Exploratory Research in Clinical and Social Pharmacy 14 (2024) 100451

Contents lists available at ScienceDirect

Exploratory Research in Clinical and Social Pharmacy

journal homepage: www.elsevier.com/locate/rcsop

Automated dispensing cabinets and their impact on the rate of omitted and delayed doses: A systematic review

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ARTICLE INFO

Keywords:
Automated dispensing cabinet
Omitted doses
Electronic prescribing and medicines administration

ABSTRACT

Use of automated dispensing cabinets (ADCs) is increasing in hospital settings. ADCs bring various potential benefits, among which are improvements to patient safety and reduction of medication errors. A core function of ADCs is to prevent medication stock outs by triggering an order when stock is reaching low levels. A quantifiable patient safety measure is the occurrence of omitted or delayed doses, which can range in severity from being negligible, to potentially fatal. The purpose of this review is to identify and synthesise the existing evidence regarding the impact of ADCs situated in secondary and tertiary care inpatient settings, on the rate of omitted and delayed doses as a specific subsection of medication errors. In April 2024 searches were conducted in Embase, PubMed and CINAHL, with additional articles discovered through citation searching and from colleagues. A total of 375 articles were returned from the search. Nine articles met the inclusion criteria. The most common reason for exclusion was due to lack of relevance. The included papers were focused on centres which had implemented six or fewer ADCs. The studies mostly presented findings which suggest ADCs have a positive impact on the rate of omitted or delayed doses, although crucially only two papers correlated missed doses due to unavailability of medications The studies highlighted other factors which should be considered prior to the implementation of ADCs. Factors included staffing requirement, type of stock held in the cabinets, and interoperability with other systems. Studies only reported omitted or missed doses, none reported results on delayed doses. It is widely accepted that ADCs can prevent medication unavailability but there is a paucity of evidence linking the improved availability of medications through the utilisation of ADCs with the perceived impact on missed or delayed doses. Further multi-centre studies are needed to determine this causality.

1. Introduction

The use of automated dispensing cabinets (ADCs) in hospitals and other healthcare settings is becoming increasingly common. ADCs provide an electronic medicines management solution whereby medicines can be securely stored and dispensed near the point of care whilst enabling the controlling and tracking of drug distribution. ADCs can be used either on inpatient wards, or centrally within pharmacy departments. At present, approximately half of the National Health Service (NHS) Trusts throughout the United Kingdom use electronic prescribing and medicines administration (EPMA) systems, however the use of ADC technology is not yet widespread.[1,2] ADC benefits broadly described in literature include the streamlining of nursing medication workflow, live tracking of stock levels, decreasing pharmacy resource requirement for drug distribution, and improving medication safety.[3] The theoretical medication safety advantages include reducing the opportunity for medication administration errors (MAEs) such as the reduction of medication selection error and omitted or delayed doses.

Another useful component of ADCs is their assistance with stock control. Hospitals can draw upon their own usage data to determine appropriate maximum, reorder, and critical levels for medicines stocked in ADCs. This allows the ADCs to automatically trigger orders for stock replenishment, which should reduce the incidence of stock running out. In turn, this should reduce nursing and pharmacy staff time required to order and fulfil ad-hoc stock requests, and reduce the incidence of omitted, or delayed doses of medicines held in ADCs. Time saving for nursing and pharmacy staff is hugely valued, as it can allow the staff member to reallocate the time to patient facing activities. Increasing time spent on patient facing activities was a key priority outlined in a 2015 report aiming to optimise NHS hospitals' productivity.[4] This is exceptionally pertinent in the current climate, with significant short staffing and unsafe nursing workload across the NHS.[5] It has been shown

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https://doi.org/10.1016/j.rcsop.2024.100451
Received 25 February 2024; Received in revised form 3 May 2024; Accepted 6 May 2024
Available online 8 May 2024

that nursing shortages can increase patient mortality therefore, automation has the potential to improve patient outcomes.[6]

There are a number of published systematic reviews which have investigated the effect of ADCs on medication errors and patient safety. Ahtiainen et al. aimed to review automated and semi-automated drug distribution systems and evaluate their effect on medication safety, time and cost of medication related care.[7] This research found that many studies showed an improvement in patient safety, and reduction of medication errors after the introduction of automated dispensing systems (ADS), without specifying details of the types of medication errors. They refer to two studies who reported a reduction in missing drugs due to unavailability, without elaborating further or providing quantitative results and or statistical analysis.[8,9] Another systematic review was published in 2021 which sought to summarise the literature describing the clinical and economic benefits of automated dispensing systems.[10] Their inclusion criteria included medication errors, including those of omission. Their search revealed studies which showed reductions in medication errors without specification of type, and time savings for both nursing and pharmacy staff, as well as economic savings. Oren et al. published a systematic review which investigated the evidence regarding the effect of different technologies on medication errors and adverse drug events.[11] The technologies included computerised physician order entry (CPOE), ADCs, barcode medication administration (BCMA), and computerised medication administration records. The ADC focused studies mostly reported lower medication error rates, with one study with ward based cabinets reporting decreased nursing time spent on medication activities, and increased pharmacist time spent on clinical activities. The results of these studies did not differentiate between types of medication errors. Neither Batson et al., or Oren et al. reported outcomes associated with omitted & delayed doses after the introduction of ADCs.

There are multiple reasons why a dose might be omitted or delayed. Clinical reasons include the patient's state of consciousness, vomiting, no intravenous access, or patient nil by mouth. Non-clinical reasons include unavailability of the medicine, patient refusal, or the patient is not available.[12] ADCs can influence only one of these reasons – omissions due to stock unavailability.

Omitted and delayed doses can range in consequence from being negligible to causing serious harm. For example, it is unlikely that a statin given one hour late will have any clinical consequence, however in contrast it is well documented that in patients with sepsis, for every hour where antibiotic initiation is delayed, the risk of mortality increases.[13] A 2019 study examined ten years of submissions to the National Reporting and Learning System (NRLS), which collects data on all patient safety incidents for England and Wales.[14] The study sought to better understand the types of medication administration errors that resulted in deaths. Of the 229 incidents which resulted in death, 72 (31.4%) were as a result of an omission of medicine or ingredient. This was the most common error category.

At present, there are no systematic reviews which seek to synthesise the evidence of the effects of ADCs on omitted or delayed doses, due to unavailability of stock.

The aim of this systematic review is to identify and synthesise published literature on the impact of ADCs on the rate of omitted and delayed doses, due to unavailability, and identify implications for practice and future research.

2. Methods

Database searches included Embase (1974–2024), Pubmed (1974–2024) and CINAHL (1996–2024). Search parameters for dates of publication included all eligible studies from inception through to 11th April 2024. The search strategy for each database can be found in Supplementary Material 1. The search was not limited to these databases but also included additional studies from reference lists of selected publications and relevant reviews and other sources such as colleagues.

The entire set of titles and abstracts was collated and duplicates were removed, using Microsoft Excel. Beyond this, screening was independently completed by two reviewers in accordance with defined inclusion and exclusion criteria – Table 1 below. Titles and abstracts were screened by two reviewers to determine suitability for inclusion before full text articles were obtained. As part of the next stage, the same reviewers independently screened the full text papers. Where full articles were read but subsequently excluded, the reason for exclusion was recorded. No criteria were applied with regards to study design at the screening stage to ensure maximum yield was obtained, as it was anticipated that the existing evidence would be limited. Disagreements or uncertainties regarding study inclusion during the title, abstract or full text review process were resolved by discussion and gaining a consensus between the two reviewers. Once the final list of articles for inclusion was agreed upon, key information regarding study aims, setting and intervention were extracted. Key findings were also extracted, and this information was collated in Table 2, to provide an overview of each article. The information was also extracted first by one reviewer and checked against the original article by the second reviewer.

The included articles were assessed for risk of bias by two reviewers, using the ROBINS-I tool.[15] Each domain was assessed for risk of bias and rated either low, moderate, serious, critical or no information. Due to the inconsistent reporting of outcomes, a formal quantitative evidence synthesis of results was not feasible. As a result, a qualitative summary of results was reported.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was used to guide reporting.[16]

3. Results

A total of 287 studies were identified in the search of electronic databases, after duplicates were removed. After reviewing titles and abstracts, in total 251 studies were excluded and 36 studies were deemed potentially relevant. On completion of full text article review, six studies were eligible for inclusion. Reference searching and additional sources identified a further three studies eligible for inclusion. This resulted in a total of nine studies which met the inclusion criteria for this systematic review. The PRISMA flow diagram is presented in Fig. 1.

The primary reason for an article revealed by the search, but subsequently excluded, was lack of relevance. Systematic reviews were ultimately excluded but were checked for citations which met the inclusion criteria.[7,17–20] Studies not featuring an ADC or where the

Table 1
Description of inclusion and exclusion criteria.

	Inclusion criteria	Exclusion criteria
Population (P)	Studies in inpatient hospital settings, with individual dose administration at ward level, by nursing staff	Studies in outpatient or community settings
Intervention (I)	Studies with ADCs Studies with ADCs combined with other technologies eg EPMA	Studies without ADCs or different automation technologies such as robots Studies where an ADC is used to create multi-dose packs/blister pack
Comparison (C)	The same ward prior to ADC implementation A comparable ward without an ADC	–
Outcomes (O)	Rate of omitted/delayed/missed doses	No measurement of any of omitted/delayed/missed doses
Study Design (S)	Nil restrictions	–
Time (T)	Nil time restriction	–
Language	English language	Non-English language

Table 2
Summary of included studies.

Ref.	Study design	Study aim	Study setting	Key findings and omitted/delayed Dose Outcomes	Omissions due to unavailability	Other key information or findings
Schwarz & Brodowy, 1995[47]	Prospective before & after implementation study	To describe the implementation process of an ADC and evaluate the effect on missing doses, medication errors, workload and nurse attitudes towards the ADC.	Tertiary care teaching hospital in San Francisco, United States. Data was collected for ADCs implemented on one surgical unit and one cardiovascular ICU. ADCs stocked controlled drugs and 'as required' drugs. It is implied that the ADC held non-patient specific stock.	In both units there was a reduction in overall medication errors with an increase in pharmacy workload related to routine unit dose functions. Errors were detected by reviewing missing medication documentation sent to pharmacy. Decrease in missing doses per day from 13.8 to 3.3 in surgical unit and from 3.3 to 1.2 in ICU. Student's *t*-test confirmed there were significantly fewer missing doses post-ADC implementation.	Not specified	ADCs were in profiled mode, where prescriptions were sent to the pharmacy and entered into the pharmacy computer system which linked to the ADC. Conclusion that ADCs improved efficiency compared to the traditional unit dose cassette exchange system.
Borel & Rascati, 1995[48]	Prospective before & after study	To determine the effect of ADC implementation on rates of medication errors, to measure any variation on error rates between nursing units and to determine the effect of ADCs on dose deviation from scheduled times.	600 bed teaching hospital in Dallas, Texas, United States. ADCs were implemented in 3 different clinical locations. In Phase 1, only narcotics and certain ward stock medications were kept in the ADCs, with everything else in unit dose exchange carts. In phase 2, additional medications were added to the ADC. It is implied that the ADC held non-patient specific stock.	The total error rate reduced from phase 1 to phase 2, with a rate of 16.9% and 10.4% respectively. Errors by type were described and quantified and included omitted doses. There were 36 incidences of omission in phase 1 (24.3% of total errors), and 10 incidences of omission in phase 2 (10.3% of total errors). The total number of doses observed were comparable between phase 1 and phase 2. There was a significant reduction in overall errors. No statistical analysis was reported for omissions in isolation.	Not specified	ADCs were in profiled mode, where prescriptions were sent to the pharmacy and entered into the pharmacy computer system which linked to the ADC. The authors suggest that the rate of omitted doses may have decreased in phase 2 as all prescribed medications were visible on the cabinet screen which may have acted as an additional reminder for the nurses to administer all prescribed doses. It was concluded that the ADC contributed to a reduction in rate of medication errors.
Martin et al., 2000[46]	Prospective before & after implementation study	To assess the effect of ADC implementation on four different clinical locations of a large teaching hospital	Tertiary hospital in Adelaide, Australia. Cabinets were located on a general medical ward, a neurosurgical ward, an ICU and an HDU. Prior to intervention, an individual patient supply system was used on the general wards, with medications stored in bedside lockers, in addition to general ward stock items available on the ward. The ICU and HDU primarily used a ward stock system with non-patient specific stock held in the ADCs.	Medication supply workload reduced by 46% for pharmacists, and increased by 36% for pharmacy technicians. On the two wards, missed doses due to unavailability reduced from 29% to 24% for all missed doses, a 17% RR. Missed doses as a percentage of all doses given reduced from 13% to 12%. Missed doses were not reported for the ICU and HDU. Statistical analyses were not reported.	Yes	The two ward based cabinets, were in profiled mode, where patient prescriptions were sent to the pharmacy, downloaded to the Pyxis central console, which then linked to the ADCs.[3] The ICU and HDU cabinets were not interfaced with patient prescription data. The number of medicines available increased by 324% using ADCs. Over 95% of required items were available.
Franklin et al., 2007 [8]	Prospective before & after implementation study	To assess the impact of EPMA, ADCs and BCMA on prescribing and administration errors	One general surgical ward within a teaching hospital in London, England. Prior to the intervention, prescriptions were written on paper drug charts, and medicines stored in trolleys and in cupboards. The ADCs held both non-patient specific ward stock, and patient-specific non-ward stock medicines.	The prescribing error rate reduced from 3.8% to 2%. Total medication administration error rate fell from 8.6% to 4.4%. Omission due to unavailability went from 26 occurrences (1.6% of 1644 OEs) pre-intervention, to 25 occurrences (2.1% of 1178 OEs) post-intervention. Omissions for other reasons went from 42 (2.6%) to 11 (0.9%).	Yes	The intervention included introduction of EPMA, BCMA and ADCs. The authors suggest that the reduction in total non-IV MAEs (mainly wrong dose & omissions) as ADCs allow access to only the correct product, unlike medication trolleys which were being used pre-intervention.

(*continued on next page*)

Table 2 (*continued*)

Ref.	Study design	Study aim	Study setting	Key findings and omitted/delayed Dose Outcomes	Omissions due to unavailability	Other key information or findings
Risor et al., 2015 [50]	Prospective, before & after implementation study	To evaluate the success of ADC on reducing MAEs and integrating ADC with BCMA, and EPMA	Two haematology wards in a Danish university hospital, where one received the intervention and the other acted as a control. The ADC held patient-specific stock.	There was a statistically significant reduction in total MAEs. No statistical analysis for omitted doses was performed. The overall rate of MAEs decrease from 0.35 to 0.17 in the intervention ward, and from 0.37 to 0.35 in the control ward. Omitted doses results were inconclusive as the control ward had a high prevalence of omissions at follow up. Some were due to intentional omissions as a result of prescribing errors e.g. to avoid double dosing. Statistical analyses therefore excluded omissions. There was an overall reduced risk of errors of 57% in the intervention ward, which was a statistically significant reduction.	Not specified	EPMA had already been implemented at the hospital. The intervention also included BCMA. The authors suggest that EPMA, BCMA and ADC can be a successful combination but advise that institutions consider the cost prior to committing to implementation
Chapuis et al., 2015[9]	Before and after implementation study	To evaluate the economic impact of ADC in 3 surgical ICUs	University hospital in Grenoble, France. ADCs were implemented in three ICUs (cardiac, neurosurgical and trauma units). Prior to intervention, a traditional floor stock system was used. It is implied that the ADC held non-patient specific stock.	Nursing time spent on pharmacy related activities decreased, with an increased demand on pharmacy technician time. The problem of expired drugs was eliminated and the project was ultimately financially profitable. Incidence of missing medicines was reduced from 84 to 37 (56%) occurrences within a month. It is unclear whether missing medicines translates to missed doses, therefore whether the intervention had an impact on medication error rates. No statistical analysis was reported.	Not specified	The ADCs were not linked with prescription data. It was not reported whether there was an EPMA solution, therefore it can be inferred that there was no BCMA solution. Few details were reported regarding missing medicines, as the primary focus was the financial impact. A shift in types of missing medicine was noted pre vs post-implementation, from frequently used medication such as antibiotics, vs infrequently used medication such as ropinirole, respectively.
Risor et al., 2018[49]	Before & after implementation study	To evaluate the effectiveness of an ADC in reducing MAEs	Set in two Danish acute medical units, one control and one intervention unit. Baseline data was collected. First intervention 10 months later: complex automated medication system (cAMS) which combined electronic medication administration record (eMAR) with and ADC and BCMA. The ADC stocked pre-packed patient specific medications. Second intervention 20 months after baseline: non-patient specific AMS (npsAMS) where the medication room was stocked with pre-packed tablets without patient details, with BCMA but no ADC.	The intervention ward showed a reduction in proportion of errors from baseline to the first intervention at 10 months, from 0.15 to 0.06, but an increase to 0.09 during the second intervention at 20 months post baseline. The control ward went from 0.09 at baseline to 0.06 during at 10 month follow up, and increased to 0.07 at the 20 month follow up. During the cAMS intervention there were 6 omissions out of 565 OEs (0.01), compared to 3 omissions out of 520 OEs (0.006) on the control ward. During npsAMS intervention, there were 2 omisions of 527 OEs (0.004), vs 15 of 552 (0.03) on the control ward. The cAMS intervention showed a statistically significant decrease in overall	Not specified	eMAR was already in use prior to the interventions. The cAMS intervention combined eMAR and BCMA with the ADC. The npsAMS intervention utilised eMAR and BCMA, with no ADC. Omission of dose was the most frequently occurring clinical error. Reasons for omission were not reported.

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Table 2 (*continued*)

Ref.	Study design	Study aim	Study setting	Key findings and omitted/delayed Dose Outcomes	Omissions due to unavailability	Other key information or findings
				errors compared to the control. No significant difference was found between the control, and npsAMS, or between the two interventions. No statistical analysis was performed on the change on omitted doses.		
Jessurun et al., 2021 [51]	Prospective before & after interventional study	To assess the effect of ADC and BCMA on MAEs	Study performed in six clinical wards in a medical centre in Rotterdam, the Netherlands. An ADC was implemented in the hospital pharmacy which was used to prepare unit doses which did not display patient details but were sent to the ward packaged together with other medicines for the same patient.	Reduction of probability of all medication errors from 19.5% to 15.8% and potentially harmful errors from 2.9% to 0.3%. The rate of dose omissions fell from 4.6% to 2.0% of observed medicine administrations. A univariable and multivariable analysis reports there is a statistically significant difference post-intervention. The actual *p*-value has not been documented.	Not specified	Prior to intervention, EPMA and CPOE were already in use. The intervention also added BCMA to workflows, as well as the central ADC. Reasons for dose omission were not provided, however observations were excluded from analysis if a patient refused a dose ($n = 71$).
Svirsko et al., 2022 [52]	Analytical study	To determine a cost effective and safe way to distribute medicines by minimising distribution cost and missing dose rate.	Set in a hospital in Pennsylvania, United States. Three distribution pathways were analysed: cart fill via pharmacy robot, cart fill via pharmacy technician, and an ADC. Data was collected for ADCs located in five inpatient units: one orthopaedic ward, two medical/surgical units, one cardiac unit and one ICU. The ADCs contained unit doses, and it is unclear whether these were patient specific.	A mathematical model was devised to determine a cost effective way to distribute medications, while minimising missed doses. The mathematical model can conclude that effective use of ADCs can decrease the missing medication rate but in doing so will drastically increase required technician/nurse effort.	Not specified	Use of other technologies are not reported The model proved that the missing dose rate was lower when the ADC was more adequately stocked and included stat and first doses.

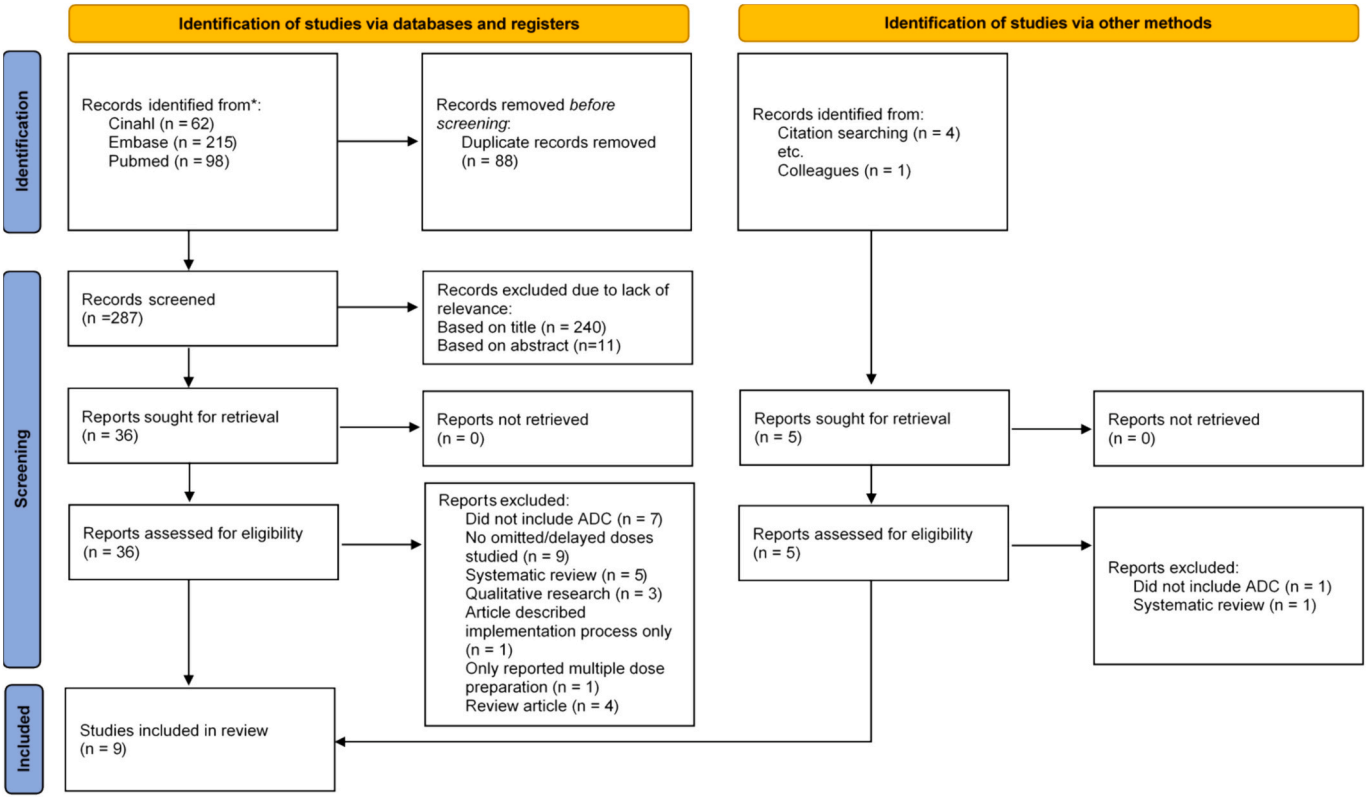

Fig. 1. Results of the search strategy presented using the PRISMA 2020 flow diagram (16).

automated solution was not a dispensing cabinet, such as a dispensing robot, were excluded.[21–27] If omitted or delayed doses were not a measured outcome, these articles were excluded.[28–36] Qualitative research was not included.[37–39] Studies only reporting on the implementation process of an ADC were excluded.[40] One study was excluded because the intervention included an ADC in the central pharmacy, and only reported multiple dose preparation.[41] Review articles were also excluded.[42–45]

Nine articles met the inclusion criteria for review. The included papers were of the following types; eight before and after studies and one analytical study. There were three papers from the United States, two from Denmark, and one paper each from the Netherlands, Australia, France, and England.

Chapuis et al. implemented ADCs in three intensive care units (ICU). Prior to the intervention, nurses were responsible for inventory management, including restocking the medicine cabinet. If missing medicines were identified, they were responsible for retrieving them from another location or obtaining from the central pharmacy. The intervention saw ADCs implemented in non-profiled mode, with the aim of the cabinets storing at least 90% of each unit's pre-intervention stock list. Non-profiled mode refers to cabinets which are not linked with the EPMA solution, where the nurse selects the patient, then finds the required medicine from the list of all medicines stocked in the cabinet. Pharmacy technicians were responsible for restocking ADCs. Across the course of one month of observation each pre and post-implementation, there was a 56% reduction in incidence of missing medicines, from 84 to 37 events.[9]

Franklin et al. implemented an ADC in a 28 bed surgical ward, which kept ward stock medicines in individual compartments as well as medicines individually dispensed for patients. Drug rounds were observed pre and post-implementation, and medication administration errors were recorded. Pre-intervention, the number of omissions due to unavailability was 26 out of 1644 opportunities for error (OE) (1.6%). Post ADC implementation, the number of omissions due to unavailability was 25 out of 1178 OEs (2.1%). This demonstrates a small increase in omitted doses due to unavailability. The overall rate of MAEs reduced from 8.6% to 4.4% of OEs. The authors did not provide commentary as to why omissions due to unavailability may have increased post intervention, and it was not reported whether the omissions were associated with ward stock or individually dispensed medicines for patients, both of which were held in the ADC.[8]

Martin et al. published their study in two parts; the implementation process and the outcomes. In this study, ADCs were implemented on two general wards, an ICU and a high dependency unit (HDU) in an Australian hospital, with the cabinets on general wards in profiled mode (linked to EPMA) those in ICU and HDU were non-profiled. The cabinets in profiled mode allow the nurse to select the patient, then select the required medicine from the list of prescriptions displayed on screen. The outcomes assessed included omitted doses, clinical interventions, staff satisfaction, staff time requirement, and impacts on drug inventory and distribution. The rate of omitted doses due to unavailability reported is expressed as a percentage of doses omitted for any reason. The authors reported that most omitted doses were withheld for a clinically appropriate reason. They did not differentiate between omitted and delayed doses. In the pre-implementation data, unavailable medicines accounted for 29% of missed doses, while post-implementation this dropped to 24%, a 17% relative reduction.[3,46]

Schwarz & Brodowy published their experience of ADC implementation in an emergency department, post-anaesthesia care unit, surgical unit & an ICU.[47] The cabinets implemented in the surgical unit & ICU were interfaced with prescribing software, and missing dose rate was measured before and after implementation in these locations only. They did not provide the definition of a missing dose. The cabinets in the surgical unit & ICU routinely held drugs for as required doses, and controlled drugs. Patient specific medications were dispensed by the central pharmacy as needed, every 12 h, and kept in a dedicated drawer within the ADC. The missing dose rate was reduced in the surgical unit and ICU, after ADC implementation but no link was made to whether the

reduction of missed doses was due to improved availability.

Borel and Rascati investigated the effect of expanding the range of medicines available in their ADCs, on the rate of medication errors.[48] Prior to the intervention, their cabinets contained only controlled drugs and certain ward stocked items. The intervention saw additional medications added to the ADCs. The study took place on three inpatient units in a large teaching hospital in the United States. The cabinets were interfaced with prescribing software. Medication administration rounds were observed pre and post-intervention to identify medication errors, and they found that the rate of omitted doses decreased after the intervention from 24.3% to 10.3% of medication errors. The number of medication administration observations were comparable pre and post-intervention. There was a statistically significant decrease in the overall rate of medication errors, with 148 and 97 incidences pre and post-intervention, respectively. The authors suggest that reduction in omissions may not only have been due to an adequately stocked cabinet, but also by the nurses receiving a visual prompt of all due doses on the cabinet screen.

Three of the studies involved other technology implemented simultaneously which means that results can not be solely attributed to introduction of the ADC.[49–51] Jessurun et al. implemented barcode patient administration alongside ADC dispensing, where the ADC was located in the central pharmacy rather than on the ward.[51] Svirsko et al. devised a mathematical model to identify the most cost effective, and safe method of drug distribution, hence measurement of omitted or delayed doses was not their primary focus.[52]

The nine included studies are summarised in Table 2 below.

3.1. Bias assessment

The nine included articles were assessed for bias following the ROBINS-I tool, independently by two reviewers.[15] The bias assessment for each domain is presented in Table 3 below. Pre-intervention refers to bias which may have been introduced through confounding, or recruitment of participants. At intervention bias refers to bias introduced during classification of intervention, and post-intervention bias refers to bias introduced through deviations from the intervention, outcome measurement, missing data or data reporting. While the ROBINS-I tool was carried out independently by two reviewers, who reached consensus where there was disagreement, it is acknowledged that ultimately these assessments are subjective.

There were a few commonly occurring sources of bias in the included studies. In all studies, the participants were aware of the intervention, an unavoidable bias which may favour the intervention. Four studies[8,48,49,51] may have introduced bias as results were collected using direct observation (Hawthorne effect).[53] Chapuis et al. may have introduced some bias at the reporting stage, as they reported the number of missing medicines during the study period, but did not report the total number of medicines prescribed.[9]

4. Discussion

To the authors' knowledge, this is the first systematic review to summarise the current evidence on the impact of ADCs on the rate of omitted or delayed doses, as a specific subsection of medication errors. Due to heterogeneity of study methods and measured outcomes, it was not possible to quantitatively synthesise this evidence. The included studies highlighted the various methods of implementing ADCs, where different implementation methods or combinations of technologies may yield a different effect on the rate of omitted or delayed doses.

The majority of included studies present positive conclusions. Seven studies present a positive conclusion regarding the effects of ADCs on patient safety, through reducing medication administration errors such as omitted doses.[8,46,48–52] Chapuis et al. published a financial analysis and therefore did not present a conclusion regarding patient safety.[9] Schwarz & Brodowy could not provide a definitive conclusion regarding the impact of ADCs on patient safety due to limited data.[47] They also acknowledge a potential increase in MAE risk as nurses will often have access to multiple drugs within the drawer they're accessing, combined with the ability to override prescriptions to obtain other medicines held within the cabinet.

Only two studies explicitly specified that their reported omissions were due to unavailability.[8,46] Chapuis et al. measured missing medicines but it is unclear whether any doses were subsequently omitted.[9] Two studies defined an omission as a dose which was not administered[49,50] and two provided a more specific definition based on time of administration in relation to the scheduled time of the dose.[51,52] Two studies did not provide any definition for an omitted dose.[47,48] As previously identified, there is a vast range of clinical and non-clinical reasons for the occurrence of a missed dose. Omissions due to unavailability are the only type that ADCs may be able to influence. Therefore, only omission results reported by Martin et al., and Franklin et al., are likely to be directly correlated with ADC implementation. This aligns with the prediction that existing evidence in this field is sparse.

4.1. Implications for practice

A recurring theme identified in the included papers was the staffing

Table 3
Bias assessment of the included studies, following the ROBINS-I tool.

Study	Pre-intervention		At intervention	Post-intervention				Overall
Study	**Domain 1**	**Domain 2**	**Domain 3**	**Domain 4**	**Domain 5**	**Domain 6**	**Domain 7**	**Overall**
Schwarz & Brodowy [47	Low	Low	Low	Low	Low	Moderate	Low	Low
Borel & Rascati [48]	Low	Low	Low	Low	Low	Moderate	Low	Low
Martin et al [46]	Low	Low	Low	Low	Low	Moderate	Moderate	Low
Franklin et al [8]	Low	Low	Low	Low	Low	Moderate	Low	Low
Risor et al 2015 [50]	Low	Low	Low	Low	Low	Moderate	Serious	Moderate
Chapuis et al [9]	Low	Low	Low	Low	Serious	Moderate	Low	Moderate
Risor 2018 [49]	Low	Low	Moderate	Low	Low	Moderate	Serious	Moderate
Jessurun et al [51]	Low	Low	Low	Low	Low	Moderate	Moderate	Low
Svirsko et al [52]	Low	Low	Low	Low	No Information	Moderate	Low	Low

Domain 1: Baseline confounding.
Domain 2: Bias in selection of participants.
Domain 3: Bias in classification of interventions.
Domain 4: Bias due to deviations from intended interventions.
Domain 5: Bias due to missing data.
Domain 6: Bias in measurement of outcomes.
Domain 7: Bias in selection of the reported result.

requirement to replenish stock. An increase in omitted doses will be inevitable if the cabinets are inadequately stocked. Svirsko et al., Martin et al. & Chapuis et al. all noted an increased requirement for pharmacy staff in order to maintain stock, with Svirsko even warning that ADC implementation success is dependent on staffing resource.[9,46,52] Risor et al. explicitly stated the importance of weighing up the options when deciding on a technical solution aimed to improve patient safety, with the acknowledgement that funding in healthcare is finite and allocation must be well considered.[50]

The same can be said when considering the implementation of other technologies such as EPMA and BCMA. This review included studies which used a combination of technological solutions in tandem with ADCs. EPMA was in its infancy in the late 1990s[54] and was not in use during the included studies published in 1995[47,48] and 2000.[46] Four of the included studies were either already using EPMA, or introduced this solution as part of the intervention.[8,49–51] Now its use is widespread, and as described previously, is currently more prevalent in the UK than ADC use. Extrapolating this UK data, it is likely that many hospitals considering the implementation of ADCs, may already be using EPMA. The same four studies which already used or implemented EPMA, also implemented BCMA.[8,49–51] Closed loop prescribing and medication administration comprises EPMA, ADCs and BCMA. Franklin et al. sought to evaluate the impact of closed loop prescribing and medication administration, and suggested the benefits of these technologies together are more effective than any one solution alone.[8] Only the three papers which did not utilise any other solutions are able to clearly isolate the effect of the ADC on the rate of omitted doses, all three of which were published over twenty years ago.[46–48] Hospitals considering implementing any of these solutions must interpret these findings in context and careful consideration should be made when deciding which of these technologies should be prioritised.

4.2. Implications for research

Due to heterogeneity of ADC configurations and overall limited evidence, it was not possible to draw conclusions regarding the most effective stock type held in the ADCs (patient specific, non-patient specific or a mix of both). Six of the included studies implemented ADCs which held non-patient specific stock, all of which saw a decrease in rate of omitted doses/missing medicines.[9,46–48,51,52] Franklin et al. kept both non-patient specific ward stock, and patient specific non-ward stock medicines in the ADC. They found a decrease in rate of dose omissions of all causes, but an increase of omissions specifically due to unavailability, however there was no commentary as to why this might be.[8] Risor et al. (2015) kept patient-specific stock in the ADC but could not draw a conclusion on the effect on omitted doses due to an unexpectedly high rate on the control ward at follow up.[50] Risor et al. (2018) trialled both methods, and found a higher rate of missed doses while trialling patient specific stock, and a lower rate with non-patient specific stock, when compared to the control ward.[49] Notably, the Society of Hospital Pharmacists of Australia recommends individual patient-based distribution systems, as this method has shown to result in fewer medication errors.[55] To the author's knowledge, there is no current recommendation from equivalent governing bodies in the United Kingdom. The evidence found in this review suggests that ADCs holding ward stock (non-patient specific) may contribute to a reduction in omitted doses, however more research is required in this area to more clearly ascertain how to best configure ADCs.

Individually packaged doses are the standard of care in the United States.[56] This was first introduced to support nursing medication administration & reduce waste. It also has the benefit of simplifying billing for patients, which is not an issue in the United Kingdom as there is no cost incurred by the patient for treatment provided at NHS hospitals.[57] It is not uncommon for manufacturers to pre-package medicines into unit dose containers although this can also be done by pharmacies.[56] The included papers had medicine distribution systems employing both whole packs, and individually packaged medicines. This difference in distribution model is a pertinent difference when applying evidence derived from the United States to the United Kingdom, which limits generalisability. The different funding models across the United States and United Kingdom mean that best practice in one country may not be best practice for the other. It is worth noting that two ADC market leaders, Pyxis and Omnicell, are United States based companies.[58,59] Further research is required to ascertain whether the benefits promoted by these corporations, are achievable in the United Kingdom.

The aim of this review was to investigate not only omitted, but also delayed doses. None of the included studies collected data on delayed doses, either omitted or missing doses but never both. There is a clinically important difference between omitted and delayed doses, particularly with high risk medicine groups such as antimicrobials or antiseizure medicines. Further studies which differentiate between omitted and delayed doses, reporting the degree of delay, would provide additional benefit when assessing the impact of ADCs which is another identified gap in the literature.

4.3. Limitations

The results of this systematic review has several potential limitations. Firstly, the database search was restricted to English language publications which may have excluded other relevant articles and may limit the global relevance of findings.

The small number of papers and lack of both consistent study designs and reported study outcomes across publications limits the ability to quantitatively assess the true impact of ADCs on the rate of omitted and delayed doses, with only a qualitative summary reported.

Many of the included studies utilised an observational method of data collection which is known to be linked with a positive bias, the Hawthorne effect, which can impact outcome measurements as the person being observed may intentionally or unintentionally modify their behaviour.[53]

5. Conclusions

The studies included in this review present findings which generally align with other published research, concluding that ADCs have a positive impact on the rate of medication errors. To the authors knowledge, this is the first systematic review to focus specifically on the effect of ADCs on the rate of omitted doses. The majority of the included papers present a positive conclusion, and suggest that ADCs may reduce the rate of omitted doses. There is a paucity of evidence regarding omissions due to unavailability.

Other key findings from this review include additional elements that decision makers in healthcare settings should appraise, when considering the use of ADCs. These include:

- The location of the ADCs
- The types of medicines to be stored in the ADCs
- Profiled vs non-profiled ADCs
- Whether there is suitable pharmacy staffing in place to maintain and stock the ADCs
- Whether to keep only patient specific medication, stock medication or both within the ADCs

There is limited evidence, and many variables which influence the effect of ADCs on the incidence of omitted doses. A recurring theme was the requirement for adequate staffing levels to support the change in workflow associated with ADC implementation. Adequate stock maintenance is essential in preventing omitted doses due to unavailability. In the right setting, with bespoke configuration and thorough planning, ADCs could reduce the incidence of omitted doses. A study looking at the delayed and omitted doses pre- and post-implementation of ADCs at a large teaching hospital in London is currently in progress. The results

from this will be crucial to expanding the literature available in this area.

CRediT authorship contribution statement

Emma Jeffrey: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Melanie Dalby:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Conceptualization. **Áine Walsh:** Writing – review & editing, Visualization, Supervision, Conceptualization. **Kit Lai:** Writing – review & editing, Visualization, Supervision, Conceptualization.

Declaration of competing interest

The author is an Editorial Board Member/Editor-in-Chief/Associate Editor/Guest Editor for Exploratory Research in Clinical and Social Pharmacy and was not involved in the editorial review or the decision to publish this article.

Melanie Dalby is a Guest Editor for the special issue of ERCSP titled *The Use of Automated Dispensing Cabinets in Hospitals*. She will have no involvement in the peer-review of the article and has no access to information regarding its peer-review.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rcsop.2024.100451.

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