BMJ Open

Interdisciplinary systematic review: does alignment between system and design shape adoption and use of barcode medication administration technology?

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To cite: 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**:e044419. doi:10.1136/bmjopen-2020-044419

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2020-044419).

Received 03 September 2020
Accepted 09 June 2021

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ABSTRACT

Background In order to reduce safety risks associated with medication administrations, technologies such as barcode medication administration (BCMA) are increasingly used. Examining how human factors influence adoption and usability of this technology can potentially highlight areas for improvement in design and implementation.

Objective To describe how human factors related determinants for BCMA have been researched and reported by healthcare and human–computer interaction disciplines.

Data sources The Cumulative Index of Nursing, and Allied Health Literature, PubMed, OVID MEDLINE and Google Scholar.

Study eligibility criteria Primary research published from April 2000 to April 2020, search terms developed to identity different disciplinary research perspectives that examined BCMA use, used a human factors lens and were published in English.

Synthesis methods Computerised systematic searches were conducted in four databases. Eligible papers were systematically analysed for themes. Themes were discussed with a second reviewer and supervisors to ensure they were representative of content.

Results Of 3707 papers screened, 11 were included. Studies did not fit neatly into a clinical or human-computer interaction perspective but instead uncovered a range of overlapping narratives, demonstrating consensus on the key themes despite differing research approaches. Prevalent themes were misaligned design and workflow, adaptation and workarounds, mediating factors, safety, users' perceptions and design and usability. Inadequate design frequently led to workarounds, which jeopardised safety. Reported mediating factors included clarity of user needs, pre/post implementation evaluations, analysis of existing workarounds and appropriate technology, infrastructure and staffing.

Limitations Most studies were relatively small and qualitative, making it difficult to generalise findings.

Conclusion Evaluating interdisciplinary perspectives including human factors approaches identified similar and complementary enablers and barriers to successful technology use. Often, mediating factors were developed to compensate for unsuitable design; a collaborative approach between system designer and end users is necessary for BCMA to achieve its true safety potential.

Strengths and limitations of this study

- The search strategy captured literature from both healthcare and human–computer interaction perspectives, providing a rich understanding of the factors.
- A second reviewer repeated the initial search with a high level of agreement and reviewed the data extraction process and theme selection to ensure findings were representative.
- The Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist was used to design the study protocol.
- Most studies included were relatively small in terms of number of participants and were usually conducted in just one or two hospitals, primarily in the USA.
- Qualitative methodology was prevalent in the selected studies, making it difficult to generalise findings.

BACKGROUND

The prevalence and subsequent harm caused by medication errors has galvanised efforts to develop systems, policies and technologies to prevent them.[1–5] Medication administration errors are the most common adverse events in hospitals; it has been estimated that a patient will experience one medication error per 24 hours as an inpatient.[6 7] Annually, an estimated 237 million 'medication errors' occur in the NHS in England, 72% do not cause harm but 66 million are clinically significant. Avoidable adverse drug reactions contribute to an estimated 1700 deaths per year, at a financial cost of £98.5 million.[4]

Medication management and administration in the hospital setting encompass a complex and interlinked series of events and individuals, including pharmacists, doctors,

nurses, stock managers and patients. There are many opportunities in this chain to intercept errors which may lead to adverse events, and it is hard to estimate how many potential errors are intercepted before they reach the patient.[4] However, medication administration has been identified as the phase where interception of a medication error is least likely to occur, with only about 2% of errors being intercepted at the point of administration.[7–10] To mitigate some of these risks, barcode medication administration (BCMA), usually in conjunction with an electronic medication administration record (eMAR), has been promoted to reduce the prevalence of medication administration errors.[1 11 12]

Bates argues that the causes of frequent medication error are relatively simple: the bulk of the systems in place were not formally designed and are not subject to the stringent regulation processes used in other high-risk industries such as aviation.[13] Furthermore, healthcare is complex: it is highly regimented and systematic while also being unpredictable, requiring clinicians to constantly learn alongside their practice, often adapting to conform to local policies; this presents many challenges for clinicians navigating safe practice.[14] Health information technologies (HITs), such as BCMA, seek to ensure safety for both patient and clinician.

BCMA technology incorporates the 'five rights of medicines administration' (right drug, right time, right patient, right dose, right route) into an automated system.[15 16] BCMA automates and records each medication administration and prompts the user to ensure it meets the required safety standard, warning the user if any discrepancy between prescription and administration detail is identified. For example, if the barcoded patient identification band does not match the selected electronic medication chart, an alert will notify the user of the mismatch and prompt them to check they have the right medication for the right patient, potentially avoiding a 'wrong patient' error.[1 11] While BCMA technology can reduce some medication errors by streamlining workflow and improving medicine and patient identification rates,[17] it can exacerbate others or even cause new types of error to occur.[11–13] The literature presents a complex picture of unintended consequences following BCMA implementation, indicating that the overall effect of a new HIT, such as BCMA, is often difficult to predict.[13 18]

From a human factors perspective, the belief that adopting HITs such as BCMA will lead to improved safety outcomes is termed 'magical thinking'; rather, successful adoption is complex, reliant on many mediating factors and context dependent.[19 20] The introduction of any new work system will have a transformative effect on the established workflow; successful adoption is not guaranteed, but a positive outcome may result from the comparison and clarification of the established and proposed systems.[20–23] However, unintended consequences such as workarounds may also occur.

Human factors models such as systems engineering in patient safety (SEIPS) have been instrumental in understanding the factors that influence successful implementation of BCMA and other HIT.[24] Such models examine the wider context in which work takes place, acknowledging that adverse events are rarely caused by one individual, but from a series in interconnected events.[25] A human factors lens can be used to examine multiple factors such as environment, organisation, technology and tasks, to gain understanding of why errors occur and how to prevent them.[25]

This literature review identifies factors which enable and limit the use of BCMA, during the implementation phase and beyond, by using a human factors lens to capture primary research from both users and implementers of the technology. Human factors approaches can often expose the root causes of undesirable outcomes, and by using a search strategy that captures research from across the spectrum of those designing and using the technology, it may be possible to develop implementation strategies that enable effective BCMA implementation and long-term use.

METHOD

Search strategy

Multiple key words were developed using terminology that would identify literature from healthcare, design,and informatics perspectives using a human factors lens. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used as a guide for literature review protocol development.[26] The Cumulative Index of Nursing, and Allied Health Literature, PubMed, OVID MEDLINE and Google Scholar were systematically searched for literature produced between April 2000 and April 2020. Search terms were combined with Boolean operators and were adapted to match database terms. A document detailing the search strategy is available as a online supplemental file (Search Strategy).

Selection process

The selection process is displayed in figure 1. Full-text, English language, peer-reviewed papers of primary research were included; grey literature and literature reviews were excluded. The results from each database were compared and duplicates removed. Abstracts of the remaining papers were reviewed against the inclusion criteria and if the study included BCMA, usability and a human factors approach, it was considered eligible and the full text was reviewed for inclusion. The paper did not have to explicitly state human factors in the title, as long as human factors principles were evident in the methodology. For example, workarounds are frequently studied in relation to BCMA; studies using human factors principle to understand the causes of workarounds were included, but studies examining workaround prevalence, in relation to error, without examining underlying causes were excluded.

Data extraction process

A second reviewer (RA) repeated the search and study selection process, resulting in a high level of agreement

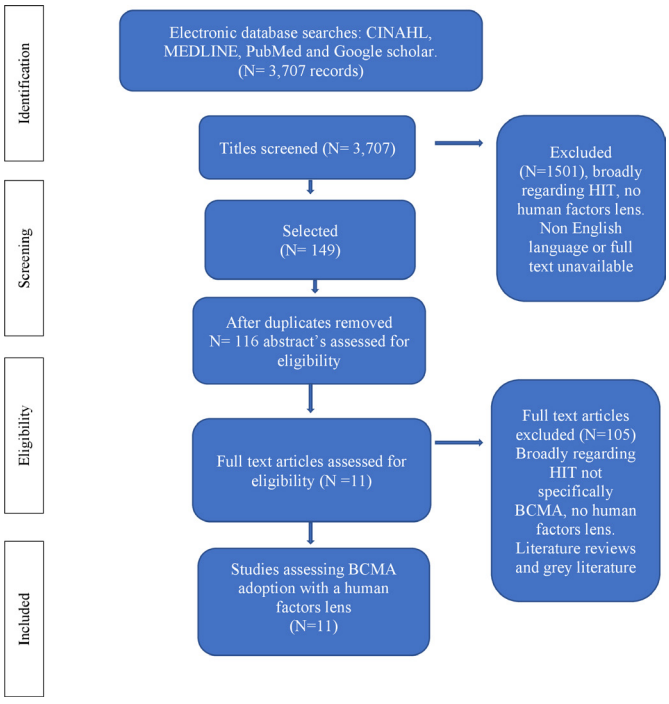

Figure 1 PRISMA flow chart. Detailing selection process of studies reviewed. BCMA, barcode medication administration; CINAHL, Cumulative Index of Nursing, and Allied Health Literature; HIT, health information technology; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

(76%) for study eligibility through titles review. The level of agreement for final inclusion was very high, with both reviewers agreeing on 10 of the 11 studies; following discussion all 11 were included in the review. Thematic data extraction was performed by RW, with the emergent themes developed iteratively through discussion with AB and YJ. RA reviewed a selection of the papers and associated thematic extraction and agreed that the identified themes were appropriate and representative of the study findings.

Patient and public involvement

No patient or public involvement was sought in the development and execution of the literature review. No personal or identifying private health information would be derived from the public sources being searched.

RESULTS

Study characteristics

Overall, 9 of the 11 papers included were primary studies. The exceptions were Novak *et al*'s 2013 study,[27] which reanalysed data from two previous studies[28 29] (both included in the selected studies) to examine a new research question and Van der Veen *et al*'s 2020 study[11] on factors which contribute to the occurrence of workarounds, which reanalysed data from their 2018 study[30] to explore a different facet to the original research (also included in the selected papers).

Various study designs and methodologies were used to investigate BCMA implementation and use. All studies were qualitative or mixed methods, gathering data by observation of practice or a combination of observation, survey, focus groups and interviews. Multiple papers also collected quantitative data, such as medication error reports[31] and BCMA override data.[7 32] Theoretical frameworks were used in all studies except for Van der Veen *et al*'s work.[11 30] The majority of the frameworks originated in the human factors field, including SEIPS, the technology acceptance model and complexity theory. Full details of the frameworks used are listed in table 1. Three studies used statistical methods to analyse their findings, Patterson *et al* established statistical significance of a higher incidence of workarounds in long-term care when compared with acute care (93% vs 23%, p<0.001).[32] Van der Veen *et al* used logistic regression analysis to assess the association between workarounds and medication error and identify factors which contribute to the occurrence of workarounds.[11 30] Holden *et al* used regression models to predict acceptance of new technologies, using general linear mixed models with repeated measures to examine user perception of BCMA both pre and post implementation.[20] Further studies led by Rack *et al*[31] and Koppel *et al*[7] presented survey results and override data as percentages of agreement but did not present any further statistical analysis. The remaining studies used thematic analysis to establish emergent themes, with differing methods. Holden *et al*'s 2013 study used descriptive coding[28] and Novak *et al*'s 2012 study used qualitative data analysis software to transcribe and analyse fieldnotes,[29] whereas Novak *et al*'s 2013 study used researchers independently assessing their fieldnotes for themes before discussing as a group and finalising theme inclusion.[27] Staggers *et al*'s study[33] differed from the others in terms of data collection and analysis: this team studied online BCMA training routinely undertaken by nurses. The researchers used heuristic evaluation methods to establish usability problems with the technology and rate how this affected users' situational awareness. A severity score was then assigned to the usability problem to establish the safety risk posed by the usability issue identified. Studies varied in terms of length, number of participants, use of comparison sites, pre/post analysis and settings as detailed in table 1.

Research focus

The studies included in this review use human factors methods with a range of research focuses and diverse narratives on BCMA adoption, use and success. Holden *et al*,[28 34] Novak *et al*[29] and Staggers *et al*[33] studied the design and usability of BCMA systems and the effects of pre-existing workflows at various stages of BCMA implementation and use. The safety risks introduced by poorly aligned BCMA design and clinical workflow were acknowledged as a distal outcome of poor design but were not the focus of these studies. Rather, this group of studies highlights how workarounds can identify design flaws. This is in line with Koppel *et al*'s[7] and Rack *et al*'s[31] studies on the causes

Table 1 Extracted characteristics of selected studies

Author	Aim	Study design	Research methods	Framework	Setting	Technology	Research focus
Holden *et al* [28]	To study workflow alteration following BCMA implementation.	Comparison groups—pre/post BCMA implementation.	▶ Observation of nursing practice (post 47 hours, pre 89.5 hours). ▶ Interviews with 45 nurses post BCMA Implementation. ▶ Data collection February to March 2008.	Cognitive systems engineering approach.	▶ Paediatric hospital. ▶ 236 beds. ▶ USA. ▶ ICU, haematology/oncology unit and a general medical/surgical unit.	Software vendor: Centricity pharmacy (GE Healthcare). integrated BCMA with CPOE, PIS and eMAR. Implemented: December 2016.	▶ Notes BCMA research often focused on distal outcomes (adverse events). ▶ Often BCMA research does not explore underlying causes. ▶ Does not focus on impact on safety as an outcome. ▶ Usability and design focus.
Holden *et al*[20]	To study how BCMA may improve or worsen outcomes using a human factors lens.	Comparison between BCMA and non-BCMA hospitals.	▶ Nurse survey conducted pre/post implementation. ▶ Additional data of 200 hours of nurse practice observation and 68 short interviews with BCMA users. ▶ Additional data collected during a previous study.	The human factors model of health IT impact.	▶ Two large paediatric hospitals. ▶ USA.	Software vendor: Unclear. Integrated BCMA and CPOE with pharmacy checking of orders in place (PIS). BCMA accessible via eMAR. Implemented: December 2006.	▶ States that safety is not the outcome of interest. ▶ Focus on nursing workflow, usability and design issues.
Novak *et al*[29]	To identify strategies that mitigate the risks associated with BCMA implementation.	An ethnographic case study.	▶ 50 hours observation of mediator/nurse interaction during BCMA implementation. ▶ Additional data: Unstructured interviews, training, meeting minutes and emails.	Technology use mediation framework.	One US hospital with an Informatics support team.	Software vendor: Unclear. CPOE and EHR in use prior to BCMA implementation.	▶ Implementation process may influence safety outcomes, but not examined by this study. ▶ Highlights that clinical staff cannot communicate design issues identified with designers.
Novak *et al*[27]	To study collisions between nursing orientation (practice frame) and the technology orientation (the system frame) and resulting adaptions.	Mixed methods study.	▶ Study (a) 120 hours observation during implementation of BCMA, interviews with 27 nurses post implementation and notes from meetings and emails. ▶ Study (b) 90 hours observation pre and 47 hours post BCMA implementation. ▶ Interviews with 45 nurses post implementation.	Frames of reference— Author discussed finding in terms of system frame and practice frame.	▶ Two large paediatric hospitals. ▶ USA.	Software vendor: Unclear. BCMA and CPOE with pharmacy checking of orders in place (PIS). BCMA accessible via eMAR. Study (a) 2007 BCMA rollout, and study (B) 2006 BCMA rollout.	▶ Implementation and design the focus not safety. ▶ Designs impact on workflow and workarounds discussed. ▶ Current separation in the research between user concerns (patient safety), and design concerns (usability). ▶ A balance of user and design perspectives could improve overall design.

Continued

Table 1 Continued

Author	Aim	Study design	Research methods	Framework	Setting	Technology	Research focus
Rack *et al*[31]	To determine the existence, frequency and potential causes of workarounds and to determine whether workarounds were a factor in serious medication error, to determine if BCMA could have prevented the error.	Mixed method study.	▶ Survey (n=220 respondents). ▶ Focus groups with nurses (six conducted, 12 nurses in each). ▶ Review of medication errors and how they related to BCMA. ▶ Interviews with nurses responsible for medication errors.	Complexity theory.	▶ One 765 beds hospital. ▶ USA. ▶ Three different BCMA systems implemented in 3 years.	Software vendor: Unclear. BCMA implemented in 2004, CPOE introduced in 2008.	▶ Need for design and clinical collaboration highlighted. ▶ Focus on how poor design leads to nurse workarounds. ▶ Safety not the outcome of interest.
Staggers *et al*[33]	To understand how BCMA affects situational awareness in nurses and to identify the usability issues responsible.	Evaluation.	▶ Evaluators completed the BCMA web-based training for nurses in order to develop a list of usability problems. ▶ BCMA co-ordinators reviewed and refined usability issues.	▶ Heuristic evaluation (Zhang). ▶ Severity rating (Nielsen).	▶ One veteran's hospital. ▶ USA. ▶ Hospital included ICU, medical and surgical units.	Software vendor: Vista. Include EHR, computerised patient record system, rated stage 7 HIMSS. BCMA and eMAR implemented in early 2000.	▶ Focus on usability problems, design improvement recommended. ▶ Poor design could impact on patient safety but that was not a primary outcome of this study. ▶ Designers need to better understand clinic task prior to design.
Van der Veen *et al*[30]	To study the association between workarounds and medication administration errors when using BCMA and to determine frequency, type of workaround and type of error.	A prospective observational study.	Direct observation of 5793 medication administrations on 1230 inpatients.	No theoretical framework used.	Four Dutch hospitals of varying size.	BCMA and CPOE implemented in all four hospitals using a variety of software.	▶ Safety as outcome measure. ▶ Association between med error and workarounds studied. ▶ General design issues identified as a possible cause of workarounds but not specifically studied. ▶ Need for collaboration not discussed.
Holden *et al*[34]	To identify predictors of nurses' acceptance of BCMA.	A cross-sectional survey.	Survey (n=83). ▶ August to November 2007.	Technology acceptance model.	▶ Paediatric hospital. ▶ Recently implemented BCMA. ▶ 236 beds. ▶ USA. ▶ PICU, haematology/oncology/bone marrow transplant unit and a medical/surgical unit surveyed.	Software vendor: Centricity pharmacy, GE healthcare). BCMA, CPOE, PIS and automated medication-dispensing cabinets. Implementation 2007.	▶ Study of predictors of technology acceptance to influence design. ▶ Safety not an outcome of interest.

Continued

Table 1 Continued

Author	Aim	Study design	Research methods	Framework	Setting	Technology	Research focus
Koppel *et al*[7]	To study the occurrences, causes and threats to safety of workarounds.	Mixed method study.	▶ Analysis of BCMA data of 307 698 medication administrations. ▶ Observations N=62. ▶ Shadowing N=31. ▶ Semistructured interviews N=29. ▶ 13 specialists, including pharmacists and nurse leaders interviewed. ▶ Data collection 2003–2006.	System engineering in patient safety model used.	▶ Two large hospitals for the observed. ▶ Five hospitals interviewed. ▶ USA.	Software vendor: Siemens medication administration check and McKesson, BCMA and display eMAR.	▶ Poor design and implementation lead to workarounds. ▶ Design issues explored, medication error as a result not examined. ▶ Importance of collaboration between designer and user highlighted.
Patterson *et al*[32]	To identify the types and extent of workaround strategies with the use of BCMA.	A prospective ethnographic study.	▶ Direct observation n=15 acute care and n=13 long-term care nurses. ▶ 79 hours of observation in total. ▶ Opportunistic interviews with observees. ▶ BCMA override data analysed.	Standard activity protocol.	▶ Small, medium and large veteran's administration hospitals. ▶ USA.	Software vendor: Unclear. BCMA in use since 2000. CPOE and PIS.	▶ Safety risk of workarounds. ▶ Practical hardware design issues. ▶ Usability of BCMA not explored. ▶ Context of use should be a design consideration.
Van der Veen *et al*[11]	To identify possible risk factors associated with workarounds using BCMA technology.	A prospective observational study.	Direct observation of 5793 medication administrations on 1230 inpatients.	STROBE checklist for reporting data.	Four Dutch hospitals of varying size.	BCMA and CPOE implemented in all four hospitals using a variety of software.	▶ Workarounds as risk to safety. ▶ System design not discussed. ▶ Practical factors such as staffing discussed and how they have safety consequences.

BCMA, barcode medication administration; CPOE, computerised physician order entry; EHR, electronic health record; eMAR, electronic medication administration record; HIMSS, Health Information and Management Systems Society; ICU, intensive care unit; PICU, paediatric intensive care unit; PIS, pharmacy information system; STROBE, Strengthening Reporting of Observational Studies in Epidemiology.

and frequency of workarounds; they concluded that poor design could increase their prevalence and have long-term consequences for safety while not explicitly studying design issues or safety outcomes and instead focusing on workarounds. In parallel, Van der Veen *et al*[11 30] and Patterson *et al*[32] studied the patient safety risk presented by the use of workarounds in the clinical setting, focusing on the consequences of circumventing the safety features of BCMA, acknowledging that their root may be in poor design, but not further commenting on particular design failures. Holden *et al*[34] examined users' perspectives of BCMA use pre and post implementation, adding another dimension to understanding technology acceptance and suggesting that user perception and not just the study of workarounds can aid iterative design. A further perspective is presented in Novak *et al*'s[27] study of an informatics team which implemented BCMA technology into clinical practice; as professionals with both clinical and informatics expertise, their experience is highly valuable to those planning to implement BCMA technology into the healthcare setting.

The differing research focuses in the field of BCMA study is discussed in two of the papers.[27 28] Holden *et al*[28] noted that BCMA research routinely focuses on the relationship between adverse events and workarounds, arguing that investigating the outcome alone does not enable identification of the causes of workarounds and neglects design issues that may be responsible. Novak *et al*[27] propose that future research must do more to understand the perspective of the workers, designers and implementers, to better understand factors affecting successful BCMA use.

THEMES

Each study employed unique approaches to better understand BCMA use and success; nevertheless, many themes were evident in multiple studies. The main themes identified were misaligned design and workflow, adaptation and workarounds, factors which mediate BCMA use, safety, users' perception and design and usability. A summary of these themes is presented in table 2.

Misaligned design and workflow

Many studies found that BCMA system design and clinical workflow were misaligned, limiting the user's ability to plan ahead and prioritise.[20 27–33] This mismatch seemed to result from BCMA design underestimating the complexity of nurses work and how frequently they have to adapt to individual, environmental, institutional and technological factors beyond their control.[31]

During direct observation, nurses were seen to frequently adapt and reorganise their work to achieve their goals and optimise patient care, putting them at odds with the sometimes inflexible BCMA design.[27 33] A frequent observation was that BCMA design focuses the user on single timepoints, assuming that nurses complete tasks at scheduled times, whereas in practice nurses' work involves prioritisation, making the importance of timeliness context dependent.[20 27 31 33] BCMA design attempts to focus the user on the specific task of medication administration, but multiple studies found that nurses could not easily access additional information required to safely administer medication such as vital signs, medical history and information regarding previous or future doses.[27 31 33] Holden *et al* found that this prescriptive design limited users' critical thinking and therefore posed a safety risk.[34] Nurses were observed to use paper to record pertinent information because the BCMA design did not give them an overview of their tasks or patients and limited their ability to communicate with colleagues.[28] Staggers *et al*'s study of situational awareness found 99 usability issues with the BCMA system studied, of which 15 were rated catastrophic, arguing that the design did not match the way nurses think or work.[33] Van der Veen *et al* also found that the BCMA did not fit well with daily workflow of nurses who encountered both software and hardware blockades.[11]

Adaptations and workarounds

All studies which conducted observation in the clinical setting reported workarounds associated with BCMA technology. Although the consequences and causes of workarounds varied greatly, there was agreement that workarounds undermined the safety features of BCMA technology.

Patterson *et al*'s BCMA compliance study found that workarounds reduced technology effectiveness and increased the risk of adverse events.[32] Van der Veen *et al* found a statistically significant relationship between workarounds and medication error: 6% of the workarounds resulted in the wrong dose being administered and 78% of the workarounds were medication omissions.[30] Van der Veen *et al* reanalysed these data to look for factors which made workarounds more likely, finding a statistically significant relationship between high patient to nurse ratios and workarounds, arguing that increased work pressures led to an increase in the prevalence of workarounds.[11]

Holden *et al* found that BCMA triggered multiple types of problem-solving behaviours. They noted that the problem solving itself was a 'double edged sword', preventing failures missed in the design process, thus concealing design flaws, preventing redesign.[28] For example, the use of paper artefacts to record patient information is potentially dangerous because it is not available to the wider clinical team and the shared information may be out of date. The use of paper artefacts conceals the user need and introduces a safety risk, which could be alleviated by better design.

Using the SEIPS framework to examine technological, task, organisational, patient related or environmental causes of workarounds, Koppel *et al* found that workarounds were complex, resulting from numerous causes and themselves creating additional workarounds.[7] Koppel *et al* and Holden *et al* suggest that workarounds

Table 2 Human factors related themes from the studies

Author, date	Misaligned design and workflow	Adaptation and workarounds	Usability and design	Factors which mediate BCMA use	User perception	Safety
Holden *et al*[28]	▶ BCMA limited ability to plan ahead. ▶ Narrowed field of vision of user. ▶ Focused on specific timepoints. ▶ Limited user access to vital patient information. ▶ Did not reflect the complexity of clinical work. ▶ Did not fulfil user need.	▶ Workarounds mask design flaws. ▶ The designer and organisation maybe unaware of these design flaws and/or workarounds.	▶ Poor BCMA usability. ▶ Poor fit between BCMA and existing technology. ▶ Paper documentation used to communicate information lost between BCMA and existing technology.			▶ Safety concerns regarding the use of paper documentation identified.
Holden *et al*[20]	▶ BCMA transformed existing workflow. ▶ Changed health outcomes. ▶ Poor designer understanding of original workflow led to poor acceptance of technology.	▶ Healthcare workers adapt to new work systems with their own goal achieving strategies. ▶ Poor compliance with design use is frequently observed.		▶ Studying user perception of BCMA can improve design and acceptance.		
Novak *et al*[29]	▶ BCMA was misaligned to technology use practices.	▶ Workarounds frequently identified in study.	▶ Iterative process of design and evaluation advocated.	▶ Implementation mediators can help mitigate negative unintended consequences caused by BCMA implementation and limit the development of workarounds.	▶ Expectations should be set for nurses prior to implementation of BCMA so they understand its advantages and disadvantages.	
Novak *et al*[27]	▶ Temporal design focused on timepoints. ▶ Difficulty planning ahead. ▶ Design not reflective of the complexity of clinical work. ▶ Inflexible when a plan changes. ▶ Design based too rigidly around the five rights. ▶ Clinical judgement of nurses not considered. ▶ Poor design led to the use of paper handover documents for communication.	▶ Workarounds implemented to improve efficiency. • Safety features of BCMA not aligned with user safety concerns, resulting in workarounds.	▶ Iterative process of design and evaluation advocated.		▶ Stigma of late doses, resulting in nurse's avoidance strategies. ▶ Compliance with BCMA used as a performance measure. ▶ Nurses show willingness to comply with BCMA but are still having the resort to workarounds to complete tasks.	▶ Rigid design can reduce critical thinking in nurses, potentially increasing risk of error. ▶ Simply implementing BCMA does not improve medicines safety. ▶ Safety features of BCMA not aligned with user safety concerns.

Continued

Table 2 Continued

Author, date	Misaligned design and workflow	Adaptation and workarounds	Usability and design	Factors which mediate BCMA use	User perception	Safety
Rack *et al*[31]	▶ Design focused user on single timepoint. ▶ Difficulty accessing information on previous medication administration. ▶ Reduced ability to communicate concerns/errors with wider team. ▶ Vital patient information difficult to access, delaying administration. ▶ Five rights used as BCMA design basis too rigid.	▶ Workarounds in response to poor design.	▶ BCMA technology should be designed in such a way that using it appropriately is easier than working around the system.	▶ Regular Maintenance of hardware reduces frustration for users and improves compliance with use. ▶ Responsibility for the maintenance of hardware should be considered prior to implementation.	▶ Nurses should not be given the impression that BCMA use is faster. ▶ Safety benefits should be emphasised.	
Staggers *et al*[33]	▶ Workflow twice as long with BCMA use. ▶ Poor fit with existing workflow and user need. ▶ Temporal focus on time point can blinker users to wider issues. ▶ Design too inflexible for the complexity of clinical work. ▶ Five rights interpreted too rigidly during design process.	▶ Workarounds discussed in relation to misaligned design and workflow. ▶ Workarounds developed in response to poor design.	▶ High volume of usability issues identified. ▶ Better design needed to improve user situational awareness. User-centred design advocated. ▶ Design should support patient journey through the hospital.		▶ User perception discussed in relation to misaligned design and workflow.	▶ Poor usability and design are a safety risk. ▶ Safety features of BCMA compromised by workarounds. ▶ Reduced situational awareness led to increased safety risk.
Van de Veen *et al*[30]	▶ BCMA did not fit well with existing workflow. ▶ Issues with hardware and software identified.	▶ Statistically significant association between workarounds and medication administration errors	▶ Poor human–machine interface result in healthcare workers working around the system, compromising safety.	▶ Post implementation evaluation recommended for BCMA to achieve it full benefits.		▶ Poor design resulting in workarounds produces a safety risk.
Holden *et al*[34]	▶ May not be financially worthwhile for organisation.	▶ Poor design results in a lack of acceptance and workarounds.	▶ Design and usability discussed in relation to workarounds. ▶ BCMA difficult for some to use.		▶ BCMA users' perceptions of new technologies should be studied in order to influence their acceptance. ▶ Studies of acceptance can predict technology use.	
Koppel *et al*[7]		▶ SEIPS model used to identify causes of workarounds. ▶ Workarounds can increase medication error risk. ▶ Workarounds have multiple causes and cause subsequent workarounds.	▶ Organisational and technology related causes were found to be associated with all 15 of the identify workarounds.	▶ Study of workarounds can highlight design issues and find solutions.		▶ Workarounds have the potential to present a safety risk.

Continued

Table 2 Continued

Author, date	Misaligned design and workflow	Adaptation and workarounds	Usability and design	Factors which mediate BCMA use	User perception	Safety
Patterson *et al*[32]	▶ Design did not reflect context of use. ▶ To prevent adverse events following BCMA implementation, existing workflow should be studied and designed accordingly.	▶ Workarounds increase error risk by bypassing safety technology of BCMA. ▶ Workarounds may go undetected or be acknowledged and tolerated by organisations. ▶ Nurses expressed concern of how workarounds reflect on them as professionals.	▶ Redesign could reduce frequency of workarounds. ▶ Redesign could improve efficiency. ▶ User perception of inefficiency increased workarounds. ▶ Improved reliability of hardware would reduce workarounds.		▶ Nurses who felt their goals were jeopardised by inefficient BCMA justified the use of workarounds. ▶ Disciplining non-compliance found to be ineffective if the nurse felt they were acting in the interest of the patient.	▶ Workarounds are a safety risk.
Van der Veen *et al*[11]		▶ Workarounds more frequent on busy weekdays than weekends. ▶ More likely to occur with a higher patient to nurse ratio. ▶ Not associated with ability to scan barcode. ▶ Increased work pressure increased workarounds.		▶ Increased staffing. ▶ Redesign to make BCMA more efficient.	▶ As work pressure increases, the frequency of workarounds also increases.	

BCMA, barcode medication administration; SEIPS, system engineering in patient safety.

may be unavoidable when introducing technologies that transform workflow. Koppel *et al* argue that the study of workaround can highlight design flaws in order to remedy them, while Holden *et al* suggest that workarounds can be pre-empted and controlled through design.[7 34]

Koppel *et al* also posit that workarounds are made more prevalent by poor design. Koppel *et al* found that workarounds were not only negative but were also sometimes perceived by users as necessary to deliver patient care, finding that consequences of workarounds could be positive, neutral or negative.[7] Both Koppel *et al* and Patterson *et al* advocate human factors approaches to study the causes of workarounds instead of simply introducing policies to increase compliance with intended workflows.[7 32]

Van der Veen *et al*'s study[11] examining the factors that contribute to workarounds recommended mandatory nurse to patient ratios, as they found this to be a mediating factor to reduce dangerous workarounds.

Design and usability

Design and usability issues were identified by most studies as a factor influencing successful BCMA use.

The studies reviewed linked poor design and implementation to increased medication errors and reduced situational awareness.[7 33] Patterson *et al*'s observational study found that many workarounds could be eliminated by redesign and many of the processes could be made more efficient.[32] Holden *et al* argue that usability should be a priority, noting that if the difficulty of use outweighs the benefit, from the user's perspective, workarounds and non-compliance will be more prevalent.[28] Rack *et al* argue that the goal of design should be to work in such a way that it is easier to use it correctly than workaround the system to achieve goals.[31]

Many of the papers identified issues with poorly designed hardware and software. Staggers *et al* reported frustration and multiple login requests to access the BCMA and eMAR systems studied. Also, the systems could not accommodate patients moving to different areas in the hospital, due to design, which caused confusion regarding whether or not medications had been given. Staggers *et al* reasoned that better interoperability and patient-centred design could alleviate many of these issues.[33] Patterson *et al*, Koppel *et al* and Rack *et al* identified hardware issues such as barcode scanner tethers being too short, workstations on wheels being too bulky to enter treatment rooms and inadequate internet connectivity leading to delays in workflow.[7 31 33] Van der Veen *et al* found that inadequate human–computer interfaces result in frustration and workarounds.[30]

The majority of papers advocated evaluation and re-evaluation during implementation and beyond to take full advantage of safety features and identify the causes of workarounds in order to redesign the system.[27 28 30–33] Koppel *et al* and Novak *et al* advocate ensuring that the designers of the BCMA system understand the current medication administration workflow and environmental and technical factors that may result in poor acceptance and reduce utilisation of new technology. This process should include a pre-implementation assessment to understand user needs and ongoing evaluation, allowing for redesign as issues occur.[7 27]

Factors which mediate BCMA use

Many studies identified factors which can ease BCMA implementation, reduce unintended consequences such as workarounds and improve acceptance of new technologies. Factors identified include conducting research that establishes user needs and perceptions of technologies, engaging individuals who act as mediators for both users and designers, ensuring users are aware of system capabilities and limitations and organisational commitment to ensuring hardware is maintained and appropriate for the environment, including sufficient staffing levels.

Holden *et al*'s[20] study into user perception and acceptance examined expectations of use pre and post BCMA implementation. Three aspects of medication administration were studied: matching medication to MAR, checking patient ID and documentation. After BCMA implementation, nurses reported decreased likelihood of error, increased likelihood of error detection, increased usefulness, accuracy and consistency for matching medication and identifying the patient. However, they also reported decreased time efficiency and decreased usefulness with regard to documenting actions on the BCMA system. Holden *et al* suggest that while HITs such as BCMA have a transformative impact on workflow, these changes are measurable and can be mediated by design, if users' expectations and needs are explored prior to development and implementation.

Similarly, when examining how to reduce unintended consequences when switching to a new system such as BCMA, Novak *et al*[29] argued that users' expectations should be set prior to implementation for them to develop an understanding of system capability and limitations. Novak *et al*'s study followed a group of mediators who acted as user advocates during BCMA implementation, maintaining timely communication with hospital management and system designers, resulting in a more iterative and evolving implementation process. This style of implementation helped to mitigate negative unintended consequences.

Rack *et al*[31] conducted a survey of 220 nurses using BCMA and held focus groups. Although 90% of survey respondents agreed that BCMA was safer, many recounted situations where compliance with the BCMA system was not possible, 63% reported instances of giving medication without scanning the patient, 72% reported occasions when they did not scan the medication barcode and 40% reported sometimes scanning medication post administration. Focus groups discussed scenarios where compliance with BCMA was problematic. Overall, 30 scenarios were identified where a workaround was necessary to administer medication. Rack *et al* emphasises the need to set user expectation prior to BCMA implementation, presenting BCMA as no more time efficient but safer.

In addition, they note that technology will need maintenance and this needs to be delegated to avoid the frustration of failing or inappropriate equipment. Koppel *et al* also noted that users overestimate the risk elimination ability of BCMA and underestimate the safety features. There is a need for ongoing education to encourage correct use, and for hospital management to thoroughly examine their technological, environmental and social contexts before choosing a BCMA technology.[7]

User perceptions

Two papers reported that user perception impacted on successful implementation and user compliance.[33 34] The use of BCMA compliance as a performance measure was found to be unsuccessful and resulted in resistance, particularly where users felt they were acting in the best interests of their patients by employing workarounds. However, users also reported feeling guilt and stigma if they were unable to complete an administration in line with the BCMA system workflow.

Both Novak *et al*[29] and Holden *et al*[34] identified a reported stigma regarding late doses and how nurses attempted to avoid this stigma via workarounds. In reanalysing these studies, Novak *et al*[29] identifies an issue with using BCMA compliance as a performance measure, finding that nurses withholding medication for a legitimate reason were not able to communicate this, resulting in the feeling that they had done something wrong. One hospital punished non-compliance staff and used it as a performance measure, while the other provided continual coaching of staff with the emphasis on safety. Koppel *et al*[7] suggest that it is not enough to tell staff to comply; rather, a constant evaluation of BCMA use is necessary to improve safety. Holden *et al*'s later study[34] of nurses' acceptance of BCMA found that nurses already dissatisfied with BCMA are unlikely to use it to its full capacity, only being compliant enough to achieve their goals. Patterson *et al*[32] also found that policies, sanctions and training were unlikely to improve compliance if users felt that BCMA use jeopardised their ability to provide adequate patient care and achieve their goals. The increased use of workarounds during times of high work pressure reported by Van der Veen *et al* suggests that users perceive BCMA as being inefficient, only fully complying with the technology when they have time to do so.[11]

Safety

The main purpose of BCMA is to improve patient safety; the majority of studies included in this review did not focus on the safety benefits of BCMA but instead used human factors methods to establish the underlying causes of unintended consequences. Nonetheless, there is some evidence that BCMA has this intended effect; for example, Koppel et al analysed 307 698 BCMA alerts as well as focused observations, and found over 23 000 alerts that appeared to lead to the user changing their action.[7] However, these studies are unable to conclude that BCMA is safer, instead finding that BCMA has the potential to improve safety.[20 27 28] The issue of improved safety with BCMA technology is complex, and simply having the technology does not make medication administration safer. Increased safety is context dependent, relying on numerous other factors. Rack *et al*[31] found that the majority of nurses believed BCMA technology was safer but also reported numerous scenarios where they had to bypass the safety features to administer medication.

DISCUSSION

The aim of this literature review was to identify how human factors influenced the usability and adoption of BCMA use. Studies using a human factors approach revealed a mismatch between BCMA system design and the existing workflow, caused by poor system design, which led to poor user acceptance and the development workarounds which presented a safety risk to patients. A secondary objective was to describe how human factors related determinants for BCMA have been researched and reported by healthcare and human–computer interaction disciplines. However, it became apparent that the studies included could not easily be divided into these two disciplines. Instead, the use of a human factors approach yielded a wide range of narratives, differing time points, outcomes of interest and measures of success. Despite the variety of research focuses, the themes identified were largely complementary and most studies acknowledged how their area of interest was connected to and had consequences for, the overall themes. What does differ is the measures of success in terms of BCMA use. For those studying design, technologies which fit the existing workflow, address clinical demand and improve user situational awareness are considered successful.[20 27 28] For those researching the safety consequences of workarounds, increased compliance with BCMA use, reduced workarounds and hence safer medication administration are markers of success.[7 11 30–32] For users, increased efficiency was a priority,[34] while implementers were concerned with user acceptance and appropriate use of the new BCMA system.[29] While the measures of success differ, they are all clearly related; the voice missing from this research is that of designers themselves: there is a consensus that system designers do not fully understand user needs and this may be the cause of many of the reported issues; how this is shared with those designing the systems is less clear.

The themes of this review are broadly in line with previous systematic and scoping literature reviews examining BCMA use[14 35 36]; it differs by capturing diverse research focuses and outcomes of interest to represent multiple perspectives. Combined, these provide valuable insights into the successful use of BCMA from numerous actors within the process. The inclusion of human factors highlighted the many different research interests and measures of success regarding BCMA use. Some previous literature reviews focused on particular areas of BCMA use, such as safety or design.[35 36] Others explored the connection between workarounds and safety, concluding

that BCMA has the capacity to reduce medication errors if used correctly.[14 37] Voshall *et al*[35] advocated improved compliance to realise the safety benefits of BCMA, while Hassink *et al*[36] highlighted how system design, workflow mismatch and implementation strategies influence the safety of BCMA but noted that the studies reviewed often did not elaborate on how BCMA was implemented or how the workflow mismatch was addressed. Debono *et al*'s review[14] focuses on workarounds and why nurses use them to achieve their goals; they consider the wider context of healthcare delivery and conclude that the nurses' perspective must be understood to reduce workarounds and improve bedside care. More recent studies show that medication related factors, such as the time of the medication round and route of administration, and other factors, such as the barcode integrity, may also influence the likelihood of workarounds.[11 38] By using human factors research to draw on many different voices within BCMA research, this review provides themes across a spectrum of activity for BCMA, from design to adoption.

By reviewing human factors studies which focus on system design, workflow mismatch, informatics and users, it becomes clearer how the identified themes relate to each other. The misalignment in system designed workflow and clinical workflow stems from designers not fully understanding the nature of work in the healthcare setting, as discussed by eight of the selected papers.[19 26 27 29–31 33] The juxtaposition of complex tasks coupled with changing priorities seems to clash with the rigid, temporally focused BCMA design reported by several studies.[27 28 31 33] The use of the five rights of medication administration was discussed by Novak *et al* and Rack *et al*,[27 31] suggesting that its use as a guide for BCMA design results in an overly rigid system.

The 'five rights' check list which is designed for use by nurses at the point of medication administration is in practice applied with more flexibility than is acknowledge by BCMA system design. In reality, there are many occasions when a nurse may have to reframe or rationalise one or more of the 'five rights', such as availability of stock, urgency of medication and patient access.[28] There is an apparent assumption that a formulaic, stepwise BCMA system will lead to increased safety, but healthcare is complex, the ability to adapt to changing situations is essential and inflexible systems may clash with the nature of work[39] and result in resistance, workarounds and increased safety risks.

Nurses are frequently required to reorganise their work to achieve quality care, often in response to factors beyond their control such as policy, organisational pressure, available technology and demand.[27 40] An important part of the nurse's role is to effectively manage these competing pressures and to advocate for their patients' needs. This review found many examples of problem-solving behaviours in nurses.[20 27] Overly prescriptive design in technology challenges nurses' identity and role.[14]

Policies enforcing compliance with BCMA technology and disciplining non-compliant users was not found to be effective.[32] The BCMA systems studied frequently reduced perceived efficiency, failed to make essential information available and reduced critical thinking and situational awareness.[26 27 30 31] Poorly designed BCMA creates additional hurdles to patient care and bypassing the BCMA system could be perceived as justifiable if it is in the interests of the patient.[33] However, the resulting workarounds circumvent the safety features of BCMA and expose the patient to increased risk of medication error. This conflict was evident in the literature reviewed: nurses agreed that BCMA use was safer but frequently encountered scenarios where they could not complete a task and use the BCMA technology correctly.[31] Conversely, users can sometimes overestimate the risk reduction capability of BCMA, relying on the technology to identify an error rather than a combination of the technology and their own clinical judgement.[31]

Workarounds were witnessed in every observational study in the review, but the terminology used to describe them differed: from adaptive and problem-solving behaviours to deviations and errors.[27 30] The use of different terminology surrounding workarounds implies either negative or positive attitudes towards them.[14] In the studies presented, safety focused papers often examined workarounds as an adverse event risk, while design and usability focused papers often described them as unavoidable and even informative.[28] Many of the papers were divided on the consequence of workarounds.[9] While the association between workarounds and medication errors is concerning, most studies acknowledge that workarounds are unavoidable when introducing a transformative technology into an existing workflow, and it is poor design and implementation that make them problematic.[7 30]

Studies included in this review agree that many of the problems with BCMA use are rooted in designers not fully understanding the complexity of clinical work. Measures to manage these design mismatches include careful and long-term implementation strategies, organisational and technological structures which encourage correct BCMA use and close monitoring of workarounds. However, many of these strategies seem to be compensating for less than adequate design; how to redesign systems to better match clinical need is not really addressed and the designer perspective is absent from the studies reviewed. However, the differing findings and perspectives act as a powerful message that there is a greater need for close working throughout design and deployment for BCMA to achieve its recognised potential in improving patient safety.

Implications for clinicians and policy-makers

The literature identified many mediating factors and potential strategies for enhancing BCMA use for clinicians, policy-makers and users. An understanding of users' perceptions of a new technology prior to implementation can be predictive of overall acceptance and can guide design.[20] Employing staff who are trained to act as mediators to ease implementation and act as

a bridge between users and designers was found to be helpful by Novak *et al*.[29] Ensuring that software and hardware are appropriate for the environment and properly maintained to reduce frustration and mistrust in technology, along with appropriate staffing levels, require an organisational commitment and cannot be achieved by an individual nurse.[11 31] Most studies recommended pre implementation evaluation and constant re-evaluation during the implementation phase with human factors frameworks to identify the causes of poor compliance with technology and inform redesign of the BCMA system. Success is dependent on collaboration between designers, informatics experts, users and the organisation to prevent workarounds persisting and becoming risks to safety. It may be necessary to view BCMA (and other HIT) system vendors as long-term partners, establishing a good understanding of user needs, organisational capability and how usability issues will be addressed following implementation.

Recommendations for further research

As noted above, the designers of BCMA systems are rarely visible in the discourse around their implementation and use. Studies of workarounds tend not to question the details of specific BCMA design, but to focus more on the complexity of the broader system. Further research is needed to better understand how new technologies can be designed and safely implemented into complex healthcare settings. This review, along with others,[14 35 36] has made it clear that BCMA technology is a component within a complex system of medication administration. Further interdisciplinary research is needed to better understand how technology to support safer medication administration can be designed to accommodate the complexities of use while also supporting staff in managing that complexity. In parallel, it is important to improve both user experience and patient safety. Future research should also examine the long-term effects of BCMA, not just at the point of implementation but as use evolves over years, to evaluate whether its safety benefits are sustainable as the environment and users change.

Limitations and strengths

Most studies included in this review were small in sample size and conducted in the USA. They relied on qualitative research methodologies such as observation, focus groups and surveys. Many of the studies triangulated their qualitative findings with quantitative data, such as BCMA compliance reports, to better understand what was being observed in practice and to make their findings more generalisable.

As this study particularly examined BCMA implementation with a human factors lens, many BCMA studies were excluded, resulting in only 11 papers being included in the final review. This has given a focused view of the available research including evidence from both healthcare and human–computer interaction perspectives.

The search strategy of this review was independently repeated by a second reviewer to reduce the risk of bias, and a good level of agreement was achieved.

CONCLUSION

This review found that successful BCMA use is eased by a clear understanding of existing workflow and user needs. Evaluation of BCMA technology pre, during and post-implementation can help to identify workarounds and guide redesign, organisational commitment to understanding and resolving issues with BCMA acceptance and collaboration between users and system designers. Human factors principles can be used to understand causes of poor BCMA use and acceptance in the complex healthcare setting, and can unify the voices and experiences of those using the technology. This should not just enable people to compensate for poor design but also guide system designers to improve system design and therefore patient safety.

Acknowledgements RW completed this work during her UCLH NHS Foundation Trust CEO and UCLH-UCL CMORE clinical research fellowship.

Contributors RW: Protocol design, literature review development, literature search, analysis and manuscript writing. RA: Independent second literature search, review of themes and manuscript review. AB: Protocol guidance, review and guidance on search strategy, identified themes and manuscript review and finalising. YJ: Protocol guidance, review and guidance on search strategy, identified themes and manuscript review and finalising.

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; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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Eligibility criteria

Inclusion

1. Studies referring to both BCMA and human factors.
2. Studies referring to usability and/or systems design and enabling and inhibiting factors to adoption of BCMA.
3. Studies after April 2000.
4. Primary studies which have been peer reviewed.

Exclusion

1. Studies not linking human factors to BCMA.
2. Studies researching BCMA and medication errors without human factors.
3. Literature published before April 2000.

Information sources

CINAHL, PubMed, Medline, google scholar.

Search strategy and information sources

Initial google scholar search of systematic reviews to refine key words using search terms: medication administration, BCMA, human factors, systematic reviews, resulted in limited reviews conducted using human factors to examine BCMA. Therefore, keywords were expanded to include the following.

Keywords:

1. Human factors, systems design, usability, usability testing, human computer interaction, HCI, unintended consequences, workarounds.
2. BCMA, EHRS, electronic health record system, barcode medication administration, eMAR, electronic medication administration record, EPMA, electronic prescribing and medication administration, EPA, electronic prescribing and administration.
3. Medication administration, medicines administration, drug administration.

Search database

Google scholar search to be conducting using keywords above and manually reviewing the findings, chaining citation lists from appropriate papers.
CINAHL and PubMed searches also to be conducted in the following format:

	CINAHL	PubMED	Medline	Google scholar
1.	Human factors OR usability OR usability testing OR human computer interaction OR HCI OR unintended consequences OR workarounds OR system design	"Human factors" OR "usability" OR "usability testing" OR "human computer interaction" OR "HCI" OR "unintended consequences" OR "workarounds" OR "system design"	Human factors OR usability OR usability testing OR human computer interaction OR HCI OR unintended consequences OR workarounds OR system design	Human factors OR usability OR usability testing OR human computer interaction OR HCI OR unintended consequences OR workarounds OR system design
2.	BCMA OR EHRS OR electronic health records OR barcode medication administration OR eMAR OR electronic medication administration record OR EPA OR electronic prescribing and administration OR EPMA OR electronic prescribing and medication administration	"BCMA" OR "EHRS" OR "electronic health records" OR "barcode medication administration" OR "eMAR" OR "electronic medication administration record" OR "EPA" OR "electronic prescribing and administration" OR "EPMA" OR "electronic prescribing and medication administration"	BCMA OR EHRS OR electronic health records OR barcode medication administration OR eMAR OR electronic medication administration record OR EPA OR electronic prescribing and administration OR EPMA OR electronic prescribing and medication administration	BCMA, EHRS, electronic health records, barcode medication administration, eMAR, electronic medication administration record, EPA, electronic prescribing and administration, EPMA, electronic prescribing and medication administration
3.	Medication administration OR medicines administration OR drug administration	"Medication administration" OR "medicines administration" OR "Drug administration"	Medication administration OR medicines administration OR drug administration	medication administration, medicines administration, drug administration
	1 and 2 and 3	1 and 2 and 3	1 and 2 and 3	One search

Screenshot of CINAHL search