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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

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ABSTRACT

Background: Technology in the form of Automated Dispensing Cabinets (ADCs), Barcode Medication Administration (BCMA), and closed-loop Electronic Medication Management Systems (EMMS) are implemented in hospitals to assist with the supply, use and monitoring of medications. Although there is evidence to suggest that these technologies can reduce errors and improve monitoring of medications in general, little is known about their impact on controlled medications such as opioids.

Objectives: This review aimed to fill this knowledge gap by synthesising literature to determine the impact of ADCs, BCMA and closed-loop EMMS on clinical work processes, medication safety, and drug diversion associated with controlled medications in the inpatient setting.

Methods: Eight databases (Medline, Pubmed, Embase, Scopus, Web of Science, PsycINFO, CINAHL, and ScienceDirect) were searched for relevant papers published between January 2000 and May 2019. Qualitative, quantitative, and mixed-methods empirical studies published in English that reported findings on the impact of ADCs, BCMA and/or closed-loop EMMS on controlled medications in the inpatient setting were included.

Results: In total, 16 papers met the inclusion criteria. Eleven studies reported on ADCs, four on BCMA, and only one on closed-loop EMMS. Only four studies focused on controlled medications, with the remainder reporting only incidental findings. Studies reported the elimination of manual end-of-shift counts of controlled medications after ADC implementation but cases of drug diversion were reported despite introducing ADCs. Three quantitative studies reported reductions in medication errors after implementing BCMA, but medications labelled with wrong barcodes and unreadable barcodes led to confusion and administration errors.

Conclusions: More quality, targeted research is needed to provide evidence on the benefits and also risks of implementing technology to safeguard against inappropriate use of controlled medications in the inpatient setting. Processes need to be in place to supplement technological capabilities, and resources should be made available for post-implementation evaluations and interventions.

Introduction

Controlled medications, such as opioids, are frequently used in healthcare to provide patient pain relief and treatment, but their use is associated with errors,[1,2] possible addiction, and patient harm, as exemplified by the opioid epidemic in the US.[3] These medications are usually known as 'schedule 4' and 'schedule 8' ('s4' or 's8') drugs in Australia, 'controlled drugs' in the UK, and 'scheduled drugs', 'controlled substances' or 'narcotics' in North America. In most countries, supply and use of controlled medications are regulated by laws or policies.[3–6] For example, in the US and Australia, clinicians are required to store controlled medications in secure locations, keep accurate records of all transactions and available stock, and monitor and report incidents.[3,5] Thus, considerably more work goes into safeguarding

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controlled medications than regular medications, placing a burden on clinicians' workloads.[7] Despite having these policies and processes in place, diversion (theft or misuse) of controlled medications by healthcare professionals is a problem, albeit rarely acknowledged.[3,4,8] Diversion could lead to serious harm to both staff and patients and have repercussions for the hospital organisation.[3,9–11] To illustrate the nature of this problem, hospitals have published reports on incidents of drug diversion, including diversion of opioids and other controlled medications.[12,13]

Increasingly, technology, in the form of Automated Dispensing Cabinets (ADCs), Barcode Medication Administration (BCMA), and closed-loop Electronic Medication Management Systems (EMMS), is being introduced in hospitals to reduce medication errors, safeguard medications from improper use, and improve efficiency of medication processes (see Table 1).[14–17] Studies suggest that ADCs have the potential to reduce medication errors,[15,18–22] storage errors,[15,23] and nurse time on medication administration and drug inventory activities.[20,24] However, a systematic review on the clinical and economic impacts of ADCs warned that any positive impact may be institution-specific, and success depends on the integration of this technology with the medication distribution process in place at each local setting.[25] Research on BCMA has also yielded mixed results. Although BCMA has been associated with reduced medication errors,[17,26,27] studies have uncovered pharmacist and nurse dissatisfaction as a result of usability and technological issues,[28,29] leading to errors and workarounds while using BCMA.[30,31] Two systematic reviews which investigated the impact of BCMA on medication errors concluded that this technology has the potential to reduce errors but rates of reduction varied between studies, and technology alone did not guarantee improved error rates.[27,32] Close-loop EMMS are less common,[14,16,33,34] but evidence suggests that implementation can reduce time to first dose,[14] and reduce prescribing and medication administration errors (MAEs).[16,33]

In addition to potential benefits, like most technology introduced in healthcare, there are unexpected negative consequences and new safety risks associated with the use of ADCs, BCMA and closed-loop EMMS.[24,36,37] While there is some evidence of their impact on medications in general, little is known about how these technologies affect controlled medications specifically. Previous reviews by Tsao et al. on ADCs,[25] and Strudwick et al. and Hassink et al. on BCMA,[27,32] focused on outcomes of health technology implementation without investigating if controlled medications are impacted differently than general medications. Given that work processes are more stringent for the dispensing and administration of controlled medications, it is prudent to synthesise evidence on whether implementation of health technologies has the intended effect in improving safety and efficiency when handling these medications in the hospital setting. Before designing and carrying out new studies, this review aimed to fill this knowledge gap by synthesising literature on the impact of these three frequently used health technologies on controlled medications specifically. In particular, we aimed to gather both quantitative and qualitative evidence to determine how ADCs, BCMA and closed-loop EMMS impacted on (1) clinical work processes when handling controlled medications, including time spent on medication related activities and workarounds performed to bypass perceived inefficiencies (2) monitoring (e.g. identifying and assessing discrepancies in documentation), and safeguarding of controlled medications from theft, misuse or abuse (drug diversion), (3) rate of medication errors and adverse drug events when dispensing and administering controlled medications, and (4) new system-related errors not possible when paper processes were in place.

Table 1
Technology for medication dispensing and administration – definitions and examples.

Technology	What is it?
Automated Dispensing Cabinets (ADC)	ADCs are locked medication cabinets. When data are entered on digital screens (for example, user identification, item requested), only selected drawer(s) open giving users access to selected items. Each transaction is recorded electronically.[35]
Barcode Medication Administration (BCMA)	BCMA refers to the use of barcode scanning at the time of medication administration. Typically, both the medication and the patient wristband are scanned to ensure the right medication is being administered to the right patient.[30]
Closed-loop Electronic Medication Management Systems (EMMS)	A closed-loop EMM system consists of technological components that support prescribing, dispensing, and medication administration, and includes ADCs and BCMA.[14] They enable the tracking of single medication items (e.g. unit doses) across the entire medication workflow.

Methods

Selection criteria

Qualitative, quantitative, and mixed-methods studies published in English that reported findings on the impact of ADCs, BCMA and/or closed-loop EMMS on controlled medications were included. The review was limited to the use of these technologies in the inpatient hospital setting, including the emergency department. Outpatient settings were excluded, as their workflows are likely to be substantially different from inpatient settings. We limited the review to peer-reviewed empirical studies published in journals (e.g. review papers, conference abstracts and dissertations were excluded). Studies were also excluded if they provided no data on the effects of technology on controlled medications. Some of these technologies have been in place in hospitals since the mid-1990s[19]; thus studies published in the past 20 years, from January 2000 to May 2019 were included.

Search process

The following eight databases were searched for relevant papers: Medline, Pubmed, Embase, Scopus, Web of Science, PsycINFO, CINAHL, and ScienceDirect. The search was completed on May 6, 2019. In addition, reference lists of review papers and included studies were scanned to identify other relevant studies.

Search terms included variations in nomenclature for ADCs, BCMA and closed-loops EMMS (e.g. unit dose dispensing), combined with terms for controlled medications (e.g. narcotics in the US, and schedule 8 medications in Australia), and keywords for the hospital setting (e.g. inpatients). The search strategy used for one database is presented in Online Resource 1.

Study selection & data collection

Search results were scanned by title, by abstract, and then by full-text by at least two researchers (WYZ, VL & BVD) to select studies for inclusion. Disagreements were resolved by consensus. Quality assessment of each included study was conducted at the point of data extraction.

All data relating to the impact of technology on controlled medications were extracted from each of the included studies by at least two researchers (WYZ, VL & BVD), based on a data extraction form specifically designed for this task. The data extracted by the researchers were compared and disagreements were resolved by consensus.

In addition to demographic variables including country of origin, study setting, study type, technology implemented, and name/class of controlled medications included in the study, quantitative and qualitative data related to the following four categories were extracted from papers: (1) the impact of technology on work processes, (2) the impact of technology on monitoring and diversion, (3) the impact of technology on medication errors, and (4) new system-related errors.

This review was structured according to the PRISMA guidelines with all applicable items from the checklist included. The PROSPERO registration number is CRD42020135531.

Risk of bias

Quality assessment of included studies was conducted using the Critical Appraisal Skills Programme (CASP) checklist for Cohort Study for quantitative studies,[38] and the CASP checklist for Qualitative Research for qualitative studies.[38] Only studies deemed 'worth continuing' by the CASP checklists were included in the synthesis.

Synthesis of results

We found that different outcome measures were used by quantitative studies included in this review (e.g. number of alerts triggered that prevented medication administration errors, time spent on clinical tasks per month). Therefore, we deemed a meta-analysis not appropriate for synthesis of results. Instead, a narrative synthesis approach was taken to combine and present extracted data in a meaningful way.

Results

In total, 16 papers met the inclusion criteria (See Fig. 1). Of the 16 included studies, 10 were quantitative, three were qualitative, and three used mixed-methods (Table 2). Only four studies focused on controlled medications.[6,39–41] The other 12 studies reported data on controlled medications, but this was not the study's focus (Table 3). As a result, only limited relevant data could be extracted from these papers. Eleven studies reported on ADCs, four on BCMA, and only one on closed-loop EMMS. Eight studies were from the US, three from Canada, and one each from Australia, Spain, Italy, South Korea, and Qatar. Six studies assessed the impact of technology shortly after implementation (within one year), four studies between one and two years, and four studies reported findings at three to five years (Table 2). There were no longitudinal studies.

Risk of bias

Using the CASP checklists, all 16 studies were rated as 'worth continuing'. For quantitative studies, this meant that the study addressed a clearly focused issue and the sample was recruited in an acceptable way. For qualitative studies, the research aims were clearly stated and a qualitative methodology was appropriate for the study. However, only four quantitative studies were pre-post evaluations,[6,40,44,49] with no control groups included. Study results suffered from low generalisability (e.g. small samples). For qualitative studies, it was difficult to determine if data analysis was sufficiently

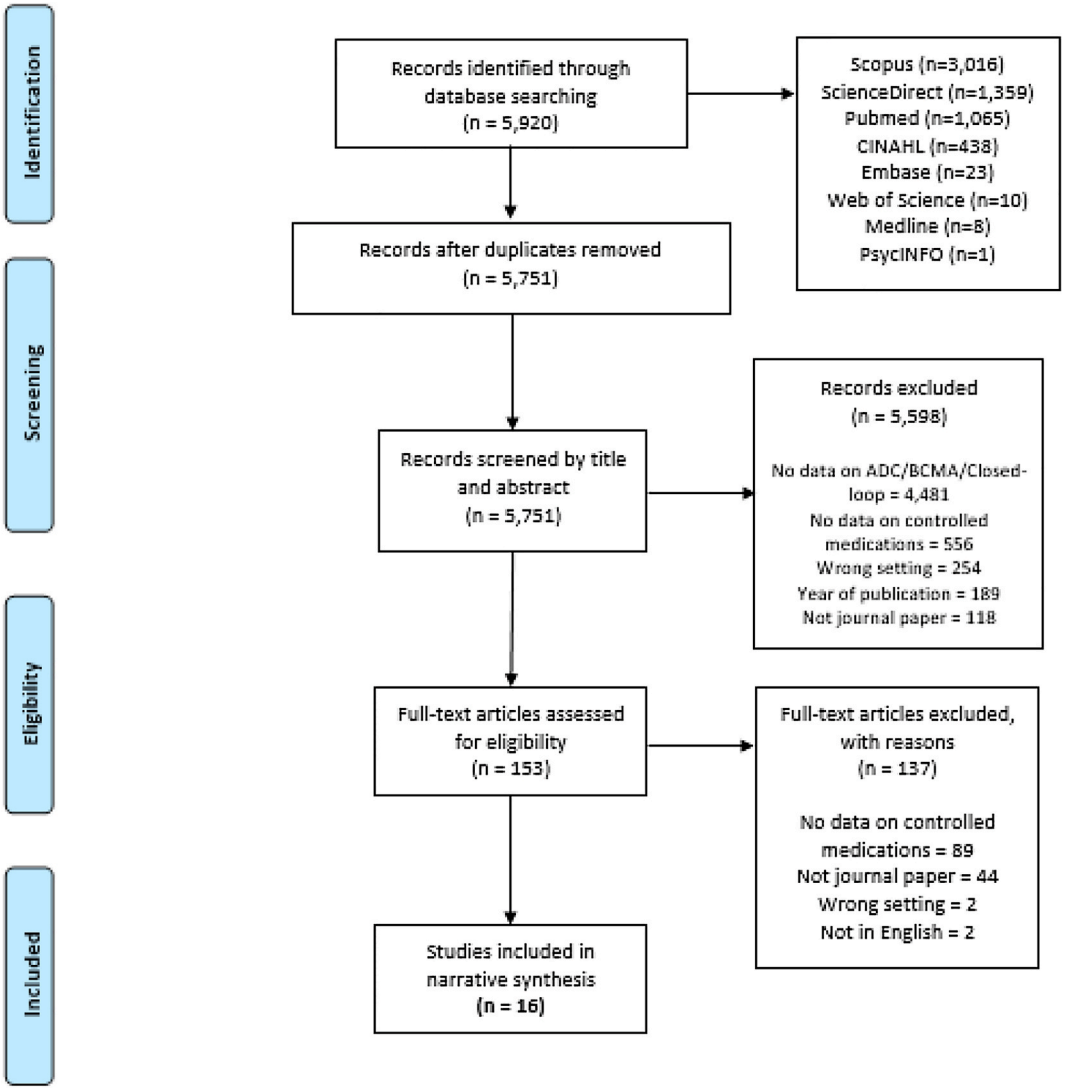

Fig. 1. Search results.

Table 2
Study characteristics.

Author, Year	Country	Setting	Study type	Study methodology (sample size)	Technology assessed	Name/class of controlled medications	Study aim	Time since implementation
Balka et al., 2007[42]	Canada	Tertiary care facility	Qualitative	Field observations & interviews (n = 411 hospital staff members)	ADC	Narcotics	To provide an overview of the automatic drug dispensing system implementation at the hospital.	During implementation and up to 16 months post implementation
Cochran et al., 2007[43]	USA	65 hospitals	Mixed methods	Review of error reports (n = 445 errors)	BCMA	Fentanyl, hydromorphone	To illustrate the effectiveness of BCMA technology and describe reported errors associated with BCMA.	N/R
DeYoung et al., 2009[44]	USA	Community teaching hospital (adult medical ICU)	Quantitative	Direct observation pre (n = 775 medication administrations) and post (n = 690 medication administrations)	BCMA	Narcotics	To study the effect of BCMA on the rate of medication errors in adult patients in a medical ICU.	One month pre and four months post implementation
Epstein et al., 2011[39]	USA	University hospital	Qualitative	Matching ADC cart transactions with case records from anaesthesia information management system (n = 5 case studies)	ADC	Fentanyl, morphine	To demonstrate prospectively the utility of a methodology to detect drug diversion.	Up to four years post implementation
Hwang et al., 2016[33]	South Korea	Tertiary teaching hospital (all general wards except the ICU and ER)	Quantitative	Secondary analysis of medication administration data and error logs (n = 35,082 alerts)	In-house closed-loop medication administration system using radio frequency identification, hand-held point-of-care devices, and CPOE	Opioids	To determine the risk factors and rate of MAE alerts by analysing large-scale medication administration data and related error logs.	Up to five years post implementation
Kowiatek et al., 2006[45]	USA	University affiliated academic medical centre	Quantitative	Review of ADC override activity data (n = 27 medications removed)	ADC	Opioids	To describe the organisation's experience and lessons learned from an intervention to prevent unauthorised and inappropriate medication overrides.	Up to three years post implementation
Morriss et al., 2011[40]	USA	NICU within University of Iowa Children's hospital	Quantitative	Observations pre and post BCMA installation (n = 618 patients)	BCMA	Opioids	To study the risk of adverse drug events in neonates treated with opioids and the effect of a BCMA system.	19 weeks pre implementation and 19 weeks post implementation
Novek & Rudnick, 2000[46]	Canada	Riverview health centre (Long term care building)	Mixed methods	Questionnaires (n = 102) and interviews (n = N/R)	ADC	Narcotics	To assess the reaction of nursing staff and supervisors to the effects of the Meditrol automated medication dispensing system on nursing workloads.	Eight months post implementation
Portelli et al., 2018[6]	Italy	Surgical unit of the National Cancer Institute of Milan	Quantitative	Review of paper registries (pre: n = 3395 drug movements) and ADC generated records (post: n = 3353 drug movements)	ADC	Narcotics: Morphine, Fentanyl & Ketamine	To assess the impact of the introduction of an automated dispensing system on narcotics dispensing management.	Eight months pre implementation and up to 12 months post implementation
Rochais et al., 2014[47]	Canada	Mother & Child Hospital	Mixed methods	Questionnaires (n = 172 nurses) and a focus group (n = 5 nurses)	ADC	Narcotics	To evaluate how nursing staff felt about the impact of ADCs on the safe delivery of health care and workplace ergonomics.	18 months post implementation
Rodriguez-Gonzalez et al., 2012[48]	Spain	Two gastroenterology wards	Mixed methods	Observations (n = 2314 medication administrations)	ADC	Transdermal fentanyl	To identify the frequency of medication administration errors and their potential risk factors in units using a computerized prescription order entry program and profiled automated dispensing cabinets.	Five years post implementation
Roman et al., 2016[49]	Australia	Major adult referral hospital	Quantitative	Time and motion method pre (n = 1030 medication	ADC	Schedule 8 (S8) and Schedule 11 (S11) medications	To examine the change in medication retrieval times, number of medications retrieved and staff perceptions before	Six weeks pre implementation and up

(*continued on next page*)

Table 2 (*continued*)

Author, Year	Country	Setting	Study type	Study methodology (sample size)	Technology assessed	Name/class of controlled medications	Study aim	Time since implementation
				retrievals) and post (991 medication retrievals)			and after the installation of automated dispensing machines.	to nine months post implementation
Sakowski, Newman, & Dozier, 2008[50]	USA	Six community hospitals	Quantitative	Review of error logs (n = 945 errors)	BCMA	Narcotics	To study the severity of medication administration errors detected by BCMA.	N/R
Vigoda, Gencorelli & Lubarsky, 2007[41]	USA	Large academic hospital	Quantitative	Review of data from systems (n = 11,603 cases)	ADC	Narcotics & Ketamine	To detect discrepancies between medications recorded as removed from automated medication dispensing system with medications recorded as administered.	Two years post implementation
Wakefield et al., 2010[51]	USA	Nine hospitals within a health network	Qualitative	Interviews (n = 16) & document review (n = N/R)	ADC & BCMA	Narcotics	To explore factors underlying the successful implementation of ADC and BCMA across a network of hospitals.	During and up to four months post implementation
Zaidan et al., 2016[52]	Qatar	Cancer centre and heart hospital	Quantitative	Cross sectional survey study (n = 403 nurses)	ADC	Narcotics	To assess nurses' perceptions of and satisfaction with the use of ADCs.	18 months (site 1) and 24 months (site 2) post implementation

Abbreviations: ADC; Automated dispensing cabinet, BCMA; Barcode medication administration, CPOE; Computerized provider order entry, ICU; Intensive care unit, ER; Emergency room, MAE; Medication administration error, NICU; Neonatal intensive care unit, N/R; Not reported.

rigorous. Assessment results for each study can be found in Online Resource 2.

Detailed findings related to ADCs, BCMA, and closed-loop EMMS on controlled medications from each study are outlined in Tables 4 and 5. A synthesis of results for each category is presented below.

The impact of technology on work processes

No studies reported on the impact of BCMA and closed-loop EMMS on work processes. Six studies reported on the impact of ADCs on work processes of clinicians in dealing with controlled medications.[6,42,46,47,49,51] Of these, two were qualitative,[42,51] two were quantitative,[6,49] and two used mixed-methods.[46,47] Qualitative data from three studies suggested that the introduction of ADCs resulted in the elimination of manual end-of-shift counts of controlled medications.[42,46,47] In a study that compared time spent on clinical tasks before and after the introduction of ADCs, a large reduction in nursing time spent compiling and correcting errors in drug registries was observed post-ADC (36 vs. 2 h/month).[6] Pharmacy time dedicated to inspecting stock and responding to ward requests also reduced from roughly 9 h per month to 1 h per month.[6] Interviews with key stakeholders within a US health network revealed that ADCs saved nurse time by implementing a 'blind count', replacing several daily counts independent of medication retrieval.[51] In a survey study, up to 80% of nursing staff expressed satisfaction with narcotic drug management after adoption of ADCs.[47] However, it was revealed that bulk liquid forms of narcotics could not be stocked in ADCs, and manual counts remained mandatory for these products.[47] A time and motion study in an Australian emergency department found that the retrieval of controlled medications was significantly quicker post ADC implementation (decreased by 36.1 s), with electronic documentation also replacing manual record keeping.[49]

The impact of technology on monitoring and diversion

Four studies reported findings on the impact of ADCs on monitoring and diversion of controlled medications.[6,39,42,52] Two were quantitative,[6,52] and two were qualitative.[39,42] In a study that compared errors made by nursing staff before and after ADC implementation, results showed that load and unload errors were eliminated after implementing ADCs, with no reported wastage of controlled medications.[6] In addition, the number of registry corrections, where amendments are made due to previous errors in documentation, also reduced dramatically from 232 in an 8-month period pre-ADC to 10 errors in a subsequent 8-month period after ADC implementation.[6] In a survey study conducted in two hospitals in Qatar, 75% (n = 304/403) of nurses agreed that there were rarely discrepancies in the controlled medication count with ADCs, although no evidence was provided to support this.[52] On the other hand, a US study described a case where up to 60 mg of morphine per day was diverted as wastage by a clinician, suggesting that ADCs could be 'tricked'.[39] However, the same study showed that diversion could be detected, investigated and stopped by auditing transaction logs from ADCs.[39] A Canadian study which used interviews and observations during and after ADC implementation found the elimination of manual end-of-shift counts of controlled medications after introducing ward-based ADCs to be problematic, as discrepancies could go unnoticed and left unaddressed for extended periods of time because the hospital pharmacy was short staffed and unable to deal with ADC discrepancy reports.[42] A unit manager commented that: '*Before people would go at the end of a shift and were careful about resolving narcotic discrepancies. Now they just adjust the numbers on the machine.*'[42]

The impact of technology on medication errors

Five studies reported on the impact of ADCs, BCMA and closed-loop EMMS on medication errors.[33,40,44,48,50] Three studies focused on

Table 3
Overview of studies providing data on impact of automated dispensing cabinets, barcode medication administration and closed-loop EMM systems on work processes, monitoring and diversion, medication errors and new system-related errors in relation to controlled medications.

Author, Year	Study focused on controlled medications?	Data available on work processes?	Data available on monitoring & diversion?	Data available on medication errors?	Data available on new system-related errors?
Balka et al., 2007[42]		✓	✓		
Cochran et al., 2007[43]					✓
DeYoung et al., 2009[44]				✓	
Epstein et al., 2011[39]	✓		✓		✓
Hwang et al., 2016[33]				✓	
Kowiatek et al., 2006[45]					✓
Morriss et al., 2011[40]	✓			✓	
Novek & Rudnick, 2000[46]		✓			
Portelli et al., 2018[6]	✓	✓	✓		
Rochais et al., 2014[47]		✓			
Rodriguez-Gonzalez et al., 2012[48]				✓	
Roman et al., 2016[49]		✓			
Sakowski, Newman, & Dozier, 2008[50]				✓	
Vigoda, Gencorelli & Lubarsky, 2007[41]	✓				✓
Wakefield et al., 2010[51]		✓			
Zaidan et al., 2016[52]			✓		

BCMA, and found benefits of using this technology to detect[50] and eliminate MAEs (from 2% (3/153) to 0 (0/60)),[44] and to reduce the risk of preventable adverse drug events in paediatric patients treated with opioids (Hazard ratio (95% CI): 0.48 (0.23–0.98), $p < .05$).[40] One study assessed MAEs associated with ADCs and found the system contributed to the omission of a controlled medication (fentanyl) that led to potential temporary damage to the patient.[48] In a South Korean study, alert data from an in-house closed-loop EMMS over a 12-month period was examined and credited with preventing a large number of MAEs (overdose or wrong patient) related to opioids (n = 1,446, 0.05% of total MAEs prevented).[33]

New system-related errors associated with technology use

Three studies identified system-related errors which would not have been possible before the introduction of ADCs,[39,41,45] and one study reported on errors associated with use of BCMA.[43] A US study that examined ADC logs for atypical transactions described wrong-patient errors as a result of medications being dispensed to subsequent patients while still logged into a previous patient's record.[39] An intervention study that examined nurse-ADC interactions highlighted potential problems with medication overrides, the practice of nurses removing medications from the ADC before pharmacist review. This practice led to MAEs, and resulted in the revision of the override medication list to minimize these errors.[45] A retrospective review that compared records of medications recorded as removed from ADCs with medications recorded as administered reported a number of data entry errors while using ADCs including not recording wasted controlled medications, documenting more than the actual amount of medication given to the patient, and removing controlled medications from the ADC and administering them to patients without documentation.[41] The study on BCMA reported a case in which unreadable barcodes led to a controlled medication being erroneously administered to the patient (Hydromorphone 1 mg was administered instead of Meperidine 50 mg).[43] Medication labelled with the incorrect barcode also led to confusion about the correct dosage of packaged medication (Fentanyl patch).[43]

Discussion

To our knowledge, this is the first systematic review to address the question of how ADCs, BCMA, and closed-loop EMMS affect the supply and use of controlled medications in the inpatient setting. We found limited evidence in the existing literature. Specifically, only four studies focused on controlled medications, with other studies providing only incidental findings. The majority of the studies related to the use of ADCs, with few studies investigating the effects of BCMA and closed-loop EMMS on controlled medications.

Diversion and abuse of controlled medications by clinicians can lead to problems with addiction, spread of infections, and even death.[9,53] There is evidence to suggest that opioids are among the most commonly diverted medications.[12] Our results showed that ADCs can support monitoring of controlled medications by eliminating load and unload errors while stocking and removing medications.[6] In addition, ADCs automatically record all transactions with controlled medications and may increase transparency and accountability. On the other hand, it is also possible for more medications to be removed than documented. For example, removing medications for multiple patients while the cabinet is open.[54] Compared to manual processes, ADCs have the advantage of recording data that may be extracted and used to flag suspicious transactions for detailed investigation.[39] However, the technology is not in itself sufficient to prevent diversion, as demonstrated by cases in which clinicians were able to exploit loopholes in the system software to divert medications as wastage.[39] Therefore, standard processes should be established including periodic audits of ADC transaction logs, possibly supported by analytics software.[39,55–57] In addition, some hospitals have put in place prevention programs involving regular mandatory education, enhanced skill building for detection of drug impairment, and the use of random drug screening.[58] However, it is important to note that the success of such programs appears to be dependent on time, money, and staff buy-in.[59]

Consistent with research on medications in general,[17,26] our findings showed that BCMA was associated with reductions in MAEs and preventable adverse drug events related to controlled medications.[40,44,50] However, as highlighted by previous evaluations of BCMA systems, in order for the technology to be effective, complementary strategies need to be implemented.[27] For example, nurse training and patient education are important for successful use of BCMA in clinical practice.[27] Previous studies have shown that workarounds performed by nurses while using BCMA can pose serious threats to the safe use of medications. For example, in one study, nurses prepared, scanned, and transported medications for more than one patient at the same time in order to save medication administration time.[37] We found no evidence of workarounds in the studies we included in our review, most likely due to the fact that workarounds were not the focus of any of the included studies. There was however evidence to suggest that damaged and unreadable

Table 4
Overview of qualitative data extracted from included studies.

Author, Year	Technology	Findings
Work processes		
Improved efficiency		
Balka et al., 2007[42]	ADC	Nurses reported the elimination of end-of-shift narcotics counts
Novek & Rudnick, 2000[46]	ADC	Nurses reported the elimination of the narcotics count as a positive of implementing ADCs
Wakefield et al., 2010[51]	ADC	Nurses reported that ADCs saved nursing time by instituting a 'blind count' where remaining doses are entered at the time controlled medications are removed. This replaced several daily counts independent of medication removal
Limitations of technology		
Rochais et al., 2014[47]	ADC	Nurses reported that ADCs cannot handle bulk liquid forms of narcotics. They are left out of ADCs and manual counts are still mandatory for these products
Monitoring & diversion		
Monitoring		
Balka et al., 2007[42]	ADC	Nurses reported that discrepancies can go unnoticed at the end of the shift and left unaddressed for days until the unit manager receives the discrepancy reports from pharmacy
Diversion		
Epstein et al., 2011[39]	ADC	An examination of ADC transaction logs revealed a clinician exploited a weakness in the ADC software to divert morphine as wastage
Medication errors		
Rodriguez-Gonzalez et al., 2012[48]	ADC	Investigation of an observed omission of transdermal fentanyl suggest 'potential temporary damage' may have been caused to the patient
New system-related errors		
Cochran et al., 2007[43]	BCMA	A nurse reported that fentanyl patch 75 mcg was mistakenly barcoded as 100 mcg A nurse reported that a patient was administered hydromorphone 1 mg instead of meperidine 50 mg. The BCMA failed to detect the error. It was found that the purchased injectable containers included the lot number with the bar codes, which rendered them unreadable
Epstein et al., 2011[39]	ADC	An examination of ADC transaction logs revealed that drugs were dispensed for subsequent patients while still logged into the first patient's record.

ADC; Automated dispensing cabinet, BCMA; Barcode medication administration.

Table 5
Overview of quantitative data extracted from included studies.

Author, Year	Technology	Findings
Work processes		
Improved efficiency		
Portelli et al., 2018[6]	ADC	Nurses responsible for compiling and correcting errors in drug registries dedicated less time per month (reduced from 36hrs to 2 hrs/month) Inspections of stock and response to ward requests performed by pharmacists reduced from 9hrs to 1hr/month
Rochais et al., 2014[47]	ADC	77% of surveyed nurses agreed that time needed for the shift count was reduced 81% of surveyed nurses agreed that time needed for medication dose selection was reduced
Roman et al., 2016[49]	ADC	Retrieval of S8 or S11 medications was significantly quicker post-implementation (−36.1s; $p < .01$)
Monitoring & diversion		
Improved record keeping		
Portelli et al., 2018[6]	ADC	Load and unload errors were reduced from 90 during an eight-month period pre-implementation to 0 during an eight-month period post-implementation Registry corrections reduced from 232 pre-implementation to 10 post-implementation
Zaidan et al., 2016[52]	ADC	Nurses from two hospitals (n = 304/403) agreed that narcotics count discrepancies were rare after ADC implementation
Medication errors		
Medication administration errors		
DeYoung et al., 2009[44]	BCMA	MAEs related to pain relievers or narcotics reduced from 2% (3/153 MAEs) pre-implementation to zero post-implementation (0/60 MAEs)
Hwang et al., 2016[33]	Closed-loop	MAEs (overdose or wrong patient) related to opioids were prevented by electronic alerts (n = 1,446, 0.05% of total MAEs)
Sakowski, Newman, & Dozier, 2008[50]	BCMA	14.8% (n = 140/945) of MAEs detected by the BCMA involved narcotics 1.1% (10/945) of detected MAEs related to narcotics were rated moderate or severe
Reduced risk of adverse drug events		
Morriss et al., 2011[40]	BCMA	The BCMA system reduced the risk of a preventable ADE [Hazard ratio (95% CI): 0.48 (0.23–0.98), $p < .05$]
New system-related errors		
Kowiatek et al., 2006[45]	ADC	Nurses removed opioids without pharmacist review (override) during 24.5% of retrievals in an eight-month period
Vigoda, Gencorelli, & Lubarsky, 2007[41]	ADC	Data entry errors were identified, including: Wasted medications not recorded in ADC but later accounted for using a Discrepancy Form (4.71%; 547/11,603 cases); Medication is removed from ADC and given to patient without documentation (2.49%; 289/11,603 cases); Incorrect amount of waste recorded (1.46%; 169/11,603 cases); Quantity of medication documented is more than the actual amount given to the patient (1.91%; 222/11,603 cases).

ADC; Automated dispensing cabinet, BCMA; Barcode medication administration, MAE; Medication administration error, s8/s11; schedule 8/11 medications.

barcodes, and medications labelled with incorrect barcodes led to problems, resulting in MAEs and confusion over whether the scanned medication was the correct medication to administer to the patient.[43] Future research could explore if specific workarounds are created for the process of administering controlled medications to patients using BCMA systems.

Based on our findings, in order to optimise benefits of introducing dispensing and administration technologies such as ADC, BCMA and closed-loop EMMS in the inpatient setting, resources and education need to be available post-implementation to support capabilities of technologies. For example, the end-of-shift count of controlled medications was reportedly eliminated after implementing ADCs, saving nursing time on this clinical task.[6,42,46,51] However, the lack of pharmacy resources to deal with discrepancy reports produced by ADCs potentially compromised safe medication practices.[42] In addition, for exceptions such as liquid forms of narcotics, which could not be stored in ADCs,[47] it is imperative that staff are educated about the importance of continuing with traditional manual record keeping methods to account for and monitor the supply and use of controlled medications in this form. In these cases, technology contributed to the emergence of safety and workflow problems.

There were limited studies on the impact of ADCs and closed-loop EMMS on medication errors when using controlled medications. Omission errors (i.e. missed doses) occurred as a result of possible stock shortages in ADCs,[48] demonstrating the importance of having standard processes and protocols in place in such situations to supplement the capabilities of technology. Lack of stock in the ADC should be clearly communicated to pharmacy, the prescriber, and nursing staff, to ensure that an appropriate substitute is administered to the patient. The only study that reported findings on the impact of a closed-loop EMMS on controlled medications found that MAEs related to the use of opioids, which could have led to overdose or medication administered to the wrong patient, were prevented by electronic alerts generated by the system.[33] However, the study did not investigate which alerts actually prevented the MAEs, limiting the conclusions that can be drawn about this. As adoption of closed-loop EMMS become more widespread, studies should investigate which component (prescribing, dispensing, or administration) of the system is most effective in detecting and preventing errors related to controlled medications.

The introduction of technology often comes with unanticipated problems and errors.[37,60] Studies in this review suggest that log-in errors, data entry errors, and override errors could all have compromised patient safety and record keeping by allowing controlled medications to be prescribed under the wrong patient name, incorrect documentation of medication transactions, and administration of medications without pharmacy review.[39,41,45] The emergence of these system-related errors suggest that resources need to be made available post-implementation to identify and rectify new and unanticipated issues. For example, one study described the process a hospital used to address the nurse override issue, which permitted the removal of medications from ADCs without pharmacy review.[45] Using overrides to access medications from the ADC can result in errors (e.g. patient allergy not checked), with the potential to cause harm to the patient.[61] An expert panel was convened to review the override medication list, and tailored education on the appropriate use of the override function was delivered to nurses.[45] This led to an initial drop in the opioid override rate. Such intervention would have been resource intensive and required early identification of system-related problems. Thus, to maximise benefits from technologies, resources should be allocated for post-implementation evaluations and if required, redesign of systems and associated processes.

Limitations & recommendations for future research

This review was limited by a dearth of research evidence currently available in the literature. As a result, conclusions are based on a small number of studies. Only four studies focused on controlled medications. Studies not published in English were not considered which might have provided additional data. Most studies were conducted in developed nations (e.g. U.S. & Canada), with only two studies in Asia. These findings highlight a need for more high-quality research on the impact of health technology on controlled medications in general, but also in developing nations as adoption of health technology becomes more widespread. Studies in this review used different outcome measures (e.g. load error, medication administration error, adverse drug events) which prevented a meta-analysis from being carried out to provide an estimate of effects. In moving forward, we suggest that standard units of measurement are adopted, such as medication errors as a percentage of total number of medications dispensed or administered, which will allow consolidation of findings and meaningful comparisons between studies. The quantitative studies in this review did not include control groups, so confounding factors were not considered. To optimise the quality of study results, it is imperative that future studies take into account potential confounding factors (e.g. size of the hospital, number of controlled medications dispensed or administered), include control groups where appropriate, and carry out pre-post evaluations, with longitudinal follow-ups.

Conclusions

As hospitals seek to improve the efficiency and safety of their medication processes for controlled medications, there is an urgent need for high-quality targeted research to provide evidence on the benefits and also risks of implementing technology. Results from this review are important as they provide evidence that technologies can potentially reduce errors, save time spent on clinical tasks and improve monitoring of controlled medications. However, processes need to be in place to support and supplement technological capabilities, and resources need to be made available to monitor and minimize unanticipated problems post-implementation.

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CRediT authorship contribution statement

Wu Yi Zheng: contributed to conception and design of the study, undertook data collection and analysis, all authors contributed to data interpretation, Writing - original draft, and approved the final manuscript for submission. **Valentina Lichtner:** contributed to conception and design of the study, undertook data collection and analysis, all authors contributed to data interpretation, Writing - original draft, and approved the final manuscript for submission. **Bethany A. Van Dort:** contributed to conception and design of the study, undertook data collection and analysis, all authors contributed to data interpretation, Writing - original draft, and approved the final manuscript for submission, and. **Melissa T. Baysari:** contributed to conception and design of the study, all authors contributed to data interpretation, Writing - original draft, and approved the final manuscript for submission.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sapharm.2020.08.001.

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