuring medication errors is therefore the key to establishing a baseline to medication safety, however a consensus on what methods should be used to measure the desired medication-related event is lacking. One reason might be that the development of methods to measure medication-related events has not followed the development of technologies to prevent events. However, the two, measuring and preventing medication errors, cannot be evaluated apart, that is, we cannot prevent errors we know little about.

Moreover, in order to detect errors potentially caused by technologies introduced in the medication management process, organizations need validated and robust methods to monitor technology use and demonstrate the medication safety over time.

The purpose of this thesis is to improve understanding of the error-producing conditions in the medication management process in hospitals. The thesis also outlines the safety benefits of technology use and presents a novel methodology to monitor the technology use as an innovative approach to improve medication safety.

1.1 Measuring medication safety

The WHO defined patient safety as "*the prevention of errors and adverse effects to patients associated with health care"* [24]. In order to prevent errors, it is necessary to detect errors and understand why they occur. In this thesis, prevention of errors and patient harm is associated with medication use. Therefore, translated from the WHO patient safety definition, medication safety can be viewed as the tools, resources, and required actions in medication management to reduce and prevent medication errors and patient harm. Medication safety is defined as "*the freedom from preventable harm from medication use"* [25]. This process is approached first by measuring errors and harm, understanding their causes, developing measures to prevent or reduce errors and monitor the impact of implemented solutions. Figure 1 illustrates the process of strengthening medication safety.

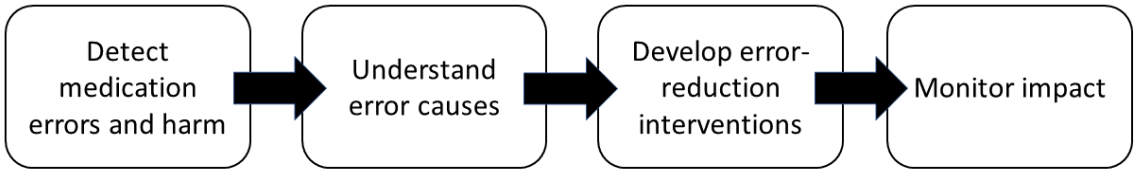

Figure 1 Process of strengthening medication safety.

1.2 Medication-related events

In this thesis, we use the terms incident, event, medication error and adverse drug event (ADE) to describe medication-related events. Medication errors and adverse drug events vary in their preventability and harm - their relationship is illustrated in Figure 2.

An adverse drug event is defined as *an injury or patient harm resulting from medication use* [26].

Medication error is defined as *any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is under the control of a health care professional, patient, or consumer* [14].

Medication error is essentially an error of either commission (doing something wrong) or omission (failing to do the right thing) at any step in the medication management process [19], from the medication is prescribed by a clinician to the medication intake by a patient.

ADEs can be potential i.e., an event that has the potential to cause patient harm, and actual ADEs that have reached the patient and caused some grade of harm [26].

All potential ADEs are preventable while actual ADEs can be preventable, ameliorable or non-preventable. An ADE is preventable for example when a patient received a higher dose of a medication than prescribed. However, ameliorable ADEs are not fully preventable but measures could have been taken which could reduce the patient harm caused by the event substantially. The example is when a patient receives a correct dose of a medication, but the dose adjustment has not been optimal over time and patient develops harm. Non-preventable ADEs do not result from a medication error and are attributable to adverse drug reactions e.g., harm occurred at doses normally used in patients. These are widely accepted definitions that have been used in many studies evaluating medication safety [3, 27-30].

Only a small number of medication errors are adverse drug events, while all potential adverse drug events are medication errors. Which also means that fortunately only a small portion of medication errors reach the patient and cause some grade of harm. This thesis will for the most focus on preventable ADEs and medication errors.

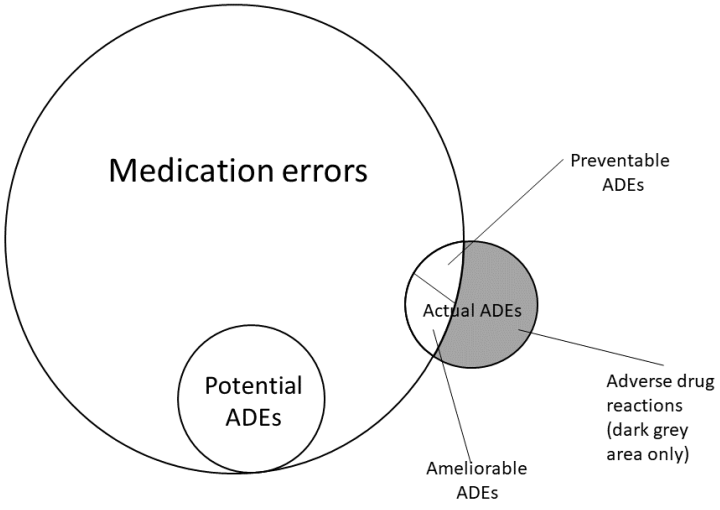

Figure 2 The relationship between adverse drug events and medication errors. Adapted from Bates (1995).

An important difference between medication errors and ADEs is that medication errors seldom result in patient harm, while ADEs are per definition associated with patient harm. Therefore, their detection and prevention measures should be addressed differently. For example, if a patient does not receive atorvastatin at the correct time, by many definitions this is a medication error. However, intuitively we understand that giving a cholesterol- lowering drug 1-2 hours

late will not expose the patient to harm. Detecting medication errors aims to recognize the importance of correct medication management process. Contrary, ADEs detection is guided by whether the patient is exposed to harm from medication use. Organizations may fail to distinguish between medication errors and adverse drug events, which can result in non-effective measures to detect and prevent both.

In order to prevent medication errors and reduce the risks of harm, organizations need tools to detect them. The following section gives an overview of available methods for detecting and measuring medication errors and adverse drug events.

1.3 Overview of detection methods for medication errors and adverse drug events

'No news is bad news when it comes to safety.'

Carl Macrae [31]

Methods used to detect medication- related events can be categorized into five main categories: incident reporting, direct observation, record review, computerized surveillance and interviews.

Incident reporting is frequently adopted by organizations to detect events recognized by health professionals. Analysis of events might identify system flaws. However, incident reporting systems alone cannot be used to measure incidence, as they are simply a reflection of a safety culture in a given organization. High reporting rates may indicate an organization devoted to reporting and preventing errors and ADEs rather than a truly high rate [32]. Incident reporting is not a reliable system if health professionals sustain from reporting because they are afraid of consequences, the reporting process is time-consuming, or they do not recognize any added value of reporting in terms of prevention of future events. An estimated 5-10% of all incidents are detected with incident reporting [33]. The limitations of incident reporting, as the sole method of event detection, are well documented [34, 35].

Direct observation usually involves observation of medication administration by trained health professionals, frequently nurses and pharmacists who compare the administered medications with the prescribed medications. Observation is a prospective method and detects the greatest numbers of medication errors. The additional value of direct observation is that it can highlight the contextual factors and causes to errors not detected with other methods. Considering that this method is resource and time-consuming, observation is recommended for in-depth studies or periodical monitoring [34]. The presence of the observers might change the behavior of the

health professionals being observed, which is an important limitation of the observation method, also known as the Hawthorne effect [36].

Record review involves retrospectively evaluating patient health records to identify events that indicate an adverse event might have happened. Record review can either be untargeted (manual) or targeted. Manual record review is time and resource consuming as it involves a review of complete patient health records and thus is suitable for periodical review of a specific unit or institution. Targeted record review is less time consuming as it applies specific triggers/rules such as diagnostic codes (ICD-9 codes), symptoms (nausea, pain, new rash, vomiting), prescription of antidotes (naloxone, vitamin K) or triggers of laboratory abnormalities occurring in the presence of certain drugs (INR $\geq$ 6, serum glucose < 2.8 mmol/l) to identify records for review. Utilizing such triggers is considered to be an effective ADE detection method when applied as a two-stage review [27, 37] such as applied in the Harvard Medical Practice Study and the Global Trigger Tool (GTT), both involving a set of triggers to identify potential events [38]. The Harvard Medical Practice Study involved an extensive full chart review, and a number of questions in addition to triggers, determining preventability is a standard, with no time limit per case. The GTT applies a recommended time limit per review (usually 20 minutes) and randomly selected records to design a sampling method that produces small samples over time, for example 10 records from one population or institution, twice monthly, and is not aimed to detect every adverse event. The GTT is a promising, structured method for estimating and monitoring adverse event rates over time and can be applied for screening of large populations e.g., national screening of all hospitals. In the first stage of GTT, a health care professional (e.g., nurse) screens health records using specific criteria. In the second stage a physician validates the potential events identified in the first stage to confirm the adverse event. The GTT is more feasible and less time consuming than the Harvard Medical Practice Study as it (originally) does not determine the preventability of the event [39], although this determination has been included in several studies [40-42]. Since its development in 2003, the GTT has been expanded from small scale studies, or quality improvement organizations to being used by hundreds of hospitals worldwide [38, 43]. In the Nordic countries, the utilization of GTT has been on the rise in the last decade to measure adverse drug events and assess the rate of harm [44]. By focusing on triggers within methods, GTT has showed to detect ten times more events than other ADE detection methods [37].

Computerized surveillance has evolved with the increased introduction of electronic health records that allow for automated detection of adverse drug events. Computerized surveillance

provides prospective, active monitoring and improves the efficiency of ADE detection while decreasing the time and personnel resource. This method can monitor events in real time and potentially allow for concurrent interventions limiting patient harm. The implementation of computerized surveillance requires technological sophistication and integration of comprehensive information sources such as laboratory, radiology, microbiology, and pharmacy. The ADE detection with computerized surveillance relies on numeric or coded medical data, including various clinical triggers such as medication discontinuation, abnormal laboratory values or transfer to the intensive care unit. Cases flagged by computerized surveillance are validated by dedicated surveillance personnel. The method can potentially detect greater number of ADEs if extended with analyzing physician narratives or notes with computer-based free-text searching [45]. This extensive adaptation allows for detecting ADEs which would not be detected with triggers e.g., “drowsiness from morphine” [46]. Text word searches add further challenges in identifying key phrases and require adaptation to the local synonyms, abbreviations, or language. These challenges can be facilitated with Natural Language Processing, through pattern matching and development of algorithms through machine learning [47]. Additionally, computerized surveillance requires maintenance to increase the sensitivity of the rules with the changing medical practice such as introduction of new medications or new indications to existing medications.

Strengthening the partnership between patients, their relatives and health care professionals is an important approach in promoting medication safety and identifying medication-related harm [10]. *Interviewing patients* for symptoms related to medications has also been used in identifying potential ADEs [34]. Furthermore, health care professionals can be interviewed to see whether any incidents have occurred. This method can for example be performed by trained health staff during nurse shift changes [19].

1.4 Literature review

This chapter reviews the methodologies described above which are utilized for detecting and measuring preventable adverse drug events and other medication errors. The aim of this review is to provide evidence of the current methodologies to detect and measure medication errors and discuss their advantages and limitations.

Evidence supporting current methodologies for detecting medication errors and adverse drug events

A literature search was conducted in PubMed and EMBASE which comprised key words adverse drug events, medication errors, medication safety and was limited with different keywords such as detecting, measuring, and surveillance.

The search was restricted to articles from the inpatient setting, published in English, until October 2021. To be able to compare the detection methods in terms of efficiency, a key inclusion criterion was that studies used and compared at least two methods. Studies that evaluated event detection of one single trigger criterion, disease, drug, drug class or route of administration were not included.

The literature search identified 172 citations, which were reviewed for title and abstract. Of these, 53 articles were retrieved and reviewed in full. Articles were excluded (n=45) because they lacked sufficient information regarding ADEs, did not involve at least two detecting methods, or were from outpatient setting. Two additional articles were identified from manually searching the references of included articles. The final analysis included 10 articles, summarized in Table 1.

Table 1 Characteristics of the reviewed studies on detection methods for medication errors and adverse drug events.

Reference, country	Study design, setting and population	Event type detected	Results
Ferranti et al. (2008) [48], USA	Prospective over 14 months, pediatric inpatients of one hospital, 4711 patients	ADEs, medication errors	**Computerized surveillance** detected 78 ADEs, **Voluntary reporting** detected 93 ADEs,
Flynn et al. (2002) [49], USA	Retrospective and prospective, 85,197 doses from 36 hospitals	Medication errors	2556 doses were compared for three methods: 457 medication errors detected (100%): **Direct observation**: 300 (66%) medication errors **Chart review**: 17 (3,7 %) medication errors **Incident reporting**: 1 (0,2%) medication error
Franklin et al. (2009) [50], UK	Prospective and retrospective, surgical ward of one hospital during two 4-week periods, 207	Medication (prescribing) errors	In total: 135 (100%) prescribing errors detected **Ward pharmacist alone**: 48 (35%) prescribing errors **Record review**: 86 (69%) prescribing errors **Ward pharmacist and record review**: 7 (5%) prescribing errors **Spontaneous reporting**: 1 (1%) prescribing errors **Trigger tool**: No errors detected
Franklin et al. (2010) [51], UK	Retrospective pilot study, surgical ward of one hospital for two 4-week periods, 207 patients	ADEs, ADRs, medication errors	**Trigger tool**: 7 ADEs detected, 5 non-preventable ADEs (ADRs) and 2 medication errors **Health record review**: 5 medication errors
Jha et al. (1998) [52], USA	Prospective cohort, 21,964 patient-days on 9 medical and surgical wards for 8 months	ADEs, preventable ADEs	In total: 617 ADEs and 86 potential ADEs detected **Computer-monitor strategy**: 2 potential ADEs; 275 ADEs of which 70 preventable **Chart review**: 23 potential ADEs; 398 ADEs of which 109 preventable **Voluntary reporting** (stimulated): 61 potential ADEs; 23 ADEs of which 9 preventable ADEs
Kilbridge et al. (2006) [53], USA	Prospective cohort over 8 months at two hospitals (one university and one community hospital) 33,206 patients 146,416 patient days	ADEs	**Automated surveillance**: University hospital: 520 ADEs detected Community hospital: 283 ADEs detected **Voluntary reporting**: University hospital: 144 ADEs detected Community hospital: 23 ADEs detected

Reference, country	Study design, setting and population	Event type detected	Results
Maaskant et al. (2018) [54], The Netherlands	Cross-sectional study, 369 patients, 4 pediatric wards at one hospital for 2 months	Medication errors, harmful medication errors (ADEs)	**Multifaceted method**: 242 medication errors detected, of which 33 harmful medication errors (ADEs) **Record review**: 27 harmful medication errors-ADEs **Incident reports**: 5 harmful medication errors-ADEs **Direct observations and pharmacy logs**: No ADEs detected **Trigger tool**: No harmful medication errors-ADEs detected When trigger tool was modified (added pain, nausea/vomiting symptoms) 19 ADEs were detected.
O'Leary et al. (2013) [55], USA	Retrospective, 250 randomly selected patients	AEs, ADEs	In total: 66 (100%) ADEs detected **Traditional trigger tool**: 44 (67%) ADEs detected **Enterprise data warehouse screening**: 46 (70%) ADES detected
Tinoco et al. (2011) [56], USA	Retrospective, 2137 patient admissions, surgical services of one hospital for 14 months	AEs, ADEs	In total: 195 ADEs (100%) **Computerized surveillance**: 102 ADEs detected (52%) **Manual chart review**: 96 ADEs detected (51%)
Yun et al. (2012) [57], Korea	Retrospective, 30 wards, one hospital, for 14 moths	ADEs	In total: 1539 ADEs **Spontaneous reporting**: 1055 (66%) ADEs detected **Ward rounds with chart review**: 309 (20%) ADEs detected **Clinical data repository**: 229(14%) ADEs detected

AE=adverse event, ADE= adverse drug event, ADR=adverse drug reaction

Studies were published from 1998 to 2018. Two studies were conducted on pediatric patients [48, 54] while the remaining studies involved the general population.

Study methods characteristics

All studies have directly compared at least two methods. Seven studies used incident reports to measure baseline. The incident reporting was voluntary spontaneous reporting within institutions for the majority of studies. One study used stimulated, confidential reporting [52] where the nursing and pharmacy staff were asked about possible events to report. The majority of studies used record review (n=8) which involved a non-targeted and/or targeted review which utilizes triggers. The included studies varied considerably in the information sources used, and type and number of triggers. Computerized surveillance i.e., automated detection method was used in four studies [48, 52, 53, 55]. Using targeted triggers was common for all computerized detection methods, however the application of the triggers and the data sources used varied greatly in these studies as well. One study involved prospective pharmacist surveillance of prescription records [50] and two studies involved direct observation [49, 54].

Four studies differed between preventable and non-preventable ADEs [48, 51, 52, 54]. Two studies detected adverse events in general and detected ADEs as a subgroup within these [55, 56]. Two studies detected medication errors alone [49, 50].

Efficiency of detection methods from the literature review

Incident reporting detected the lowest percentage of ADEs in the majority of the reviewed studies. Targeted record reviews have detected ADEs in rates substantially greater than incident reporting [52]. However, this does not apply for all populations or event types. In one study conducted on pediatric patients, the trigger tool did not detect any harmful medication errors (ADEs) of the 33 harmful medication errors that were detected as baseline by a multifaceted method [54]. The reasons for this poor efficacy of the trigger tool are many, but it is likely that the trigger tool was not properly adopted to the specific setting and population. In another study that evaluated prescribing errors in a surgical hospital ward, the trigger tool method detected only 2% of prescribing errors, while manual record review detected 83% and pharmacist surveillance detected 24% prescribing errors [50]. Targeted record review alone is not the method of choice to measure medication safety in prescribing errors [50]. In a multicenter study on medication errors, targeted record review detected 3,7% while direct observation detected 66% of medication errors [49].

Computerized surveillance detected ADEs at a rate 3.6 times greater than incident reporting at a university hospital, and 12.3 times greater at a community hospital [53]. Similar results were found in the study by Jha et al., that detected ADEs with a computerized strategy at a rate 12 times higher than incident reporting [52]. When compared with record review, computerized surveillance detected similar numbers of ADEs [55, 56]. In a study focusing on medication errors in pediatric patients, Ferranti et al., found that computerized surveillance did not detect drug omissions, meaning the detection was entirely reliant on incident reporting to detect these type of events [48].

It is important to note that there was generally poor overlap between events detected with more than one method. Although incident reporting detected small number of events, these events were not detected by other methods [54]. This applies for other methods as well. Tinoco et al. found that overlap between events detected with record review and computerized surveillance was only 3% [56].

There were substantial differences in time and resources required for utilizing the different methods. Jha et al. evaluated time needed to conduct the different methods and found that chart review was most time consuming and required 55 person hours per week, computer strategy required 11 person-hours per-week, and voluntary reporting required 5 person-hours per week [52]. Record review was also found to be resource-intensive in other studies [49, 51].

The evaluated methods vary in the number and type of events they detect. This is best illustrated in a study performed in 36 hospitals and skilled-nursing facilities that compared three methods for medication error detection and found that direct observation was more efficient and accurate than reviewing charts and incident reports in detecting medication errors. For ADEs detection, on the other hand, observation was least effective to detect ADEs [54] when compared to other methods. While known as a low-cost method that provides rich data within or across healthcare systems or nation-wide, the incident reporting data detected least ADEs and cannot be used to establish ADE rates. Chart review is the most effective method for ADE detection in the majority of studies but requires a trained and experienced reviewer and is resource intensive. The role of computerized surveillance in detecting ADEs is important as it integrates comprehensive information sources, and it can identify ADEs missed by clinicians more quickly and inexpensively than other methods.

Table 2 Advantages and limitations of reviewed methods for medication errors and adverse drug event detection.

Method	Advantages	Limitations
Incident reporting (voluntary and stimulated)	Detect events not detected by other methods Require minimal training of HCPs to report an event Identifies system failures, potential ADEs (non- harmful medication errors), omissions, medication administration errors that are not detected by trigger tools (targeted record review) Can identify ADE trends Stimulated reporting is likely to detect more events than voluntary	Detect small number of ADEs Underreporting Reporting bias- health care providers report rather severe events HCP must be aware of an event to report Higher reporting rates do not indicate higher rate of ADEs, but a culture devoted to reporting
Record review: manual (untargeted) and triggers (targeted)	Utilizes readily available data Well adopted and commonly used Targeted review less time-consuming than manual review Detects more ADEs than incident reporting Effective to detect ADEs when applied as a two-stage review	Dependent on training and experience of reviewers, and the rules to be adjusted to specific setting Interrater reliability issues between reviewers Time and resource intensive- best suited for periodical review Not effective in detecting latent errors, non-harmful medication errors Many false positive signals
Automated monitoring (computerized)	Can monitor ADEs in real time and thus potentially prevent harm Integrates multiple data sources Inexpensive after initial implementation, but needs maintenance to increase trigger sensitivity Identifies events associated with known areas of risk (high-risk medications) and harmful events	Applies for setting with full electronic records Costly to implement, requires software Integrating multiple data sources takes time (years) Vulnerable to programming errors Not effective in detecting latent errors, non-harmful
Direct observation	Prospective method Preferred approach for detection of medication errors and potential ADEs Provides data otherwise unavailable such as near misses, latent failures, contextual and human factors of the error environment Provides clues to error causes	Not suitable for detection of ADEs Require experience and training of observers (data collectors) in observation technique and appropriate medication knowledge Costly, recommended for periodical monitoring Observers' presence may affect the observed (Hawthorne effect)
Interviews (Patients, health care professionals)	Detect more incidents than record review or incident reporting Could be combined with discharge /medication review/reconciliation to optimize resource and time use Unique perspective	Only patients that are conscious and healthy enough can participate Time from the ADE occurred to interview affects detect rates, especially in discharged patients

HCP= Health care professionals; ADE= Adverse drug event

More important, there was poor overlap between ADEs detected with record reviews, computerized surveillance, and incident reporting. The results of the literature review are consistent with prior studies [34, 58, 59] and confirm the need of complementary detection methods as a standard for measuring ADEs and medication errors. The main advantages and limitations of the reviewed methods are presented in Table 2.

1.5 Conceptualizing the medication management process in hospitals

Medication management process is a process used by health organizations to ensure safe use of medicines. The process starts with prescribing the medication, follows by preparing/ dispensing, administering and monitoring of the patient for medication effects and side effects [60].

Each of the stages in the medication management process comprises a variety of tasks, activities and involve different health professionals, adding complexity in a risk-prone work environment. Medication errors can occur in any stage in the medication management, however most frequently in the prescribing and administration stage [19, 61, 62]. Medication administration errors are the most common type of errors in hospitals and have been studied most extensively [16, 63, 64]. For example, in a US study on about 1000 medication errors in children, approximately 30% were prescription errors, 25% were dispensing errors and 40% were administration errors [65]. In another study on clozapine medication errors reported to the National Reporting and Learning System in UK, 60% of all medication errors occurred in the administration stage [33]. Maidment and colleagues found that medication administration errors were most frequent among errors in older people with mental health problems [66]. Medication administration is the last stage before the patient receives the medication, thus medication errors that occur during administration are less likely to be intercepted by other health professionals. One multicenter study found that whereas 48% of prescribing errors, and 34% of dispensing errors were intercepted before they reached patients, only 2% of drug administration errors were detected before they reached the patient [67].

Regardless of the population, setting or medications being administered, nurses have the main responsibility for medication administration carried out in the hospital wards [68, 69]. One systematic review found that about one-third of all errors causing harm to hospitalized patients occured during the medication preparation and administration phase, predominately nursing

activity [70]. Nurses have been guided by the ‘5 rights’ of medication administration in both education and practice for many decades, that include: the right patient, right medication, right route, right time and right dose [71]. Studies have examined the adequacy of the 5 rights and even proposed to include more rights that refer to correct orders and to support the patient role in medication administration [72]. Although following rights provides consistency in nursing medication management, organizations, including the Institute for Safe Medication Practices has argued that solely following the rights will not prevent medication errors and argued for adding additional safety steps in the medication dispensing and administration process as a more efficient measure to prevent errors [73].

1.6 Causes of errors

It is imperative to understand how and why errors occur in order to develop effective prevention mechanisms. Establishing the error cause is primarily depending on the available data source and the purpose of the analysis. For example, collecting qualitative data, e.g., observation or interviews will normally provide more details to understand the cause of an error than will incident reports. Regardless, data from incident reports are used to explain contributing factors [74, 75] although health professional’s understanding of the error and the amount of information provided in the report will influence the established causes.

In the early medication errors research, the concept of systems failures as the underlying causes of errors was not widely accepted, whereas blaming individuals received much attention [76]. Ever since, the approach to understanding medication errors has focused to ensuring the attention to safety that is achieved in other high-risk industries [6]. Reason’s model of accident causation was introduced to healthcare from the aviation and engineering industry and provides a systems approach that is broadly applied in understanding medication errors. In a US study from 1995, Leape et al. used the Reason’s model to identify causes to medication errors [67]. These were lack of knowledge, lack of information about the patient, failure to follow procedures, slips of individuals, problems in communication during transition between units, preparation errors involving calculating and mixing errors. Similar causes to errors were found using the Reason’s model in a systematic review that found similar factors to cause errors including slips of individuals e.g., misreading medication or patient names, communication, mix-up of sound-alike and look-alike medications, poor supervision by senior colleagues, working culture e.g., working double shifts, organizational decisions, and lack of knowledge about medications [77]. One systematic review that analyzed contributing factors to errors differed between individual and systems factors [78]. Other studies have also found that nurses’

unsatisfactory knowledge of medications has contributed errors, in particular errors with intravenous medications and dose calculation errors [79-81]. Medication dose calculation involves tasks with numbers [82], such as understanding of units or volumes during dilution or proportion calculations. The literature suggests that numeracy skills of nurses are poor despite qualifying for the required level of competency [83, 84]. Although medication calculation errors have been associated with nurses' poor mathematical skills [85-87] and have led to harmful events, other systems factors have also contributed to these errors [88, 89].

Root cause analysis (RCA) and Failure mode and effect analysis (FMEA) are considered two leading techniques in health care quality assessment [90]. While the RCA is a retrospective approach that asks 'Why did the system fail in the past?' the FMEA is prospective and asks 'How could the system fail in the future?' [91]. Although widely applied within organizations to investigate causes to individual incidents, these approaches have received criticism for not meeting their primary aim – and failed to prevent errors [92, 93]. A systematic review that evaluated causes to medication errors concluded that there is lack of consistency in medication error causation research [77]. One study that analyzed fatal medication errors found that 65% errors were caused by human factors [94]. Literature on medication causation has pointed out that problems with equipment (availability, design) [95, 96] and general working environment (noise, light, high workload) [97, 98] has contributed to errors. Evaluating how health professionals interact with their workspace has provided deeper understanding of the error causation [99]. With the introduction of new devices, gadgets and technology in the medication management process, this approach is promising in error causation research. Understanding the etiology of medication errors contributes to designing impactful measures to reduce errors. The topic of error reduction interventions is elaborated in the following section.

1.7 Error reduction interventions

Double- checking is widely rooted in nursing practice as an intervention against preparation and administration errors and associated harm. Hospital medication management procedures often require independent double checks for drug calculations and preparation of high-risk medications, pediatric medications and compounding intravenous medications [100, 101]. The independent double-checking must be separately performed by the requesting and the checking nurse, and without them sharing information. In contrast, double-checking in clinical practice is frequently preformed with primed double checks [102], whereby one nurse shares the information about the double checking with the other nurse, for example, the name of the medication to be checked. Primed double-checking can lead to confirmation bias [81] and rather

than confirming that the calculation is correct, the checking nurse should do the calculation themselves. Safety concerns have been raised regarding nurses' ability to calculate drug doses and compound intravenous medications whilst providing patient care [85, 87]. The utilization of double checks is resource-consuming, while the impact double checks have to prevent and reduce error rates and patient harm is limited [103, 104].

The role of information technology

Information technology in healthcare play an important role in improving the safety, quality and efficiency [105-107] and different technologies are designed to address specific stages of medication management. An overview of some studies that evaluated error reducing interventions and their impact is presented in Table 3.

The electronic prescribing or computerized physician order entry is a core information technology that addresses safety and quality at the very beginning in the medication management process. The technology involves orders entered digitally (no handwriting), directly (not through a unit secretary) and through standardized, preexisting order sets [108]. Electronic prescribing has a range of potential benefits including reduction of some medication errors [109]. In some cases, electronic prescribing had negative effects on patient safety and led to occurrence of new errors [110, 111]. The incorporation of electronic prescribing into patient care is an essential criterion for the implementation of electronic Medication Administration Record (eMAR).

The eMAR has revolutionized the medication management process and has been the foundation for the development of a series of other technologies in the medication administration stage. *Automated dispensing cabinets (ADCs),* also known as unit-based dispensing allow for safer and faster administration of medications. ADCs are locked cabinets that facilitate traceability in medication dispensing. After login, nurses select the patient and intended medication. The ADC only allows the nurse to access to the compartment for that exact medication. Back in 2008, ADCs have been introduced in more than 80% US hospitals [112], and have standardized the medication administration process and reduced medication errors. A UK hospital study found that ADCs decreased time for medication administration, and to some extent reduced error rates [113].

Smart infusion pumps are computerized infusion devices connected to the electronic medication administration record that check the programmed infusion rates against present limits within a drug library. Smart pumps reduce some types of errors [114], but dose limits can be over-ridden, and intravenous medication administration errors still persist [115]. Smart pumps have showed

to reduce programming errors, while errors caused by the incorrect use of the pump or the software have also been reported [114, 116]. Overall, the evidence regarding the impact of smart pumps to patient safety is mixed [117, 118].

Barcode medication administration (BCMA) technology involves scanning the barcode on the patient ID wristband and the barcode on the medication to confirm the 'five rights' of medication administration: right patient, right medication, right dose, right route, and right time. The literature suggests a beneficial role for BCMA in reducing medication errors rates [119, 120], specifically certain types of errors such as wrong patient, wrong dose and wrong medication [121, 122]. However, the disrupted workflow with the use of BCMA has resulted in workarounds, also described as deviations from policies [123-127]. For example, carrying trays with prescanned medications instead of scanning medications at the bedside leads to non-intended use of the technology and has resulted in new errors associated with the use of the technology [124, 128]. Additionally, preventing errors is dependent on appropriate implementation of the technology within the hospital environment [124, 125, 129-131]. One systematic review found that human factors and technology issues are standing in way of achieving full benefits of the BCMA technology [132]. Although the impact of successful implementation of BCMA is acknowledged to be imperative to medication safety, there is limited research to disclose why deviations from intended use occur and what causes this known phenomenon [133].

The ability of the technologies described above to reduce error rates vary from convincing results for the BCMA technology to limited impact for smart infusion pumps. However, the literature is consistent that success depends on proper implementation and adaptation of the technology to the given hospital. In addition, safety issues are associated with technology itself.

Table 3 Overview over studies evaluating error reduction interventions.

Intervention	Reference	Design	Effect of the intervention
Double-check	Koyama et al. [134]	Systematic review	Insufficient evidence that double checks lead to reduction in medication error rates or reduced harm.
	Westbrook et al. [104]	Before/after analysis	Did not show to reduce error rates.
Computerized physician order entry	Bates et al. [109]	Before/after analysis	Nonintercepted serious medication errors reduced 55%, from 10.7 events per 1000 patient-days to 4.86 events per 1000. Errors decreased in all stages of the medication management process.
	Leung et al.[110]	Before/after analysis	Decreased preventable adverse drug events by 33% but increased overall adverse drug events.
Electronic medication administration record	Oliveros et al. [135]	Before/after analysis	Significant reduction in error rates from 48% to 36.9%.
Automated dispensing	Cottney et al. [113]	Before/after analysis	Reduction in error rates from 8.9% to 7.2%.
	Fanning et al. [136]	Before/after analysis	Reduction in medication dispensing and preparation error rate from 1.96% to 0.96%, a reduction of 64.7%.
	Chapuis et al. [137]	Before/after analysis	Significant impact of the automated dispensing system in reducing preparation errors, from 20.4% to 13.5%.
Smart infusion pump	Ohashi et al. [114]	Systematic review	Smart pumps reduce but do not eliminate programming errors.
	Lyons et al. [115]	Before/after analysis	Little effect on reducing programming errors, similar error rates with and without a smart pump (10.3% vs. 10.8%).
	Schnock et al. [117]	Before/after analysis	Despite the use of smart pumps high error rates identified with the administration of intravenous medications.
Barcode medication administration	Poon et al. [119]	Before/after analysis	Reduction in error rate from 11.5% to 6.8% (excluding timing errors), a reduction of 41%.
	Hassink et al. [138]	Before/after analysis	Reduction in error rate from 8.6% to 5.3% (excluding timing errors).
Barcode medication administration, combination with other types of technology	Shah et al. [132]	Systematic review	All studies included in the review (n=3) suggested that BCMA has the potential to reduce error rates for non-timing administration errors and total errors.
	Zheng et al. [139]	Systematic review	Three studies from the review reported reductions in error rates, but new errors occurred due to medications labelled with wrong or unreadable barcodes.
	Ros et al. [140]	Before/after analysis	Reduction in dispensing error rate from 3.1% to 1.7%, a reduction of 47%.

1.8 Safety culture

Humans make mistakes. Not so long ago the approach of addressing errors was to identify the individual responsible for the error and act punitively. Although the punitive approach is not entirely abandoned, and has led to health professionals being charged or suspended after serious medication errors [141], organizations have shifted the accountability from individuals [142], and moved focus from the "shame and blame" strategy towards identifying system flaws that can prevent future errors [143].

Organizational culture is defined as 'the shared values, beliefs, or perceptions held by employees within an organization' [144]. Within a hospital, culture can be considered as the glue that holds an organization together. The term *safety culture* was first used in a post-accidental report after the nuclear power disaster in Chernobyl in 1986. The culture within health organization is influenced by the attitudes of the leaders that consequentially shape the behavior of employees. Patient safety is best served with the adoption of a safety culture – '*an organizational commitment to continually seeking to improve safety* ' [19]. To achieve a safety culture, senior leadership must prioritize and dedicate resources to continuous quality and safety improvement [145]. In a blame-free, just culture there is an understanding that experienced health professionals can make mistakes, and the attention is aimed to identifying system-based causes to errors and acknowledging the contribution of human factors to errors [142].

1.9 Theoretical framework in the thesis – a systems approach

This thesis is based on a systems approach that focuses on improving the processes, systems, and environment in which people work rather than attempting only to improve individual skills and performance. The systems approach relies on the assumption that errors are caused by systemic failures [146]. In this body of work, the systems approach allows for broader understanding of error causality and interactions within the medication management process [146]. Embracing the systems approach implies that errors can be prevented by building a system that is resilient to expected human errors [25]. For example, avoid mix-up of two look-alike medications by placing them in separate drawers.

The model of causal factors

Understanding the causality of medication errors from a systems point of view focuses not only in identifying the causes of medication errors but exploring what those causes say about the safety in the medication management process. We applied the model of causal factors to explore the causality of medication errors, more specifically numeracy errors such as miscalculation of

medication dosage. The model has previously been applied to analyze tenfold medication errors [88, 89], also a type of numeracy errors. Additional models that were considered to explore causality, such as the Reason's model of accident causation, Root cause analysis, and Failure mode and effect analysis, are described earlier in the thesis (p.15).

The model of causal factors evaluates medication errors as a consequence of the process, and allows for in-depth exploration of the error causality by identifying causal factors. Through addressing the nature and causes of errors, this model further allows for discussing the systems' defects in the medication management process.

Human factors approach- the SEIPS model

While the model of causal factors provided understanding of the medication errors causality, the human factors approach provided the underlying theoretical framework to aid in exploring the interactions in the work system during medication administration.

Human factors focuses on humans and how they interact with products, devices, procedures, and the work environments [147].
System Engineering Initiative for Patient Safety (SEIPS) model is an approach combining human factors and quality improvement models in healthcare. It was originally funded by the Agency for Healthcare Research and Quality [148].

Human factors systems approaches are crucial for improving quality and safety in healthcare. The approach originates from concepts of ergonomics and systems engineering. Although it was applied to analyze work system contributors to medication errors in 1960 [149], the imperative role of the human factors approach in medication safety research was not acknowledged until proposed in the pivotal report "To Err Is Human" in 1999 [3]. The SEIPS model, a human factors approach for patient safety, has been utilized in the past 15 years to study and improve healthcare [150-152]. In this thesis, the SEIPS model is applied as theoretical framework to improve understanding of the complex interactions in the medication management process in hospital and their impact to patient safety.

The SEIPS model has evolved with time, from the original SEIPS model [150], SEIPS 2.0 [152], SEIPS 3.0 [153], to the recently published SEIPS 101 [154]. The versions vary in their applications and complexity. In this thesis, we applied the original SEIPS model that has been broadly applied in medication safety studies [99, 155] and across healthcare [151, 156]. The

SEIPS model comprises three main parts: work systems, work processes and work outcomes, as is illustrated in Figure 3 [150].

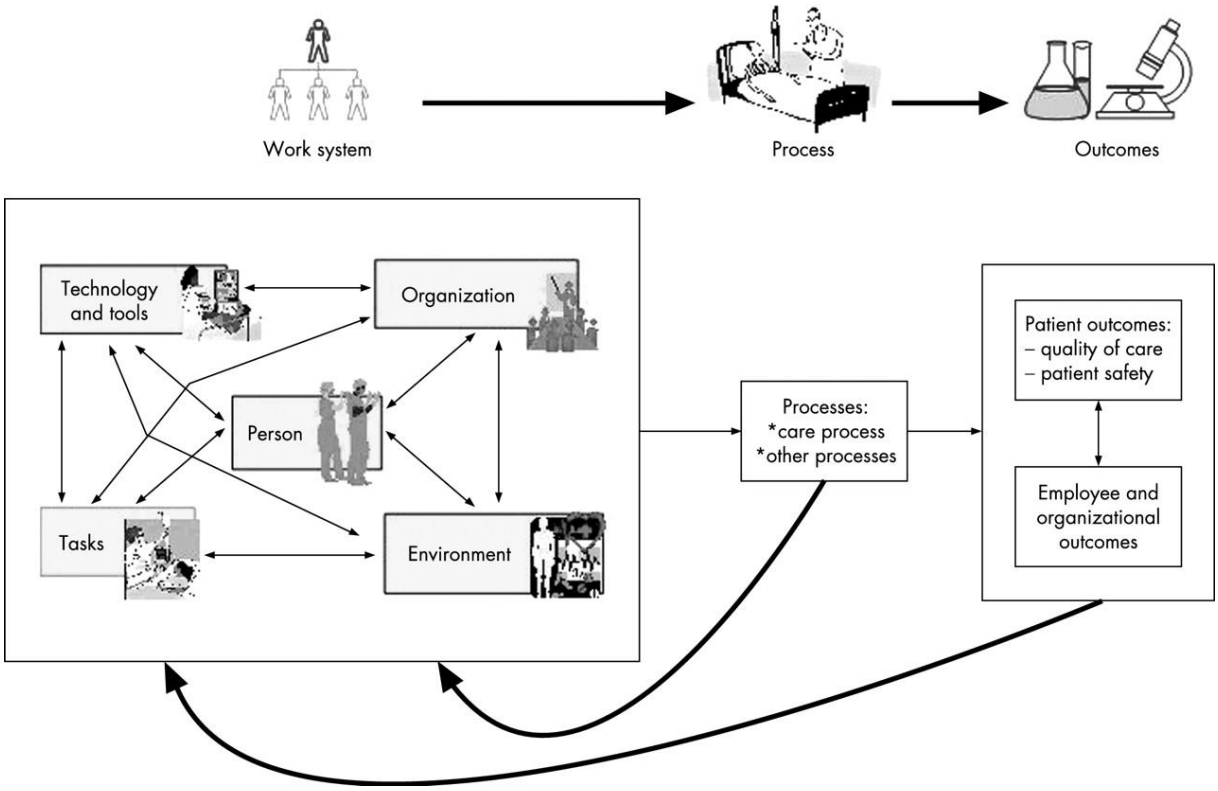

Figure 3 The SEIPS model of work system and patient safety. Duplicated with permission from Carayon et al. (2006).

Work systems comprise five interacting elements: tasks, technology, organization, environment and person in the center. *The process* refers to how the work is done i.e., workflow. *The outcome* results from work system and process, and includes patient outcomes such as patient safety, or outcomes associated with health professionals or organizations. The arrows between the work system, processes, and patient or health professional outcomes, referred to as feedback loops, indicate interactions. As a dynamic model, the change in one part will in response lead to adaptation of other parts of the model. A key characteristic of the feedback loops is that they can be used to identify problems and initiate measures for redesigning the work system. One study that evaluated BCMA use in pediatric hospitals serves as a good example of this feature of the SEIPS model [155]: Introducing the BCMA technology led to nurses compensating for the flaws of the technology by creating, at times, dangerous solutions. The human factors analysis provided insight into how different types of workarounds affected nurse and patient outcomes. Based on the identified problems, the authors used the SEIPS model to suggest improvements which altered the use of BCMA to achieve desired outcomes.

1.10 Scope of the thesis

Overall, the introduction has highlighted that a considerable number of patients are harmed by preventable medication errors. In particular, methods used to detect medication errors and adverse drug events are described. Choosing a multimethod approach is recommended in measuring harm and identifying flaws with systems and processes. Medication errors that occur in the administration stage are most common and most likely to cause patient harm. Specific types of errors, such as miscalculation of medication dosages, have led to harmful events, however they are poorly investigated in the literature. Therefore, better understanding of the causation behind errors is needed to facilitate the design of more impactful error reduction interventions, for example technology. However, the use of technologies during medication management is not problem-free and can lead to new errors.

In describing the literature, it was apparent that choosing only one medication error detection method would not result in achieving a broad understanding of the safety in the medication management process- which is the overall purpose of this thesis. Therefore, we choose incident reporting to get an overview of errors in the whole medication management process, and direct observation as an in-depth approach to the medication administration. We used these two methods to address the knowledge gaps highlighted above and to provide a better understanding of the safety aspects along the stages of the medication management process. Figure 4 gives an overview of the medication error detection methods throughout the different stages of the medication management process. The black arrows in the figure illustrate the work covered in this thesis and its place in the research field.

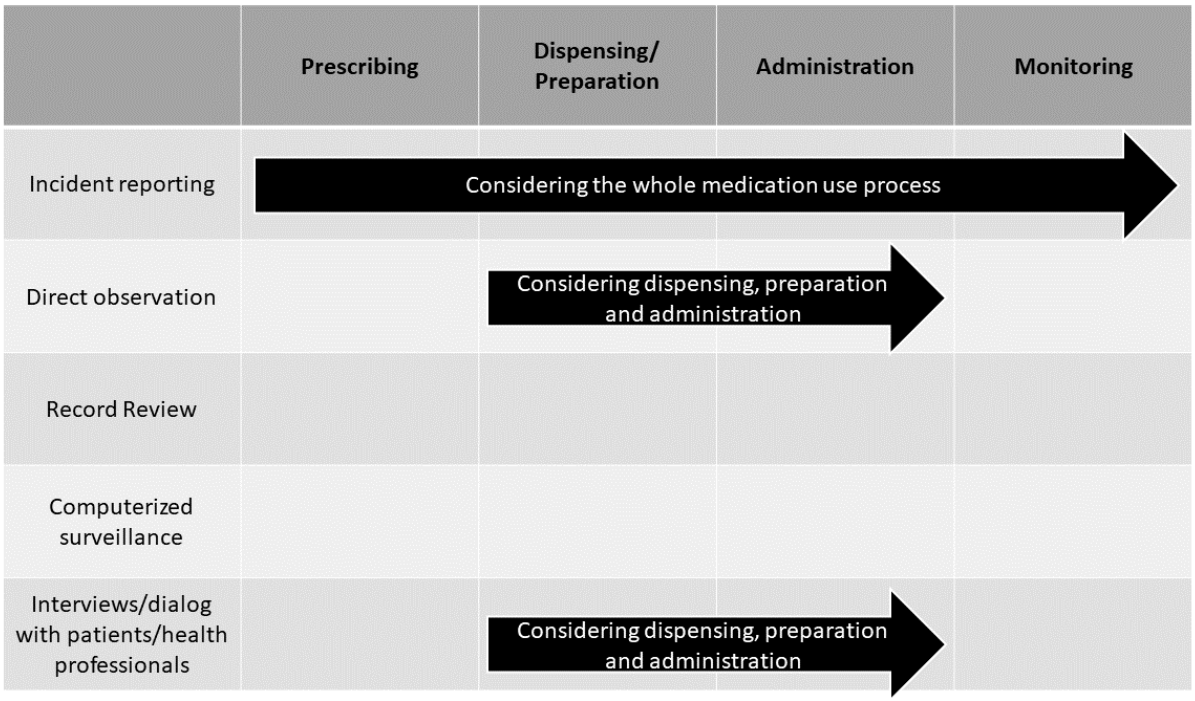

Figure 4 Illustration of this thesis' place in the research field of measuring safety in the medication management process

2 Aims of the thesis

The overall aim of this thesis was to gain a comprehensive understanding of the error-producing conditions across the medication management process in Norwegian hospitals. Specific focus was given to the most harmful events and understanding the role of technological interventions to improve the safety of medication administration.

The specific objectives were (number of the original publication is provided in brackets):

• To describe the frequency, stage in the process, and type of medication related incidents reported from Norwegian hospitals with emphasis on severe and fatal medication errors (Paper I).

• To investigate medication dose calculation errors and other numeracy mishaps and analyze their causal factors (Paper II).

• To develop and pilot an observational tool to register data during medication administration with the use of barcode technology (Paper III).

• To gain in-depth understanding of nurses' use of barcode technology during medication dispensing and administration (Paper III).

• To register and analyze the number and type of policy deviations with the use of barcode medication administration and investigate their causes using a human factors approach (Paper III).

We addressed these objectives in three empirical studies, Paper I-III, which are published in three international peer reviewed scientific journals.

3 Materials and methods

We conducted three studies in order to answer the overall aims of the thesis. Paper I investigated medication-related events reported to the Norwegian Incident Reporting System with emphasis on the most serious events. Paper II investigated the nature and causality of medication calculation errors and numeracy mishaps. Paper III investigated nurses' use of the barcode medication administration at two hospital wards and involved development of the observation methodology for data collection.

All three papers can be integrated within the medication management process considering the whole or some specific stages of the process (Figure 5).

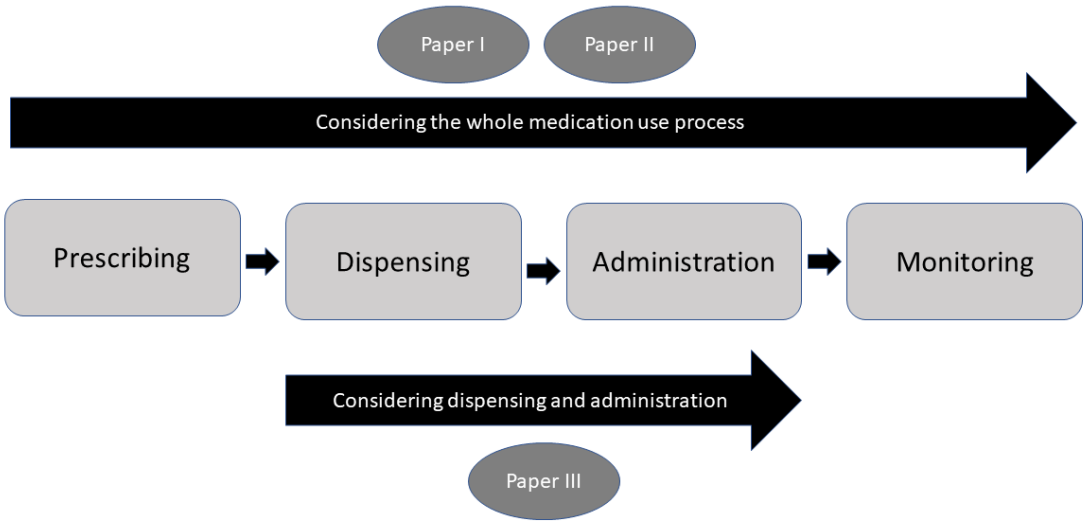

Figure 5 Flowchart illustrating the integration of the thesis papers within the medication management process.

The methodological characteristics of Paper I-III are summarized in Table 4.

3.1 Medication errors reported from Norwegian hospitals (Paper I and II)

Study design and setting

This was a retrospective, incident reports review of medication errors reported to the Norwegian Incident Reporting System from 1 January 2016 - 31 December 2017. The Norwegian Incident Reporting System, operated by the Norwegian Directorate of Health was a mandatory, anonymous, and digital reporting system of incident reports for all hospitals across Norway. The central Government has overall managerial and financial responsibility for the hospital

sector. There are four regional health authorities that control the provision of specialized health care services through 27 health enterprises [157]. Most hospitals in Norway are public, funded and owned by the state. A small number of hospitals are privately owned. The incident reports in the study were reported from both public and private hospitals. During the two-year study period medication errors were reported from 64 hospitals in 2016 and 55 hospitals in 2017. In addition to medication-related incidents, the Norwegian Incident Reporting System received reports on other types of incidents that occurred in hospitals. The most frequently reported incident categories were clinical procedures, medication errors and patient accidents. Of the approximately 20 000 incident reports that were reported in the study period, medication errors accounted for about 17 % of all reported incidents. Health professionals were obligated by law to report incidents that could have or had cause patient harm. The staff employed at the Norwegian Incident Reporting system promoted patient safety by analyzing incidents and identifying trends where safety barriers failed and led to errors across institutions. These were published in so- called "Learning Notes" that addressed different subjects such as the double-checking procedure, intravenous potassium administration, medication mix-ups [158].

During the study period, the electronic prescribing rollout was in early stage and our data reflected both paper-based and electronic prescribing. The electronic Medication Administration Record (eMAR) was introduced in a few hospitals at this point in time, and most of the medication administration described in the reported incidents were paper based. The dispensing process in the reporting hospitals was decentralized, medications were stocked in ward-based medication rooms and required dispensing, dilution, and further preparation by nursing staff before administering to the patient. Exceptions from the decentralized dispensing process were chemotherapeutics, cassettes for pain pumps and parenteral nutrition, which were compounded and dispensed by the hospital pharmacy. The national medication management policy mandates adherence to the "5 rights" (p. 18) of medication administration and independent double-checking before stages in medication management that are considered as risk areas, such as: handling narcotics and medications with narrow therapeutic range, preparing more than one dose, or handling injections and infusions [101].

Table 4 Overview of the methodological aspects for Paper I-III.

	Title and journal	**Period**	**Design**	**Material/ Subjects**	**Data collection instrument**
Paper I	Severe and fatal medication errors in hospitals: findings from the Norwegian Incident Reporting System *European Journal of Hospital Pharmacy*	Jan 2016-Dec 2017	A retrospective incident reports review	Medication errors (n=3357) reported from 64 hospitals in 2016 and 55 hospitals in 2017 across Norway.	Norwegian Incident Reporting System
Paper II	Medication dose calculation errors and other numeracy mishaps in hospitals: analysis of the nature and enablers of incident reports *Journal of Advanced Nursing*	Same as Paper I	A retrospective review and thematic analysis of numeracy errors	Medication dose calculation errors and other numeracy mishaps (n=100) from hospitals across Norway.	Same as Paper I
Paper III	Barcode medication administration technology use in hospital practice: a mixed-methods observational study of policy deviations *BMJ Quality & Safety*	Oct 2019-Jan 2020	A concurrent triangulated mixed-methods design involving structured observation (quantitative data) registering data on a digital observational tool and field notes and nurses' comments (qualitative data)	Observation of 44 nurses while administering 884 medications to 213 patients at two hospital wards.	Digital observational tool

Data collection and inclusion /exclusion process

The inclusion and exclusion of reported incidents for Paper I and II are illustrated in Figure 6. Incident reports consisted of quantitative, categorical data (e.g., patient age, incident date, day of the week), and qualitative free-text descriptions (e.g., incident description, description of the cause, patient consequences, prevention measures, caseworker's comments). Reports varied, from short reports to rich and detailed descriptions of the incidents. Paper I and II involved review of the same dataset, Paper II zoomed in on the dosage errors identified in Paper I. During the two-year period, 3,557 medication errors were reported. We excluded errors which were not medication related, not from a hospital setting, intentional overdoses or reported more than once (n=185). In Paper I, 3,372 medication errors met the inclusion criteria.

In Paper II, we included medication dosage errors that resulted from a miscalculation of the medication dose or a numerical misconception of the medication dosage or its unit. We included only real events that reached the patient. In total, 116 incident reports were classified as miscalculations or numeracy mishaps. Of these, we excluded three reports due to errors that were prevented from reaching the patient; five reports due to either insufficient and unclear information; seven reports were excluded due to the calculation error being not dosage related (n=7); and one calculation error did not occur in a hospital setting. Medication calculation errors and numeracy mishaps are further in the thesis collectively referred to as numeracy errors. Difference between the methodological approaches in Paper I and II is presented in Table 5.

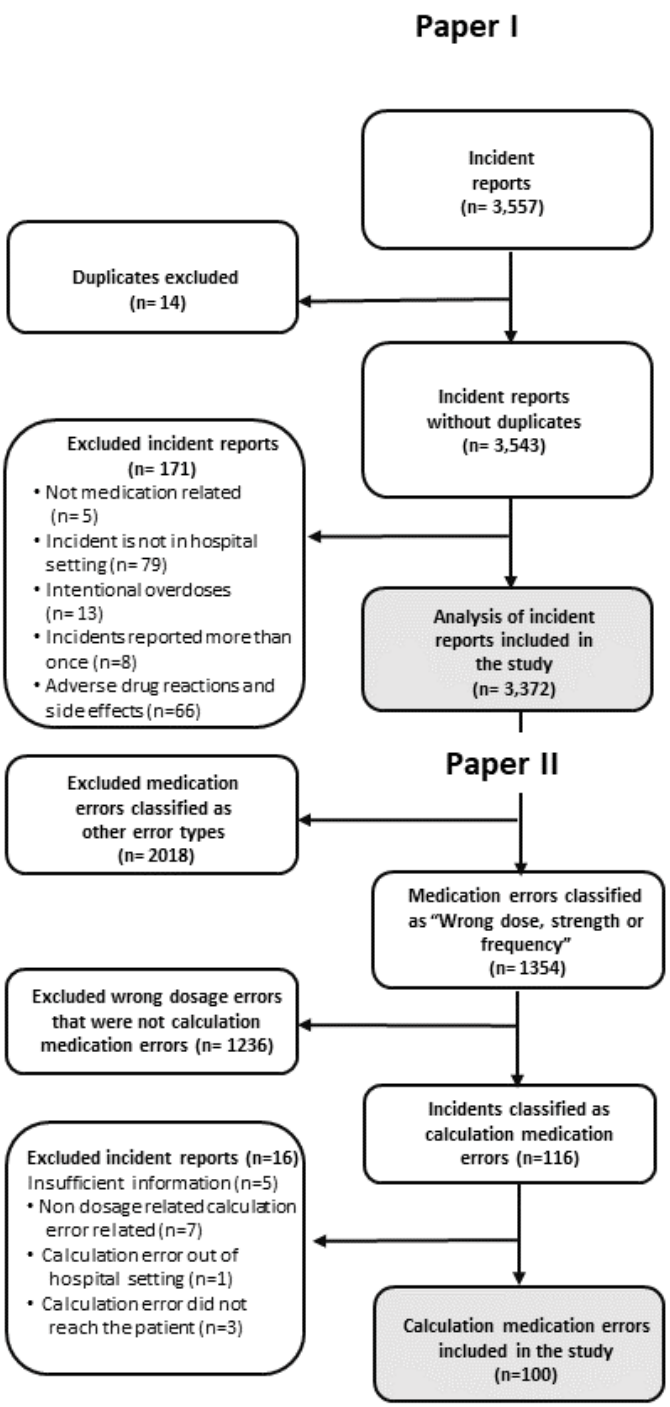

Figure 6 Inclusion and exclusion of reported incidents to the Norwegian Incident Reporting System in 2016 and 2017 for Paper I and Paper II**.**

Table 5 Difference between the methodological approach in Paper I and II.

	Paper I	**Paper II**	
Included incident reports	All medication errors	Dosage errors	
Applied classification of the severity of medication errors	Adapted WHO degree of harm classification to: • No harm • Mild • Moderate • Severe • Death	Adapted NCCMERP classification: Error, no harm: C and D Error, harm: E, F, G, H Error, Death: I	
Patient outcome	Near misses and actual events	Actual events that reached the patient	
Analysis	Descriptive statistics in SPSS. Classification of incidents: • Error type • Stage in the process • Therapeutic class • Degree of harm Descriptive statistics in SPSS.	Quantitative analysis of characteristics of numeracy errors. Descriptive statistics in SPSS.	Qualitative thematic analysis of free text descriptions to error source, mechanism, and enabler; and degree of harm
Interpretation	Cross checking of different variables and interpretation of results.	Integrating the quantitative and qualitative findings with emphasis on the qualitative strand (casual factors)	

Definitions and classification system

For this study, we employed the commonly used definition of medication errors provided by The National Coordinating Council for Medication Error Reduction and Prevention (NCCMERP), as stated earlier (p. 3). To classify the errors, we used an adopted version of the WHO classification system: the Conceptual Framework for the International Classification for Patient Safety [159]. The employees at the Norwegian Incident Reporting System had classified two-thirds of the reports by stage in the medication process and error type. The PhD candidate thoroughly read all the reports to familiarize herself with the data and classified the remaining one-third of the incident reports. The stages in the medication process were prescribing, preparation/dispensing, administration, and storage. The error types were wrong patient, wrong drug, wrong dose/strength or frequency, wrong route, wrong dispensing label or instruction, wrong storage, contraindication, omitted medicine or dose and adverse drug reaction.

The degree of harm for Paper I was classified due to the following five-point scale [159]: (1) no harm: an incident had the potential to cause harm, but was prevented (near miss) or ran to completion, but no harm occurred; (2) low harm: a patient required extra observation or minor treatment; (3) moderate harm: significant, but no permanent harm, where the patient required

treatment measures; (4) severe harm: significant treatment/harm that required surgery, transfer to an intensive care unit, a prolonged hospital stay or permanent harm and (5) death: the error may have contributed to or resulted in a patient's death. To enhance validity and reliability [160] we classified the degree of harm for all incidents, which involved correcting the degree of harm for some incidents originally classified by the employees at the Norwegian Incident Reporting System. Incidents with unclear descriptions and those that were difficult to interpret were discussed by two researchers until consensus was met. Incidents that lacked sufficient information to establish the degree of harm were classified as missing.

The degree of harm in Paper II was classified according to the internationally acknowledged NCCMERP harm scale [14] to facilitate comparison with published literature. Also, we classified the reports by medication name and therapeutic area at Anatomical Therapeutic Chemical (ATC) level 2 [161]. Medication name was not a mandatory field on the electronic reporting form, and therefore it was not possible to classify for all reports.

Paper II involved analysis of incidents to error sources, mechanisms and enablers. Error source was defined as the initiating factor that precipitated the error e.g., writing slips, dose calculation, misinterpretation of the written order, etc. Error mechanisms were defined as the act or practice that led to the error source e.g., 10-fold errors, omitted calculations, mixed up units, mental dose calculations, etc. Error enablers were those factors that made it more likely for errors to occur e.g., double check omitted or deviated, small volume or quantity of the drug, paper-based prescribing, etc.

Understanding the setting

To approach the analysis process, it was essential to get familiarized with the context where errors occur and are reported. Getting to know the setting helped us understand and use the detailed descriptions of incidents and probable causes and facilitated for a deeper interpretation. We, the PhD candidate and the principal supervisor of the thesis (AGG), performed fieldwork at two hospital wards where we shadowed nurses during medication preparation, dispensing and administration. We also wanted to gain a deeper understanding of the reporting system from a local or regional level where the PhD candidate performed semi-structured interview with two employees devoted to quality of care at the hospital. To understand the incident reporting system from a national level, we held several meetings with the caseworkers at the Norwegian Incident Reporting System.

Data analysis

The analysis process for Paper I comprised in frequency analysis and descriptive statistics of error type, stage in the medication process, degree of harm, therapeutic area, which were performed using IBM SPSS V25. Crosschecking the frequencies of different variables helped identify trends in the reported incidents and assisted interpretation, e.g., crosschecking the stage in the process with the degree of harm to investigate the stage in the medication process where most harmful errors occurred.

Paper II involved a quantitative and a qualitative analysis of the incident reports. The quantitative analysis was similar to Paper I, comprised frequency analysis, and descriptive statistics of general characteristics of medication errors in SPSS. In addition to the previously categorized characteristics of medication errors in Paper I, for Paper II we also categorized incidents by medication name, route and formulation, as well as overdosage or underdosage. Since Paper II included only numeracy errors containing sufficient information about the event to allow for analysis of causal factors, the emphasis of the analysis was on the qualitative data strand. To analyze the nature and causal factors of numeracy errors we adapted a method applied in previous studies [88, 89]. All reports were thoroughly read, and themes were identified as they emerged from the data. To enhance validity and reliability during classification and interpretation the first and second authors independently categorized the themes of error sources, mechanisms and enables. Both authors also described the outcome by grading the severity of medication errors according to the adapted NCCMERP classification system [14]. We discussed each reports' analysis until we reached agreement. We then presented the analysis of causal factors to the last author and discussed these until agreeing on the final categories, as presented in the findings.

3.2 Observation of Barcode medication administration (Paper III)

Study Design

We employed a mixed methods design for this study, combining quantitative and qualitative research approaches.

Mixed Methods methodology

Mixed methods research is a methodology that involves using both qualitative and quantitative data when exploring a single phenomenon. The basic purpose of integrating the two methods is to answer the research question with a synergistic utilization of the data sources and analysis compared to the separate qualitative and quantitative methods [162].

Rationale for using a mixed methods approach

Words or narratives can add the meaning to numbers, thus the rationale for using a mixed methods approach when observing nurses during medication administration was to expand the strengths of both quantitative and qualitative methods when answering the study aims, which were in summary:

- to gain an insight into nurses' use of the barcode medication administration technology
- to record the policy deviations when using the technology and investigate their causes

Specifically, rationale for the use of quantitative methods was to record the number and type of policy deviations; and qualitative methods were used to provide a platform for understanding the causes to policy deviations and the interactions between the nurses, the technology they use and the environment in which they work. We used the mixed methods to leverage on the strengths of the two data sets and to integrate the data as a means of understanding and achieving the study aims.

Types of mixed methods

The methodological field of mixed methods involves a number of research designs and different approaches to evaluate when choosing the design. The key principle is to determine the reasons for mixing methods [162]. These include but are not limited to triangulation (seeking for convergence of results from different methods- enhanced validity), complementarity, explanation, different research questions, context, diversity of views, etc.

Another principle is to recognize whether the mixed methods design is fixed (predetermined) or emergent (a second approach qualitative or quantitative is added while the study is underway). In addition to defining the reasons and distinguishing between fixed and emergent design, researchers use a typology-based approach, which involves the researcher to make two primary decisions when choosing an appropriate mixed methods design [163, 164]. These are:

- To determine the priority of the qualitative and quantitative components- whether one wants to operate largely within the qualitative or quantitative approach or not.
- To determine the timing whether one wants to apply the qualitative and quantitative components concurrently or sequentially. The timing often refers to the time the data were collected, but also, more importantly, the order in which the two data components were analyzed.

Rationale for using a concurrent triangulated mixed-methods approach

Figure 7 illustrates the concurrent triangulated strategy that was used in this study. The quantitative and qualitative are presented in capital letters, which according to a notation system for mixed methods [163] denotes priority and means the two datasets were equally prioritized. The two datasets were collected at the same stage of the research process, analyzed at the same stage but independently, and then integrated during overall interpretation using a triangulated approach. For example, this approach allowed the number of the policy deviations using barcode medication administration and their causes to be examined collectively. The concurrent triangulated mixed methods design used in this thesis is also known as convergent parallel design [164].

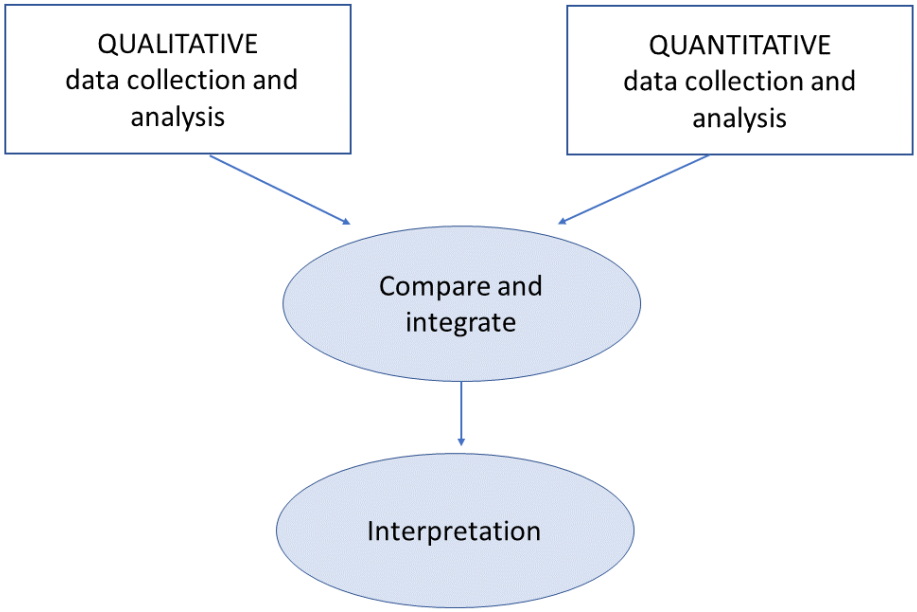

Figure 7 Illustration of the concurrent triangulated mixed methods approach.

Strengths and weaknesses of the mixed methods approach

The use of mixed methods is time consuming as it involves extensive data collection, analysis and integration of the two data sources. It can be difficult for a single researcher to conduct both the qualitative and quantitative research, especially if the two approaches are carried out concurrently. In our study, this process involved a research team. On the other hand, mixed methods approach can provide deeper understanding of the phenomenon that is investigated by overcoming limitations and utilizing strengths of quantitative methods (large sample size, quick

precise data collection, generalization, lack local context) with those of qualitative methods (small sample size, contextual factors, stakeholders' needs, time-consuming data collection, researchers' role) [163].

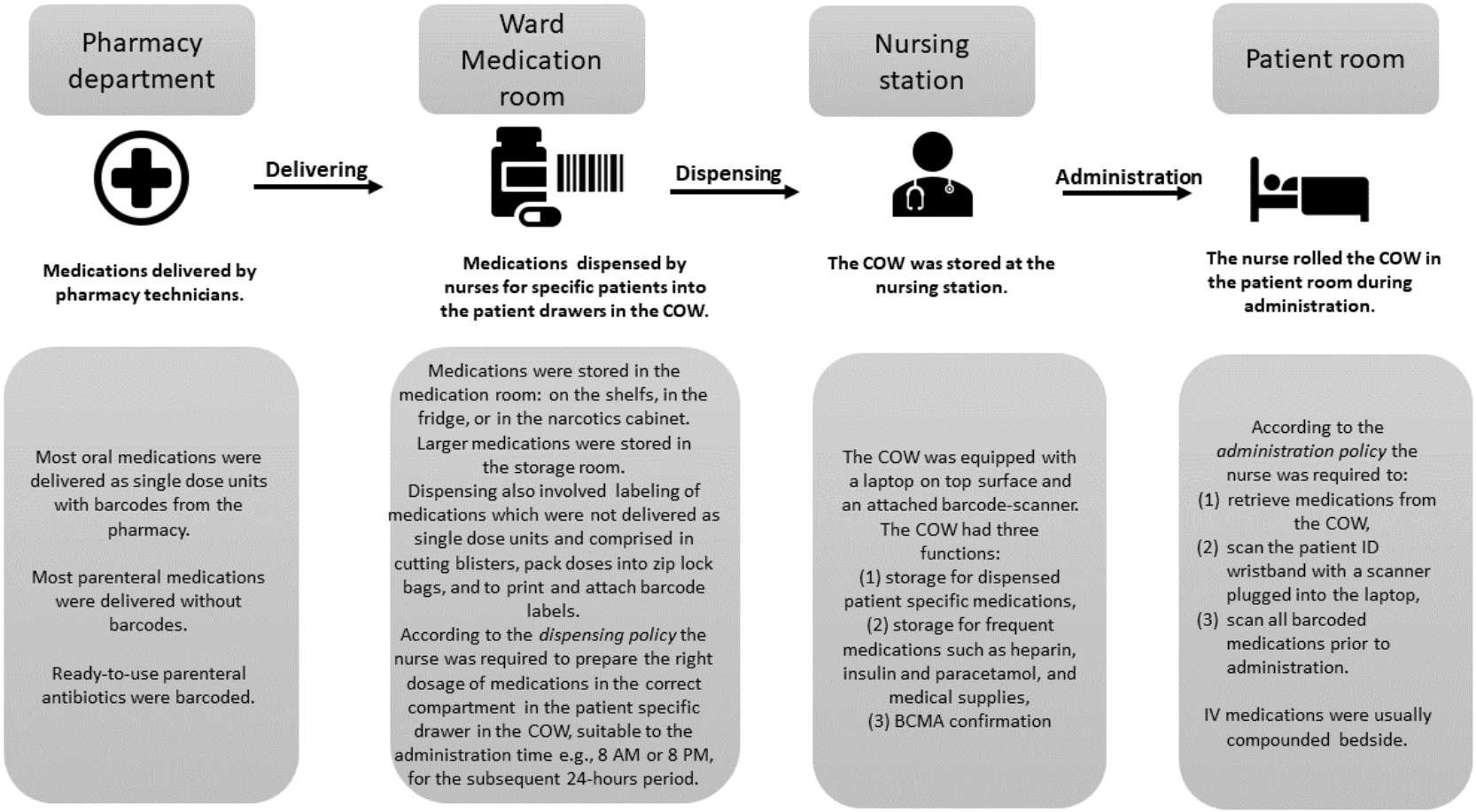

Figure 8 Description of the dispensing and administration process at the study hospital.

BCMA= barcode medication administration; COW= computer on wheels (medication cart); IV= intravenous

Data collection

We collected data on hospital wards at a 700-bed hospital from October 2019 to January 2020. The medication dispensing at the hospital was decentralized and was a nurse-operated task in the wards' medication room. Medications were dispensed by nurses for specific patients in the medication cart which was then stored at the nursing station until administration. During medication rounds the nurse would roll the medication cart in the patient room and scan the patient ID wristband and all barcoded medications prior to administration. The description of the delivery, dispensing and administration process with respective policy descriptions is illustrated in Figure 8. The hospital had implemented the BCMA technology and eMAR over a 3-year period prior to the study start, and the studied electronic system was a part of MetaVision, iMDsoft. In addition to the digitalized medical records and scanning during medication dispensing and administration, the BCMA also comprised of physical components: patient ID wristbands, single dose medication units, medication carts containing medications in drawers and a laptop on the top surface (Figure 9). We collected data on a cardiac medical ward and a geriatric intensive care ward. One nurse cared for up to 9 patients during the day shifts and up to 13 patients during the evening/night shifts. Other ward characteristics and observation details can be found in the Supplementary Appendix 1 in the published manuscript of Paper III.

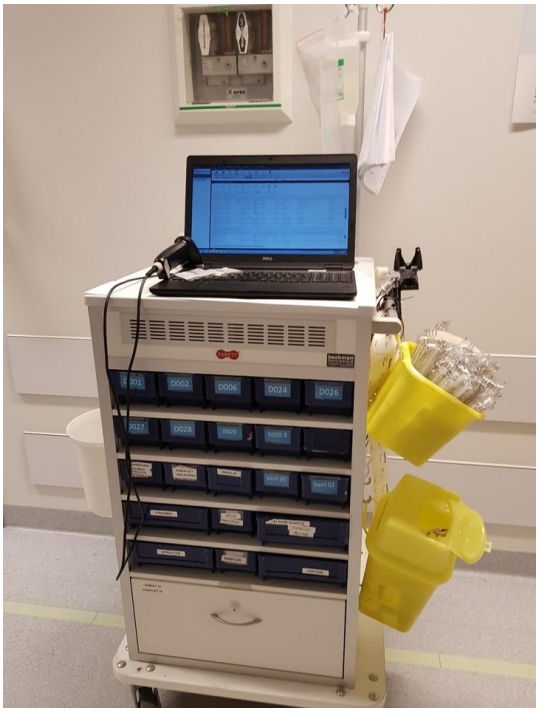

Figure 9 Medication cart with patient drawers containing medications and a laptop with attached scanner on top surface.

Development and piloting of the data collection tool

Using a secured web-based data survey software [165], we developed a digital registration tool for data collection during medication administration. We piloted the tool on two medical wards where two observers independently followed nurses during medication rounds and observed medication administrations for 30 patients. The pilot data were not included in the main study but were used to validate the observational tool and prepare for the main study. The results of the pilot were evaluated by our interprofessional research team. The interpretation of the pilot assisted to thorough utilization of the tool, to evaluate the relevance of each question in the observational tool for the study purpose, and to improve design for registration during data collection. We developed separate tools for the oral and parenteral medications because of differences in the administration processes (Supplementary Appendix 2 and 3 in the published manuscript of Paper III), which contained in total 28 questions (14 questions in each tool). The questions were aligned with the workflow during medication administration, as described in the hospitals policies. The tool could collect data on the following:

- The use of scanning during medication administration:

(a) number of medications (total, scannable and scanned medications)

(b) number of scanned ID wristbands

- Policy deviations with dispensing, labeling, storage or scanning
- Technological discrepancies with equipment or software
- The storage of inpatients private medications: storage and administration
- Further comments field: comments during observations were registered in the free text field of the tool.

Identifying policy deviations

In this thesis, the term *policy* is used to describe specific and practical working procedures that should provide a consistent way of conducting tasks among employees. This should not be confused with the general term of policy that outline organization's standards and expectations. Paper III refers to two specific medication management policies in the study hospitals: medication dispensing and medication administration policy.

According to the hospital's dispensing policy, the nurse was required to prepare the right dosage of medications in patient-specific drawers in the medication cart. According to the hospital's administration policy, the nurse was required to scan patient ID wristband with barcode scanner plugged into the laptop on the medication cart and scan all barcoded medications prior to

administration.

We defined a *policy deviation* as the act of dispensing or administering a medicine that was not in accordance with the hospital policy. *Task-related deviations* were failures with tasks involving use of barcode scanning during dispensing and administration. *Organizational policy deviations* included violations of hospital medication management policies, for example dispensing the wrong dose of the medication in the patient drawer placed in medication cart. *Technology-related factors* included technological discrepancies (hardware and software) associated with the BCMA. *Environmental factors* included elements of the physical environment that affected the BCMA. *Nurse-related factors* were related to the practice or comments of individuals. The five types of deviations/ factors defined above are in accordance with the SEIPS model (p. 22).

Data analysis

Data from the oral and parenteral observational tool (quantitative data) were merged to fit one observation per patient. To analyze the quantitative data, we used descriptive statistics in IBM SPSS V.25. This involved the analysis of scanning rates and the frequency of policy deviations. Qualitative data were analyzed with inductive thematic analysis. Two researchers read the entire data thoroughly and identified preliminary themes that emerged from the text. The researchers coded the data assigning utterances to these themes. The manner in which the data fitted into the themes was discussed regularly to reach consensus. After the separate analysis of the qualitative and quantitative data, we integrated the findings using a triangulated approach. Complimentary findings from both qualitative and quantitative data sets were identified and compared to enhance validity, and to provide an in-depth understanding of the context around policy deviations and their causes. The integrated findings were then categorized according to the five elements of the SEIPS model for interpretation. The analysis process is illustrated in Table 6, where Step 1 and 2 present the stages of independent data collection and analysis of the qualitative and quantitative data, Step 3 presents the triangulation of the two datasets, and Step 4 presents categorization of the data and interpretations according to the SEIPS model

Table 6 Procedures in the mixed methods design in Paper III.

STEP1	**Design the quantitative approach** • State quantitative research question • Define the quantitative data: data registered in the digital tool • Design the tool for data collection **Collect the quantitative data** • Obtain permissions and access to the wards • Pilot observations: Data registering data in the digital tool and evaluation of pilot data in the research team • Redesigning the digital tool to fit the research question • Main study: Data collection with the digital tool	AND	**Design the qualitative approach** • State qualitative research question • Define the qualitative data: Field notes and nurses' comments **Collect the qualitative data** • Identify the qualitative sample • Keep track on qualitative data registering and field notes diary Merge all qualitative data from both observers' field notes and nurses' comments.
STEP2	**Analyze the Quantitative Data** • Merge data from the oral and parenteral digital tool • Descriptive statistics in SPSS • Analysis of scanning rates and the frequency of policy deviations	AND	**Analyze the Qualitative Data** • Inductive thematic analysis • Two researchers read the data thoroughly to identify emerging teams • Utterances (codes) were assigned to the themes • Researchers discussed the teams and coding to enhance rigour to the thematic analysis
STEP3	**Triangulation:** **Integrate the findings from the two data sets by** • Identified complimentary findings from both datasets • Identify and examine differences between the two datasets • Compare complimentary findings to enhance validity, and synthesize the results		
STEP4	**Interpretation of the findings: Human Factors Approach** • Categorize the findings according to the five elements of the work system in SEIPS model [150] • Interpret the findings evaluating the interactions between the elements of the work system • Identify causes to policy deviations		

SEIPS= System Engineering Initiative for Patient Safety

The use of human factors theory

The SEIPS model, a human factors approach, was applied as a theoretical framework that allowed for a more systematic approach to analysis. We sought to categorize and interpret the findings with a structured framework that would aid in exploring the interactions between the nurses, the barcoding technology, and the environment in which they use the technology with an overall focus on patient safety. Once we integrated the qualitative and quantitative data, we applied the theoretical framework to categorize and interpret the data according to the five elements of the SEIPS model [151]: (1) tasks, (2) organizational factors, (3) technology, (4) physical environment, and (5) individuals. The SEIPS model allowed us to evaluate all the factors of the work system involved in use of the BCMA technology during medication administration in the study setting (p. 22).

Ethical considerations

We were granted access to anonymized incident reports for Paper I and II by the Norwegian Directorate of Health where the Norwegian Incident Reporting System was located. Ethical approval was not required for this study. Paper III was approved by the institutional data protection board at the study hospital and did not require an ethical approval since we collected anonymous data about the working process during medication dispensing and administration. No patient related information was collected. The submitted application for the institutional approval is attached in Appendix 1. The e-mail response from the hospital is attached in Appendix 2.

A number of ethical issues were evaluated during the design and course of the observational study. Conducting ethical research involves that participants are informed about the purpose of the study and how the data will be used [166]. To ensure this, observers have prior to observation start, explained the participating nurse the purpose of the study, what participating involves, and how the data are registered and will be used. All participating nurses signed an informed consent form (Appendix 3) containing information about the study, data collection and contact information to the principal investigator. Upon entering the patient room, the nurse informed the patient about the presence of the observer and study purpose. All nurses were voluntarily recruited with the option to withdraw from the project. One participant chose to withdraw from the study before the observation started.

An ethical issue in patient safety research is the duty to intervene or report when observing a medication error which the research staff believes is highly likely to result in direct, severe or irreversible harm [167]. The researchers evaluated this issue and described in the consent form

that the observer will notify the nurse if they observe a deviation with potential to cause severe patient harm. One such situation occurred during observation and the observer discretely informed the nurse to prevent the medication error reaching the patient. The nurse realized the error and rectified it. Study observers registered, however, several other situations that involved potentially unsafe practices such as inadequate conditions for sterile intravenous infusion preparation or medication errors without direct or severe consequences for the patients.

Researcher's role

Researchers are a part of the inherent reality they observe, which means that they should be aware of their preconceptions and reflexivity to produce valid results. Reflexivity has been described as researchers having an ongoing self-awareness process during the research process to ensure accuracy in analyzing the data [168]. The following are the reflections of the PhD candidate on this: I recognize the viewpoints and possible preconceptions I have brought with me. As a pharmacist by training, I am raised in a culture devoted to ensuring accuracy and punctuality. The nature of the pharmacist and nursing education have the fundamental difference that nurses are guided with providing care while pharmacists are guided with providing a correct answer whether it be the correct dosage or medication or control [169, 170]. Coming from a community pharmacy culture where dispensing errors are extremely rare and working around procedures is a seldom exception, to a culture where deviations are normalized, it was possible to make judgements on nurses' adopting unsafe practices without reflecting over them being unsafe. In order to identify and rectify these potential preconceptions, I sought clarification from nursing staff about their typical work processes and their experience with the medication systems during convenient times in observation periods. Comments were included in field notes and aided in my understanding of nurses' medication management on a typical day.

Through observations, I gained a broader understanding for the nurses' role in patient care. For instance, one late night during observation, at the end of the shift, the nurse tired from a long, intensive day, choose not to roll the medication cart in the patient rooms and refrained from scanning. The nurse had not had time to eat or drink herself during the whole shift but passed meals and drinks to patients with kindness and care. What struck me then, was that the nurse instead of finishing their shift and heading home, stayed, looked at the eMAR, deeply worried about a patient that was transferred to the surgery department, which was not their responsibility any longer. The nurse wondered whether the personnel at the surgery department would remember to stop the patient's anticoagulation treatment prior to surgery, as this could

adversely lead to postoperative bleeding. That moment zoomed in on the nursing role and how it is caring for the individual, their quality of life, if they need an extra pillow or glass of water or covering them with a blanket when they seemed cold, to allow patients feel dignity even if very ill and hospitalized. I learned about the greatness of the nursing role and it being much larger than just “administering medications safe”. This understanding has early on softened the beliefs and preconceptions I had when starting my project and has led to drawing on some implications mentioned later in the thesis, that concern the overwhelming number of tasks nurses have in the medication management process.

These personal reflections above indicate that pharmacists as health professionals are extremely engaged in accuracy and are therefore valuable to identify risky behavior. Yet, it might also mean that pharmacists are not the natural observer of nursing practice, because they might be criticizing without understanding what it takes to do the job. Nurses and pharmacists, along with human factors engineers, would be an ideal, symbiotic team for observing the safety of medication administration [99]. However, this combination is seldom described in the literature and the majority of scientific publications, opinions letters and safety initiatives on medication errors are signed by pharmacists.

4 Main findings

The main findings will be presented separately for the three papers including a description of how the findings from the first paper contributed to forming later studies.

4.1 Paper I Severe and fatal medication errors in hospitals

Paper I aimed to describe the frequency, stage in the process, and type of medication-related incidents reported from Norwegian hospitals with emphasis on severe and fatal medication errors.

In total, 3372 medication errors met the inclusion criteria. Errors occurred most frequently during medication administration (68%), followed by prescribing (24%), and dispensing/preparation (6%) stage of the medication management process. The most commonly reported error types were wrong dose errors (38%), omissions (23%), and wrong drug (15%). Nurses reported most incidents. More than half of all reported errors in 2016-2017 caused some grade of patient harm. 177 patients (5.2%) were severely harmed, and 27 patients had a fatal outcome after experiencing a medication error. Most severe errors occurred in the administration stage and most fatal errors were due to wrong dose errors. Table 7 exemplifies the richness of qualitative descriptions in the incident reports of one fatal and one severe case as an illustration of how this allowed further utilizing the data for in-depth analysis of the incidents in Paper II.

Table 7 Examples of one severe and one fatal incident report from Norwegian Incident Reporting System.

Incident information	**Incident description**
Error type: Wrong dose/ Degree of harm: Severe Patient age (years): >65 Medication process: Administration I.V. Solutions- Electrolytes	A patient with hypocalcemia should have received 0.3 mmol/kg of $CaCl_2$ according to his weight of 100 kg. The junior doctor showed the doctor in charge how she had calculated the dose, i.e., 0.3 mmol/kg x 100 kg=130 mmol. The doctor in charge did not spot the wrongly calculated dose of 130 mmol, instead of the correct 30 mmol. The patient became acutely ill, was moved to the intensive care unit, and received fluids to eliminate the calcium and continuous heart monitoring.
Error type: Wrong route Degree of harm: Death Patient age (years): 0-17 Medication process: Administration Antineoplastic agents and immunomodulating agents (L01-L04)	The patient was prescribed two drugs, methotrexate (intrathecal) and vincristine (intravenous). During administration, the vincristine syringe was mixed up with the methotrexate syringe and injected intrathecally. The error was intercepted after 25 minutes but it was too late. The child died due to the consequences of the histotoxic drug. Vincristine was delivered in a syringe similar to methotrexate.

Paper I highlighted that:

- A substantial number of patients in Norwegian hospitals were harmed by preventable medication errors.
- The error-prone medication administration stage needs to be further investigated to elaborate the reasons why 7 of 10 errors occurred in the administration stage.
- There is an urgent need for error-prevention strategies for the whole medication management process, and specifically strategies aimed to reduce dosage errors and improve safety in the medication administration stage.

The findings of Paper I contributed to forming the design of Paper II and Paper III.

4.2 Paper II: Medication dose calculation errors in hospitals

In Paper I, dosage errors were identified as the most common and most harmful error type. These results pointed at error-prevention strategies aimed to reduce dosage errors and introduce safety barriers to prevent dosage errors to reach patients and cause harm. Medication dose calculation errors, as a subtype of dosage errors, were present in our data, however is not profoundly elaborated in the literature.

The aim of Paper II was to investigate medication dose calculation errors and other numeracy mishaps and analyze their causal factors.

The analysis comprised 100 medication calculation errors. One third of all errors affected children (<18 years), and 77% were associated with the parenteral administration route.

One third of calculation errors were 10-fold or 100-fold errors, such as administering 10 mg of morphine instead of 1mg.

Intravenous medications were used in more than half of the serious errors. Dilution of intravenous bolus injection of opiates was found to be specifically error prone. During prescribing, medication calculation errors occurred due to writing slips or misinterpretations. These errors were difficult to intercept since the clinicians' orders are not routinely reviewed by another health professional, yet these errors were associated with harm. High-risk medications were associated with almost half of all numeracy errors, and besides opiates involved digoxin, insulin, methotrexate and others.

Double checks, which are an error prevention strategy, seemed to provide false safeguard for nurses. We found that errors reached 28 patients, even though the dose was double-checked by another nurse.

Errors during proportional dose calculations, unsatisfactory understanding of units, volumes and formulas for safe handling medications, have also contributed to errors.

Paper II highlighted that:

- There are major flaws in barriers to intercept errors in all stages of the medication management process.
- Safety barriers either did not exist (prescribing) or were not efficient in preventing errors (administration: double checks, dilution of intravenous medications, programming infusion pumps).

- To avoid the most harmful calculation medication errors, health care organizations should aim to deliver high-risk medications labeled and “ready-to use” to hospital wards.
- Measures at organizational, technological and educational level are required to assist health professionals in safe medication management and prevent future medication calculation errors.

4.3 Paper III: Barcode medication administration technology use in hospital practice

Paper I called for investigating the safety of the medication administration stage since most errors that occurred in this stage reached the patient. These results pointed at the necessary for implementation of interventions to act as safety barriers within the medication management process. One intervention to improve safety and reduce errors is the barcode medication administration, which involves scanning of the barcode to quality-assure verification of the right medication for the right patient. This intervention was evaluated in Paper III.

In Paper III, we aimed to gain understanding of how nurses use the BCMA technology during medication dispensing and administration by using the human factors analysis of the work system. The study involved observation of 44 nurses while administering medication to 213 patients at two hospital wards. The results were categorized in accordance with the five elements of the work system.

At a task level, we found that deviations with medications dispensed in the medication cart (dispensing) affected 6 of 10 patients, and deviations that occurred by the patient bed (administration) affected 7 of 10 patients.

At an organizational level, most deviations occurred due to a complex dispensing process. The lack of standardized dispensed doses led to variations in how the medications were dispensed and placed in the medication cart. This caused policy deviations such as medications not dispensed in the medication cart, barcode label was missing, or the wrong dose of a medication was dispensed. During medication administration, organizational deviations occurred such as not scanning 29% of medications and 20% of patient ID wristbands.

Although technology-related factors involved laptops not being charged before the administration started and borrowing of scanners across wards, the medication carts with laptops made the strongest impact to nurses' workflow. The carts were bulky and difficult to maneuver in and out of patient rooms. The fact that the scanners were tethered (i.e., attached to the laptops with a cord) made the administration troublesome.

The physical distance from medication room to patient rooms also seemed to affect medication safety because retrieving any missing medications was often postponed or collectively retrieved for several patients. These interruptions to the workflow occasionally resulted in omissions

when the nurse had to run back and forth to the medication room. The small patient drawer in the medication cart also led to dispensing omissions.

Most nurses reported to be in favor of the automatic verification of medications and patients with the scanning technology, however they also reported that the technology overall slowed the administration and therefore refrained from scanning.

Paper III revealed a number of reasons as to why the medication dispensing and administration process had many deviations. It was difficult for nurses to conduct the medication administration without deviating from policies, because the use of technology was incompatible with their workflow, and deviations stemming from medication dispensing affected administration. A wrong mediation dispensed by one nurse must be detected and rectified by another nurse during the administration round. Even with the many challenges with use, the technology did detect errors. In our study, scanning medications detected wrongly dispensed medications and prevented potential errors for 5% of patients.

Paper III highlighted that:

- Deviations from policies with use of BCMA technology were frequent and affected over half of all observed patients during medication dispensing and administration.
- The observational tool used in the study was effective to detect a number of deviations.
- Deviations were caused due to unclear policies, a complex, semi manual-semi automatic dispensing process and with suboptimal technology design.
- Monitoring the use of technology after implementation is important to identify system flaws, unsafe practices and to measure medication safety.

5 Discussion

The findings of this thesis highlighted that the current medication management process is characterized with a number of serious issues that may threaten both the safety and also positive outcomes of the process. Each step of the process, which encompasses prescribing, dispensing and administration in particular, needs various improvements and further study.

In this thesis, we have elaborated on the lack of safety barriers in all stages of the medication management process, addressed at times inefficient existing safety barriers such as double checks, and investigated the potential of barcoding technology to improve medication safety.

Findings of the three papers have allowed us to identify trends in unsafe practices associated with stages in the medication management process, error types or medications. Below, I discuss the main findings of the individual papers and methodological considerations, followed by a synthesis of the challenges in the medication management process.

The reported errors suggested that it was unlikely for a once occurred medication error to be intercepted in the current medication management in hospitals, without system-oriented measures to prevent errors. The pillars of safe medication practices are to establish safeguards to prevent errors from reaching patients [6]. Since humans handle medications, errors are expected to occur. Therefore, the aim is not to prevent all errors from occurring, but to establish effective mechanisms that can prevent once occurred errors to reach the patient and cause harm. These mechanisms should be established in all stages of the medication management process and address specific tasks that are prone to errors, many of them identified in this thesis.

5.1 Discussion of main findings of individual papers

Paper I and II: Medication errors reported from Norwegian hospitals

In the review of over 3000 medication errors reported from Norwegian hospitals we found that a substantial number of patients were harmed by medication errors. Although our findings showed higher rate of harmful events than other national reporting systems, the comparison is difficult because of the vague denominator and selection bias in incident reporting. Nevertheless, 177 patients were severely harmed, and 27 patients died in 2016 and 2017 after experiencing a medication error. These numbers are substantial considering that most of these errors could have been prevented. Some of the errors occurred in very ill and fragile patients and errors as such may, or may not, have been the actual cause of severe harm.

Medication errors in general, and specifically harmful errors, occurred most frequently in the administration stage. The administration stage is the last line of defense in medication management, thus errors that occur during administration are more likely to reach the patient [171]. Others have also found that error most frequently occurred during administration [16, 33, 63, 64]. However, the administration stage is overrepresented in our data, i.e., 68% of all reported medication errors, whilst other studies found much higher percentage of prescribing errors than in our study [61, 62, 64]. Almost all tasks after the physician has prescribed a drug to the drug is taken are under nurses' supervision, which makes errors difficult to prevent.

The in-depth analysis of medication dose calculation errors in Paper II identified several weak points in the administration process that allowed for errors to occur. The administration of high-risk medications, that pose a greater risk of medication errors than other types of medications [172], were associated with almost half of all medication dose calculation errors in Paper II. Miscalculation when withdrawing insulin, mixing-up milligrams and micrograms in digoxin tablets, and wrong dilution of intravenous opiates caused patient harm. Handling high-risk medications is known to be error-prone [173, 174] and has therefore resulted in specific measures, many of which are aimed to move the high-risk processes of preparing patient-specific doses from the ward to the hospital pharmacy. Although we found that some individuals' lack of knowledge about medications and conceptual understanding of volumes and units contributed to errors, the origin of these errors lies in the system that lack effective measures to intercept them. The established measures, double checks, appeared not only inefficient in detecting errors, but provided false security for the nurse, misleading them to believe that the checked dose was correct, when in fact it might for instance be a double-checked lethal 10-fold oxycodone overdosage. In Paper II, double checks were either omitted, or when adhered to, did not intercept the error. Although analyzing incident reports is not appropriate to establish the efficiency of double checks as such, others that used more reliable methods, such as observation of medication administration, also found that double checks were skipped [103]. Our findings and the literature indicate that double checks in many cases are regrettably not effective in preventing errors [104, 175]. Ready-to-use medications should therefore be provided so that nurses, when possible, are relieved from performing high-risk calculations.

Handling intravenous medications and infusion pumps were also associated with errors and harm but seemed to lack effective measures to ensure safe administration. A specific error type of diluting opiates for bolus administration resulted in errors due to the seemingly lack of understanding of the exact concentration after dilution. Taxis et al. evaluated intravenous

medication errors and found that most intravenous errors occurred when giving bolus doses [79]. Calculation tasks were also identified as a systemic cause to intravenous medication errors in a recent systematic review [176]. We found that errors occurred when performing sensitive tasks such as calculating doses and diluting medications whilst caring for patients. These findings illustrate that the complexity of tasks nurses have to manage at times were not compatible with safety culture principles.

In the medication errors reported from Norwegian hospitals the prescribing stage was associated with 40% of severe and fatal errors (Paper I). When we evaluated causes for medication dose calculation errors, we found that the prescribing errors were due to communication issues and writing slips. Physician orders in Norwegian hospitals are not routinely verified by other health professionals, yet half of the dose calculation errors in Paper II were due to writing or typing slips. Although others have found that prescribing errors were more likely to be intercepted since the error occurred earlier in the process, 48% at the prescribing stage vs 0% at the administration stage [27], in our study there were no such barriers in place to detect prescribing errors. The fact that pharmacists in Norwegian hospitals do not check physicians' orders, may partly explain the relatively high severe and fatal errors during prescribing in our study.

In summary, harmful, yet preventable medication errors have occurred during the whole medication management process due to the apparently suboptimal safety environment and the lack of proper safeguards to prevent errors. Identifying the right task for the right health professional at the appropriate time during medication management should influence design of prevention strategies. Our findings based on nationally reported incidents calls for a debate of the need for a change in national hospital medication management policies.

Paper III: Observation of Barcode medication administration

Policy deviations with BCMA technology

Observing nurses' use of the BCMA technology provided an understanding of the many obstacles leading to deviation from medication dispensing and administration policies. The technology has introduced new tasks into the process of dispensing and administering medications in addition to already heavy workload. To compensate for this, nurses at times skipped some tasks which may have negatively impacted patient safety. For example, when one nurse deviated from the dispensing policy and did not dispense a medication in the medication cart, another nurse (during the medication administration) had to retrieve the medication and interrupt their workflow. This may be a potential threat to patient safety. Alternatively, when

the other nurse postponed retrieving the drug, it resulted in medication omissions, i.e., actual medication errors.

The analysis of the work system elements allowed us to look deeper into policy deviations and their causes. The factors such as the complex dispensing process, lack of standardized doses, suboptimal technology design and undersized patient drawers have individually and collectively contributed to policy deviations and thus resulted in an obstructed workflow. Although the scanning rates in our study, 71% for medications and 80% for patients, were considerably lower than the 95% standard goal [177], and lower than rates provided in other studies [124, 178], the rate found in our study is mostly a reflection of the underlying causes as to why scanning was not used. Very few nurses voluntarily chose not to scan. The root of the problem was in the discrepancies stemming in the dispensing process or technological issues, which obstructed nurses in conducting intended tasks, including scanning. The bulky medication carts were difficult to maneuver, and tethered scanners limited flexibility when administering medications, which resulted in medications being scanned outside the patient room. These are by no means novel findings in the BCMA research. Bulky medication carts [128] and tethered scanners [155] have stood in the way for safe medication administration and led to deviations for others as well. In fact, our findings of how BCMA affected patient safety is in line with other studies, for instance low batteries on laptops, conflicting workflow efficiency vs. BCMA use [128], nurses scanning medications but not wristbands [124], and scanning barcodes that were not attached to medications [99]. In contrast, we identified additional types of deviations linked to manual tasks during dispensing that were not found in unit-based systems [124, 128, 179]. Moreover, we also observed that the more manual work that was done by nurses at the ward (printing, packing, labeling, preparing patient specific doses, mixing), the more deviations it resulted in. We quantified these deviations and found that they affected more than half of all observed patients during medication dispensing and administration. Although we have only observed two hospital wards, these are important findings that raise the question of whether BCMA should have been implemented if it is not used as intended half the time. On the other hand, when dispensed medications were prepacked single dose units, the administration workflow was smooth, fast, and with minimal deviations, highlighting the importance of more standardized doses delivered on ward.

BCMA scanning detected dispensing errors and potentially prevented wrongly dispensed medication to reach patients. This indicates that the technology has potential to reach its overall aim - to improve patient safety. In order to achieve this safety aim, sustainable solutions are

needed in the, in my view, overly complicated dispensing process. It is therefore advisable to improve the technology design by for example introducing mobile solutions, and to aim for a better compliance between policy and workflow.

Importance of evaluating the BCMA use over time

Paper III demonstrated that implementing BCMA had both positive and negative consequences for patient safety. Therefore, monitoring and evaluation of the technology is important since it can identify safety gaps before they may present actual safety threats for patients. Future periodical observations of the technology use in the wards, similar to the method used in this study, can assist nurses and policy makers to identify workflow and system issues specific to the observed environment. Additionally, this could allow end-users to give feedback on the potential difficulties and to suggest what they consider important system and process improvements. In our study, in addition to policy deviations and understanding the interactions in the work system, the observers identified some issues with for instance invalid barcodes and a few system bugs that were reported back to the responsible IT staff at the hospital. Informal, confidential, and voluntary patient safety rounds are recommended as safety and quality improvement initiatives [3, 180]. One hospital that initially experienced difficulties with BCMA implementation, for instance introduced BCMA safety rounds twice each month and reviewed all observed issues in the BCMA committee [131]. Their observers also asked for feedback from end-users on any BCMA-related issues which improved satisfaction of the staff because they witnessed the implementation of improvements that they themselves requested. In our study, nurses' acquaintance with the BCMA technology varied. Nurses who were more familiar with the functionality, intuitively understood the source of the problem during BCMA and thus what the solution would be. On the other hand, some nurses struggled to understand that medications which were not scanned during the dispensing process, could not be scanned during the administration process, which understandably resulted in some frustrations. The monitoring with soliciting end-users can also provide training in system functionality issues and build their confidence in using the BCMA [128, 131].

I would agree that there is little value in comparing different systems and vendors, because the varying integration of information across systems might lead to organizations experiencing completely different problems. For example, a study similar to ours, that evaluated implementation of BCMA from a human factors perspective, found major issues related to the information flow of patients clinical information during BCMA use [155], while we found no such issues, and nurses were able to retrieve the lab values and patient history information

without obstructing their workflow. Therefore, postimplementation efforts should primarily focus on learning from the organizations' own use of the technology, policy and workflow changes. That said, sharing experiences across institutions with similar systems and processes can also lead to improved knowledge and may be of great assistance and support to those hospitals that are still to introduce BCMA.

The role of Human factors approach

The success of the BCMA implementation has until now been demonstrated with the direct impact to patient safety, that is measuring reduction of error rates in before and after studies [119, 121, 132]. However, the advances of BCMA to patient safety in one setting cannot guarantee success in another setting. We, and a few others before us [99, 155, 181], argue from a human factors' perspective that the influence of BCMA to safety is impacted by a change in the work processes. Therefore, the work system must be investigated in addition to measuring medication error rates.

Accordingly, the human factors approach allowed us to investigate how organizational interventions change the nature of work and how workers adapt following that change [182]. Also, understanding the work system helped us to propose improvement measures. For example, we suggested improving the physical design of the technology by introducing a mobile BCMA device. But without understanding the organizational context in which this technology will be used, the tasks of the people that will use it, the physical environment in which it will be used and the need of other technologies to complete the task, the intervention might not be useful. Therefore, interventions that do not evaluate the whole work system before they are implemented, are unlikely to have a significant and sustainable impact on patient safety [151].

5.2 Methodological considerations

Incident Reporting (Paper I and II)

When using incident reporting to describe errors, several points are essential to elaborate. Firstly, we are aware that the reported incidents present the top of the iceberg of all events that have occurred. Underreporting is a known limitation of incident reporting systems and numbers that are reported are likely to be an underestimation of error rates and harm [35, 75, 183]. With this in mind, in Paper II we focused on the qualitative descriptions to identify causal factors to errors. This allowed for detecting valuable patterns of unsafe practices that have resulted in patient harm. Secondly, it is possible that the administration stage in Paper I is overrepresented because nurses reported most incidents, and health professionals are likely to report incidents that involved themselves [184]. Also, in Norwegian hospitals, the tasks of dispensing and administering medicines are performed by nurses, which can mask the origin stage of the error in the incident report. Thirdly, subjective interpretation of the health professionals could have influenced the severity of harm. Assigning harm score by the reviewers from the Norwegian Directorate of Health is affected by interrater reliability. To address this, we graded the harm for all severe and fatal events in Paper I. For Paper II, two authors individually graded severity of harm and then discussed until we reached consensus. Despite these efforts, assigning harm score in the study has some uncertainty because incidents describe harm that was known when the event was reported. The final outcome for the patient may be unknown because incidents are usually reported shortly after they occurred [185, 186], and in our study within 24 hours. This limitation influenced our decision to strengthen the inclusion criteria and choose a more specific harm classification in Paper II.

Paper I and Paper II involve all Norwegian hospitals that reported errors in the study period, which gives broad national overview compared to studies that have focused on specific hospitals [61] medications [33, 187] or patient groups [188]. However, the medication management process in Norwegian hospitals may differ from the medication management process in other countries, which limits the transferability of our findings to hospitals outside Norway. Also, our findings that refer to medication administrations documented on paper, such as errors due to unclear writing, might not be of importance for hospitals with electronic medication administration record.

The focus of the study was on specific stages in medication management, mainly prescribing, dispensing /preparation and administration. Monitoring of medications after intake received

little attention, which could limit the transferability of our findings to other healthcare settings, for instance primary healthcare which has higher focus on monitoring.

Although patient's role in improving medication safety was not the focus in this body of work, the partnership of patients, relatives and health professionals should be acknowledged as an important aspect of improving patient safety [10, 12, 13, 189]. Patients have a role in detecting and preventing errors by being aware of the prescribed treatment, by being attentive and actively involved in their treatment [190].

Observation of medication administration (Paper III)

To fully learn about the impact of interventions, both qualitative and quantitative approaches are needed. The mixed methods approach allowed us to measure and understand nurses' BCMA use. Combining the quantitative and qualitative approach made it possible to measure policy deviations and understand their probable causes. Others have found it difficult to make a quantitative assessment of the frequency of workarounds, or policy deviations [155]. Our observational tool was effective in identifying deviations from work procedures that are not detected with other medication errors or adverse event detection methods, yet can produce latent conditions and have important implications to patient safety [191]. Although focusing on normal deviations is a strength, it is also a limitation because the study does not measure the direct effect of BCMA to patient safety.

Despite every effort to minimize the observer bias, we acknowledge that the observers' presence has influenced nurses' behavior in some observations. We asked nurses to conduct medication administration tasks as they would in a typical day. Only a few nurses chose not to use the scanning at all during the whole medication round to demonstrate their typical behavior during medication administration. Other nurses admitted that they were using the technology because being observed. However, observers' presence has not influenced nurses' behavior during dispensing, since medications were dispensed in medication carts before observation start, usually by nurses from the previous shift.

It can be challenging for a single researcher to conduct both the qualitative and quantitative research, especially if the two approaches are carried out concurrently. This might require more than one observer, and preferably observers with interprofessional background. Similar studies have been conducted in pair, typically a nurse and pharmacist [192], or a human factors engineer and a pharmacist [99]. However, more researchers in the field would have introduced other challenges. Nurses in the field could have experienced the researchers' presence as more

intrusive which would have influenced their behavior to a greater extent. Our observers, pharmacists, provided clinical knowledge about the processes and medications, but not necessarily about nursing work. Our data were reviewed and discussed with an interprofessional team, including a nurse, who provided viewpoints about nursing work. We trained observers in the observation method to collect data regarding medications, procedures, technology and the environment. Early on, during the pilot study, we emphasized agreement between observers during data collection. After each completed observation day in the pilot study, the observers reviewed and discussed the manner in which they registered the data in the observation tool. These discussions increased the agreement between observers and reliability during data collection. However, we did not measure the interrater reliability between the two observers.

Nurses' comments included in the qualitative data, should be interpreted with caution as not all nurses were asked the same questions. They sporadically commented on their experience with using the BCMA technology. Although not systematically collected, nurses' comments were valuable to gain a deeper understanding of the technology use on a typical day when observers are not present.

There were also other human factors that were not measured because of the practical feasibility of the data registration. These include organizational factors such as interruptions, and medication administration for patients in isolation rooms, environmental factors such as light, that was frequently dimmed in patient rooms during evening observations, individual factors such as knowledge and experience of the observed nurse. Instead, we focused on factors in the medication management processes concerning the technology use that were relevant for patients and medication administrations in general.

We have studied a specific dispensing and administration system integrated with barcode scanning. This might limit its generalizability because the data are related to the details of this particular context and most of the issues regarding to workflow and specific tasks during dispensing will relate to the observed context. However, the Human factors theoretical framework supported interpretation of findings across the five elements of the work system (tasks, organization, technology, environment, and person) that exist in almost any health-care institution. For example, findings that relate to the suboptimal technology design which limited nurse's flexibility, the location of the medication room, the lack of standardized doses and the evaluation of the interactions of nurses and the BCMA technology. All of these can be useful in broader health care settings.

5.3 Interpretation

Below follows an overall interpretation of the three papers in this thesis.

Medication errors

We identified that safeguards were absent or failed to intercept errors in prescribing, dispensing and administration of the medication management process. Starting with prescribing, writing slips and severe overdosages due to miscommunication or wrong dose calculation were not possible to be intercepted in our study. In Norwegian hospitals, once physician orders are made, the medication is available for dispensing by nurses and is not checked by pharmacists. The possibilities to intercept the error is thus very low in such systems. Severe harm from prescribing errors has facilitated regulation changes in for instance the USA [180] and resulted in mandated medication order validation by pharmacists after physician ordering as the key safety activity to prevent prescribing errors [193]. Order validation is even more achievable with electronic prescribing that allows for a remote order validation, for example from the hospital pharmacy. However it requires pharmacy services round- the- clock, which are not the case in Norway. Further down the line in the medication management process, we found that dispensing and administration medication errors comprised over 70 % of all errors. Although dispensing and administration are two separate stages of the medication management process, they are difficult to discuss apart, because these stages are the sole responsibility of nurses, and sometimes even operated by the same individual. Additionally, managing medications is one of nurses' many different tasks. In cases when double checks failed to prevent errors, there appeared to be no other error prevention mechanism in place. This emphasizes the wide responsibility and vast knowledge nurses must demonstrate to be able to handle medications safely. Our observations of the barcode medication administration technology use revealed that many steps were required to dispense and manually label a medication which resulted in a lack of standardized doses, and temporary "quick fixes" to save time. In addition to the dispensing process being complexed, there were few safeguards in place against errors that may occur during dispensing and preparation. We observed BCMA, a safety intervention aimed to prevent administration errors, however a number of deviations during dispensing stood in the way of achieving the full benefits of the technology to patient safety. Based on our findings and recommendations from medication safety and quality organizations [194-196] we advocate for strengthening the collaboration between hospital wards and the hospital pharmacy to leverage from a sharpened safety approach and knowledge about medications. This could for instance be that pharmacy personnel would prepare ready-to use doses of high-risk medications,

intravenous medications and provide patient specific dispensing to avoid deviations that conflict with patient safety.

Achieving a culture of safety through medication safety regulation

While the role of hospital pharmacy in providing safe and sustainable medication management is vital [197], the hospitals and hospital pharmacies are regulated by separate health enterprises which is not ideally set up for collaboration. In Norwegian hospitals, the hospital pharmacy does not have routine access to the patient health records and their working hours are only during daytime. Therefore, to systematically address quality assurance and safety of each stage in the medication management process, a nation-wide safety focus may well be required at the regulation and legislation level. At the European level, several recommendations on patient safety have been made [198]. One EU report from 2006 proposed best practices to prevent medication errors, which include: pharmacist review of prescriptions inclusive that pharmacists should have access to the patient's medical record, a centralized preparation of injectable medications at the hospital pharmacy, unit dose drug dispensing - except for emergencies dispensing to individual patients from the hospital pharmacy, and dispensing of high-risk medications to clinical areas only in ready-to-use forms [13]. We argue that many medication errors and harm identified in this thesis could have been avoided if these measures had been implemented. One recent study that evaluated implementation of medication safety practices across hospitals in 11 European countries, found that successful implementation requires presence of safety culture and committed leadership [199]. The best way to improve medication safety is through the adoption of a culture of safety. It is the organizations' job to allocate sufficient resources to establish safety teams and invest in technologies that have proven to improve medication safety [19], such as electronic medication administration record and barcode medication administration. In Norway, the health institutions themselves have the responsibility to learn from medication errors and implement necessary measures [200]. At the same time, few recommendations on how organizations should address this issue exist. Also, there seems to be a lack of an overall structural approach to safety in the medication management process. Consequentially, the competence and knowledge about methods for analyzing errors and their causes is apparently poor, while the number of medication errors needed to be analyzed and prevented are high. This thesis is therefore a valid contribution in providing evidence for understanding error producing conditions and the methods utilized to explore the causality.

The substantial number of patients harmed due to medication errors in hospitals make a strong case for taking further steps to tackle unsafe practices. It raises questions about the political interest, at the top level, in the topic of medication safety. To date, the responsibilities at the institutional level are unclear as to whom in particular should ensure that safe medication practices are followed, that new technologies are implemented and evaluate their use, that medication error data are collected and analyzed for risky practices. In other countries, where healthcare systems demonstrate commitment to safety, these tasks are conducted by health professionals solely dedicated to medication safety, often called 'medication safety specialists'. Without an organizational culture that supports and promotes learning from errors, health professionals are unable to perform their work effectively and successfully utilize and technologies to reduce harm.

Technology: implementation, evaluation, and monitoring

Most health technology studies focus on patient safety as the only outcome. As a consequence, these studies often do not capture the contextual understanding behind the medication error rates they identify, although error rates usually reflect the local safety environment in a given organization. Additionally, studies that focused primarily on identifying medication errors have acknowledged that there is inconsistency in medication error rates across studies due to different definitions and error type inclusions [50, 51, 117]. This approach is valuable to establish status quo, however it lacks the improvement feature since error rates across studies can vary to a grade that makes them hardly useful. Unlike those studies, this thesis suggests a broader approach to medication safety research when technologies are applied. We focused on the impact technology has on work and the consequential effect on patient safety. By considering how technology transforms the work system and the work processes, organizations can better predict the outcomes that the technology might produce [201]. Accordingly, our study showed that health professionals often have to compensate for suboptimal conditions of work. While the hospital may be unaware of the consequences of this compensatory behavior, we found that it has resulted in both potential and actual medication errors. When implementing new technologies, organizations should expect new errors from incorrect or not intended use of the technology. It is advisable that while still in implementation stage, one should plan for how these expected errors may be captured in the monitoring stage. Others have used and advocated monitoring of technology use as necessary to identify challenges that will not be identified by other means of monitoring medication errors: incident reports, record review or analyzing scanning logs [202].

The results in this thesis highlight the importance of systematically incorporating medication safety at an early architectural stage throughout the medication management process. The physical aspect of the medication room distance and undersized patient drawers in the medication cart, at times had direct impact to patient safety in our study.

Technology implementation can be more successful if it is supported by the design of the work environment and work processes. Our findings demonstrated that when barcode scanning technology was introduced in the medication management process, it resulted in deviations from medication management policies because the use of technology was not properly adapted to the workflow.

5.4 Contribution to research field and clinical practice

The Paper I and II in this thesis present the first national studies on medication errors in Norway. In April 2019, during the writing of Paper I, the Norwegian Incident Reporting System was closed by the Ministry of Health. This decision, made against international recommendations [13], has disabled a national overview of medication errors including possibility to learn from errors across healthcare institutions. Since then, incident reports are collected at a local or regional level in Norwegian hospitals. While other Nordic countries operate with well-established national incident reporting systems [203, 204], the Ministry of Health in Norway argued that the Norwegian Incident Reporting System had not sufficiently contributed to improved patient safety in hospitals. One study that explored factors associated with successful implementation of medication error reporting systems from 16 countries found that implementing a reporting system without adequate analysis and feedback on reports did not support learning from events [205]. The publication of Paper I received media attention that resulted in series of interviews where I and my main supervisor (AGG) were interviewed by several national and local newspapers, radio channels, and pharmacy and nursing journals in Norway [206]. This reflects that the public and scientific environment has interest in learning from medication errors. Additionally, Paper I has been already been cited for the numbers of patients harmed in hospitals and was used to exemplify some specific incidents. Paper I and II may contribute to the debate on how to avoid preventable harm due to medication errors. Future national publications on medication errors are to some extent hindered without a national overview of medication errors.

Medication dose calculation errors in clinical practice have to my knowledge not been defined or analyzed earlier. We have specifically aimed to address this literature gap by analyzing medication dose calculation errors and identified specific areas prone to errors such as preparing bolus doses, programming infusion pumps and harm associated with dose calculation errors for opiates.

Current knowledge on implementing technological interventions in the medication safety process is approached by measuring medication errors rates. Few studies have quantified the deviations or workarounds during medication administration and elaborated their causes [124, 128]. There is limited knowledge on research combining a process-oriented and human factors approach to investigate the medication management process. In addition to analyzing medication errors, this thesis provides new evidence to the existing human factors and medication safety research as well as addressing the practical challenges with implementing

technology aimed to improve safety in hospitals. In Paper III, we developed a novel, innovative, observational tool that allowed for the detection of unsafe practices and obstacles for using the technology during medication dispensing and administration. We argue that the implementation grade of the intervention relates to its capability to influence safety and reveals reasons to the obstacles that stand in way of success. The combination of the human factors framework and the observational tool have provided an in-depth understanding of hitches in the dispensing and administering process and provide guidance towards a more successful implementation of the barcode medication administration.

By evaluating specific error types, stages in the medication management process, and interventions, this thesis proposes implications for a safer and more sustainable medication management process.

5.5 Clinical implications and future perspectives

- The findings of this thesis indicate that medication errors are not likely to be intercepted in the current medication management process in hospitals. Sustainable and evidence supported safe medication practices must be systematically engrained in each stage consisting of prescribing, dispensing/preparing and administering medication.
- National regulation of medication safety and institutional safety culture is imperative to safeguard the medication management in hospitals. In order for medication safety to be systematically incorporated in the medication management process, decisions at a higher level are needed which involve requirement on personnel devoted to medication safety in each institution. Senior leadership is essential for building a safety culture, through promoting safety initiatives and allocating sufficient resources to support the work of safety teams.
- Health care resources are limited, however considerable resources in hospitals are spent every day on double-checking procedures that have shown not to lead to improved patient safety. There is a need to re-organize the working process and establish proper, long-lasting safety measures. The number of double checks in the clinical areas should be minimized by centralized preparation of high-risk medications and injectables at the hospital pharmacy.
- The effect of double checks should be evaluated through observational studies that distinguish between primed and independent double checks and measure their impact to detect medication errors.
- Physicians, pharmacists, nurses, information technology and quality improvement staff members must collaborate closely if the medication management in the hospitals is to work optimally.
- The human factors approach can be used to predict the deviations, the adaptive behavior of health professionals to overcome the obstacles in their work. This might support the understanding of the work processes and the impact deviations have on patient safety.
- Changes in workflow and policies will result in new deviations. Therefore, when implementing improvement interventions, such as the barcode medication administration, the evaluation must be ongoing.

- The observational tool developed in this study could be utilized to investigate the challenges associated with technology implementation and capture the causal perspective, either for research, or for routine clinical purposes.
- Implementation of a technology is a process that unfolds over time and should be studied over many years to understand how humans, polices, tasks, and organizations are affected with the introduction of the technology. Longitudinal qualitative studies, for example focus groups of end-users could contribute to understanding the challenges and safety culture on ward, including the nurses' perspectives on redesigning the technologies.

Box 1
5 interventions for consideration to improve safety in the medication management process

1. **Pharmacist validation of medication orders in hospitals**
   - Allow pharmacists access to the patient electronic medical record.
   - Mandate medication order review to prevent prescribing errors.
2. **Limit the number of high-risk procedures on hospital wards**
   - Dispense high-risk medications and injectables in ready- to-use or ready-to-administer forms to prevent the most harmful errors.
3. **Standardize the dispensing process**
   - Unit-dose dispensing – provide more standardized doses.
   - Minimize manual tasks during dispensing (patient specific doses should be dispensed ready-to-use by the hospital pharmacy to avoid medication dose calculation errors).
   - Enforce manufacturer barcoding on primary packaging or automated dispensing.
4. **Support monitoring of implemented technologies**
   - Periodical observation of medication administration to identify risky behavior or suboptimal design before it causes errors and patient harm.
5. **Establish safety culture within organizations**
   - Establish error reduction initiatives (routine analysis of incident reports, evaluating of the safety of processes and procedures, follow up on deviations from policies, actively promote safety).
   - Introduce medication safety specialists in each hospital.
   - Increase knowledge on safety initiatives in institutions to allow for a system-oriented management of processes and practice.
   - Reintroduce a national reporting system to support learning from medication errors across regions and institutions.

6 Conclusion

This thesis has studied safety in the medication management process in hospitals through analyzing medication errors reported from hospitals and observing medication administration rounds. Errors in the medication management process were elaborated through causal perspectives, interactions in the working environment and safety culture.

Through analyzing medication errors, we found that a substantial number of patients were harmed by preventable events. Although high-risk medications were associated with the most harm, severe harm also occurred from non-potent medications due to erroneous handling and unsafe practices. Medication errors most frequently occurred during the administration stage, and most commonly involved dosing errors. In our in-depth analysis of medication dose calculation errors, we found that specific tasks during medication management seemed to be error-prone, such as writing or typing slips during prescribing, calculating medication doses, programming infusion pumps, mixing-up bolus injections and handling high-risk medications. The medication management process appeared to lack safeguards to intercept errors in all stages and raised the need for sustainable and structural measures to reduce harm from medication errors.

Furthermore, this thesis opens up new perspectives for detecting and preventing medication errors and emphasizes the role of "normal" deviations in creating error-producing conditions. Registering the use of barcode medication administration with our observational tool allowed for an in-depth understanding of how the technology is used and how it affected safety. We have identified a lack of consistency in performing tasks during dispensing that resulted in workarounds during medication administration. Deviations from medication management policies occurred in over half of all observations and conflicted with patient safety. The human factors approach allowed for a process-oriented analysis of how the technology altered nurses work by analyzing deviations from policies and their causes. The issues with technology design, unclear policies and lack of standardized dispensed doses suggest the need to adopt the processes to nurses' workflow.

The barcode medication administration prevented medication errors even in suboptimal working conditions. However, without systematic monitoring of the technology use, through observation of medication rounds and analyzing events associated to failed use, hospitals will fail to achieve the full benefits of BCMA to patient safety. Therefore, organizations need to

welcome technologies in a prospective manner and implement these while predicting how to avoid undesired consequences from technology.

With the currently ongoing emphasis on digitalization in healthcare, and the concurrent numbers of patients harmed due to medication errors in hospitals, this body of work is a timely reminder of the need to focus on safety in all stages along the medication management process.

Future interventions should focus on increasing knowledge on medication safety, measuring errors and adverse drug events, analyzing incident data, and strengthening a safety culture within organizations.

7 Literature

1. Helse Bergen siktet etter cellegiftoverdose på Haukeland [Health Bergen charged after a chemotherapy overdosage at Haukeland]. Aftenposten. 2020. Avaliable: https://www.aftenposten.no/norge/i/rABpdm/helse-bergen-siktet-etter-cellegiftoverdose-paa-haukeland [Accessed 20 Oct 2021].

2. European Comission. Patient Safety and Quality of Care. Special Eurobarometer 411. 2014. Avaliable: https://europa.eu/eurobarometer/surveys/detail/1100 [Accessed 09 Nov 2021].

3. Kohn LT, Corrigan JM, Donaldson MS. To Err Is Human: Building a Safer Health System. Washington, D.C.: National Academy Press; 2000. 49-66 p.

4. Makary MA, Daniel M. Medical error—the third leading cause of death in the US. *BMJ* 2016;353.

5. Shojania KG, Dixon-Woods M. Estimating deaths due to medical error: the ongoing controversy and why it matters. *BMJ Quality & Safety* 2017;26(5):423-8. doi:10.1136/bmjqs-2016-006144.

6. Bates DW, Singh H. Two Decades Since To Err Is Human: An Assessment Of Progress And Emerging Priorities In Patient Safety. *Health affairs (Project Hope)* 2018;37(11):1736. doi:10.1377/hlthaff.2018.0738.

7. Schwendimann R, Blatter C, Dhaini S, et al. The occurrence, types, consequences and preventability of in-hospital adverse events – a scoping review. *BMC Health Services Research* 2018;18(1):521. doi:10.1186/s12913-018-3335-z.

8. Leape LL, Brennan TA, Laird N, et al. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. *New England Journal of Medicine* 1991;324(6):377-84. doi:10.1056/nejm199102073240605.

9. de Vries EN, Ramrattan MA, Smorenburg SM, et al. The incidence and nature of in-hospital adverse events: a systematic review. *Quality & Safety in Health Care* 2008;17(3):216-23. doi:10.1136/qshc.2007.023622.

10. Donaldson LJ, Kelley ET, Dhingra-Kumar N, et al. Medication Without Harm: WHO's Third Global Patient Safety Challenge. *Lancet* 2017;389(10080):1680-1. doi:10.1016/s0140-6736(17)31047-4.

11. Spencer E, Walshe K. National quality improvement policies and strategies in European healthcare systems. *Quality and Safety in Health Care* 2009;18(Suppl 1):i22-i7. doi:10.1136/qshc.2008.029355.

12. Council of Europe. Recommendation Rec(2006)7 of the Committee of Ministers to member states on management of patient safety and prevention of adverse events in health care. 2006 (b). Avaliable: https://wcd.coe.int/ViewDoc.jsp?id=1005439&Site=CM [Accessed 03 Mar 2022].

.

13. Council of Europe. Creation of a better medication safety culture in Europe: building up safe medication practices. Expert Group on Safe Medication Practices (P-SP-PH/SAFE). 2006 (a). Avaliable: http://optimiz-sih-circ-med.fr/Documents/Council_of_Europe_Medication_Safety_Report_19-03-2007.pdf [Accessed 23 Aug 2019].

14. NCC MERP. National Coordinating Council for Medication Error Reporting and Prevention. Index for Categorizing Medication Errors. Avaliable: https://www.nccmerp.org/about-medication-errors [Accessed 08 Nov 2021].

15. Lisby M, Nielsen LP, Mainz J. Errors in the medication process: frequency, type, and potential clinical consequences. *International Journal for Quality in Health Care* 2005;17(1):15-22. doi:10.1093/intqhc/mzi015.

16. Keers RN, Williams SD, Cooke J, et al. Prevalence and nature of medication administration errors in health care settings: a systematic review of direct observational evidence. *Annals of Pharmacotherapy* 2013;47(2):237-56. doi:10.1345/aph.1R147.

17. Cottney A, Innes J. Medication-administration errors in an urban mental health hospital: a direct observation study. *International Journal of Mental Health Nursing* 2015;24(1):65-74. doi:10.1111/inm.12096.

18. Roughead EE, Semple SJ, Rosenfeld E. The extent of medication errors and adverse drug reactions throughout the patient journey in acute care in Australia. *International Journal of Evidence-based Healthcare* 2016;14(3):113-22. doi:10.1097/xeb.0000000000000075.

19. Institute of Medicine Preventing Medication Errors. Washington, DC: The National Academies Press; 2007. 480 p.

20. Department of Health. The Report of the Short Life Working Group on reducing medication-related harm. London 2018. Avaliable: https://www.gov.uk/government/publications/medication-errors-short-life-working-group-report [Accessed 08 Nov 2021].

21. The Norwegian Patient Safety Programme: In Safe Hands. 2021. Avaliable: https://www.itryggehender24-7.no/om-i-trygge-hender-24-7. [Accessed 08 Nov 2021].

22. Nasjonal handlingsplan styrker innsatsen for pasientsikkerhet [National Action Plan strengthens the efford for Patient Safety]. Avaliable: https://www.pasientsikkerhetsprogrammet.no/aktuelt/nyheter/en-felles-innsats-for-pasientsikkerhet [Accessed 05 Jul 2019].

23. McKibbon KA, Lokker C, Handler SM, et al. The effectiveness of integrated health information technologies across the phases of medication management: a systematic review of randomized controlled trials. *Journal of the American Medical Informatics Association* 2012;19(1):22-30. doi:10.1136/amiajnl-2011-000304.

24. World Health Organization. Patient safety. Avaliable: https://www.euro.who.int/en/health-topics/Health-systems/patient-safety/patient-safety [Accessed 05 Nov 2021].

25. Institute for Safe Medication Practices Canada. Definitions of terms. Avaliable: https://www.ismp-canada.org/definitions.htm. [Accessed 03 Mar 2022].

26. Bates DW, Boyle DL, Vander Vliet MB, et al. Relationship between medication errors and adverse drug events. *Journal of General Internal Medicine* 1995;10(4):199-205. doi:10.1007/bf02600255.

27. Bates DW, Cullen DJ, Laird N, et al. Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group. *Journal of the American Medical Association* 1995;274(1):29-34. doi:10.1001/jama.1995.03530010043033.

28. Gurwitz JH, Field TS, Harrold LR, et al. Incidence and preventability of adverse drug events among older persons in the ambulatory setting. *Journal of American Medical Association* 2003;289(9):1107-16. doi:10.1001/jama.289.9.1107.

29. Gandhi TK, Burstin HR, Cook EF, et al. Drug complications in outpatients. *Journal of General Internal Medicine* 2000;15(3):149-54. doi:10.1046/j.1525-1497.2000.04199.x.

30. Field TS, Gurwitz JH, Harrold LR, et al. Strategies for Detecting Adverse Drug Events among Older Persons in the Ambulatory Setting. *Journal of the American Medical Informatics Association* 2004;11(6):492-8. doi:10.1197/jamia.M1586.

31. Macrae C. When no news is bad news: communication failures and the hidden assumptions that threaten safety. *Journal of the Royal Society of Medicine* 2017;111(1):5-7. doi:10.1177/0141076817738503.

32. Larson CM, Saine D. Medication Safety Officer's Handbook: American Society of Health-System Pharmacists, Bethesda, MD; 2013.

33. Dabba K, Elswood M, Ameer A, et al. A mixed methods analysis of clozapine errors reported to the National Reporting and Learning System. *Pharmacoepidemiology and Drug Safety* 2019;28(5):657-64. doi:10.1002/pds.4727.

34. Erstad BL, Patanwala AE, Theodorou AA. Comparison of methods for the detection of medication safety events in the critically ill. *Current Drug Safety* 2012;7(3):238-46. doi:10.2174/157488612803251270.

35. Franklin BD, Taxis K, Barber N. Parenteral drug errors. Reported error rates are likely to be underestimation. *BMJ (Clinical research ed)* 2009;338:b1814. doi:10.1136/bmj.b1814.

36. McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *Journal of Clinical Epidemiology* 2014;67(3):267-77. doi:10.1016/j.jclinepi.2013.08.015.

37. Classen DC, Resar R, Griffin F, et al. 'Global trigger tool' shows that adverse events in hospitals may be ten times greater than previously measured. *Health Aff (Millwood)* 2011;30(4):581-9. doi:10.1377/hlthaff.2011.0190.

38. Hanskamp-Sebregts M, Zegers M, Vincent C, et al. Measurement of patient safety: a systematic review of the reliability and validity of adverse event detection with record review. *BMJ Open* 2016;6(8):e011078. doi:10.1136/bmjopen-2016-011078.

39. Griffin FA, Resar RK. IHI Global Trigger Tool for Measuring Adverse Events (Second Edition). IHI Innovation Series white paper. Cambridge, MA: Institute for Healthcare Improvement. 2009. Avaliable: www.IHI.org [Accessed 05 Nov 2021].

40. Kennerly DA, Saldaña M, Kudyakov R, et al. Description and evaluation of adaptations to the global trigger tool to enhance value to adverse event reduction efforts. *Journal of Patient Safety* 2013;9(2):87-95. doi:10.1097/PTS.0b013e31827cdc3b.

41. Hwang JI, Chin HJ, Chang YS. Characteristics associated with the occurrence of adverse events: a retrospective medical record review using the Global Trigger Tool in a fully digitalized tertiary teaching hospital in Korea. *Journal of Evaluation in Clinical Practice* 2014;20(1):27-35. doi:10.1111/jep.12075.

42. Schildmeijer KG, Nilsson L, Arestedt K, et al. The assessment of adverse events in medical care; lack of consistency between experienced teams using the Global Trigger Tool. *BMJ Quality & Safety* 2013;22(3):271-2. doi:10.1136/bmjqs-2012-001587.

43. Hibbert PD, Molloy CJ, Hooper TD, et al. The application of the Global Trigger Tool: a systematic review. *International Journal for Quality in Health Care* 2017;28(6):640-9. doi:10.1093/intqhc/mzw115.

44. Doupi P, Svaar H, Bjørn B, et al. Use of the Global Trigger Tool in patient safety improvement efforts: Nordic experiences. *Cognition, Technology & Work* 2015;17(1):45-54. doi:10.1007/s10111-014-0302-2.

45. Bates DW, Evans RS, Murff H, et al. Detecting adverse events using information technology. *Journal of the American Medical Informatics Association* 2003;10(2):115-28. doi:10.1197/jamia.m1074.

46. Stockwell DC, Kane-Gill SL. Developing a patient safety surveillance system to identify adverse events in the intensive care unit. *Critical Care Medicine* 2010;38(6 Suppl):S117-25. doi:10.1097/CCM.0b013e3181dde2d9.

47. Melton GB, Hripcsak G. Automated detection of adverse events using natural language processing of discharge summaries. *Journal of the American Medical Informatics Association* 2005;12(4):448-57. doi:10.1197/jamia.M1794.

48. Ferranti J, Horvath MM, Cozart H, et al. Reevaluating the safety profile of pediatrics: a comparison of computerized adverse drug event surveillance and voluntary reporting in the pediatric environment. *Pediatrics* 2008;121(5):e1201-7. doi:10.1542/peds.2007-2609.

49. Flynn EA, Barker KN, Pepper GA, et al. Comparison of methods for detecting medication errors in 36 hospitals and skilled-nursing facilities. *American Journal of Health-System Pharmacy* 2002;59(5):436-46. doi:10.1093/ajhp/59.5.436.

50. Franklin BD, Birch S, Savage I, et al. Methodological variability in detecting prescribing errors and consequences for the evaluation of interventions. *Pharmacoepidemiology and Drug Safety* 2009;18(11):992-9. doi:10.1002/pds.1811.

51. Franklin BD, Birch S, Schachter M, et al. Testing a trigger tool as a method of detecting harm from medication errors in a UK hospital: a pilot study. *International Journal of Pharmacy Practice* 2010;18(5):305-11. doi:10.1111/j.2042-7174.2010.00058.x.

52. Jha AK, Kuperman GJ, Teich JM, et al. Identifying adverse drug events: development of a computer-based monitor and comparison with chart review and stimulated voluntary report. *Journal of the American Medical Informatics Association* 1998;5(3):305-14. doi:10.1136/jamia.1998.0050305.

53. Kilbridge PM, Campbell UC, Cozart HB, et al. Automated surveillance for adverse drug events at a community hospital and an academic medical center. *Journal of the American Medical Informatics Association* 2006;13(4):372-7. doi:10.1197/jamia.M2069.

54. Maaskant JM, Smeulers M, Bosman D, et al. The Trigger Tool as a Method to Measure Harmful Medication Errors in Children. *Journal of Patient Safety* 2018;14(2):95-100. doi:10.1097/pts.0000000000000177.

55. O'Leary KJ, Devisetty VK, Patel AR, et al. Comparison of traditional trigger tool to data warehouse based screening for identifying hospital adverse events. *BMJ Quality & Safety* 2013;22(2):130-8. doi:10.1136/bmjqs-2012-001102.

56. Tinoco A, Evans RS, Staes CJ, et al. Comparison of computerized surveillance and manual chart review for adverse events. *Journal of the American Medical Informatics Association* 2011;18(4):491-7. doi:10.1136/amiajnl-2011-000187.

57. Yun IS, Koo MJ, Park EH, et al. A comparison of active surveillance programs including a spontaneous reporting model for phamacovigilance of adverse drug events in a hospital. *Korean Journal of Internal Medicine* 2012;27(4):443-50. doi:10.3904/kjim.2012.27.4.443.

58. Forster AJ, Jennings A, Chow C, et al. A systematic review to evaluate the accuracy of electronic adverse drug event detection. *Journal of the American Medical Informatics Association* 2012;19(1):31-8. doi:10.1136/amiajnl-2011-000454.

59. Hooper AJ, Tibballs J. Comparison of a Trigger Tool and voluntary reporting to identify adverse events in a paediatric intensive care unit. *Anaesthesia and Intensive Care* 2014;42(2):199-206. doi:10.1177/0310057x1404200206.

60. Awami S, Doogue M, Calabretto J-P, et al. IT Support for the Medication Management Process in Hospitals: IADIS International e-Health Conference; 2009.

61. Wahr JA, Shore AD, Harris LH, et al. Comparison of intensive care unit medication errors reported to the United States' MedMarx and the United Kingdom's National Reporting and Learning System: a cross-sectional study. *American Journal of Medical Quality* 2014;29(1):61-9. doi:10.1177/1062860613482964.

62. Thomas B, Pallivalapila A, El Kassem W, et al. Investigating the incidence, nature, severity and potential causality of medication errors in hospital settings in Qatar. *International Journal of Clinical Pharmacy* 2021;43(1):77-84. doi:10.1007/s11096-020-01108-y.

63. Cousins DH, Gerrett D, Warner B. A review of medication incidents reported to the National Reporting and Learning System in England and Wales over 6 years (2005-2010). *British Journal of Clinical Pharmacology* 2012;74(4):597-604. doi:10.1111/j.1365-2125.2011.04166.x.

64. Pham JC, Story JL, Hicks RW, et al. National study on the frequency, types, causes, and consequences of voluntarily reported emergency department medication errors. *Journal of Emergency Medicine* 2011;40(5):485-92. doi:10.1016/j.jemermed.2008.02.059.

65. Miller MR, Clark JS, Lehmann CU. Computer based medication error reporting: insights and implications. *Quality & Safety in Health Care* 2006;15(3):208-13. doi:10.1136/qshc.2005.016733.

66. Maidment ID, Haw C, Stubbs J, et al. Medication errors in older people with mental health problems: a review. *International Journal of Geriatric Psychiatry* 2008;23(6):564-73. doi:10.1002/gps.1943.

67. Leape LL, Bates DW, Cullen DJ, et al. Systems Analysis of Adverse Drug Events. *Journal of American Medical Association* 1995;274(1):35-43. doi:10.1001/jama.1995.03530010049034.

68. Greengold NL, Shane R, Schneider P, et al. The impact of dedicated medication nurses on the medication administration error rate: a randomized controlled trial. *Archives of Internal Medicine* 2003;163(19):2359-67. doi:10.1001/archinte.163.19.2359.

69. Huckels-Baumgart S, Baumgart A, Buschmann U, et al. Separate Medication Preparation Rooms Reduce Interruptions and Medication Errors in the Hospital Setting: A Prospective Observational Study. *Journal of Patient Safety* 2021;17(3):e161-e8. doi:10.1097/pts.0000000000000335.

70. Smeulers M, Verweij L, Maaskant JM, et al. Quality indicators for safe medication preparation and administration: a systematic review. *PLoS One* 2015;10(4):e0122695. doi:10.1371/journal.pone.0122695.

71. Kron T. stepping beyond the 5 rights of administering drugs. *American Journal of Nursing* 1962;62:62-3.

72. Macdonald M. Patient safety: examining the adequacy of the 5 rights of medication administration. *Clinical Nurse Specialist* 2010;24(4):196-201. doi:10.1097/NUR.0b013e3181e3605f.

73. Institute for Safe Medication Practices. The five rights: a destination without a map. Avaliable: http://www.ismp.org/newsletters/acutecare/articles/20070125.asp. [Accessed 30 Aug 2021].

74. Gonzales K. Medication administration errors and the pediatric population: a systematic search of the literature. *Journal of Pediatric Nursing* 2010;25(6):555-65. doi:10.1016/j.pedn.2010.04.002.

75. Rishoej RM, Almarsdóttir AB, Christesen HT, et al. Medication errors in pediatric inpatients: a study based on a national mandatory reporting system. *European Journal of Pediatrics* 2017;176(12):1697-705. doi:10.1007/s00431-017-3023-8.

76. Leape LL. Error in Medicine. *Journal of American Medical Association* 1994;272(23):1851-7. doi:10.1001/jama.1994.03520230061039.

77. Keers RN, Williams SD, Cooke J, et al. Causes of medication administration errors in hospitals: a systematic review of quantitative and qualitative evidence. *Drug Safety* 2013;36(11):1045-67. doi:10.1007/s40264-013-0090-2.

78. Brady AM, Malone AM, Fleming S. A literature review of the individual and systems factors that contribute to medication errors in nursing practice. *Journal of Nursing Management* 2009;17(6):679-97. doi:10.1111/j.1365-2834.2009.00995.x.

79. Taxis K, Barber N. Causes of intravenous medication errors: an ethnographic study. *Quality & Safety in Health Care* 2003;12(5):343-7. doi:10.1136/qhc.12.5.343.

80. Rodriguez-Gonzalez CG, Herranz-Alonso A, Martin-Barbero ML, et al. Prevalence of medication administration errors in two medical units with automated prescription and dispensing. *Journal of the American Medical Informatics Association* 2012;19(1):72-8. doi:10.1136/amiajnl-2011-000332.

81. Dickinson A, McCall E, Twomey B, et al. Paediatric nurses' understanding of the process and procedure of double-checking medications. *Journal of Clinical Nursing* 2010;19(5-6):728-35. doi:10.1111/j.1365-2702.2009.03130.x.

82. Jones JH, Treiber L. When the 5 rights go wrong: medication errors from the nursing perspective. *Journal of Nursing Care Quality* 2010;25(3):240-7. doi:10.1097/NCQ.0b013e3181d5b948.

83. Simonsen BO, Daehlin GK, Johansson I, et al. Differences in medication knowledge and risk of errors between graduating nursing students and working registered nurses: comparative study. *BMC Health Services Research* 2014;14:580. doi:10.1186/s12913-014-0580-7.

84. Fleming S, Brady A-M, Malone A-M. An evaluation of the drug calculation skills of registered nurses. *Nurse Education in Practice* 2014;14(1):55-61. doi:10.1016/j.nepr.2013.06.002.

85. Wright K. Do calculation errors by nurses cause medication errors in clinical practice? A literature review. *Nurse Education Today* 2010;30(1):85-97. doi:10.1016/j.nedt.2009.06.009.

86. Wright K. Student nurses need more than maths to improve their drug calculating skills. *Nurse Education Today* 2007;27(4):278-85. doi:10.1016/j.nedt.2006.05.007.

87. Warburton P. Poor numeracy skills must be tackled to cut medication errors. *Nursing Times* 2010;106(9):13.

88. Doherty C, Mc Donnell C. Tenfold medication errors: 5 years' experience at a university-affiliated pediatric hospital. *Pediatrics* 2012;129(5):916-24. doi:10.1542/peds.2011-2526.

89. Tse Y, Tuthill D. Incidence of paediatric 10-fold medication errors in Wales. *Archives of Disease in Childhood* 2021;106(7):656-61. doi:10.1136/archdischild-2020-319130.

90. Shaqdan KW, Aran S, Daftari Besheli L, et al. Root-cause analysis and health failure mode and effect analysis: two leading techniques in health care quality assessment. *Journal of the American College of Radiology: JACR* 2014;11 6:572-9.

91. Davis S, Riley W, Gurses AP, et al. Advances in Patient Safety. Failure Modes and Effects Analysis Based on In Situ Simulations: A Methodology to Improve Understanding of Risks and Failures. In: Henriksen K, Battles JB, Keyes MA, Grady ML, editors. Rockville (MD): Agency for Healthcare Research and Quality (US); 2008.

92. Peerally MF, Carr S, Waring J, et al. The problem with root cause analysis. *BMJ Quality & Safety* 2017;26(5):417-22. doi:10.1136/bmjqs-2016-005511.

93. Franklin BD, Shebl NA, Barber N. Failure mode and effects analysis: too little for too much? *BMJ Quality & Safety* 2012;21(7):607-11. doi:10.1136/bmjqs-2011-000723.

94. Phillips J, Beam S, Brinker A, et al. Retrospective analysis of mortalities associated with medication errors. *American Journal of Health-System Pharmacy* 2001;58(19):1835-41. doi:10.1093/ajhp/58.19.1835.

95. Nichols P, Copeland TS, Craib IA, et al. Learning from error: identifying contributory causes of medication errors in an Australian hospital. *Medical journal of Australia* 2008;188(5):276-9. doi:10.5694/j.1326-5377.2008.tb01619.x.

96. Taxis K, Barber N. Causes of intravenous medication errors - Observation of nurses in a German hospital. *Journal of Public Health* 2004;12:132-8. doi:10.1007/s10389-004-0019-4.

97. McBride-Henry K, Foureur M. A secondary care nursing perspective on medication administration safety. *Journal of Advanced Nursing* 2007;60(1):58-66. doi:10.1111/j.1365-2648.2007.04378.x.

98. Izadpanah F, Nikfar S, Bakhshi Imcheh F, et al. Assessment of Frequency and Causes of Medication Errors in Pediatrics and Emergency Wards of Teaching Hospitals Affiliated to Tehran University of Medical Sciences (24 Hospitals). *Journal of Medicine and Life* 2018;11(4):299-305. doi:10.25122/jml-2018-0046.

99. Carayon P, Wetterneck TB, Hundt AS, et al. Evaluation of Nurse Interaction With Bar Code Medication Administration Technology in the Work Environment. *Journal of Patient Safety* 2007;3:34-42.

100. Mueller BU, Neuspiel DR, Fisher ERS, et al. Principles of Pediatric Patient Safety: Reducing Harm Due to Medical Care. *Pediatrics* 2019;143(2). doi:10.1542/peds.2018-3649.

101. Legemiddelhåndteringsforskriften med kommentarer [Medication management policy with comments]. Oslo: The Norwegian Directorate of Health. 2015. Rundskriv IS-7/2015. Avaliable: https://www.helsedirektoratet.no/rundskriv/legemiddelhandteringsforskriften-med-kommentarer/Legemiddelh%C3%A5ndteringsforskriften%20med%20kommentarer%20(rev)%20%E2%80%93%20Rundskriv.pdf/_/attachment/inline/506142af-6a2f-407f-8f3d-b87d3adc3cd5:81191d21a0a9e3131cb80deff61f723499f3f65c/Legemiddelh%C3%A5ndteringsforskriften%20med%20kommentarer%20(rev)%20%E2%80%93%20Rundskriv.pdf [Accessed 30 Aug 2021].

102. Armitage G. Double checking medicines: defence against error or contributory factor? *Journal of Evaluation in Clinical Practice* 2008;14(4):513-9. doi:10.1111/j.1365-2753.2007.00907.x.

103. Alsulami Z, Choonara I, Conroy S. Paediatric nurses' adherence to the double-checking process during medication administration in a children's hospital: an observational study. *Journal of Advanced Nursing* 2014;70(6):1404-13. doi:10.1111/jan.12303.

104. Westbrook JI, Li L, Raban MZ, et al. Associations between double-checking and medication administration errors: a direct observational study of paediatric inpatients. *BMJ Quality & Safety* 2021;30(4):320-30. doi:10.1136/bmjqs-2020-011473.

105. Buntin MB, Burke MF, Hoaglin MC, et al. The benefits of health information technology: a review of the recent literature shows predominantly positive results. *Health Aff (Millwood)* 2011;30(3):464-71. doi:10.1377/hlthaff.2011.0178.

106. Agrawal A. Medication errors: prevention using information technology systems. *British Journal of Clinical Pharmacology* 2009;67(6):681-6. doi:10.1111/j.1365-2125.2009.03427.x.

107. Ahtiainen HK, Kallio MM, Airaksinen M, et al. Safety, time and cost evaluation of automated and semi-automated drug distribution systems in hospitals: a systematic review. *European Journal of Hospital Pharmacy* 2020;27(5):253-62. doi:10.1136/ejhpharm-2018-001791.

108. Khanna R, Yen T. Computerized physician order entry: promise, perils, and experience. *The Neurohospitalist* 2014;4(1):26-33. doi:10.1177/1941874413495701.

109. Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *Journal of American Medical Association* 1998;280(15):1311-6. doi:10.1001/jama.280.15.1311.

110. Leung AA, Keohane C, Amato M, et al. Impact of vendor computerized physician order entry in community hospitals. *Journal of General Internal Medicine* 2012;27(7):801-7. doi:10.1007/s11606-012-1987-7.

111. Koppel R, Metlay JP, Cohen A, et al. Role of computerized physician order entry systems in facilitating medication errors. *Journal of American Medical Association* 2005;293(10):1197-203. doi:10.1001/jama.293.10.1197.

112. Pedersen CA, Schneider PJ, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: dispensing and administration--2008. *American Journal of Health-System Pharmacy* 2009;66(10):926-46. doi:10.2146/ajhp080715.

113. Cottney A. Improving the safety and efficiency of nurse medication rounds through the introduction of an automated dispensing cabinet. *BMJ Quality Improvement Reports* 2014;3(1). doi:10.1136/bmjquality.u204237.w1843.

114. Ohashi K, Dalleur O, Dykes PC, et al. Benefits and risks of using smart pumps to reduce medication error rates: a systematic review. *Drug Safety* 2014;37(12):1011-20. doi:10.1007/s40264-014-0232-1.

115. Lyons I, Furniss D, Blandford A, et al. Errors and discrepancies in the administration of intravenous infusions: a mixed methods multihospital observational study. *BMJ Quality & Safety* 2018;27(11):892-901. doi:10.1136/bmjqs-2017-007476.

116. Klarich A, Noonan TZ, Reichlen C, et al. Usability of smart infusion pumps: A heuristic evaluation. *Applied Ergonomics* 2022;98:103584. doi:10.1016/j.apergo.2021.103584.

117. Schnock KO, Dykes PC, Albert J, et al. The frequency of intravenous medication administration errors related to smart infusion pumps: a multihospital observational study. *BMJ Quality & Safety* 2017;26(2):131-40. doi:10.1136/bmjqs-2015-004465.

118. Rothschild JM, Keohane CA, Cook EF, et al. A controlled trial of smart infusion pumps to improve medication safety in critically ill patients. *Critical Care Medicine* 2005;33(3):533-40. doi:10.1097/01.ccm.0000155912.73313.cd.

119. Poon EG, Keohane CA, Yoon CS, et al. Effect of bar-code technology on the safety of medication administration. *New England Journal of Medicine* 2010;362(18):1698-707. doi:10.1056/NEJMsa0907115.

120. Helmons PJ, Wargel LN, Daniels CE. Effect of bar-code-assisted medication administration on medication administration errors and accuracy in multiple patient care areas. *American Journal of Health-System Pharmacy* 2009;66(13):1202-10. doi:10.2146/ajhp080357.

121. Franklin BD, O'Grady K, Donyai P, et al. The impact of a closed-loop electronic prescribing and administration system on prescribing errors, administration errors and staff time: a before-and-after study. *Quality & Safety in Health Care* 2007;16(4):279-84. doi:10.1136/qshc.2006.019497.

122. Seibert HH, Maddox RR, Flynn EA, et al. Effect of barcode technology with electronic medication administration record on medication accuracy rates. *American Journal of Health-System Pharmacy* 2014;71(3):209-18. doi:10.2146/ajhp130332.

123. Rack LL, Dudjak LA, Wolf GA. Study of nurse workarounds in a hospital using bar code medication administration system. *Journal of Nursing Care Quality* 2012;27(3):232-9. doi:10.1097/NCQ.0b013e318240a854.

124. van der Veen W, van den Bemt P, Wouters H, et al. Association between workarounds and medication administration errors in bar-code-assisted medication administration in hospitals. *Journal of the American Medical Informatics Association* 2018;25(4):385-92. doi:10.1093/jamia/ocx077.

125. Samaranayake NR, Cheung STD, Cheng K, et al. Implementing a bar-code assisted medication administration system: effects on the dispensing process and user perceptions. *International Journal of Medical Informatics* 2014;83(6):450-8. doi:10.1016/j.ijmedinf.2014.03.001.

126. Cheung RB, Aiken LH, Clarke SP, et al. Nursing care and patient outcomes: international evidence. *Enfermeria Clinica* 2008;18(1):35-40. doi:10.1016/s1130-8621(08)70691-0.

127. Reason J, Manstead A, Stradling S, et al. Errors and violations on the roads: a real distinction? *Ergonomics* 1990;33(10-11):1315-32. doi:10.1080/00140139008925335.

128. Koppel R, Wetterneck T, Telles JL, et al. Workarounds to Barcode Medication Administration Systems: Their Occurrences, Causes, and Threats to Patient Safety. *Journal of the American Medical Informatics Association* 2008;15(4):408-23. doi:10.1197/jamia.M2616.

129. Bonkowski J, Carnes C, Melucci J, et al. Effect of barcode-assisted medication administration on emergency department medication errors. *Academic Emergency Medicine* 2013;20(8):801-6. doi:10.1111/acem.12189.

130. Risør BW, Lisby M, Søresen J. Cost-Effectiveness Analysis of an Automated Medication System Implemented in a Danish Hospital Setting. *Value in Health* 2017;20:886-93. doi:10.1016/j.jval.2017.03.001.

131. Wideman MV, Whittler ME, Anderson TM. Advances in Patient Safety. Barcode Medication Administration: Lessons Learned from an Intensive Care Unit Implementation. In: Henriksen K, Battles JB, Marks ES, Lewin DI, editors. Advances in Patient Safety: From Research to Implementation (Volume 3: Implementation Issues). Rockville (MD): Agency for Healthcare Research and Quality (US); 2005.

132. Shah K, Lo C, Babich M, et al. Bar Code Medication Administration Technology: A Systematic Review of Impact on Patient Safety When Used with Computerized Prescriber Order Entry and Automated Dispensing Devices. *The Canadian Journal of Hospital Pharmacy* 2016;69(5):394-402.

133. Lainer M, Mann E, Sönnichsen A. Information technology interventions to improve medication safety in primary care: a systematic review. *International Journal for Quality in Health Care* 2013;25(5):590-8. doi:10.1093/intqhc/mzt043.

134. Koyama AK, Maddox CS, Li L, et al. Effectiveness of double checking to reduce medication administration errors: a systematic review. *BMJ Quality & Safety* 2020;29(7):595-603. doi:10.1136/bmjqs-2019-009552.

135. Vicente Oliveros N, Gramage Caro T, Pérez Menendez-Conde C, et al. Effect of an electronic medication administration record application on patient safety. *Journal of Evaluation in Clinical Practice* 2017;23(4):888-94. doi:https://doi.org/10.1111/jep.12753.

136. Fanning L, Jones N, Manias E. Impact of automated dispensing cabinets on medication selection and preparation error rates in an emergency department: a prospective and direct observational before-and-after study. *Journal of Evaluation in Clinical Practice* 2016;22(2):156-63. doi:10.1111/jep.12445.

137. Chapuis C, Roustit M, Bal G, et al. Automated drug dispensing system reduces medication errors in an intensive care setting. *Critical Care Medicine* 2010;38(12):2275-81. doi:10.1097/CCM.0b013e3181f8569b.

138. Hassink JJM, Essenberg MD-v, Roukema JA, et al. Effect of bar-code-assisted medication administration on medication administration errors. *American Journal of Health-System Pharmacy* 2013;70(7):572-3. doi:10.2146/ajhp120257.

139. Zheng WY, Lichtner V, Van Dort BA, et al. The impact of introducing automated dispensing cabinets, barcode medication administration, and closed-loop electronic medication management systems on work processes and safety of controlled medications in hospitals: A systematic review. *Research in Social & Administrative Pharmacy* 2020. doi:10.1016/j.sapharm.2020.08.001.

140. Ros H, de Vreeze-Wesselink E. Reducing the number of dispensing errors by implementing a combination of a CPOE system and a bar-code-assisted dispensing system: the BAP concept. *European Journal of Hospital Pharmacy Science* 2009;15:86-92.

141. Ferner RE. Medication errors that have led to manslaughter charges. *BMJ (Clinical research ed)* 2000;321(7270):1212-6. doi:10.1136/bmj.321.7270.1212.

142. Boysen PG, 2nd. Just culture: a foundation for balanced accountability and patient safety. *The Ochsner journal* 2013;13(3):400-6.

143. Reason J. Human error: Cambridge university press; 1990. 1-19 p.

144. Körner M, Wirtz MA, Bengel J, et al. Relationship of organizational culture, teamwork and job satisfaction in interprofessional teams. *BMC Health Services Research* 2015;15:243. doi:10.1186/s12913-015-0888-y.

145. Halligan M, Zecevic A. Safety culture in healthcare: a review of concepts, dimensions, measures and progress. *BMJ Quality & Safety* 2011;20(4):338-43. doi:10.1136/bmjqs.2010.040964.

146. Reason J. Human error: models and management. *BMJ (Clinical research ed)* 2000;320(7237):768-70. doi:10.1136/bmj.320.7237.768.

147. Sanders MSMEJ. Human factors in engineering and design. New York: McGraw-Hill; 1993.

148. Carayon P, Smith MJ. Work organization and ergonomics. *Applied Ergonomics* 2000;31(6):649-62. doi:10.1016/s0003-6870(00)00040-5.

149. Chapanis A, Safrin MA. Of misses and medicines. *Journal of Chronic Diseases* 1960;12:403-8. doi:10.1016/0021-9681(60)90065-5.

150. Carayon P, Schoofs Hundt A, Karsh BT, et al. Work system design for patient safety: the SEIPS model. *Quality & Safety in Health Care* 2006;15 (Suppl 1):i50-i8. doi:10.1136/qshc.2005.015842.

151. Carayon P, Wetterneck TB, Rivera-Rodriguez AJ, et al. Human factors systems approach to healthcare quality and patient safety. *Applied Ergonomics* 2014;45(1):14-25. doi:10.1016/j.apergo.2013.04.023.

152. Holden RJ, Carayon P, Gurses AP, et al. SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. *Ergonomics* 2013;56(11):1669-86. doi:10.1080/00140139.2013.838643.

153. Carayon P, Wooldridge A, Hoonakker P, et al. SEIPS 3.0: Human-centered design of the patient journey for patient safety. *Applied Ergonomics* 2020;84:103033. doi:10.1016/j.apergo.2019.103033.

154. Holden RJ, Carayon P. SEIPS 101 and seven simple SEIPS tools. *BMJ Quality & Safety* 2021;30(11):901-10. doi:10.1136/bmjqs-2020-012538.

155. Holden RJ, Rivera-Rodriguez AJ, Faye H, et al. Automation and adaptation: Nurses' problem-solving behavior following the implementation of bar coded medication administration technology. *Cognition, Technology & Work* 2013;15(3):283-96. doi:10.1007/s10111-012-0229-4.

156. Odberg KR, Hansen BS, Aase K, et al. A work system analysis of the medication administration process in a Norwegian nursing home ward. *Applied Ergonomics* 2020;86:103100. doi:https://doi.org/10.1016/j.apergo.2020.103100.

157. The Norwegian health care system and pharmaceutical system. The Norwegian Medicines Agency. 2016. Avaliable: https://legemiddelverket.no/english/about-us/the-norwegian-health-care-system-and-pharmaceutical-system [Accessed 04 Mar 2022].

158. Læringsnotater fra Helsedirektoratet. [Learning notes from the Norwegian Directorate of Helath]. The Norwegian Directorate of Helath. 2017. Avaliable: https://www.helsedirektoratet.no/produkter?tema=laeringsnotat [Accessed 30 Aug 2021].

159. Conceptual Framework for the International Classification for Patient Safety. World Health Organization. 2009. Avaliable: https://www.who.int/patientsafety/implementation/taxonomy/ICPS-report/en/ [Accessed 10 May 2019].

160. Whittemore R, Chase SK, Mandle CL. Validity in qualitative research. *Qualitative Health Research* 2001;11(4):522-37.

161. WHO collaborating Centre for Drug Statistics Methodology Anatomical therapeutic chemical (ATC) classification index with defined daily doses (DDD). Avaliable: https://www.whocc.no/ [Accessed 23 Aug 2019].

162. Schoonenboom J, Johnson RB. How to Construct a Mixed Methods Research Design. *Kolner Zeitschrift fur Soziologie und Sozialpsychologie* 2017;69(Suppl 2):107-31. doi:10.1007/s11577-017-0454-1.

163. Johnson RB, Onwuegbuzie AJ. Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher* 2004;33(7):14-26. doi:10.3102/0013189x033007014.

164. Creswell JW, Plano Clark VL. Designing and conducting mixed methods research; 2010.

165. Nettskjema. University in Oslo. Avaliable: https://www.uio.no/english/services/it/adm-services/nettskjema/ [Accessed 18 May 2020].

166. Polgar S. Introduction to research in the health sciences / Stephen Polgar, Shane A. Thomas. Thomas SA, editor. Oxford: Churchill Livingstone; 2013.

167. World Health Organization. Ethical issues in patient safety research: interpreting existing guidance. Geneva: World Health Organization; 2013.

168. Pillow W. Confession, Catharsis, or Cure? Rethinking the Uses of Reflexivity as Methodological Power in Qualitative Research. *International Journal of Qualitative Studies in Education* 2003;16:175-96. doi:10.1080/0951839032000060635.

169. Bell HT, Granas AG, Enmarker I, et al. Nurses' and pharmacists' learning experiences from participating in interprofessional medication reviews for elderly in primary health care - a qualitative study. *BMC Family Practice* 2017;18(1):30. doi:10.1186/s12875-017-0598-0.

170. Hung MY, Wright DJ, Blacklock J, et al. Identification of the benefits, enablers and barriers to integrating junior pharmacists into the ward team within one UK-based hospital. *Integrated Pharmacy Research & Practice* 2017;6:181-90. doi:10.2147/IPRP.S146630.

171. McLeod M, Barber N, Franklin BD. Facilitators and Barriers to Safe Medication Administration to Hospital Inpatients: A Mixed Methods Study of Nurses' Medication Administration Processes and Systems (the MAPS Study). *PLoS One* 2015;10(6):e0128958. doi:10.1371/journal.pone.0128958.

172. Grissinger M. Your High-Alert Medication List Is Relatively Useless Without Associated Risk-Reduction Strategies. *Pharmacy and Therapeutics* 2016;41(10):598-600.

173. Cousins D, Rosario C, Scarpello J. Insulin, hospitals and harm: a review of patient safety incidents reported to the National Patient Safety Agency. *Clinical medicine (London, England)* 2011;11(1):28-30. doi:10.7861/clinmedicine.11-1-28.

174. Tyynismaa L, Honkala A, Airaksinen M, et al. Identifying High-alert Medications in a University Hospital by Applying Data From the Medication Error Reporting System. *Journal of Patient Safety* 2021;17(6):417-24. doi:10.1097/pts.0000000000000388.

175. Pfeiffer Y, Zimmermann C, Schwappach DLB. What are we doing when we double check? *BMJ Quality & Safety* 2020;29(7):536-40. doi:10.1136/bmjqs-2019-009680.

176. Kuitunen S, Niittynen I, Airaksinen M, et al. Systemic Causes of In-Hospital Intravenous Medication Errors: A Systematic Review. *Journal of Patient Safety* 2021;17(8):e1660-e8. doi:10.1097/pts.0000000000000632.

177. Leapfrog Hospital Survey. Factsheet: bar code medication administration, 2019. Available: https://ratings.leapfroggroup.org/sites/default/files/2020-08/2020-BCMA-Fact-Sheet.pdf [Accessed 04 Dec 2020].

178. Barakat S, Franklin BD. An Evaluation of the Impact of Barcode Patient and Medication Scanning on Nursing Workflow at a UK Teaching Hospital. *Pharmacy (Basel)* 2020;8(3):148. doi:10.3390/pharmacy8030148.

179. Taxis K, Dean B, Barber N. Hospital drug distribution systems in the UK and Germany - a study of medication errors. *Pharmacy World and Science* 1999;21(1):25-31. doi:10.1023/A:1008616622472.

180. Institute of Medicine Committee on Quality of Health Care in America. Crossing the Quality Chasm: A New Health System for the 21st Century. Washington (DC): National Academies Press (US); 2001.

181. Williams R, Aldakhil R, Blandford A, et al. Interdisciplinary systematic review: does alignment between system and design shape adoption and use of barcode medication administration technology? *BMJ Open* 2021;11(7):e044419. doi:10.1136/bmjopen-2020-044419.

182. Woods D, Dekker S. Anticipating the effects of technological change: A new era of dynamics for human factors. *Theoretical Issues in Ergonomics Science* 2000;1:272-82. doi:10.1080/14639220110037452.

183. Linden-Lahti C, Takala A, Holmström AR, et al. What Severe Medication Errors Reported to Health Care Supervisory Authority Tell About Medication Safety? *Journal of Patient Safety* 2021;17(8):e1179-e85. doi:10.1097/pts.0000000000000914.

184. Lawton R, Parker D. Barriers to incident reporting in a healthcare system. *Quality and Safety in Health Care* 2002;11(1):15-8. doi:10.1136/qhc.11.1.15.

185. Cooper J, Williams H, Hibbert P, et al. Classification of patient-safety incidents in primary care. *Bulletin of the World Health Organization* 2018;96(7):498-505. doi:10.2471/BLT.17.199802.

186. Gates PJ, Baysari MT, Mumford V, et al. Standardising the Classification of Harm Associated with Medication Errors: The Harm Associated with Medication Error Classification (HAMEC). *Drug Safety* 2019;42(8):931-9. doi:10.1007/s40264-019-00823-4.

187. Chung LS, Tkach A, Lingenfelter EM, et al. Tissue Plasminogen Activator Prescription and Administration Errors within a Regional Stroke System. *Journal of Stroke and Cerebrovascular Diseases* 2016;25(3):565-71. doi:10.1016/j.jstrokecerebrovasdis.2015.11.014.

188. Maaskant JM, Vermeulen H, Apampa B, et al. Interventions for reducing medication errors in children in hospital. *Cochrane Database of Systematic Reviews* 2015(3):Cd006208. doi:10.1002/14651858.CD006208.pub3.

189. Manias E, Street M, Lowe G, et al. Associations of person-related, environment-related and communication-related factors on medication errors in public and private hospitals: a retrospective clinical audit. *BMC Health Services Research* 2021;21(1):1025. doi:10.1186/s12913-021-07033-8.

190. Informed patients can help prevent medication errors. European Patient Forum. Avaliable: https://www.eu-patient.eu/news/News-Archive/informed-patients-can-help-prevent-medication-errors/ [Accessed 30 Nov 2021].

191. Young J, Slebodnik M, Sands L. Bar code technology and medication administration error. *Journal of Patient Safety* 2010;6(2):115-20. doi:10.1097/PTS.0b013e3181de35f7.

192. Furniss D, Lyons I, Franklin BD, et al. Procedural and documentation variations in intravenous infusion administration: a mixed methods study of policy and practice across 16

hospital trusts in England. *BMC Health Services Research* 2018;18(1):270. doi:10.1186/s12913-018-3025-x.

193. Joint Commission on the Accreditation of Healthcare Organizations. Proposed revisions to Standards MM.4.10 and MM.8.10. 2007. Avaliable: www.jointcommission.org/NR/rdonlyres/A53CAB2B-2B5F-442E-8B5E-0412BD5838FD/0/proprevisions_mm_stds.pdf [Accessed 13 Jun 2019].

194. Rich DS, Fricker MP, Jr., Cohen MR, et al. Guidelines for the Safe Preparation of Sterile Compounds: Results of the ISMP Sterile Preparation Compounding Safety Summit of October 2011. *Hospital Pharmacy* 2013;48(4):282-94. doi:10.1310/hpj4804-282.test.

195. Institute for Safe Medication Practices. Safe Practice Guidelines for Adult IV Push Medications. A compilation of safe practices from the ISMP Adult IV Push Medication Safety Summit. 2015. Avaliable: https://www.ismp.org/sites/default/files/attachments/2017-11/ISMP97-Guidelines-071415-3.%20FINAL.pdf [Accessed 30 Aug 2021].

196. National Patient Safety Agency (2009) Safety in Doses: Improving the Use of Medicines in the NHS. London: NPSA. https://nationalpatientsafetysuite.vctms.co.uk/assets/content/35497/story_content/external_files/NRLS-0486-safety-in-doses-PSO-2007-v1.pdf.pdf [Accessed 18 Jan 2021].

197. Schepel L, Aronpuro K, Kvarnström K, et al. Strategies for improving medication safety in hospitals: Evolution of clinical pharmacy services. *Research in Social & Administrative Pharmacy* 2019;15(7):873-82. doi:10.1016/j.sapharm.2019.02.004.

198. Council of the European Union. Council recommendation on patient safety, including the prevention and control of healthcare associated infections. 2009. Available: http://www.euro.who.int/__data/assets/pdf_file/0015/111507/E93833.pdf [Accessed 15 Nov, 2021].

199. Linden-Lahti C, Holmström A-R, Pennanen P, et al. Facilitators and barriers in implementing medication safety practices across hospitals within 11 European Union countries. *Pharmacy Practice* 2019;17(4):1583-. doi:10.18549/PharmPract.2019.4.1583.

200. Aase K. Patient safety. Theory and practice. [Pasientsikkerhet. Teori og praksis]. 3rd ed: Universitetsforlaget; 2018.

201. Holden RJ, Brown RL, Alper SJ, et al. That's nice, but what does IT do? Evaluating the impact of bar coded medication administration by measuring changes in the process of care. *International Journal of Industrial Ergonomics* 2011;41(4):370-9. doi:10.1016/j.ergon.2011.02.007.

202. Portela MC, Pronovost PJ, Woodcock T, et al. How to study improvement interventions: a brief overview of possible study types. *BMJ Quality & Safety* 2015;24(5):325-36. doi:10.1136/bmjqs-2014-003620.

203. Christiansen AB, Simonsen S, Nielsen GA. Patients Own Safety Incidents Reports to the Danish Patient Safety Database Possess a Unique but Underused Learning Potential in Patient Safety. *Journal of Patient Safety* 2019. doi:10.1097/pts.0000000000000604.

204. Holmström AR, Järvinen R, Laaksonen R, et al. Inter-rater reliability of medication error classification in a voluntary patient safety incident reporting system HaiPro in Finland. *Research in Social & Administrative Pharmacy* 2019;15(7):864-72. doi:10.1016/j.sapharm.2018.11.013.

205. Holmström A-R, Laaksonen R, Airaksinen M. How to make medication error reporting systems work – Factors associated with their successful development and implementation. *Health Policy* 2015;119(8):1046-54. doi:https://doi.org/10.1016/j.healthpol.2015.03.002.

206. Dolonen, KA. I løpet av to år døde 27 pasienter og 177 ble alvorlig skadet på sykehus på grunn av legemiddelfeil. [During two years 27 patients died and 177 were severely harmed due to medication errors]. Sykepleien. 2020. Avaliable: https://sykepleien.no/2020/07/i-lopet-av-ar-dode-27-pasienter-og-177-ble-alvorlig-skadet-pa-sykehus-pa-grunn-av [Accessed 20 Oct 2021].

Appendices

Appendix 1

Spørsmål til deg som skal starte opp et masterprosjekt / videreutdanningsprosjekt

Fyll ut skjema og send det til forskningsavdelingen@ . Du vil i løpet av kort tid få beskjed om du må søke tilrådning fra sykehusets **personvernombud**.

Ditt navn: Alma Mulac (stipendiat)

Er du ansatt ved Sykehuset ?:

☐Ja

☒Nei

Hvis «Ja», ved hvilken avdeling? Klikk her for å skrive inn tekst.

Utdanningsinstitusjon: Universitet i Oslo, Farmasøytisk institutt

Er det søkt om tilrådning fra personvernombudet ved utdanningsinstitusjon?

☐Ja

☒Nei

Dersom ja: Ble det gitt?

☐Ja

☐Nei

Hva er formålet med prosjektet: Observere helsepersonell (sykepleiere, leger, farmasøyter) som tilbereder og gir (administerer) legemidler til pasienter. Prosjektet har systemfokus og studerer hvordan man bruker scanning av strekkoder på legemidlene i en såkalt «Lukket legemiddelsløyfe», og om man avviker fra sykehusets rutiner for legemiddelhåndtering (feil og avvik).

Hvilken avdeling skal du ha data fra?

Vennligst spesifiser:

Hvem inkluderes? (Kryss av)

☒Ansatte

☐Pasienter

☐Andre

Hvis «Andre» vennligst utdyp: Klikk her for å skrive inn tekst.

Hva slags data skal samles inn (f.eks. helseopplysninger, lydfiler, bilde, videopptak, andre variabler)? Opplysninger om hvordan helsepersonell/sykepleier tilbereder og administrerer legemidler til pasienter i henhold til prosedyrer for håndtering og bruk av Lukket legemiddelsløyfe. I et nettskjema registreres følgende: Observatørens navn, dato/klokkeslett, avdeling, Løpenummer for pasient og ansatt (1,2,3 osv – ikke sporbart), samt om prosedyrer følges: Sjekker elektronisk pasientjournal mot pasientens navn, armbånd, legemiddelnavn, dose, styrke, skanner legemiddelet, skanner armbånd, forteller pasienten hvilket legemiddel de får, om legemiddelet er godt merket, allergier o.l., forteller om bivirkninger, dokumenterer i den elektroniske pasientjournalen at legemidlene er gitt. Eventuelle avvik som observeres.) Se ev. nettskjema (på engelsk) https://nettskjema.no/a/118386#/page/1

Hvordan skal data samles inn? (Kryss av)

☐Intervju

☐Standard spørreskjema (f.eks. QoL)

☐Uttrekk av pasientdata fra Sykehuset kliniske systemer

☒Annen måte

Hvis «Annen måte» vennligst utdyp: Studenten observerer legemiddelhåndtering ved å skygge en sykepleier/helsepersonell.

Hvordan skal data lagres? (Kryss av)

☐Papir / elektronisk teleform

☐Lydfil/Bilde/Videofil

☒Annen måte

Hvis «Annen måte» vennligst utdyp: Basert på observasjonene føres data direkte inn i nettskjemaet som lagres på server ved Universitetet i Oslo. Ingen opplysninger om pasienten registreres.

Hvilke tekniske og fysiske tiltak sikrer personopplysningene

☐Data lagres avidentifisert (m/koblingsnøkkel)

☒Data lagres anonymt (informasjon som ikke på noe vis kan identifisere enkeltpersoner i et datamateriale, direkte gjennom navn eller personnummer, indirekte gjennom bakgrunnsvariabler, eller gjennom navneliste/koblingsnøkkel eller krypteringsformel og kode)

☐Data lagres indirekte identifiserbart (lyd/bilde/video, få inkluderte per variabel)

☐Annen måte

Hvis «Annen måte» vennligst utdyp: Klikk her for å skrive inn tekst.

Dato / Sted: Signatur:

[signature removed]

Appendix 2

From: [redacted]
Sent: onsdag 26. juni 2019 13:08
To: Alma Mulac
Subject: SV: Skjema fra Farmasøytisk institutt til Forskningsavdeling

Hei Alma,

Vi har sett på skjemaet du fylte ut og siden det her er snakk om anonyme data så trenger du ikke nr tilrådning fra vårt personvernombud. Derimot må dere ta kontakt med avdelingssjefen på [redacted] for å evt få lov til å gjøre prosjektet hos dem, samt avtale det praktiske. Avdelingssjefen heter [redacted] og har følgende epostadresse: [redacted]

Du kan jo sende med det utfylte skjemaet og gi beskjed om at forskningsavdelingen har avklart at det ikke kreves en PVO-tilrådning og at vi har gitt deg beskjed om å ta kontakt med henne. Du/dere må også signere på taushetserklæring på avdelingen.

Ta kontakt dersom du har flere spørsmål!

[redacted]

Med vennlig hilsen
[redacted]
Rådgiver[redacted]

Forskningsavdelingen
[redacted]
[redacted]

[redacted]
[redacted]

-----Opprinnelig melding-----
Fra: Alma Mulac [mailto:alma.mulac@farmasi.uio.no]
Sendt: 19. juni 2019 13:45
[redacted]
Emne: Skjema fra Farmasøytisk institutt til Forskningsavdeling

Hei

Vedlagt er skjema angående oppstart på doktorgradsprosjekt på [redacted]

Med vennlig hilsen

Alma Mulac
PhD student, MSc Pharm

Department of Pharmacy
University of Oslo
Visiting address:
Gydas vei 8
0363 Oslo
Norway

Mob: +47 48 33 74 27
alma.mulac@farmasi.uio.no

Appendix 3

UiO : Farmasøytisk institutt
Det matematisk-naturvitenskapelige fakultet

Helsepersonell på Sykehuset

FORESPØRSEL OM DELTAKELSE I FORSKNINGSPROSJEKTET

OBSERVASJONSSTUDIE: LEGEMIDDELHÅNDTERING I LUKKET LEGEMIDDELSLØYFE

Det er kjent at legemiddelhåndtering i utdelingsfasen er et risikoområde og det er derfor behov for større fokus og kunnskap om hvordan man kan forbedre pasientsikkerhet i denne fasen. Det er per i dag for liten forståelse om hvordan prosessen fungerer for helsepersonell og pasienter. Vi ønsker spesielt å studere hvordan lukket legemiddelsløyfe påvirker legemiddelhåndtering på sykehus. Vi håper at denne studien bidrar til å forbedre arbeidsmetoder og få bedret pasientsikkerhet.
Forskningsprosjektet er et samarbeid mellom Sykehuset , Sykehusapotekene og Universitetet i Oslo. Studien gjennomføres i perioden høsten 2019 og våren 2020.

HVA INNEBÆRER PROSJEKTET?

Du som helsepersonell (sykepleier) vil bli observert ved tilberedning og administrering (utdeling) av legemidler av en farmasøyt eller en farmasistudent. Studiens fokus er hvordan helsepersonell/sykepleier administrerer legemidler til pasienter i henhold til prosedyrer for håndtering og bruk av lukket legemiddelsløyfe. Observatøren er ikke deltakende på noen måte, og skal ikke forstyrre de daglige rutinene på avdelingen. Observasjonene medfører ingen ekstra tidsbruk for helsepersonell.

HVORDAN REGISTRERES DATA

Observasjoner registreres på et elektronisk skjema på nettbrett. Det registreres ikke opplysninger om pasienter eller helsepersonell, kun informasjon om prosessen ved utdeling av legemidler. Hvis vi observerer avvik som kan gi betydelig pasientskade, vil vi si ifra til sykepleier.

FRIVILLIG DELTAKELSE

Det er frivillig å delta i prosjektet. Dersom du ønsker å delta, undertegner du samtykkeerklæringen. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke på selve observasjonsdagen. Dersom du har spørsmål til prosjektet, kan du kontakte stipendiat Alma Mulac, telefon: 48 33 74 27,
e-post: alma.mulac@farmasi.uio.no

GODKJENNING

Forskningsavdelingen på Sykehuset har vurdert prosjektet og avklart at det ikke trenges tilrådning fra personvernombud siden det kun samles anonyme data.

UiO

OBSERVASJONSSTUDIE: LEGEMIDDELHÅNDTERING I LUKKET LEGEMIDDELSLØYFE

KONTAKTOPPLYSNINGER

Stipendiat Alma Mulac, telefon: 48 33 74 27, e-post: alma.mulac@farmasi.uio.no

Jeg samtykker til å delta i prosjektet

Sted og dato

Deltakers signatur

Deltakers navn med trykte bokstaver

Papers

Paper I

I

Severe and fatal medication errors in hospitals:

findings from the Norwegian Incident Reporting System

Mulac Alma, Taxis Katja, Hagesaether Ellen, Granas Anne Gerd

Eur J Hosp Pharm. 2020; 0:1-6. doi: 10.1136/ejhpharm-2020-002298.

OPEN ACCESS

Severe and fatal medication errors in hospitals: findings from the Norwegian Incident Reporting System

Alma Mulac ,[1] Katja Taxis,[2] Ellen Hagesaether,[3] Anne Gerd Granas[1]

ABSTRACT

Background Even with global efforts to prevent medication errors, they still occur and cause patient harm. Little systematic research has been done in Norway to address this issue.

Objectives To describe the frequency, stage and types of medication errors in Norwegian hospitals, with emphasis on the most severe and fatal medication errors.

Methods Medication errors reported in 2016 and 2017 (n=3557) were obtained from the Norwegian Incident Reporting System, based on reports from 64 hospitals in 2016 and 55 in 2017. Reports contained categorical data (eg, patient age, incident date) and free text data describing the incident. The errors were classified by error type, stage in the medication process, therapeutic area and degree of harm, using a modified version of the WHO Conceptual Framework for the International Classification for Patient Safety.

Results Overall, 3372 reports were included in the study. Most medication errors occurred during administration (68%) and prescribing (24%). The leading types of errors were dosing errors (38%), omissions (23%) and wrong drug (15%). The therapeutic areas most commonly involved were analgesics, antibacterials and antithrombotics. Over half of all errors were harmful (62%), of which 5.2% caused severe harm, and 0.8% were fatal.

Conclusions Medication errors most commonly occurred during medication administration. Dosing errors were the most common error type. The substantial number of severe and fatal errors causing preventable patient harm and death emphasises an urgent need for error-prevention strategies. Additional studies and interventions should further investigate the error-prone medication administration stage in hospitals and explore the dynamics of severe incidents.

INTRODUCTION

Medication errors are recognised as a major patient safety problem. WHO has a goal of globally reducing avoidable harm related to medications by 50%, by 2022.[1 2] Medication errors occur in all stages of the medication management process[3] and may lead to patient harm, prolonged hospital stay, readmission or death.[4] Based on data from error reporting systems, most medication errors occur in the administration stage, and the most common types of errors are wrong dosage errors.[5 6]

Measures to improve medication safety in hospitals have been taken, such as implementing computerised prescriber order entry, electronic medication administration record, bar code medication administration, automated dispensing devices and other clinical decision support systems.[7] Despite such measures, medication errors still occur and cause significant patient harm and even death.[4 5]

There have been numerous case reports and media stories on medication errors in Norwegian hospitals,[8 9] but little systematic research on medication errors has been done. A National Patient Safety Program was established in 2014, but medication errors were not among the target areas to improve patient safety.[10] To be able to monitor safety in the medication management process, identify unsafe practice and implement safety measures, one has to learn from errors.[4] The aim of this study is to describe the frequency, stage and error types, as well as analyse the harm caused by the medication errors reported to the mandatory Norwegian Incident Reporting System (NIRS).

METHODS

Study design and data source

This was a retrospective study of medication errors reported to the NIRS, from 1 January 2016 to 31 December 2017. The NIRS, placed under the Norwegian Directorate of Health, was a mandatory, anonymous, electronic, reporting and learning system of incident reports from all hospitals across Norway. In the 2-year study period, 64 hospitals in 2016 and 55 hospitals in 2017 reported errors. The NIRS received approximately 10 000 incident reports yearly, of which about 20% were medication errors. The most frequently reported incident categories were clinical procedures, medication errors and patient accidents.

Data collection and processing

Incident reports consisted of categorical data (eg, patient age, incident date, day of the week, etc) and free-text data (eg, incident description, description of the cause, patient consequences, prevention measures, caseworker's comments, etc). Some reports were short, whereas others had detailed free-text descriptions of the incidents. We thoroughly read all the reports. Employees (caseworkers) at the NIRS had classified two-thirds of the reports by error type and stage in the medication process in which the error occurred, we classified the remaining one-third of the reports. The classification system was a modified version of the Conceptual Framework for the International

► Additional material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/ejhpharm-2020-002298).

[1]Department of Pharmacy, Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway
[2]Unit of Pharmacotherapy, Epidemiology & Economics, Groningen Research Institute of Pharmacy, Faculty of Science and Engineering, University of Groningen, Groningen, The Netherlands
[3]Department of Life Sciences and Health, Faculty of Health Sciences, Oslo Metropolitan University, Oslo, Norway

Correspondence to
Alma Mulac, Department of Pharmacy, Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo 0316, Norway; alma.mulac@farmasi.uio.no

Received 26 March 2020
Revised 14 May 2020
Accepted 15 May 2020
Published Online First 23 June 2020

EAHP Statement 5: Patient Safety and Quality Assurance.

Check for updates

© European Association of Hospital Pharmacists 2021. Re-use permitted under CC BY-NC. No commercial re-use. Published by BMJ.

To cite: Mulac A, Taxis K, Hagesaether E, *et al*. *Eur J Hosp Pharm* 2021;**28**:e56–e61.

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

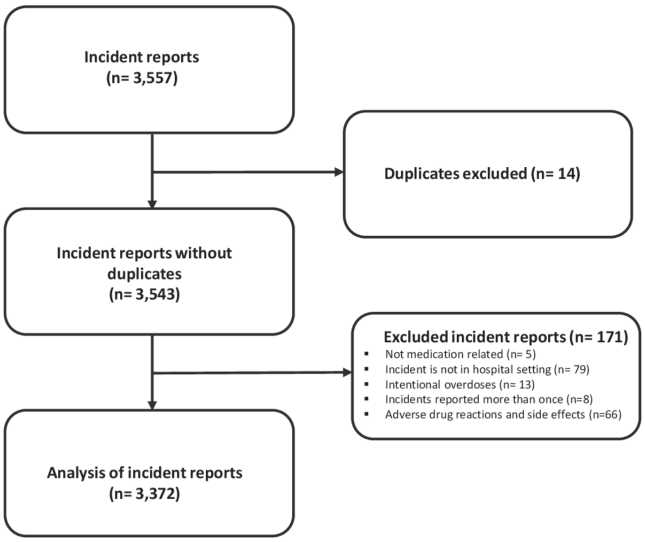

Figure 1 Inclusion and exclusion of reported incidents to the Norwegian Incident Reporting System in 2016 and 2017.

Classification for Patient Safety (WHO).[11] The error types were as follows: wrong patient, wrong drug, wrong dose/strength or frequency, wrong route, wrong dispensing label or instruction, wrong storage, contraindication, omitted medicine or dose and adverse drug reaction. The stages in the medication process were as follows: prescribing (as well as transcribing, documenting and reconciliation failure), preparation/dispensing, administration and storage. The drugs involved in the errors were not dedicated to a specific field in the reporting form. However, when possible, we extracted the drug name and the therapeutic area at Anatomical Therapeutic Chemical (ATC) level 2.[12] The statistical analysis was performed with IBM SPSS V.25.

Definitions and exclusion/inclusion process

We defined a medication error according to the National Coordinating Council for Medication Error Reporting and Prevention 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 healthcare professional, patient or consumer'.[13]

Based on this definition, we excluded incident reports of suicide events and intentional overdoses, side effects or adverse drug reactions that occurred as a result of an appropriate medication process, as well as reports which were not from a hospital setting. We included adverse drug reactions caused by medication errors (eg, administering drugs to patients with known allergies). Both harmful errors and those not causing patient harm were included.

The degree of harm was classified according to the following five-point scale[11]: (1) *no harm:* an incident had the potential to cause harm, but was prevented (near miss) or ran to completion, but no harm occurred; (2) *low harm*: a patient required extra observation or minor treatment; (3) *moderate harm*: significant, but no permanent harm, where the patient required treatment measures; (4) *severe harm*: significant treatment/harm that required surgery, transfer to an intensive care unit, a prolonged hospital stay or permanent harm and (5) *death*: the error may have contributed to or resulted in a patient's death. Incident reports with insufficient information to classify the degree of harm were coded as missing.

Understanding the context of the data

The data on medication errors provided a rich description of a large variety of medication errors from health personnel. For us, it was important to gain a broader understanding of the research questions, the nature of the reported incidents and the setting where they occurred. We therefore held several meetings with the NIRS employees who gave valuable insight into the classification of errors. We performed fieldwork observations of medication preparation, dispensing and administration, in two hospital wards by shadowing nurses on medication rounds. We also performed a semi-structured interview with two employees devoted to quality of care in the hospital.

RESULTS

In total, 3557 medication errors were reported from Norwegian hospitals to the NIRS. Of these, 185 were excluded because they were side effects or adverse drug reactions, not from a hospital setting, not medication-related, intentional overdoses or duplicates (figure 1). The 3372 medication error incidents that met the inclusion criteria are shown in table 1. Errors were classified as originating in the administration stage (68%), prescribing stage (24%) or preparation/dispensing stage (6%) of the medication process. The most commonly reported error types were wrong dose/strength or frequency (38%), omissions (23%) and wrong drug (15%) (table 1).

In total, 39% (988/2544) of the errors in the *administration stage* were due to wrong dose/strength/frequency errors (further in the text referred to as wrong dose errors) (online supplementary appendix A). Within the *prescribing stage*, wrong dose errors account for 46% (410/888) of errors.

Patient age ranged from 0 to 112 years. The majority of patients who experienced medication errors were aged over 65 years (50.8%), while there were 266 children (<18 years) who experienced medication errors (figure 2). The majority of severe and fatal errors were reported for patients aged over 65 years (59%).

In the reported errors, 62% caused patient harm, of which 5.2% caused severe harm and 0.8% were fatal errors (n=27) (table 2). Most of the fatal errors were due to wrong dose errors, while the most severe harm errors were due to medication omissions (table 2).

The majority of errors were reported by nurses (62%) and physicians (11%). However, 42% of severe and fatal errors were reported by physicians, with only 25% reported by nurses (table 2).

The therapeutic areas (ATC level 2) most frequently involved in errors were analgesics (N02), antibacterials for systemic use (J01) and antithrombotic agents (B01) (online supplementary appendix B). Medications most commonly associated with death were analgesics and antithrombotic agents. Antithrombotic agents were most commonly associated with severe harm, including 25% of all fatal errors, making it the most harmful therapeutic area in the reported incidents (online supplementary appendix B).

Table 3 exemplifies the richness of qualitative descriptions in the incident reports of five severe and three fatal cases, with the assigned medication process stage, error type and therapeutic area all specified.

DISCUSSION

Our data share similarities with the published literature, including the error type, stage of the medication process and therapeutic

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

Table 1 Medication error characteristics

Characteristic	N	%
Year of reporting		
2016	1780	53.4
2017	1572	46.6
Total	3372	100.0
Medication process stage*		
Administration	2544	67.8
Prescribing	888	23.7
Preparation/Dispensing	231	6.2
Storage	87	2.3
Error type*		
Wrong dose/strength or frequency (total)	1354	37.5
Omitted medicine or dose	836	23.2
Wrong drug	548	15.2
Wrong route	198	5.5
Contraindication	191	5.3
Wrong patient	186	5.2
Wrong formulation or presentation	94	2.6
Adverse drug reaction	77	2.1
Wrong dispensing label/instruction	66	1.8
Wrong storage	60	1.7
Reported by		
Nurse	2103	62.4
Physician	385	11.4
Other staff	169	5.0
Leader	71	2.1
Bioengineer/Engineer	43	1.3
Midwife	37	1.1
Missing	564	16.7
Total	3372	100.0
Patient age (years)		
0–9	184	5.5
10–19	101	3.0
20–29	183	5.4
30–39	202	6.0
40–49	240	7.1
50–59	342	10.1
60–69	559	16.6
70–79	734	21.8
80–89	524	15.5
90–112	180	5.3
Missing	123	3.6
Total	3372	100.0
Degree of harm		
No harm	1272	37.7
Low harm	1277	37.9
Moderate harm	538	16.0
Severe harm	177	5.2
Death	27	0.8
Missing	81	2.4
Total	3372	100.0

*The total number of error types and medication process stages was greater than the number of incidents because the classification system permitted more than one category to be selected for one incident.

area involved in errors.[3 5] In contrast to other incident reporting systems, we found a large proportion of harmful errors (62%) and a substantial number of errors associated with severe harm and death. This provides unique data to discuss error preventing strategies to target the most harmful medication errors, which are likely to have the highest impact on patient safety.[14]

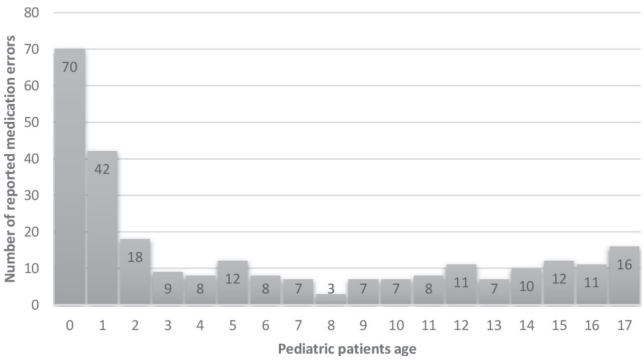

Figure 2 Distribution of medication errors in the paediatric patients reported to the Norwegian Incident Reporting System in 2016 and 2017.

Medication process stage and error type

Two-thirds of the reported errors occurred in the administration stage, and in line with other studies, the majority of severe and fatal errors occurred at this stage.[3 6 15 16] The administration stage represents the last step in the medication process before the patient receives the drug, and therefore errors are less likely to be detected and intercepted by other health professionals.[17] However, some studies, particularly from the USA, have found errors in the prescribing stage to be the most commonly reported.[5] This contrast to our findings could be due to the high implementation grade of technologies in the USA to prevent administration errors, for example, bar code medication administration.[7]

Wrong dose was the most common error type in our study, accounting for 38% of all errors. One systematic review of medication administration errors found similar results,[15] as did a review

Table 2 Severe harm and fatal reports from the Norwegian Incident Reporting System in 2016 and 2017

	All reported errors n (%)	Severe n (%)	Death n (%)
Total number of errors	3372	177 (5.2)	27 (0.8)
Error type*			
Wrong dose/strength or frequency	1354 (37.5)	47 (27)	13 (48)
Omitted medicine or dose	836 (23.2)	57 (32)	6 (22)
Adverse drug reaction	77 (2.1)	24 (13.6)	3 (11)
Wrong drug	548 (15.2)	20 (11.3)	1 (3.7)
Wrong route	198 (5.5)	10 (5.6)	1 (3.7)
Contraindication	191 (5.3)	24 (13.6)	4 (14.8)
Other	406 (11.3)	14 (7.9)	0 (N/A)
Medication process stage*			
Administration	2544 (68)	96 (54)	16 (59.3)
Prescribing	888 (23.7)	70 (39.5)	11 (40.7)
Other	118 (8.5)	11 (6.5)	0(N/A)
Health professionals reporting			
Nurse	2103 (62.4)	48 (27.0)	3 (11.0)
Physician	385 (11.4)	70 (40.0)	16 (59.0)
Other health professionals	884 (26.0)	59 (33.0)	8 (29.0)
Patient age (years)			
0–17	266	10	1
18–65	1283	63	5
>65	1698	100	21
Missing	125	4	0

*The total number of error types and medication process stages was greater than the number of incidents because the classification system permitted more than one category to be selected for one incident.

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

Table 3 Incident description of severe harm and fatal errors reported to the Norwegian Incident Reporting System in 2016 and 2017, with the assigned medication process stage, error type and therapeutic subgroup

Incident information	Incident description
Error type: contraindication Degree of harm: severe Patient age (years): 18–65 Medication process: administration Antithrombotic agents (B01)	A patient received his usual antithrombotic (apixaban) prior to surgery, although a contraindication existed. After surgery, the patient experienced bleeding in the throat and underwent another surgery to stop the bleeding.
Error type: wrong dose/strength/frequency Degree of harm: severe Patient age (years): 18–65 Medication process: administration Analgesics (N02)	A patient has received 50 mg oxycodone, but was initially prescribed 5 mg. The 10-fold dose was incorrectly transcribed from the previous record in the commentary field, while the prescription was correct. The patient became drowsy and experienced apnoea episodes up to 30 s over several hours. The patient received naloxone antidote to reverse the opiate effect.
Error type: wrong dose/strength/frequency Degree of harm: severe Patient age (years): >65 Medication process: administration Intravenous solutions: electrolytes	A patient with hypocalcaemia should have recieved 0.3 mmol/kg of CaCl according to his weight of 100 kg. The junior doctor showed the doctor in charge how she had calculated the dose, ie, 0.3 mmol/kg×100 kg=130 mmol. The doctor in charge did not spot the wrongly calculated dose of 130 mmol, instead of the correct 30 mmol. The patient became acutely ill, was moved to the intensive care unit and was given fluids to eliminate the calcium and continuous heart monitoring.
Error type: wrong storage Degree of harm: severe Patient age (years): 18–65 Medication process: administration Therapeutic subgroup: missing	The patient was readmitted to the hospital 3 days after discharge, with a stomach ache. The CT scan revealed a foreign object in the small intestine. The next day, the patient had a tablet of an intact blister pack surgically removed from the small intestine; there was a rupture and suture of two areas within the damaged intestinal wall. The blister pack had not been removed when the tablet was administered/ingested.
Error type: wrong drug Degree of harm: severe Patient age (years): 18–65 Medication process: prescribing Psycholeptics (N05)	The physician prescribed olanzapine even though the patient's medical record stated a severe reaction to this type of neuroleptics, and that he should only receive quetiapine or clozapine. The patient developed the neuroleptic malignant syndrome, was in a life-threatening state and was hospitalised for several weeks with intensive monitoring.
Error type: wrong route Degree of harm: death Patient age (years): 0–17 Medication process: administration Antineoplastic agents and immunomodulating agents (L01–L04)	The patient was prescribed two drugs, methotrexate (intrathecal) and vincristine (intravenous). During administration, the vincristine syringe was mixed up with the methotrexate syringe, and injected intrathecally. The error was intercepted after 25 min but it was too late. The child died due to the consequences of the histotoxic drug. Vincristine was delivered in a syringe similar to methotrexate. This was a well-known error and risk in hospitals.
Error type: omitted medicine or dose Degree of harm: death Patient age (years): 18–65 Medication process: prescribing Antithrombotic agents (B01)	The patient had knee surgery previously and was discharged. The patient was readmitted to the hospital in a critical state. Tests showed multiple bilateral pulmonary embolisms. The patient was very obese and no thrombosis prophylaxis was stated on his discharge report. The patient died.
Error type: wrong dose/strength/frequency Degree of harm: death Patient age (years): >65 Medication process: prescribing Antibacterials for systemic use (J01)	A patient with renal failure was to be prescribed vancomycin. The physician prescribed 3 g, while the nurse responded that the dose seemed very high. The physician however confirmed that the dose should be given. The patient died the day after the 3 g dose was administered.

of prescribing errors in hospitals, which found that dosage errors were most commonly reported by a majority of studies.[18] In our study, wrong dose errors were the error type associated with the highest severity of harm. Every fourth severe harm error and half of the fatal errors were dosage errors.

An interesting finding is that 73% of the dosing errors occurred during administration. One would normally expect the wrong dose errors to stem from the prescribing/preparation/dispensing stage. However, as the preparation, dispensing and administration are (usually) nurse's tasks in Norwegian hospitals, it is possible that these processes are taking place simultaneously (eg, in the patient's room), especially with intravenous medications (preparing and dispensing while administrating shortly after), and hence are all reported as administration errors. One study that compared medication errors from the UK (wrong dose—the most common error type) and USA (omission—the most common error type) incident reporting systems described the difference in the frequency of dosing errors as a reflection of the two countries' different medication management practices.[5] A plausible explanation could be that in the USA, pharmacists typically prepare and dispense unit doses, whereas in the UK, and Norway, those tasks are performed by nurses at the wards. More training and knowledge in handling drugs should be provided to nurses, as they are usually the last step in medication management. Changing the Norwegian hospital drug distribution systems could be an opportunity to reduce wrong dose errors.[17] Technological improvements, an increase in ready-to-use medication and improved cooperation between the wards and the hospital pharmacy could reduce medication preparation and dispensing errors including wrong dose errors (ie, calculation errors).

In Norway, prescriptions issued by hospital physicians are not routinely reviewed by clinical pharmacists, and therefore prescribing errors are difficult to spot, despite that hospital physicians in Norway have been shown to make four times as many prescribing errors as general practitioners.[19]

The severity of harm

We found that 5.2% of all medication errors were associated with severe harm, and 0.8% were fatal. A study that compared the

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

medication errors reported to the US and UK's incident reporting systems from intensive care units showed that the percentage of events associated with severe harm was below 1%, and death below 0.1%, in both systems.[5] We found a much higher rate of harmful errors compared with other incident reporting systems.[3 5 6 16] However, it is difficult to make a clear judgement as to why our data differ. The high rate of harmful errors in our data say more about trends in reporting behaviour than they say about the true underlying rate of medication errors. Some health professionals reported directly to NIRS, while others reported via their local Patient Safety Department, which tends to report real events, and filter out near misses. This could lead to a lower number of non-harmful incidents and overestimate severe errors. Some incident reporting systems, such as the National Reporting and Learning System-UK, are criticised for being 'wide and shallow' and not 'narrow and deep', that is, lacking in detailed incidents, which are less common and more serious in harm.[16]

The process of reading and analysing detailed incident reports in the NIRS data, as illustrated in table 3, has given us a unique insight into the many pitfalls of the medication management process. This knowledge makes it difficult to comprehend that, as of today, hospitals in Norway do not employ Medication Safety Officers. This is in strict contrast to many hospitals worldwide, with dedicated full-time Medication Safety Officers,[20] who lead the medication safety programme, develop protocols for high-risk medications and processes, perform root cause analysis and devise reporting systems. Why there is such a lack of overall political interest in the topic is not easy to comprehend.

Based on our analysis of a 2-year dataset on medication errors in Norwegian hospitals, we recommend introducing a medication safety programme to monitor and improve medication safety. Furthermore, a newly published National Action Plan in Patient Safety and Quality Improvement (2019–2023) has chosen medications as one of three target areas needing special attention.[21] Hopefully, this will also contribute to prioritising medication safety.

Vulnerable patient groups

In our study, 50% of all errors were associated with patients aged over 65 years. This is as expected, because older people use more medicines. The elderly constitute the majority of cases involving severe and fatal medication errors,[22] however, many elderly are also among the most frail and vulnerable patients. Interventions should focus on the safe administration of drugs to patients aged over 65 years, especially antithrombotics, as these drugs are associated with the most harm in this patient group.

A considerable proportion of incident reports involved children, and every fourth paediatric medication errors concerned the infant population (0–1 years). Errors could be due to the nature of medication preparation, dispensing and administration to children.[23] In Norway, the National Competency Network for Medication to Children contributes with developing guidelines, distributing information and supporting research.[24] However, in the 2-year study period, 10 children were severely harmed and one child died due to medication errors. This finding calls for urgent action.

Besides the integration of a clinical pharmacist in the clinical team, stronger emphasis on paediatric medication preparation[23] and technology implementation are clearly needed. Another aspect of improving medication safety is to strengthen the partnership between the patients, their relatives and the healthcare providers.[1 4]

Therapeutic area

The top three therapeutic areas most frequently reported in our data were analgesics, antibacterials for systemic use and antithrombotic agents. These three medication groups were associated with 40% of all reported errors, 50% of severe harm errors and 60% of fatal errors, somewhat similar to other studies.[3 5 15 22] Most fatal errors were associated with analgesics and antithrombotic agents. The majority of deaths in the analgesics group were associated with opioids. However, a patient with renal failure died after a high dose of paracetamol was given. Five of the six fatal errors involving antithrombotic agents were related to an intracranial haemorrhage that occurred when a thrombolytic tissue plasminogen activator (tPA) was administered to treat an acute heart attack or acute ischaemic stroke. TPA also caused severe errors, particularly when the incorrect dosage was given for the set bodyweight or if administrated before a CT head scan had ruled out a brain haemorrhage. Our five fatal tPA-related errors are in line with a tPA study on 131 patients, where 27 patients were exposed to overdosage errors, of which three were fatal.[25] Hence, tPA errors in hospitals are common, severe, and in need of a more systematic approach and education in prescribing and administration to prevent patient harm.

Strengths and limitations

A major strength with our study is that we use a national database of medication errors from all types of hospital wards, populations, medications and harm scores, in contrast to other studies which have focused on specific hospital wards,[5] populations,[23] medications[16 25] or harm scores.[22] Under-reporting is a well-known limitation of the incident reporting systems.[26] It is assumed that only one in five incidents are reported.[16] High reporting rates may indicate an organisational culture committed to identifying and reducing errors rather than a truly high rate.[20]

It is important to recognise the challenge of harm score assignment if prevention strategies are to be focused on medication errors with significant harm scores.[27]

Despite these limitations, it is crucial to acknowledge the importance of incident reporting systems in medication error research. The incident reporting systems provide an effective and low-cost tool to detect risks, which can initiate improvements in medication safety.

The primary purpose of incident reports is identifying risks in the healthcare system and determining need for further investigating and analysis, while there remains little evidence to support the critical learning from these reports.[28] Description of events and causes are often written from one person's view of a complex clinical and organisational situation, and thus discussing underlying causes and revealing flaws in healthcare systems should rather be preformed by investigating relevant and severe incidents with system analysis tools.[29 30]

Recently, the Ministry of Health closed down the NIRS, and the final legislative decision was adopted in April 2019 by the Norwegian Parliament. This decision was made against international recommendations[4]; however, the Minister of Health argued that the NIRS had not sufficiently contributed to patient safety in hospitals. The incidents of errors are as of May 2019 only to be reported at a hospital or regional level, and therefore a national overview is no longer available, which makes our dataset unique.

CONCLUSIONS

This paper shows that errors most commonly occurred during medication administration and that dosing errors were the most common error type. The substantial number of severe and fatal errors causing preventable patient harm and death emphasises

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

Key messages

What is already known on this subject

- Even with global efforts aimed to reduce medication errors, they continue to be the most frequent source of healthcare mishaps and continue to cause patient harm and death.
- Little is known about medication errors in Norwegian hospitals.
- Incident reports provide with sufficient data to describe the nature and type of medication errors.

What this study adds

- This study comprehensively examined, through the Norwegian Incident Reporting System, medication errors reported in a 2-year period, 2016 and 2017.
- Medication errors most commonly occurred during medication administration and involved most frequently dosing errors.
- The substantial number of severe and fatal errors causing preventable patient harm and death stresses an urgent need for error-prevention strategies.

an urgent need for error-prevention strategies, which includes introducing a medication safety officer in hospitals as an essential measure to monitor, prevent and improve medication safety. Additional studies and interventions should further investigate the error-prone medication administration stage in hospitals and explore the dynamics of severe incidents, emphasising incidents associated with children and the safe administration of antithrombotics to patients over 65 years.

Acknowledgements The authors would like to thank the employees at the Norwegian Incident Reporting System (Meldeordningen) for their contribution to this study and making the data available.

Contributors AGG and AM conceived of the presented idea. AGG, KT and EH were involved in planning and supervising the work. AM took lead in writing the manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; internally peer reviewed.

Data availability statement The data from the Norwegian Directorate of Health is not publicly available.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, an indication of whether changes were made, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iD

Alma Mulac http://orcid.org/0000-0001-9463-997X

REFERENCES

1 Donaldson LJ, Kelley ET, Dhingra-Kumar N, *et al*. Medication without harm: who's third global patient safety challenge. *The Lancet* 2017;389:1680–1.
2 Sheikh A, Rudan I, Cresswell K, *et al*. Agreeing on global research priorities for medication safety: an international prioritisation exercise. *J Glob Health* 2019;9:010422.
3 Cousins DH, Gerrett D, Warner B. A review of medication incidents reported to the National reporting and learning system in England and Wales over 6 years (2005-2010). *Br J Clin Pharmacol* 2012;74:597–604.
4 Council of Europe. Creation of a better medication safety culture in Europe: building up safe medication practices. expert group on safe medication practices (P-SP-PH/SAFE). Available: http://optimiz-sih-circ-med.fr/Documents/Council_of_Europe_Medication_Safety_Report_19-03-2007.pdf [Accessed 23 Aug 2019].
5 Wahr JA, Shore AD, Harris LH, *et al*. Comparison of Intensive Care Unit Medication Errors Reported to the United States' MedMarx and the United Kingdom's National Reporting and Learning System. *Am J Med Qual* 2014;29:61–9.
6 Pham JC, Story JL, Hicks RW, *et al*. National study on the frequency, types, causes, and consequences of voluntarily reported emergency department medication errors. *J Emerg Med* 2011;40:485–92.
7 Shah K, Lo C, Babich M, *et al*. Bar code medication administration technology: a systematic review of impact on patient safety when used with computerized prescriber order entry and automated dispensing devices. *Can J Hosp Pharm* 2016;69:394–402.
8 Otterlei S. Same errors happen over and over again. We are extremely worried [Samme feil skjer om og om igjen på norske sykehus. Vi er svært bekymret]. NRK Hordaland, 2019. Available: https://www.nrk.no/hordaland/professor-ut-mot-helseministeren_-_-vi-mister-muligheten-til-a-laere-av-sykehusfeil-1.14482690 [Accessed 23 Aug 2019].
9 Skjetne O, Roed R, Rosenlund-Hauglid S, *et al*. Djabrail (6) died due to a medication error. Haukeland hospital recieves masssive criticism. [Djabrail (6) døde etter feilmedisinering. Haukeland sykehus får massiv kritikk], 2017. Available: https://www.vg.no/nyheter/innenriks/i/joeWA/djabrail-6-doede-etter-feilmedisinering-haukeland-sykehus-faar-massiv-kritikk [Accessed 23 Aug 2019].
10 The Norwegian patient safety programme. In safe hands, 2016. Available: https://www.pasientsikkerhetsprogrammet.no/om-oss/english/the-norwegian-patient-safety-programme-in-safe-hands [Accessed 13 Jun 2019].
11 World Health Organization. Conceptual framework for the International classification for patient safety, 2010. Available: https://www.who.int/patientsafety/implementation/taxonomy/ICPS-report/en/ [Accessed 10 May 2019].
12 WHO collaborating Centre. For drug statistics methodology anatomical therapeutic chemical (ATC) classification index with defined daily doses (DDD). Available: https://www.whocc.no/ [Accessed 23 Aug 2019].
13 The National coordinating Council for medication error reporting and prevention (NCC-MERP) about medication errors. Available: https://www.nccmerp.org/about-medication-errors [Accessed 08 May 2019].
14 Dean Franklin B, Vincent C, Schachter M, *et al*. The incidence of prescribing errors in hospital inpatients: an overview of the research methods. *Drug Saf* 2005;28:891–900.
15 Keers RN, Williams SD, Cooke J, *et al*. Prevalence and nature of medication administration errors in health care settings: a systematic review of direct observational evidence. *Ann Pharmacother* 2013;47:237–56.
16 Dabba K, Elswood M, Ameer A, *et al*. A mixed methods analysis of clozapine errors reported to the National reporting and learning system. *Pharmacoepidemiol Drug Saf* 2019;28:657–64.
17 McLeod M, Barber N, Franklin BD. Facilitators and Barriers to Safe Medication Administration to Hospital Inpatients: A Mixed Methods Study of Nurses' Medication Administration Processes and Systems (the MAPS Study). *PLoS One* 2015;10:e0128958.
18 Lewis PJ, Dornan T, Taylor D, *et al*. Prevalence, incidence and nature of prescribing errors in hospital inpatients. *Drug Saf* 2009;32:379–89.
19 Haavik S, Soeviknes S, Erdal H, *et al*. Prescriptions from general practitioners and in hospital physicians requiring pharmacists' interventions. *Pharmacoepidemiol Drug Saf* 2011;20:50–6.
20 Larson CM, Saine D. *Medication safety officer's Handbook*. Bethesda, MD: American Society of Health-System Pharmacists, 2013.
21 National Action Plan strengthens the efford for Patient Safety [Nasjonal handlingsplan styrker innsatsen for pasientsikkerhet]. Available: https://www.pasientsikkerhetsprogrammet.no/aktuelt/nyheter/en-felles-innsats-for-pasientsikkerhet [Accessed 05 Jul 2019].
22 Härkänen M, Vehviläinen-Julkunen K, Murrells T, *et al*. Medication administration errors and mortality: incidents reported in England and Wales between 2007–2016. *Res Social Adm Pharm* 2019;15:858–63.
23 Maaskant JM, Vermeulen H, Apampa B, *et al*. Interventions for reducing medication errors in children in hospital. *Cochrane Database Syst Rev* 2015;3:Cd006208.
24 National Competency Network for Medications to Children [Nasjonalt kompetansenettverk for legemidler til barn]. Available: https://www.legemidlertilbarn.no [Accessed 13 Jun 2019].
25 Chung LS, Tkach A, Lingenfelter EM, *et al*. Tissue plasminogen activator prescription and administration errors within a regional stroke system. *J Stroke Cerebrovasc Dis* 2016;25:565–71.
26 Franklin BD, Taxis K, Barber N. Parenteral drug errors. reported error rates are likely to be underestimation. *BMJ* 2009;338:b1814.
27 Williams SD, Ashcroft DM. Medication errors: how reliable are the severity ratings reported to the National reporting and learning system? *Int J Qual Health Care* 2009;21:316–20.
28 Macrae C. The problem with incident reporting: Table 1. *BMJ Qual Saf* 2016;25:71–5.
29 Lawton R, Parker D. Barriers to incident reporting in a healthcare system. *Qual Saf Health Care* 2002;11:15–18.
30 Taylor-Adams S, Vincent C. Systems analysis of clinical incidents: the London protocol. *Clin Risk* 2004;10:211–20.

Eur J Hosp Pharm: first published as 10.1136/ejhpharm-2020-002298 on 23 June 2020. Downloaded from http://ejhp.bmj.com/ on December 10, 2021 at Oslo Universitetssykehus HF, Medisinsk Bibliotek. Protected by copyright.

Error type	Medication process stage				
	Medication errors total (n)	Administration	Prescribing	Preparation/ Dispensing	Storage
Wrong Dose/Strength or Frequency	1,354 (37.5%)	988	410	112	19
Omitted Medicine or Dose	836 (23.1%)	657	213	17	40
Wrong Drug	548 (15.2%)	398	169	49	5
Wrong Route	198 (5.5%)	195	6	5	1
Contraindication	191 (5.3%)	123	92	3	2
Wrong Patient	186 (5.2%)	173	17	2	2
Wrong Formulation or Presentation	94 (2.6%)	49	16	41	0
Adverse Drug Reaction (Allergy related error)	77 (2.1%)	65	20	0	0
Wrong Dispensing Label/Instruction	66 (1.8%)	39	19	16	0
Wrong Storage	60 (1.7%)	33	3	4	26

Appendix A *Medication errors reported to the Norwegian Incident Reporting System (NIRS) in 2016 and 2017. Error type in relation to medication process stage.*

The total number of error types and medication process stages was greater than the number of incidents because the classification system permitted more than one category to be selected for one incident.

Therapeutic subgroup (ATC level 2)	No harm	Low harm	Moderate harm	Severe ham	Death	Total medication errors (n)	Total medication errors (%)
Analgesics (N02)	158	222	77	19	7	485	14.3
Antibacterials for systemic use (J01)	207	166	51	19	3	458	13.5
Antithrombotic agents (B01)	164	113	56	44	6	398	11.8
I.V. Solutions (not an ATC category)	84	88	51	8	0	238	7.2
Psycholeptics (N05)	71	73	26	12	2	190	5.7
Antineoplastic agents and immunomodulating agents (L01-L04)	64	59	38	14	2	183	5.5
Drugs used in diabetes (A10)	57	83	29	8	0	182	5.4
Antihypertensives and Beta blocking agents (C02 and C07)	64	70	22	5	0	161	4.8
Cardiac theraphy (C01)	50	45	35	9	2	141	4.2
Other	59	45	22	9	0	137	4.1
Corticosteroids for systemic use (H02)	34	34	15	2	0	85	2.5
Anesthetics (N01)	20	26	17	6	1	70	2.1
Antiepileptics (N03)	21	29	8	2	0	62	1.8
Diagnostic agents (V04)	7	22	14	4	0	47	1.4
Diuretics (C03)	13	21	8	2	2	47	1.4
Psychoanaleptics (N06)	16	14	7	1	0	38	1.1
Other nervous system drugs (N07)	13	15	4	1	2	36	1.1
Drugs for functional gastrointestinal disorders (A03)	11	11	9	0	0	32	0.9
Vitamins and Mineral supplements (A11 and A12)	12	13	2	1	0	29	0.9
Drugs for Treatment of Bone Diseases (M05)	8	3	3	1	0	15	0.4
Drugs for obstructive airway diseases (R03)	1	8	4	0	0	13	0.4
Muscle relaxants (M03)	4	3	3	2	0	12	0.4
Lipid modifying agents (C10)	7	4	0	0	0	11	0.3
Sex hormones and modulators of the genital system (G03)	3	2	3	2	0	10	0.3
Antihemorrhagics (B02)	4	2	2	0	0	9	0.2
Immune sera and Immunoglobulins (J06)	2	1	3	1	0	8	0.2
All other therapeutic agents (V03)	3	3	0	0	0	6	0.2
Missing	N/A	N/A	N/A	N/A	N/A	269	7.9
Total	1157	1175	509	172	27	3372	100

Appendix B *Characteristics of the most commonly reported therapeutic subgroups in relation to the degree of harm reported to the Norwegian Incident Reporting System (NIRS) in 2016 and 2017*

Paper II

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

Mulac Alma, Hagesaether Ellen, Granas Anne Gerd

J Adv Nurs, 2021; Oct 10. doi: 10.1111/jan.15072. Epub ahead of print.

II

Check for updates

Received: 1 July 2021 | Revised: 30 August 2021 | Accepted: 26 September 2021

DOI: 10.1111/jan.15072

JAN Leading Global Nursing Research WILEY

ORIGINAL RESEARCH:
EMPIRICAL RESEARCH – MIXED METHODS

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

Alma Mulac[1] | Ellen Hagesaether[2] | Anne Gerd Granas[1,3]

[1]Department of Pharmacy, The Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway

[2]Department of Life Sciences and Health, Faculty of Health Sciences, Oslo Metropolitan University, Oslo, Norway

[3]Norwegian Centre for E-health Research, University Hospital of North Norway, Tromsø, Norway

Correspondence
Alma Mulac, Department of Pharmacy, The Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway.
Email: alma.mulac@farmasi.uio.no

Funding information
This research was supported by the doctoral research funding for the first author of this paper by the University of Oslo.

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

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
© 2021 The Authors. *Journal of Advanced Nursing* published by John Wiley & Sons Ltd.

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

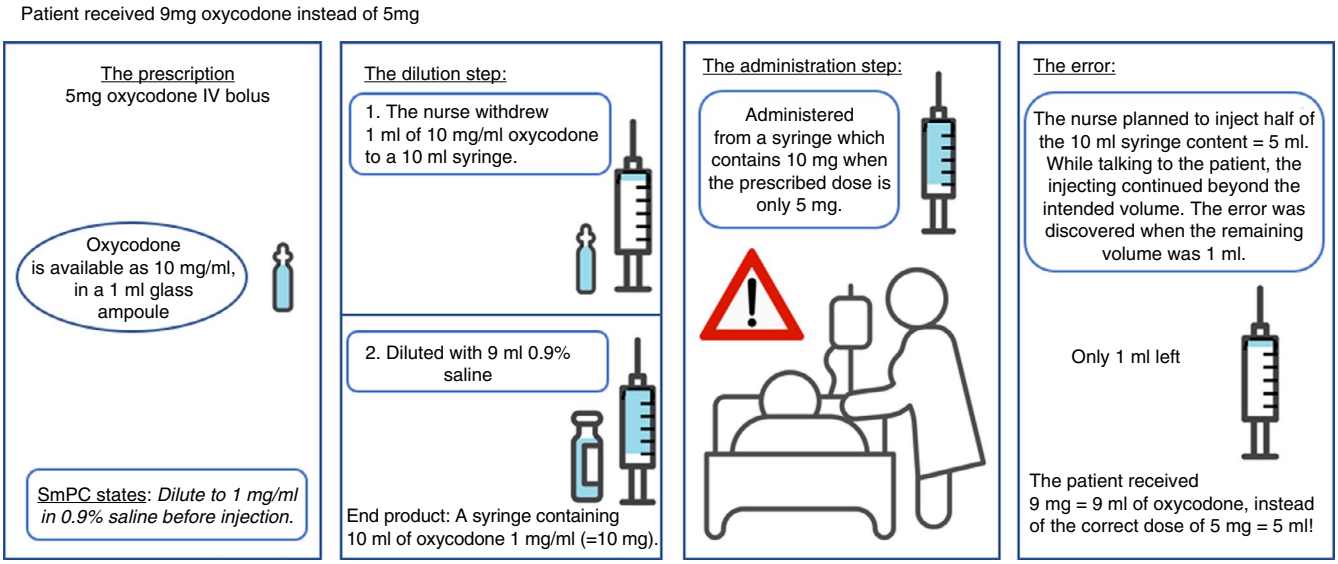

FIGURE 1 Administering from a syringe that contains more than the prescribed dose

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.

ACKNOWLEDGEMENTS

We thank Kristian Ringsby Odberg RN, PhD for his valuable review of the manuscript.

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

The peer review history for this article is available at https://publons.com/publon/10.1111/jan.15072.

DATA AVAILABILITY STATEMENT

The data is not publicly available.

ORCID

Alma Mulac https://orcid.org/0000-0001-9463-997X

REFERENCES

Alsulami, Z., Choonara, I., & Conroy, S. (2014). Paediatric nurses' adherence to the double-checking process during medication administration in a children's hospital: an observational study. *Journal of Advanced Nursing*, *70*(6), 1404–1413. https://doi.org/10.1111/jan.12303

Alteren, J., & Nerdal, L. (2015). Relationship between high school mathematics grade and number of attempts required to pass the medication calculation test in nurse education: an explorative study. *Healthcare*, *3*(2), 351–363. https://doi.org/10.3390/healthcare3020351

American Hospital Association. Health Research and Educational Trust and Institute for Safe Medication Practices. (2002). Pathways for medication safety: Looking collectively at risk. www.ismp.org/tools/pathwaysection2.pdf

Aronson, J. K. (2009). Medication errors: What they are, how they happen, and how to avoid them. *QJM*, *102*(8), 513–521. https://doi.org/10.1093/qjmed/hcp052

Bonadio, W. (2019). Frequency of emergency medicine resident dosing miscalculations treating pediatric patients. *American Journal of Emergency Medicine*, *37*(10), 1964–1965. https://doi.org/10.1016/j.ajem.2019.03.027

Bond, C. A., Raehl, C. L., & Franke, T. (2002). Clinical pharmacy services, hospital pharmacy staffing, and medication errors in United States hospitals. *Pharmacotherapy*, *22*(2), 134–147. https://doi.org/10.1592/phco.22.3.134.33551

Cohen, M., Smetzer, J., Tuohy, N., & Kilo, C. (2007). High-alert medications: Safeguarding against errors. In M. R. Cohen (Ed.), *Medication errors* (pp. 317–412). The American Pharmacist Association.

Conn, R. L., Kearney, O., Tully, M. P., Shields, M. D., & Dornan, T. (2019). What causes prescribing errors in children? Scoping review. *British Medical Journal Open*, *9*(8), e028680. https://doi.org/10.1136/bmjopen-2018-028680

Cousins, D., Rosario, C., & Scarpello, J. (2011). Insulin, hospitals and harm: A review of patient safety incidents reported to the National Patient Safety Agency. *Clinical Medicine*, *11*(1), 28–30. https://doi.org/10.7861/clinmedicine.11-1-28

Dickinson, A., McCall, E., Twomey, B., & James, N. (2010). Paediatric nurses' understanding of the process and procedure of double-checking medications. *Journal of Clinical Nursing*, *19*(5–6), 728–735. https://doi.org/10.1111/j.1365-2702.2009.03130.x

Doherty, C., & Mc Donnell, C. (2012). Tenfold medication errors: 5 years' experience at a university-affiliated pediatric hospital. *Pediatrics*, *129*(5), 916–924. https://doi.org/10.1542/peds.2011-2526

Fleming, S., Brady, A.-M., & Malone, A.-M. (2014). An evaluation of the drug calculation skills of registered nurses. *Nurse Education in Practice*, *14*(1), 55–61. https://doi.org/10.1016/j.nepr.2013.06.002

Fox, A., Portlock, J., & Brown, D. (2019). Electronic prescribing in paediatric secondary care: Are harmful errors prevented? *Archives of Disease in Childhood*, *104*(9), 895–899. https://doi.org/10.1136/archdischild-2019-316859

Franklin, B. D., Shebl, N. A., & Barber, N. (2012). Failure mode and effects analysis: Too little for too much? *BMJ Quality & Safety*, *21*(7), 607–611. https://doi.org/10.1136/bmjqs-2011-000723

Franklin, B. D., Taxis, K., & Barber, N. (2009). Parenteral drug errors. Reported error rates are likely to be underestimation. *BMJ*, *338*, b1814. https://doi.org/10.1136/bmj.b1814

Gariel, C., Cogniat, B., Desgranges, F. P., Chassard, D., & Bouvet, L. (2018). Incidence, characteristics, and predictive factors for medication errors in paediatric anaesthesia: A prospective incident monitoring study. *British Journal of Anaesthesia*, *120*(3), 563–570. https://doi.org/10.1016/j.bja.2017.12.014

Grandell-Niemi, H., Hupli, M., & Leino-Kilpi, H. (2001). Medication calculation skills of graduating nursing students in Finland. *Advances in Health Sciences Education: Theory and Practice*, *6*(1), 15–24. https://doi.org/10.1023/a:1009842501113

Grissinger, M. (2010). Reducing errors with injectable medications: Unlabeled syringes are surprisingly common. *Pharmacy and Therapeutics*, *35*(8), 428–451.

Grissinger, M. (2016). Your high-alert medication list is relatively useless without associated risk-reduction strategies. *Pharmacy and Therapeutics*, *41*(10), 598–600.

Hedlund, N., Beer, I., Hoppe-Tichy, T., & Trbovich, P. (2017). Systematic evidence review of rates and burden of harm of intravenous admixture drug preparation errors in healthcare settings. *British Medical Journal Open*, *7*(12), e015912. https://doi.org/10.1136/bmjopen-2017-015912

Institute for Safe Medication Practices. (2015). Safe practice guidelines for adult IV push medications. A compilation of safe practices from the ISMP Adult IV Push Medication Safety Summit. https://www.ismp.org/sites/default/files/attachments/2017-11/ISMP97-Guidelines-071415-3.%20FINAL.pdf

Keers, R. N., Williams, S. D., Cooke, J., & Ashcroft, D. M. (2013). Prevalence and nature of medication administration errors in

health care settings: A systematic review of direct observational evidence. *Annals of Pharmacotherapy*, *47*(2), 237–256. https://doi.org/10.1345/aph.1R147

Lesar, T. S. (1998). Errors in the use of medication dosage equations. *Archives of Pediatrics and Adolescent Medicine*, *152*(4), 340–344. https://doi.org/10.1001/archpedi.152.4.340

Lustig, A. (2000). Medication error prevention by pharmacists—An Israeli solution. *Pharmacy World and Science*, *22*(1), 21–25. https://doi.org/10.1023/a:1008774206261

Lyons, I., Furniss, D., Blandford, A., Chumbley, G., Iacovides, I., Wei, L., Cox, A., Mayer, A., Vos, J., Galal-Edeen, G. H., Schnock, K. O., Dykes, P. C., Bates, D. W., & Franklin, B. D. (2018). Errors and discrepancies in the administration of intravenous infusions: A mixed methods multihospital observational study. *BMJ Quality & Safety*, *27*(11), 892–901. https://doi.org/10.1136/bmjqs-2017-007476

Makwana, S., Basu, B., Makasana, Y., & Dharamsi, A. (2011). Prefilled syringes: An innovation in parenteral packaging. *International Journal of Pharmaceutical Investigation*, *1*(4), 200–206. https://doi.org/10.4103/2230-973X.93004

McMullan, M., Jones, R., & Lea, S. (2010). Patient safety: Numerical skills and drug calculation abilities of nursing students and registered nurses. *Journal of Advanced Nursing*, *66*(4), 891–899. https://doi.org/10.1111/j.1365-2648.2010.05258.x

Mulac, A., Taxis, K., Hagesaether, E., & Granas, A. G. (2020). Severe and fatal medication errors in hospitals: Findings from the Norwegian Incident Reporting System. *European Journal of Hospital Pharmacy*. https://doi.org/10.1136/ejhpharm-2020-002298

Naidu, M. C., & Alicia, Y. L. Y. (2019). Impact of bar-code medication administration and electronic medication administration record system in clinical practice for an effective medication administration process. *Health*, *11*, 511–526. https://doi.org/10.4236/health.2019.115044

NCC MERP. (2001). National coordinating council for medication error reporting and prevention. Index for Categorizing Medication Errors. https://www.nccmerp.org/about-medication-errors

Ohashi, K., Dalleur, O., Dykes, P. C., & Bates, D. W. (2014). Benefits and risks of using smart pumps to reduce medication error rates: A systematic review. *Drug Safety*, *37*(12), 1011–1020. https://doi.org/10.1007/s40264-014-0232-1

Peerally, M. F., Carr, S., Waring, J., & Dixon-Woods, M. (2017). The problem with root cause analysis. *BMJ Quality & Safety*, *26*(5), 417–422. https://doi.org/10.1136/bmjqs-2016-005511

Pfeiffer, Y., Zimmermann, C., & Schwappach, D. L. B. (2020). What are we doing when we double check? *BMJ Quality & Safety*, *29*(7), 536–540. https://doi.org/10.1136/bmjqs-2019-009680

Poon, E. G., Keohane, C. A., Yoon, C. S., Ditmore, M., Bane, A., Levtzion-Korach, O., Moniz, T., Rothschild, J. M., Kachalia, A. B., Hayes, J., Churchill, W. W., Lipsitz, S., Whittemore, A. D., Bates, D. W., & Gandhi, T. K. (2010). Effect of bar-code technology on the safety of medication administration. *New England Journal of Medicine*, *362*(18), 1698–1707. https://doi.org/10.1056/NEJMsa0907115

Rothman, R. L., Montori, V. M., Cherrington, A., & Pignone, M. P. (2008). Perspective: The role of numeracy in health care. *Journal of Health Communication*, *13*(6), 583–595. https://doi.org/10.1080/10810730802281791

Schnock, K. O., Dykes, P. C., Albert, J., Ariosto, D., Call, R., Cameron, C., Carroll, D. L., Drucker, A. G., Fang, L., Garcia-Palm, C. A., Husch, M. M., Maddox, R. R., McDonald, N., McGuire, J., Rafie, S., Robertson, E., Saine, D., Sawyer, M. D., Smith, L. P., … Bates, D. W. (2017). The frequency of intravenous medication administration errors related to smart infusion pumps: A multihospital observational study. *BMJ Quality & Safety*, *26*(2), 131–140. https://doi.org/10.1136/bmjqs-2015-004465

Seshia, S. S., Bryan Young, G., Makhinson, M., Smith, P. A., Stobart, K., & Croskerry, P. (2018). Gating the holes in the Swiss cheese (part I): Expanding professor Reason's model for patient safety. *Journal of Evaluation in Clinical Practice*, *24*(1), 187–197. https://doi.org/10.1111/jep.12847

Simonsen, B. O., Daehlin, G. K., Johansson, I., & Farup, P. G. (2014). Differences in medication knowledge and risk of errors between graduating nursing students and working registered nurses: Comparative study. *BMC Health Services Research*, *14*, 580. https://doi.org/10.1186/s12913-014-0580-7

Taxis, K., & Barber, N. (2003). Causes of intravenous medication errors: An ethnographic study. *Quality & Safety in Health Care*, *12*(5), 343–347. https://doi.org/10.1136/qhc.12.5.343

The Norwegian Directorate of Health. (2015). *Medication management policy with comments [Legemiddelhåndteringsforskriften med kommentarer]*. Helsedirektoratet. Rundskriv IS-7/2015. https://www.helsedirektoratet.no/rundskriv/legemiddelhandteringsforskriften-med-kommentarer/Legemiddelh%C3%A5ndteringsforskriften%20med%20kommentarer%20(rev)%20%E2%80%93%20Rundskriv.pdf/_/attachment/inline/506142af-6a2f-407f-8f3d-b87d3adc3cd5:81191d21a0a9e3131cb80deff61f723499f3f65c/Legemiddelh%C3%A5ndteringsforskriften%20med%20kommentarer%20(rev)%20%E2%80%93%20Rundskriv.pdf

Tse, Y., & Tuthill, D. (2021). Incidence of paediatric 10-fold medication errors in Wales. *Archives of Disease in Childhood*, *106*(7), 656–661. https://doi.org/10.1136/archdischild-2020-319130

Warburton, P. (2010). Poor numeracy skills must be tackled to cut medication errors. *Nursing Times*, *106*(9), 13.

Westbrook, J. I., Li, L., Raban, M. Z., Woods, A., Koyama, A. K., Baysari, M. T., Day, R. O., McCullagh, C., Prgomet, M., Mumford, V., Dalla-Pozza, L., Gazarian, M., Gates, P. J., Lichtner, V., Barclay, P., Gardo, A., Wiggins, M., & White, L. (2021). Associations between double-checking and medication administration errors: A direct observational study of paediatric inpatients. *BMJ Quality & Safety*, *30*(4), 320–330. https://doi.org/10.1136/bmjqs-2020-011473

Williams, B., & Davis, S. (2016). Maths anxiety and medication dosage calculation errors: A scoping review. *Nurse Education in Practice*, *20*, 139–146. https://doi.org/10.1016/j.nepr.2016.08.005

Wright, K. (2007). A written assessment is an invalid test of numeracy skills. *British Journal of Nursing*, *16*(13), 828–831. https://doi.org/10.12968/bjon.2007.16.13.24252

Wright, K. (2010). Do calculation errors by nurses cause medication errors in clinical practice? A literature review. *Nurse Education Today*, *30*(1), 85–97. https://doi.org/10.1016/j.nedt.2009.06.009

How to cite this article: Mulac, A., Hagesaether, E., & Granas, A. G. (2021). Medication dose calculation errors and other numeracy mishaps in hospitals: Analysis of the nature and enablers of incident reports. *Journal of Advanced Nursing*, 00, 1–15. https://doi.org/10.1111/jan.15072

The *Journal of Advanced Nursing (JAN)* is an international, peer-reviewed, scientific journal. *JAN* contributes to the advancement of evidence-based nursing, midwifery and health care by disseminating high quality research and scholarship of contemporary relevance and with potential to advance knowledge for practice, education, management or policy. *JAN* publishes research reviews, original research reports and methodological and theoretical papers.

For further information, please visit *JAN* on the Wiley Online Library website: www.wileyonlinelibrary.com/journal/jan

Reasons to publish your work in *JAN*:

- **High-impact forum: the world's most cited nursing journal, with an Impact Factor of 2.561 – ranked 6/123 in the 2019 ISI Journal Citation Reports © (Nursing; Social Science).**
- **Most read nursing journal in the world: over 3 million articles downloaded online per year and accessible in over 10,000 libraries worldwide (including over 6,000 in developing countries with free or low cost access).**
- **Fast and easy online submission:** online submission at http://mc.manuscriptcentral.com/jan.
- **Positive publishing experience:** rapid double-blind peer review with constructive feedback.
- **Rapid online publication in five weeks:** average time from final manuscript arriving in production to online publication.
- **Online Open:** the option to pay to make your article freely and openly accessible to non-subscribers upon publication on Wiley Online Library, as well as the option to deposit the article in your own or your funding agency's preferred archive (e.g. PubMed).

Paper III

Barcode medication administration technology use in hospital practice:

a mixed-methods observational study of policy deviations

Mulac Alma, Mathiesen Liv, Taxis Katja, Granås Anne Gerd

BMJ Qual Saf 2021; 0:1–10. doi:10.1136/bmjqs-2021-013223

III

OPEN ACCESS

Barcode medication administration technology use in hospital practice: a mixed-methods observational study of policy deviations

Alma Mulac ,[1] Liv Mathiesen,[1] Katja Taxis,[2] Anne Gerd Granås[1]

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjqs-2021-013223).

[1]Department of Pharmacy, Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway
[2]Pharmacotherapy and Pharmaceutical Care, University of Groningen, Groningen, The Netherlands

Correspondence to
Dr Alma Mulac, Department of Pharmacy, University of Oslo Faculty of Mathematics and Natural Sciences, Oslo, Norway; alma.mulac@farmasi.uio.no

Received 20 February 2021
Accepted 5 July 2021

Check for updates

© Author(s) (or their employer(s)) 2021. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Mulac A, Mathiesen L, Taxis K, *et al*. *BMJ Qual Saf* Epub ahead of print: [please include Day Month Year]. doi:10.1136/bmjqs-2021-013223

ABSTRACT

Introduction Barcode medication administration (BCMA) can, if poorly implemented, cause disrupted workflow, increased workload and cause medication errors. Further exploration is needed of the causes of BCMA policy deviations.

Objective To gain an insight into nurses' use of barcode technology during medication dispensing and administration; to record the number and type of BCMA policy deviations, and to investigate their causes.

Methods We conducted a prospective, mixed-methods study. Medication administration rounds on two hospital wards were observed using a digital tool and field notes. The SEIPS (Systems Engineering Initiative for Patient Safety) model was used to analyse the data.

Results We observed 44 nurses administering 884 medications to 213 patients. We identified BCMA policy deviations for more than half of the observations; these related to the level of tasks, organisation, technology, environment and nurses. Task-related policy deviations occurred with 140 patients (66%) during dispensing and 152 patients (71%) during administration. Organisational deviations included failure to scan 29% of medications and 20% of patient's wristbands. Policy deviations also arose due to technological factors (eg, low laptop battery, system freezing), as well as environmental factors (eg, medication room location, patient drawer size). Most deviations were caused by policies that interfere with proper and safe BCMA use and suboptimal technology design.

Conclusion Our findings indicate that adaptations of the work system are needed, particularly in relation to policies and technology, to optimise the use of BCMA by nurses during medication dispensing and administration. These adaptations should lead to enhanced patient safety, as the absolute goal with BCMA implementation.

INTRODUCTION

Barcode medication administration (BCMA) technology is a health information technology credited for preventing medication errors and promoting patient safety when used accurately.[1] BCMA technology automates the process of verification by scanning the barcode on the medication and the patient identification wristband, thus assisting the nurses in confirming the 'five rights' of medication administration: right patient, right medication, right dose, right route and right time.[2] In an effort to prevent consequences of medication administration errors to patients,[3] hospitals have strongly encouraged BCMA implementation.[4–7] The BCMA has shown to reduce medication administration errors significantly and to reduce harm from serious medication errors.[8] Previous studies have also reported an increase in patient identity verification rate after implementing BCMA.[9 10]

While BCMA has existed for over two decades, hospitals have struggled to adapt and implement it within their existing infrastructure,[5 11–15] and several studies demonstrate that the implementation process for BCMA is important for its overall success.[12 13] Studies have shown increased workload or disrupted workflow with the use of BCMA, resulting in workarounds,[7 12 14 16 17] such as carrying prescanned medications on carts.[18] These workarounds, also described as policy deviations, can lead to new errors created by the use of the technology.[7 12 18]

Although previous studies have identified workarounds and policy deviations with BCMA,[7 12 18] there has been limited research to disclose why deviations occur and the impact of the surrounding context to their occurrence. One systematic review that evaluated the impact of BCMA technology to patient safety concluded that human factors and technical issues are standing in way of achieving intended scanning rates and patient safety benefits.[1] Another systematic review came to a similar conclusion and highlighted the importance of analysing whether deviations that are outside the five types of medication errors can have important

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

implications to patient safety.[19] The purpose of this study, therefore, was to investigate nurses' interaction with the technology and identify policy deviations as potential unsafe practices using a human factors approach.[20] More specifically, the study aimed to (1) gain an in-depth understanding of how nurses actually use the BCMA during medication rounds, (2) to record the number and types of BCMA policy deviations during medication dispensing and administration, and (3) to investigate probable causes of policy deviations in relation to the socio-technical factors of the working environment.

METHODS

Overview

We used a concurrent triangulated, mixed-methods design comprising structured observation (quantitative data) and field notes and nurses' comments (qualitative data) of BCMA use at two medical wards at a 700-bed hospital in Norway. Structured observation, involving a digital observational tool, was used to quantify policy deviations. Field notes and nurses' comments contextualised the quantitative data, provided explanations and sometimes cued the causes to policy deviations.

Theoretical framework

We used the SEIPS model (Systems Engineering Initiative for Patient Safety)[16 20] to provide the theoretical underpinning for this study. This model explores interactions between humans, the technology they use and the environment in which they work, and has been successfully applied in the field of medication administration technologies,[16] as well as across healthcare.[20] In our study, we applied the SEIPS model to categorise the integrated qualitative and quantitative data according to the five elements of the SEIPS model[20]: (1) tasks, (2) organisational factors, (3) technology, (4) physical environment, and (5) individuals.

Setting

The study hospital was the first to introduce eMAR (electronic Medication Administration Record) and BCMA technology in Norway. The technology was implemented over a 3-year period, from 2017 to 2019. The studied eMAR and BCMA were a part of Metavision, iMDsoft. In addition to the digitalised medication records, the system comprised barcode scanners, patient identification (ID) wristbands, single-dose medication units, and scanning during dispensing and administration. The hospital used a decentralised ward-based dispensing system. The description of the delivery, dispensing and administration process with respective policy descriptions is illustrated in figure 1. Data were collected on two wards: a cardiac medical ward and a geriatric intensive care ward. Other ward characteristics and dates of observation are summarised in online supplemental appendix 1.

Definitions

We defined a policy deviation as the act of dispensing or administering a medicine that was not in accordance with the hospital policy. *Task-related deviations* were failures with tasks involving use of barcode scanning during dispensing and administration. Organisational policy deviations included violations of hospital medication management policies, for example dispensing the wrong dose of the medication in the patient drawer placed in the computer on wheels

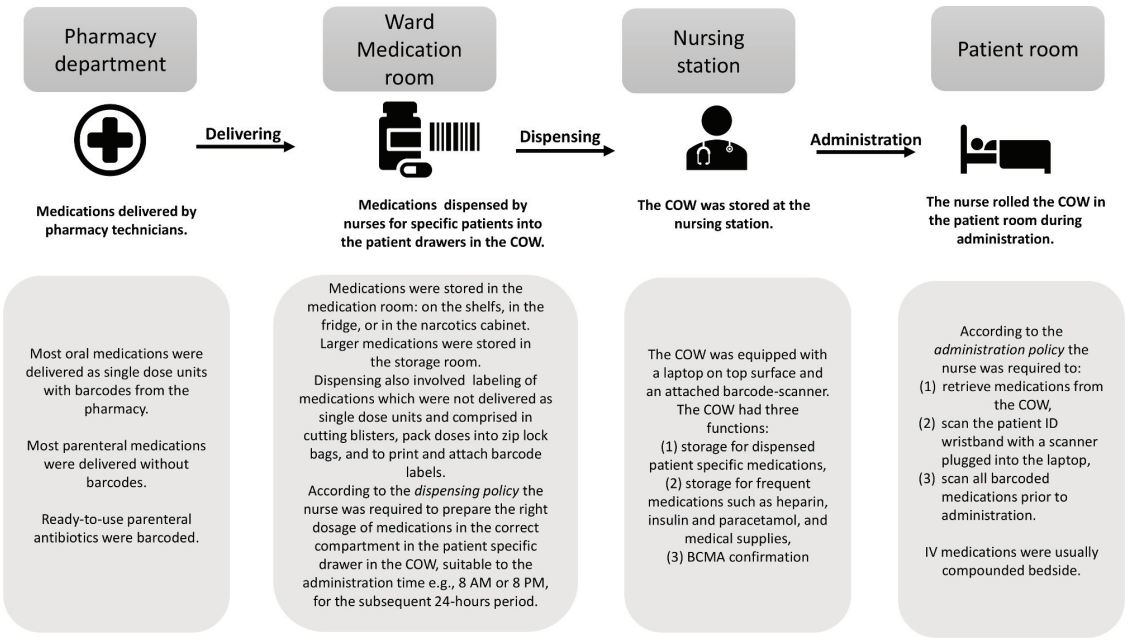

Figure 1 Description of the dispensing and administration process. BCMA,barcode medication administration; COW, computer on wheels.

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

(COW). Technology-related factors included problems with the technological equipment (hardware and software) associated with the BCMA. Environmental factors were elements of the physical environment that affected the BCMA. Nurse-related factors were related to the practice or comments of individuals.

Data collection

One registered pharmacist and one fifth-year pharmacy student observed medication administration rounds between October 2019 and January 2020. The observers contacted the assigned nurse on the respective ward prior to the medication round, explained the purpose of the study and obtained written consent. Upon entering the patient room, the nurse informed the patient briefly about the presence of the observer and the purpose of the study. To minimise observation bias,[21] the observers remained silent during observation. No patient-identifiable data were recorded. The observer alerted the nurse if they became aware of a medication error with the potential to cause patient harm.

We used a digital observational tool (described later) to record quantitative data and checked for consistency by the research team. Data were collected using handheld tablets and directly sent to a secured server for storage. After completing the structured observations of the medication rounds, the observers documented additional qualitative field notes of the medication safety environment and any comments made by the nurse.

Data collection stopped when saturation was achieved, and the research team members evaluated that additional data would not lead to new information.[22] The observers periodically met with the research team to review observation data for this determination.

Development and piloting of the data collection tool

A digital observational tool, using secure web-based data survey software,[23] was developed to collect data during medication administration. The tool was piloted for 7 days, by two observers, who observed the administration of medications to 30 patients on two medical wards. While the pilot data were not included in the main study, they were discussed by our inter-professional research team, and each question in the observational tool was evaluated for relevance to the research question and consistency with current evidence. We developed separate data collection tools for oral and parenteral medications because the differences in their administration processes (online supplemental appendices 2 and 3). The 28 questions in the oral and parenteral observational tool (14 questions in each) were aligned with the workflow described in the hospital policies and quantified data on the following:

- The total number of medications; scannable and scanned medications; number of scanned patient ID wristbands.
- Policy deviations with dispensing, labelling, storage or scanning.
- Technological problems with equipment or software.
- The storage of inpatients' own medications.
- A free-text option in the tool was available to register the observers' comments.

Analysis

Quantitative data from both observational tools were merged; any string data were converted to numeric values. Scanning rates and frequency of policy deviations were analysed using descriptive statistics with IBM SPSS V.25. Qualitative data were analysed with inductive thematic analysis[24] through an iterative process. Two researchers coded the data assigning utterances to themes which were developed as they emerged from the data. The researchers discussed the manner in which the data fitted in the themes to reach joint consensus. Following the separate analysis of quantitative and qualitative data, we integrated the two data sets using a triangulated approach.[25 26] Key findings from both data sets were identified and complimentary findings were compared to enhance validity and provide a deeper understanding of policy deviations and their causes. The integrated findings were then categorised according to the five elements of the SEIPS model.[20]

RESULTS

A total of 44 nurses were observed while preparing and administering medications; 29 during the morning and 15 during the evening medication rounds. We observed the administration of 884 medications (mean per patient, 4.2; range, 0 to 14) to 213 patients (table 1). In total, 133 patients (62%) received oral medications only, 59 patients (28%) received both oral and parenteral, while 21 patients (10%) received only parenteral medications.

Task-related policy deviations

Data source: observational tool

We registered how nurses used BCMA during dispensing and administration. Task-related policy deviations affected 140 patients (66%) during medication dispensing and 152 patients (71%) during medication administration, illustrated in figure 2. During administration, we identified three variations in nurses' BCMA use which resulted in deviations: nurses did not use BCMA; nurses partially used BCMA; nurses used BCMA correctly, but deviations still occurred.

Organisational policy deviations

Data source: observational tool, field notes and nurses' comments

Organisational deviations were deviations from the medication management policies. In terms of medication administration deviations, these arose with not scanning 29% medications and 20% patient ID wristband (table 1).

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

Table 1 Characteristics of the observed barcode medication administration

Characteristics	Ward 1	Ward 2	Total (%)
Observation duration	14 hours 35 min	17 hours 48 min	32 hours 23 min
Number of observed nurses	22 (21 female; 1 male)	22 female	44
Number of observed medication rounds	18 (12 at 8:00; 6 at 20:00)	20 (14 at 8:00; 6 at 20:00)	38
Total number of observed patients	94	119	213 (100%)
Number of patients with scanned wristband	85	85	170 (80%)
Total number of medications	447	437	884 (100%)
Number of barcoded medications	373	315	688 (78%)
Number of scanned medications	319	306	625 (71%)

We identified 10 types of policy deviations during the dispensing process. The most frequent were medication not dispensed (n=80 patients), barcode label missing (n=70 patients) and wrong dose dispensed (n=30 patients). Dispensing deviations and their connection to potential medication errors are listed in table 2. All data in table 2 are presented as deviations, although three of these deviations also classify as actual medication errors including wrong medication dispensed, wrong dose dispensed, and medication not dispensed and not administered which is a medication omission. These deviations in the COW were often revealed after the nurse had entered the patient room and resulted in a prolonged and frequently interrupted administration, which led to medication omission for 25 patients. For 11 patients, scanning in the eMAR prevented administration of the wrongly dispensed medication. The observer intervened on one occasion when a nurse dispensed a wrong (look-alike) medication from the medication room and intended to give to the patient.

We also observed deviations from the storage of patients' own medication (home-brought). According to policy, patients' own medication should be stored in the COW or the medication room. We registered a 96% deviation rate from this policy (table 2). Patients' own medications were not integrated in the BCMA and were not barcoded or scanned.

Technology-related factors

Data source: observational tool and field notes

Technology-related factors were registered with the observational tool and deviations were found in 38 observations (18%). These included low

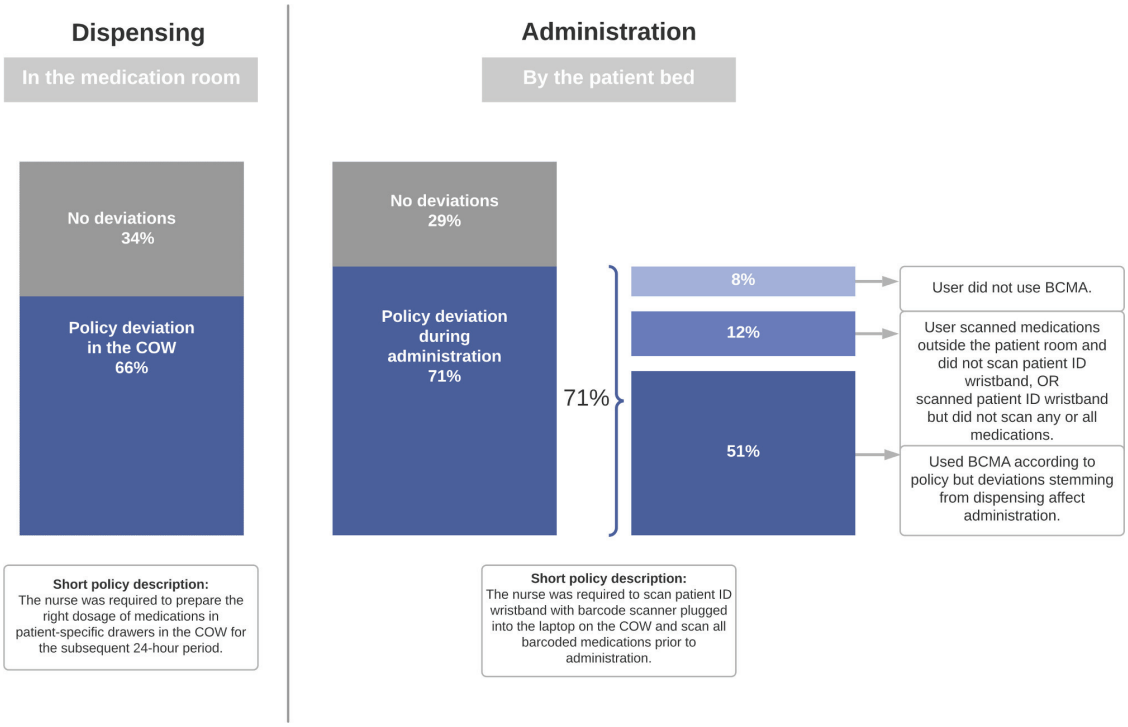

Figure 2 Task-related policy deviations with barcode medication administration. BCMA, barcode medication administration; COW, computer on wheels.

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

Table 2 Organisational policy deviations with barcode medication administration and their connection to potential medication errors

Types of policy deviations*	N	Examples and descriptions	Potential medication errors
Medication not dispensed; obtained and given during observation	55	Nurse did not check for omission of dispensing before administration round start even though some medications (eg, parenteral injectables) were not expected to be found in the COW at all	Omission
Medication not dispensed; not given during observation†	25		
Barcode label missing	70	Dispensed tablets without a barcode label, or without primary packaging	Wrong medication Wrong dose
Wrong dose dispensed†	30	Dispensed whole blister pack instead of one tablet (correct dose)	Wrong dose
Scanning failure	26	Barcode on the medication was not readable for the scanner	Wrong medication Wrong dose Wrong route
Barcode label not attached	13	Barcode label was in the patient drawer but not attached to the medication Nurses stored expired labels for future administrations to save time from printing new labels	Wrong medication
Wrong medication dispensed†	11	Dispensed extended-release tablet instead of tablet Dispensed sound-alike medication, for example, Lescol instead of Losec Dispensed 2 g Cloxacillin intravenous bag from the storage room instead of 1 g Errors discovered by scanning in eMAR	Wrong medication
COW deviations due to recent changes in the eMAR	7	Antithrombotic medication was dispensed in the patient drawer, nurse removed it during administration due to the patient being scheduled for surgery that day	Contraindication Wrong drug Wrong route
Medication placed in the wrong compartment in the drawer	5	During dispensing, medication prescribed for morning administration was placed in the compartment in the patient drawer assigned for evening administration	Wrong medication Omission or wrong time
Wrong room number on patient drawer	3	The patient changed the room, but the room number on the patient drawer was not changed	Wrong patient
Wrong label attached	1	Attached 'metoprolol' label on a generic substitute Bloxazoc (metoprolol) unit dose. Revealed after failure with scanning the label	Wrong medication Wrong dose
Patients' own medication stored in the patient room	24	We observed deviation of this policy for 24 of total 25 patients' own medications (96%)	Wrong dose Wrong medication

*The number of deviations refers to one deviation of the same type per patient even if more deviations of same type exist with one patient, for example, if one patient had wrong dose dispensed for two medications, this was counted as one deviation.
†Deviations which also classify as actual medication errors.
COW, computer on wheels; eMAR, electronic Medication Administration Record.

laptop battery in 28 observations (13%), system freezing in seven observations (3%), malfunctioning barcode scanner in two observations and the barcode scanner was unavailable for administration in one observation (online supplemental appendix 4). Software problems included slow response and the need for multiple clicking after scanning each medication. Nurses used the laptop mousepad to navigate the eMAR, and this extensive clicking was perceived by the nurses as frustrating. The size of the COW was deemed to slow the administration process and lead to deviations.

Environmental factors

Data source: observational tool, field notes and nurses' comments

Medication rooms were located some distance from the nursing stations and patient rooms. The nurses ran back and forth to the medication room multiple times during an administration round to rectify deviations in the COW. Other disruptive environmental factors affecting the BCMA workflow were the fact that the patient drawers were too small and could not contain all the patient medications. We also observed that the work surface of the COWs and at the nursing stations were often untidy and contained single-dose units from past administrations or falsely dispensed medications.

Nurse-related factors

Data source: observational tool, field notes and nurses' comments

Several nurses admitted that they did not use the barcode scanning equipment on a daily basis. If the ward was particularly busy, nurses tended to discard BCMA because they perceived it slowed down the medication administration. However, nurses who used BCMA regularly valued the automated medication verification because it confirmed that the right patient would receive the right medication.

Probable causes of BCMA policy deviations

The probable causes of BCMA deviations and their data sources are listed in table 3. Under task-related deviations, the failure to scan medications during administration occured because scanning was discarded during dispensing; a non-streamlined workflow during administration was caused by a mismatch

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

Table 3 Probable causes to barcode medication administration policy deviations according to the SEIPS categories

Probable cause	Example from observation/description	Data source
Tasks related		
Scanning discarded during dispensing	Medications which were dispensed without scanning in the eMAR failed to scan during administration	Observational tool
Workflow not adopted to required tasks during administration	Nurse makes multiple runs back and forth to the medication room to retrieve not dispensed medications which interrupts the workflow and may affect patient safety	Observational tool Nurses' comments
Suboptimal task performance	Voluminous medications (such as infusion bags, inhalers, eye drops) are routinely not scanned during dispensing because they are retrieved during administration	Observational tool Nurses' comments
Organisational		
Dispensing practices not adopted to nurse's workload, resulted in normalising deviations	Manual labelling of medications during dispensing on ward was challenging to carry out without workarounds	Observational tool
Non-standardised dispensing process resulted in frequent deviations	Medication not barcode labelled; scanning failure; wrong dose dispensed; wrong medication dispensed; medication not dispensed; wrong label attached	Observational tool
Unclear procedures or task not assigned	Varying practice between the wards on updating the dispensed medications in the COW due to recent changes in the eMAR	Observational tool Nurses' comments Field notes
Poor routines/not followed routines for changing the room number on patient drawer	Room number on patient drawer was another patient's room number (Each patient drawer was labelled with room number and this was the first step in identifying the patient's medications)	Observational tool
Unaware of hospital policies	Patient's own medications stored in the patient room. Due to policy, patients' own medication should be stored in the COW or the medication room	Observational tool
Technology		
Poor charging routines or non-compliance with routine	The laptop battery was low either at the start or during administration	Observational tool
eMAR usability issues	Slow eMAR response and need for multiple clicking after scanning each medication	Field notes
The scanners were not wireless and limited the patient ID scanning	Nurse scanned medications prior to entering the patient room and administered medications while the COW was in the hallway, meaning that the patient ID wristband was not scanned	Field notes
Suboptimal COW design	Nurses often avoided to bring the bulky COW into the patient room when administering few or one single medication The COW design was cumbersome for the desired workflow of entering patient rooms during administration rounds The COW contained medications for all patients which combined with scanning not being used is a risk for patient safety	Field notes Nurses' comments
Environmental		
Medication room location affects task efficiency and time spent administering medications	The medication room was located far from the nursing station and most of the patient rooms. This resulted in slower administration and storage of random medications in the nursing station to avoid going back and forth to the medication room	Observational tool Field notes
Patient drawer size does not allow appropriate BCMA use	The small size patient drawer led to deviations such as not dispensing the medications because only small forms of oral medications and ampoules were dispensed in the patient drawer, whereas voluminous medications were retrieved during administration	Observational tool Field notes Nurses' comments
Non-specific medication storage policy	Random single-unit doses stored on the desk in the nursing station or on the COWs and were obtained from here in case something was missing during administration. Unsafe practice as the single doses are easy to mix up when stored randomly on the COW during administration	Field notes
Nurse related		
Non-standardised dispensing allows variations	Variations in performance between nurses and inconsistency in dispensing medications for the same nurse	Observational tool Field notes Nurses' comments
BCMA slower than manual verification—leading to user dissatisfaction	Nurse did not use the BCMA at all during the whole medication round Nurse admitted to not using the BCMA on regular basis but used it during observation period	Observational tool Field notes Nurses' comments

BCMA, barcode medication administration; COW, computer on wheels; eMAR, electronic Medication Administration Record.

with the tasks required during administration. Causes for organisational deviations were associated with unclear or poorly described policies, health professionals unaware of policies or the policy was incompatible with workflow. Even when the policy was clear and excluding, deviations occurred; for example, the policy stated that only the prescribed dose should be dispensed, however occasionally whole tablet blisters were dispensed in the COW.

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

Probable causes for deviations associated with technology were poor or unclear charging routines, the scanner was not mobile but attached to the laptop, and software usability issues. In addition, the design of the COW, including its large/bulky size, sometimes prevented nurses from scanning the patient ID wristband at the bedside. Furthermore, the undersized patient drawer led to dispensing omission because there was insufficient capacity to store all the medicines. Nurse-related deviations were caused by the slow BCMA process, which led to refraining from scanning or to skip the technology use. These factors all conflicted with patient safety during medication dispensing and administration.

DISCUSSION

We observed policy deviations which affected 6 of 10 patients during dispensing and 7 of 10 patients during medication administration. The causes to policy deviations were related to a complex dispensing process, slow or cumbersome BCMA procedure, suboptimal technology design and non-specific policy description. Working with suboptimal solutions in a busy environment, it was hard for the nurses not to deviate from policies, which explains why deviations were normalised in practice.

Despite these imperfections, our findings suggest that when the scanning of medications and ID wristbands was used, it offered benefits to patient safety by preventing the administration of wrong dispensed medication for 5% of the patients.

The lack of standardised delivery of dispensed doses lead to several variations in how the medications were dispensed in the COW. Patterson *et al*[27] found that BCMA made it easier to anticipate others' actions and detect erroneous actions. In our study, however, it was difficult for other nurses to take for granted that the medications dispensed by a fellow nurse were correct. To compensate for the uncertainty, the nurses had to manually reconfirm doses before administering to patients. This practice undermines the purpose of BCMA.

The scanning rates in our study, that is, 71% for medications, 91% for scannable doses and 80% for patient ID wristbands, are considerably lower than the 95% standard goal for scanning medications and patients.[28] In a recent observational study of BCMA at a UK hospital, Barakat and Franklin registered scanning rates for medications of 83%, scannable doses of 95% and patient verification of 100%.[29] Although Barakat and Franklin had a smaller sample size, their study was undertaken with a similar ward-stock dispensing process and BCMA technology design to our study, which makes the rates broadly comparable.

A recent national study of medication errors in Norwegian hospitals, where BCMA was not used, found that 70% of all medication errors occurred during the medication administration stage.[3] We suggest that many of these errors, such as wrong dose, wrong patient and wrong medication during administration, could have been avoided if BCMA had been implemented. However, even if the technology is used accurately, hospitals may still fail to achieve the full benefits of BCMA to patient safety and unintended consequences may arise from technology implementation,[18] both demonstrated in our findings. In the current study, the technology was used as intended in only half of medication administrations. These deviations often originated in the dispensing process, such as not dispensed medications, wrong medication dispensed and wrong dose dispensed, and consequentially resulted in new deviations even when the BCMA was used correctly during medication administration.

The availability of functioning hardware is essential for the BCMA to have a preventive effect on errors. We identified a reoccurring problem with laptops not being charged and borrowing of scanners across wards, but these were not the main cause of technology-related deviations. The most important cause was the design of the technology like the bulky COW and the fact that scanners were not wireless. Those design issues limited the staffs' efficiency during medication administration. This may explain why 20% of patient ID wristbands were not scanned during observation. Others have also described the size of the medication cart getting in way of efficient use of BCMA.[4 18] One observational study concluded that nurses uniformly believed that manually confirming patient identity took less time than wheeling the large medication cart in the patient room.[27]

The distant medication rooms indirectly affected patient safety because retrieving of missing medications in the COW took a long time and led to medication omissions. Other environmental factors were in direct conflict with patient safety. Dispensing omissions were unavoidable because medications larger in size (eg, eyedrops, inhalers or syringes) could not fit in the small pocket of the COW patient drawers. Such environmental characteristics have affected medication safety in other studies as well.[30]

Our nurses also expressed that BCMA prolonged the time they spent on medication administration. Compared with others that used automated dispensing cabinets,[18] or pharmacy-operated dispensing,[12] it is important to stress that nurses in our study had more tasks to attend to during the dispensing process (eg, packaging, labelling, dispensing in the correct compartment of the patient drawer). This is likely to explain the high proportion of dispensing deviations in the current study.

This study demonstrates variations among nurses in their BCMA use: from not using the BCMA in entire administrations, to partial use, to those who were fully compliant. Much of the variability can be explained by

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

doses lacking barcodes and that the policies allowed for too many variations in the workflow. In the study of Barakat and Franklin, the BCMA led to less variability in how nurses undertake medication administration.[29] Some of this difference may be explained by safety culture differences, for example, if the BCMA technology is not used by all nurses, such as found in our study, it could result in being a burden to the workflow rather than a safety initiative. Lyons *et al*[31] have also described a similar performance variability among nurses within the use of other medication administration technologies, and addressed that this adaptive behaviour could be a source of resilience, compensating for the weaknesses of the system, but raised concerns that it could also lead to unsatisfactory outcomes.

Implications

Having the advantage of studying the use of BCMA within the actual setting, this study may provide implications to technology implementation and strategies for improvement.

- Prior to implementation, hospitals should risk-assess policies and make institution-specific decisions on how to properly integrate the technology into their workflow.
- The scanning rates could be improved if a greater number of medications are scannable. One way to address this is for the pharmaceutical industry to barcode medications on the primary packaging.[32] This could reduce the workload for the nurses and the hospital pharmacy and increase the standardisation of the dispensing process across wards.
- Ward-based medication dispensing, which is associated with significantly more medication errors than a unit-based system,[33] should be evaluated for efficiency and safety.
- Redesigning technology to fit the nurses' workflow, that is, replacing the cumbersome COW with a lightweight cart and mobile eMAR device, could create better experiences for nurses and compensate for the downsides of the currently implemented system.
- Greater attention to the usability and functionality of BCMA is required: override logs and scanning stats were not available within the BCMA system observed in this study, which limits the monitoring of the technology use significantly.
- Besides data monitoring, ongoing assessments of the actual use of the BCMA technology are mandatory as changes in policy and technology will lead to new deviations.[16] This could be accomplished through periodical observation of medication rounds,[13 34] which give an insight in the technology use with all the contextual factors in place, but also to involve end-users in making suggestions on improvement.
- Shared learning of BCMA practices between hospitals with similar systems is an important resource to improve knowledge, implementation, and staff motivation.

Strengths and limitations

The mixed-method approach provided insight into the nurses' BCMA use and understanding of the context in which deviations occur. The added value of using both the qualitative and quantitative data was that it identified frequency of deviations and their probable causes. Our observational tool allowed the detection of 'normal' deviations in practice (eg, dispensing wrong dose of medications) that often remain undetected because they are not identified using standard methods such as incident reports and chart reviews.[35] Previous studies have demonstrated that BCMA can reduce medication error rates.[4 5 7 8] In our study, the identified policy deviations indicate that workarounds occur due to system flaws that produce latent conditions which could ultimately lead to serious medication errors. However, focusing on policy deviations rather than medication errors is also a limitation because there is no direct measure of the impact of BCMA to patient safety.

Other limitations are acknowledged. First, there could be differences among observers, either in their data collection or in their interpretation and knowledge of local policy. Observers were carefully trained in observational techniques[36–38] and familiarised with local medication management policies to minimise such effect. Second, the presence of an observer might have influenced the nurses to consciously or unconsciously modify their behaviour.[39] Nurses were aware of being observed while administering medications, and the expected change in behaviour would have been in the direction of better compliance with BCMA use. Some nurses indicated that they were using the technology because they were being observed. However, the findings associated with the medication dispensing were not affected by the observation because this activity took place prior to the observation period that is, usually undertaken by nurses from the previous shift.

We studied an eMAR paired with BCMA technology in a hospital with a traditional ward-based medication dispensing operated by nurses. It is likely that our data will not be generalisable to organisations that use a pharmacy-operated or automated medication dispensing. On the other hand, hospitals that use a ward-based dispensing system can value from our findings, as there is limited research on the BCMA technology use in a ward-based medication dispensing.

CONCLUSION

This study provides an in-depth understanding of how the BCMA is used in the clinical environment. We identified policy deviations for over half of the observations, such as not scanning the patients or the medications, omission of dispensing, or wrong dose dispensed. We also identified variations in how nurses used BCMA. Deviations were caused with unclear policies, policies that interfere with appropriate BCMA use, including the labor-intensive dispensing process,

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

as well as problems with technology design. Our findings suggest that several factors in the work system need reassessment and adaptation to nurses' workflow. Deviations are expected with technology implementation in any complex system. As such, analysing policy deviations in practice is an important method of identifying and addressing system weaknesses in order to achieve the full benefits of BCMA in terms of patient safety.

Acknowledgements The authors thank the nursing staff for their participation in the study. We also would like to acknowledge the contributions provided by the staff from the Southern and Eastern Norway Pharmaceutical Trust and the Department of Information and Communication Technology at the hospital.

Contributors AM and AGG conceived of the presented idea. KT, LM and AGG were involved in planning and supervising the work. AM took lead in the data collection, analysis and in writing the manuscript. All authors have read and approved the final version of the manuscript.

Funding This study was internally funded.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval The study was approved by the institutional data protection board.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available. Additional deidentified data from the observational tool or field notes are not available as participants did not agree to share this information with a broad audience.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iD

Alma Mulac http://orcid.org/0000-0001-9463-997X

REFERENCES

1 Shah K, Lo C, Babich M, *et al*. Bar code medication administration technology: a systematic review of impact on patient safety when used with computerized prescriber order entry and automated dispensing devices. *Can J Hosp Pharm* 2016;69:394–402.
2 Keohane CA, Bane AD, Featherstone E, *et al*. Quantifying nursing workflow in medication administration. *J Nurs Adm* 2008;38:19–26.
3 Mulac A, Taxis K, Hagesaether E, *et al*. Severe and fatal medication errors in hospitals: findings from the Norwegian incident reporting system. *Eur J Hosp Pharm* 2020;0:1–6.
4 Naidu M, Alicia YLY. Impact of bar-code medication administration and electronic medication administration record system in clinical practice for an effective medication administration process. *Health* 2019;11:511–26.
5 Bonkowski J, Carnes C, Melucci J, *et al*. Effect of barcode-assisted medication administration on emergency department medication errors. *Acad Emerg Med* 2013;20:801–6.
6 Leung AA, Denham CR, Gandhi TK, *et al*. A safe practice standard for barcode technology. *J Patient Saf* 2015;11:89–99.
7 Rack LL, Dudjak LA, Wolf GA. Study of nurse workarounds in a hospital using bar code medication administration system. *J Nurs Care Qual* 2012;27:232–9.
8 Poon EG, Keohane CA, Yoon CS, *et al*. Effect of bar-code technology on the safety of medication administration. *N Engl J Med* 2010;362:1698–707.
9 Franklin BD, O'Grady K, Donyai P, *et al*. The impact of a closed-loop electronic prescribing and administration system on prescribing errors, administration errors and staff time: a before-and-after study. *Qual Saf Health Care* 2007;16:279–84.
10 Helmons PJ, Wargel LN, Daniels CE. Effect of bar-code-assisted medication administration on medication administration errors and accuracy in multiple patient care areas. *Am J Health Syst Pharm* 2009;66:1202–10.
11 Risør BW, Lisby M, Sørensen J. Cost-effectiveness analysis of an automated medication system implemented in a Danish hospital setting. *Value Health* 2017;20:886–93.
12 van der Veen W, van den Bemt PMLA, Wouters H, *et al*. Association between workarounds and medication administration errors in bar-code-assisted medication administration in hospitals. *J Am Med Inform Assoc* 2018;25:385–92.
13 Wideman MV, Whittler ME, Anderson TM. Advances in patient safety. Barcode medication administration: lessons learned from an intensive care unit implementation. In: Henriksen K, Battles JB, Marks ES, *et al*, eds. *Advances in patient safety: from research to implementation*. Volume 3: Implementation Issues. Rockville, MD: Agency for Healthcare Research and Quality (US), 2005.
14 Samaranayake NR, Cheung STD, Cheng K, *et al*. Implementing a bar-code assisted medication administration system: effects on the dispensing process and user perceptions. *Int J Med Inform* 2014;83:450–8.
15 Wright AA, Katz IT. Bar coding for patient safety. *N Engl J Med* 2005;353:329–31.
16 Carayon P, Wetterneck TB, Hundt AS, *et al*. Evaluation of nurse interaction with bar code medication administration technology in the work environment. *J Patient Saf* 2007;3:34–42.
17 Cheung RB, Aiken LH, Clarke SP, *et al*. Nursing care and patient outcomes: international evidence. *Enferm Clin* 2008;18:35–40.
18 Koppel R, Wetterneck T, Telles JL, *et al*. Workarounds to barcode medication administration systems: their occurrences, causes, and threats to patient safety. *J Am Med Inform Assoc* 2008;15:408–23.
19 Young J, Slebodnik M, Sands L. Bar code technology and medication administration error. *J Patient Saf* 2010;6:115–20.
20 Carayon P, Wetterneck TB, Rivera-Rodriguez AJ, *et al*. Human factors systems approach to healthcare quality and patient safety. *Appl Ergon* 2014;45:14–25.

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

21 Robson C. *Real world research: a resource for social scientists and practitioner-researchers*. 2nd edn. Oxford: Blackwell Publishers Ltd, 2002: 309–44.
22 Morse JM. "Data were saturated…". *Qual Health Res* 2015;25:587–8.
23 Nettskjema. University in Oslo. Available: https://www.uio.no/english/services/it/adm-services/nettskjema/ [Accessed 18 May 2020].
24 Nowell LS, Norris JM, White DE. Thematic analysis: striving to meet the trustworthiness criteria. *Int J Qual Methods* 2017;16.
25 O'Cathain A, Murphy E, Nicholl J. Three techniques for integrating data in mixed methods studies. *BMJ* 2010;341:c4587.
26 Farmer T, Robinson K, Elliott SJ, *et al*. Developing and implementing a triangulation protocol for qualitative health research. *Qual Health Res* 2006;16:377–94.
27 Patterson ES, Cook RI, Render ML. Improving patient safety by identifying side effects from introducing bar coding in medication administration. *J Am Med Inform Assoc* 2002;9:540–53.
28 Leapfrog Hospital Survey. Factsheet: bar code medication administration, 2019. Available: https://ratings.leapfroggroup.org/sites/default/files/2020-08/2020-BCMA-Fact-Sheet.pdf [Accessed 4 Dec 2020].
29 Barakat S, Franklin BD. An evaluation of the impact of barcode patient and medication scanning on nursing workflow at a UK teaching hospital. *Pharmacy* 2020;8:148.
30 Al-Jumaili AA, Doucette WR. Comprehensive literature review of factors influencing medication safety in nursing homes: using a systems model. *J Am Med Dir Assoc* 2017;18:470–88.
31 Lyons I, Furniss D, Blandford A, *et al*. Errors and discrepancies in the administration of intravenous infusions: a mixed methods multihospital observational study. *BMJ Qual Saf* 2018;27:892–901.
32 Barcoding on the primary package of medicines in hospitals. A cost-effective analysis. [Barcodering op de primaire verpakking geneesmiddelen in ziekenhuizen. Een kosten-baten analyse], 2016. Available: https://www.eahp.eu/sites/default/files/barcodering-op-de-primaire-verpakking-van-geneesmiddelen-in-ziekenhuizen.pdf [Accessed 18 Nov 2020].
33 Taxis K, Dean B, Barber N. Hospital drug distribution systems in the UK and Germany—a study of medication errors. *Pharm World Sci* 1999;21:25–31.
34 Kertland H, Satchu S, Chant C, *et al*. Safety rounds: a patient safety initiative. *Can J Hosp Pharm* 2018;71:385–8.
35 Schulson LB, Novack V, Folcarelli PH, *et al*. Inpatient patient safety events in vulnerable populations: a retrospective cohort study. *BMJ Qual Saf* 2021;30:372–9.
36 Mays N, Pope C. Qualitative research: observational methods in health care settings. *BMJ* 1995;311:182–4.
37 Unertl KM, Weinger MB, Johnson KB. Applying direct observation to model workflow and assess adoption. *AMIA Annu Symp Proc* 2006;2006:794–8.
38 Carthey J. The role of structured observational research in health care. *Qual Saf Health Care* 2003;12(Suppl 2):13ii–16.
39 McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *J Clin Epidemiol* 2014;67:267–77.

BMJ Qual Saf: first published as 10.1136/bmjqs-2021-013223 on 20 July 2021. Downloaded from http://qualitysafety.bmj.com/ on October 28, 2021 at Helsebiblioteket gir deg tilgang til BMJ. Protected by copyright.

Supplementary appendix 1 Characteristics of study wards and observations

Study wards	Medication systems and administration processes	Observations
Ward 1 Cardiac medical ward	The system comprised of electronic prescribing and eMAR paired with BCMA. Medications for the next 24 hours were dispensed in the COW by a night shift nurse. Roles to update any changes in dispensed medications during the shift, or to any newly admitted patients, were not defined. One nurse administered medications for up to five patients during the morning and nine patients during the evening rounds.	Two observers collected data individually at least one morning or evening medication round during two five-day periods from 30 October to 22 November 2019.
Ward 2 Intensive geriatric ward	The system comprised of electronic prescribing and eMAR paired with BCMA. After the morning medication round the nurse dispensed medications in the COW for the next 24 hours and one nurse in each shift was responsible to update changes in medications or to dispense medications to any newly admitted patients. One nurse administered medications for up to nine patients during the morning and 13 patients during the evening rounds.	Two observers collected data individually at least one morning or evening medication round during two five-day periods from 6-16 January 2020.

Abbreviations: COW-computer on wheels; eMAR- electronic Medication Administration Record; BCMA- Barcode medication administration;

Observational Tool Oral Med Appendix

What is your username?

Staff ID

Patient ID

Medication trolley in the patient room

Velg …

Medication administration

- [ ] Scanned ID wristband
- [ ] Wrong room number on the patient medication box
- [ ] Medication not labeled correctly

Total nummer medications?

Velg …

Total nummer medications?

Dette elementet vises kun dersom alternativet «Other» er valgt i spørsmålet «Total nummer medications?»

How many medications had a barcode?

Includes blisters with printed label, but not packed

Velg …

How many medications had a barcode?

Dette elementet vises kun dersom alternativet «Other» er valgt i spørsmålet «How many medications had a barcode?»

How many were scanned?

Scanned the barcode, not manually confirmed

Velg …

How many medications were scanned?

Dette elementet vises kun dersom alternativet «Other» er valgt i spørsmålet «How many were scanned?»

If the patient room number on the medication box was wrong, short explanation?

Dette elementet vises kun dersom alternativet «Wrong room number on the patient medication box» er valgt i spørsmålet «Medication administration»

Use keywords (patient in the hallway, wrong room number written or patient changed room, etc.)

Medications that were overrided (not scanned but manually confirmed)

Reason for not scanning if verbalized by the staff member and name of the medications

If trolley not in the patient room, why?

Dette elementet vises kun dersom alternativet «No (workaround)» eller «Other» er valgt i spørsmålet «Medication trolley in the patient room»

Medication/s NOT prepared correctly in the trolley?

Missing medication (not in the medication box).

Medication from another patient placed in the medication box.

Discontinued medications prepared.

Medication not labeled correctly

Dette elementet vises kun dersom alternativet «Medication not labeled correctly» er valgt i spørsmålet «Medication administration»

- [ ] Bar Code missing
- [ ] Bar Code placed in the box ,not attached
- [ ] Bar Code attached to plastic bag
- [ ] Other

Labelling errors-other

Dette elementet vises kun dersom alternativet «Other» er valgt i spørsmålet «Medication not labeled correctly»

Staff observed patient taking the medications?

- [ ] Yes
- [ ] No
- [ ] Other

Technological support

Any technological discrepancies observed?

- [ ] Low battery (laptop)
- [ ] System blockage
- [ ] Log in discrepancies
- [ ] The laptop was not charged during the night
- [ ] The laptop was not functioning optimally
- [ ] Unavaliable scanner for the administration (taken by other nurses or can't find)
- [ ] Scanner malfunctioning
- [ ] Other

If system blockage, how occured/resulted?

Dette elementet vises kun dersom alternativet «System blockage» er valgt i spørsmålet «Any technological discrepancies observed?»

If login discrepancy, how occured/consequences?

Dette elementet vises kun dersom alternativet «Log in discrepancies» er valgt i spørsmålet «Any technological discrepancies observed?»

If low battery on laptop how resolved/consequences?

Dette elementet vises kun dersom alternativet «Low battery (laptop)» er valgt i spørsmålet «Any technological discrepancies observed?»

If laptop not functioning optimally, how resolved/consequences?

Dette elementet vises kun dersom alternativet «The laptop was not functioning optimally» er valgt i spørsmålet «Any technological discrepancies observed?»

Answer question only IF: The patient uses his PRIVATE MEDICATIONS in hospital: write what and if administered during the observation?

*If not administered while observing, still write if this practice occurred.

Further comments

Did you observe any errors, discrepancies in the medication management process?

e.g. Undocumented/Unprescribed medications, labeling errors, system workarounds, information mismatch, wrong dose prepared of the parenteral medication,not thrown away rest of medication

e.g. The nurse was about to give medication to the wrong patient found out of it before it happened (near miss).

Se nylige endringer i Nettskjema (v1039_0rc:

Observational Tool Parenteral Med Appendix

What is your username?

Staff ID

Patient ID

Is the parenteral administration happening simultaniously/before/after an oral administration where the patient wristband was scanned?

- [ ] Yes, the oral administration is happening simultaniously/before/after
- [ ] No, this is a independent administration

Medication administration

Dette elementet vises kun dersom alternativet «No, this is a independent administration» er valgt i spørsmålet «Is the parenteral administration happening simultaniously/before/after an oral administration where the patient wristband was scanned?»

- [ ] Scanned ID wristband

Compares medications in trolley with eMAR for patient name

- [ ] Yes
- [ ] No

Medication trolley in the patient room

Velg …

If medications NOT avaliable in the trolley, describe.

Total number parenteral medications?

Velg …

Administration form

- [ ] IV
- [ ] Other parenteral (intramuscular, subcutaneous and intradermal)
- [ ] Other (inhalation, rectal, vaginal, topical)

Type of IV line

Dette elementet vises kun dersom alternativet «IV» er valgt i spørsmålet «Administration form»

- [ ] IV push (bolus, rapid injection of medication)
- [ ] IV infusion

IV

Dette elementet vises kun dersom alternativet «IV» er valgt i spørsmålet «Administration form»

- [ ] Prefilled syringe
- [ ] Prepared by the hospital pharmacy
- [ ] Prepared at the patient room
- [ ] Prepared at the medication room
- [ ] Prepared in other places
- [ ] Not thrown away syringe and rest of the medication
- [ ] Vial, ampule or syringe barcoded

Total number barcoded medications?

Dette elementet vises kun dersom alternativet «Vial, ampule or syringe barcoded» er valgt i spørsmålet «IV»

Total number scanned medications?

Dette elementet vises kun dersom alternativet «Vial, ampule or syringe

barcoded» er valgt i spørsmålet «IV»

Other parenteral administration form (intramuscular, subcutaneous and intradermal)

Dette elementet vises kun dersom alternativet «Other parenteral (intramuscular, subcutaneous and intradermal)» er valgt i spørsmålet «Administration form»

- [ ] Prefilled syringe
- [ ] Prepared by the hospital pharmacy
- [ ] Prepared at the patient room
- [ ] Prepared at the medication room
- [ ] Prepared in other places
- [ ] Vial, ampule or syringe barcoded
- [ ] Not thrown away syringe and rest of the medication

Total number barcoded medications?

Dette elementet vises kun dersom alternativet «Vial, ampule or syringe barcoded» er valgt i spørsmålet «Other parenteral administration form (intramuscular, subcutaneous and intradermal)»

Total number scanned medications?

Dette elementet vises kun dersom alternativet «Vial, ampule or syringe barcoded» er valgt i spørsmålet «Other parenteral administration form (intramuscular, subcutaneous and intradermal)»

Prepared in other places. Where?

Dette elementet vises kun dersom alternativet «Prepared in other places» er valgt i spørsmålet «IV»

Prepared in other places. Where?

Dette elementet vises kun dersom alternativet «Prepared in other places» er

valgt i spørsmålet «Other parenteral administration form (intramuscular, subcutaneous and intradermal)»

Not thrown away syringe and rest of the medication

Dette elementet vises kun dersom alternativet «Not thrown away syringe and rest of the medication» er valgt i spørsmålet «IV»

Describe where they were stored and for what purpose

Not thrown away syringe and rest of the medication

Dette elementet vises kun dersom alternativet «Not thrown away syringe and rest of the medication» er valgt i spørsmålet «Other parenteral administration form (intramuscular, subcutaneous and intradermal)»

Describe where they were stored and for what purpose

Total number of parenteral medications?

Dette elementet vises kun dersom alternativet «Other» er valgt i spørsmålet «Total number parenteral medications?»

Answer question only IF: The patient uses his PRIVATE MEDICATIONS in hospital: write what and if administered during the observation?

*If not administered while observing, still write if this practice occurred.

Further comments

Did you observe any errors, discrepancies in the medication management process?

e.g. Labeling errors, system workarounds, information mismatch, wrong dose prepared of the parenteral medication.

e.g. The nurse was about to give medication to the wrong patient found out of it before it happened (nearmiss).

Supplementary appendix 4 Technology-related policy deviations
Data source: Observational tool

Technology deviations	**n***	**Examples and Descriptions**
Low laptop battery	28	Solved by finding another laptop which prolonged the administration time or solved by refraining from scanning.
eMAR system froze	7	Solved by either restarting the eMAR and having to redo the entire scanning process or waiting out for the system to unfreeze and login again.
Scanner malfunctioning	2	The barcode scanner did not operate correctly, solved by finding another scanner.
Scanner not available	1	Scanner unavailable for medication administration. Replacement obtained from another unit from a nurse that was administering medications at the time.

*n= the number of patients with at least one deviation
Abbreviations: eMAR- electronic Medication Administration Record