Safety, time and cost evaluation of automated and semi-automated drug distribution systems in hospitals: a systematic review

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ABSTRACT

Objectives To systematically review automated and semi-automated drug distribution systems (DDSs) in hospitals and to evaluate their effectiveness on medication safety, time and costs of medication care.

Methods A systematic literature search was conducted in MEDLINE Ovid, Scopus, CINAHL and EMB Reviews covering the period 2005 to May 2016. Studies were included if they (1) concerned technologies used in the drug distribution and administration process in acute care hospitals and (2) reported medication safety, time and cost-related outcomes.

Results Key outcomes, conclusions and recommendations of the included studies (n=30) were categorised according to the dispensing method: decentralised (n=19 studies), centralised (n=6) or hybrid system (n=5). Patient safety improved (n=27) with automation, and reduction in medication errors was found in all three systems. Centralised and decentralised systems were reported to support clinical pharmacy practice in hospitals. The impact of the medication distribution system on time allocation such as labour time, staffing workload or changes in work process was explored in the majority of studies (n=24). Six studies explored economic outcomes.

Conclusions No medication distribution system was found to be better than another in terms of outcomes assessed in the studies included in the systematic review. All DDSs improved medication safety and quality of care, mainly by decreasing medication errors. However, many error types still remained—for example, prescribing errors. Centralised and hybrid systems saved more time than a decentralised system. Costs of medication care were reduced in decentralised systems mainly in high-expense units. However, no evidence was shown that implementation of decentralised systems in small units would save costs. More comparable evidence on the benefits and costs of decentralised and hybrid systems should be available. Changes in processes due to a new DDS may create new medication safety risks; to minimise these risks, training and reallocation of staff resources are needed.

INTRODUCTION

The majority of hospitalised patients need medication as part of their care. The medication-use process includes, for example, prescribing, preparing, dispensing and administering medication to the patient and following up its effects.[1–3] All these steps are prone to errors. To improve patient safety, various technology-based solutions such as computerised physician order entry (CPOE) and patient barcoding (BC) systems have been applied to the medication-use process in hospitals.[3–5]

The current evidence shows that documentation, dispensing and administration of medications to patients are especially high-risk steps in the medication-use process.[3 6–9] The majority of reported medication erros (MEs) occur in these phases of the process, having a huge negative impact on patient safety.[9] Consequently, the medication-use process has been analysed in hospitals and wards to find safer ways for medication delivery.[10] In traditional ward-stock systems, medications are usually stored in alphabetical order on open shelves and administered manually by nurses.[3 11] However, manual medication administration has been shown to be time consuming and prone to error.[3 12]

To respond to the risks of manual dispensing and administration, automated solutions have been implemented in different medication distribution systems.[13] Also, the pressure to reduce costs and time from manual distribution and to reallocate these resources to more clinical work has been a central incentive to drug distribution automatisation.[14] In decentralised systems, drug dispensing is ward-based and different types of automated drug dispensing systems (ADDSs), such as automated dispensing cabinets (ADCs), are used to help nurses in dispensing.[15] These systems usually provide computer-controlled storage, distribution and tracing of medicines.[16] Centralised drug dispensing systems are hospital pharmacy-based where carousel dispensing technology (CDT) and robotic medication picking systems are used to provide drugs for inpatients.[17] There are also hospitals where centralised and decentralised features are combined as a hybrid system.[18]

As hospitals are developing and implementing these ADDSs, evidence on their effectiveness is needed. The objective of this study was to systematically review automated and semi-automated drug distribution systems (DDSs) in hospitals to evaluate their effects on medication safety, time and costs of medication care, and to show which of these systems has more advantages compared with others.

METHODS

Literature search

The systematic review followed the PRISMA statement.[19] A literature search was conducted in MEDLINE, Embase, Cinahl (EBSCOhost) and Scopus. A combination of search terms related to

Table 1 Search strategy of the systematic literature review on medication distribution systems in hospitals

#	Search term	Boolean operator
1	Medication systems, Hospital (exp) Medication systems (exp) Medication ADJ3 system* (Medication OR Drug) adj3 (dispens* OR distribut* OR administrat*)	OR
2	(Medication OR drug OR dose) adj3 (trolley* OR cart*) (Dispensing OR medication OR drug) ADJ3 cabinet* Automated adj3 (drug OR medication OR dose) adj3 (dispens* OR distribut*) Unit dose* OR multidose* OR multi-dose* Bar code* medication administration (mp) OR BCMA NOT B-Cell (mp) Radio Frequency Identification Device (exp) OR RFID (mp) Drug therapy, computer-assisted (exp) OR Drug therap*, computer-assisted (mp) Clinical pharmacy service (mp) OR Clinical ADj3 pharmac* ADJ3 service* (mp) Pharmacy service, hospital (exp) OR hospital pharmacy service* (mp) Pharmac* ADJ3 service* ADj3 hospital* (mp) Pharmacy administration (exp) OR pharmacy ADJ3 administration* (mp) Pharmac* ADJ50 automation* Pharmac* adj50 robot*	OR
3	Hospital (mp) Ward (mp)	OR
4	Patient safety (exp) (Patient OR medication OR drug) adj3 safet* (mp) Safety management (exp) (Safety OR medication) adj3 management (mp) Medication errors (exp) Medical errors (exp) (Medication OR Medical) error* (mp) Outcome* (mp) Benefit* (mp) Cost* (mp) Cost and Cost analysis (exp) Saving* (mp) Security (mp) Time (mp) or (exp)	OR
5	1 AND 2 AND 3 AND 4	
6	limit five to yr=2005-current	
7	limit language to English	

medication distribution systems and their impacts on safety, time and costs of medication care were used based on the terms used in the previous literature (table 1). Original studies and systematic reviews published from early 2005 to May 2016 were included to provide insights into the recent evidence. The search was limited to the English language.

The search was repeated in MEDLINE and Scopus in January 2019 covering the period from 2016 to January 2019 to complete the systematic review. These data were processed and analysed separately from the other results.

Inclusion and exclusion criteria

Only studies conducted in inpatient acute hospitals such as hospital wards were included in the review (table 2). A requirement for studies was that they concerned the investigation of technologies used in the drug distribution and administration process.

Table 2 Criteria for inclusion and exclusion of articles for the literature review on effectiveness of automated and semi-automated drug distribution systems (DDSs) in hospitals

	Inclusion criteria	Exclusion criteria
Type of DDS, Problem (P)	Automated and semi-automated ward-based drug dispensing systems (eg, ADCs), pharmacy-based drug dispensing systems (eg, centralised UDSs and BC based medication dispensing carousels) and different combinations of these systems in acute hospitals	Studies performed in community settings (eg, community pharmacy or nursing homes) Inpatient units with slower than daily distribution process Studies with only manual DDS were excluded. Studies using BC or RFID medication administration to the patient, without any description or evaluation of the automated system used in hospital
Focus of the study, Intervention (I)	Automation or technology is used in drug distribution process Explores DDSs, described in articles, and evaluates their effects on medication safety, time or costs	Studies descibing only the introduction of the new automated system No description or any evaluation of the DDS
Comparison (C)	Control group is not required	–
Outcomes (O)	Studies using various research methods and outcome measures (time, cost and safety aspects) are included	–
Time (T)	Studies published from early 2005 to May 2016	Studies published before 2005 or after May 2016
Study design (S)	All methods and study designs are accepted for inclusion Peer reviewed journal articles Systematic review articles	Non-scientific publications: letters, editorials, news and commentaries. Articles published in professional publications or other non-scientific publications.
Others	English language Full-text available via University of Helsinki or online	Full-text not available via University of Helsinki or online

ADC, automated dispensing cabinet; BC, barcode;DDS, drug distribution system; RFID, radio frequency identification; UDS, unit-dose system.

Data extraction and analysis

Two researchers (HKA and MMK) completed the title analysis followed by abstract and full-text examination. Inclusion disagreements in the abstract and full-text screenings were resolved through consensus discussion with a third researcher (ARH). Studies were retained only if they clearly met the inclusion criteria. The reference lists of included articles and relevant review papers were manually searched for additional studies. To provide an overview of the included studies, the main study characteristics and outcomes of interest were extracted from the data (see online Appendix 1). The quality of the included studies was assessed based on the GRADE system.[20] A meta-analysis was not performed. Key outcomes, conclusions and recommendations of the included studies were categorised according to the dispensing method (centralised, decentralised or hybrid system) in the summary (table 3). The key conclusions and recommendations by authors of the articles were extracted from the discussion sections to provide an overview of the recommendations for development and implementation of DDSs in hospitals (table 4).

Table 3 Key outcomes of the studies (n=30) applying automation in the drug distribution process

Outcomes	Sub-themes	Key outcomes by distribution system: Centralised system (n=6)	Hybrid system (n=5)	Decentralised system (n=19)
Safety	Impact on medication errors	UDS combined with medication carts reduced MEs and UDS reduced MAEs[1 41] UDS combined with pharmacy-based ADC and BC scanning and CDT improved accuracy[34 40] The centralised daily dispensing system did not change significantly the frequency and severity of errors[28] Fewer missing drugs in UDS compared with traditional manual dispensing system[41] UDS reduced ADEs[21]	ADDSs (both single-dose and electronic prescribing combined with ADCs) and UDS combined with ADC reduced MAEs[3 26] Automation and UDS combined with ADC reduced MEs[3 17 26] UDS combined with ADC reduced severity of ME effects[3] All error types reduced[26] UDS with cartfill and ward-based ADCs increased requests for missing doses[33] CPOE reduced ADEs[17]	ADCs reduced MAEs[30 31] ADCs had no significant effect on MAE rates[2] ADDS increased MAEs[27] Decentralised automated dispensing devices and ADCs reduced MEs[13 14 29 35] MAEs persist in units with automated prescribing and ADCs[36] ADC reduced all error types but did not affect error severity[29] Decentralised automated dispensing devices did not show evidence that systems reduced MEs resulting patient harm[14] ADC: Fewer missing drugs due to unavailability on wards[25 30] ADC did not reduce the most frequent error types (eg, wrong administration technique)[36] ADC improved ADE reporting[38] ADDS reduced ADEs.[27]
	Pharmacists' clinical activity	UDS supported clinical pharmacy practice[41]	Not reported	ADC combined with drug trolleys allowed pharmacists more time to review prescriptions and detect errors[24]
	Impact on medication-use process	UDS and CDT improved processes: improved medication management and efficiency in dispensing[21 40] The new distribution system, UDS combined with medication carts, revealed risks in the medication-use process[1]	Automation and thrice-daily cart-fill process improved medication-use process[17 33]	ADCs combined with drug trolleys, ADDS and decentralised automated dispensing devices improved medication dispensing process: standardised process, improved efficiency, accuracy and quality[2 14 16 23 24 27 32 39] ADCs indicated risks in medication-use process[8 23 36] ADM improved healthcare staff knowledge of medications[37] ADC and ADC combined with drug trolley improved the quality of prescriptions[24 30]
	Other safety aspects	Security improved by UDS alone and UDS combined with medication carts: restricted access to medication and fewer missing drugs on wards[1 41] UDS with individual medication doses reached improved hygiene[21] Individual unit-dose packages contained all the necessary patient and drug information[21 28]	UDS combined with ADC improved medication safety[26]	Security improved with ADCs and ward-based MVS: restricted access to medication and less drug administered from unlocked areas[22 31] ADMs, ADCs and decentralised automated dispensing devices improved narcotic drugs management[14 35 37] ADCs and ADCs combined with drug trolleys improved patient safety[16 22–24 30–32 35] ADCs caused more documentation discrepancies because nurses did not correct missing medications to the eMAR when drug was administered[31]
Time	Time and labour	CDT reduced the amount of technician labour[40] UDS had the same dispensing time as in manual dispensing[21] In the centralised dispensing system healthcare staff experienced satisfaction with drug delivery time[28] UDS required extra staff[41]	Thrice-daily cart-fill process reduced interval between beginning of the cart-fill process and medication administration[33]	ADCs decreased medication-related logistic tasks[2 16 25] ADMs, ADCs and ADCs combined with drug trolleys increased medication-related logistic and clinical tasks (eg, ward pharmacy services, retrieving medications)[24 30 37] With more cabinets installed, nurses reported less waiting time to access the distribution system[32] Time spent on drug administration round decreased by ADC[30] Medication process became slower with ADCs[16 35] Medication process became faster with ADCs[31] With ADCs, nurses had more time for patients[31 32] Nurses thought ADMs and ADCs saved time[13 37] Decentralised automated dispensing devices, ADCs and ADCs combined with trolleys needed extra pharmacy staff, e.g. to manage the dispensing system, delivering and screening medications[14 24 25 30 32 39] Extra nursing staff were needed with ADCs[39] No definitive evidence that nurses or pharmacists spent more time with patients with the help of decentralised dispensing devices[14]
	Work-related factors	Nurses reported less workload with UDS combined with medication carts and centralised dispensing system[1 28]	Centralised dispensing system combined with ADCs had optimal nursing staff workload compared with decentralised distribution system[18]	ADCs improved working conditions and work was considered easier[13 35]
Costs	Medication costs	Centralised dispensing system slightly improved cost control[28] CDT reduced inventory costs[40] UDS did not change medicines costs[21]	Centralised dispensing system combined with ADCs was optimal in cost effectiveness (eg, staff workload required)[18]	ADCs and ADDS reduced medications costs[25 27] Decentralised automated dispensing devices did not show evidence of cost reduction[14]

Continued

Table 3 Continued

Outcomes	Sub-themes	Key outcomes by distribution system: Centralised system (n=6)	Hybrid system (n=5)	Decentralised system (n=19)
Other	Medication storage	With UDS smaller warehouses at wards were needed[21] With UDS unused drugs returned to the pharmacy[41]	Thrice-daily cart-fill process reduced waste and the number of medications returned to the pharmacy[33] Automation improved inventory control[17]	Decentralised automated dispensing devices, ADCs and ward-based MVS improved storage: drug storage reduced, improved stock control, MEs decreased[13 14 22 25] Expired drugs eliminated with ADC[25]
	Technology	Healthcare staff had positive opinions on the centralised dispensing system, UDS and UDS combined with medication carts[1 28 41] Computer system rated negatively in centralised dispensing system[28] BC connected to a centralised system decreased MEs[34] Technology needs comprehensive personnel training[34]	Errors reduced with BCMA[17]	Negative opinions (eg, frustration) by healthcare staff on the ADCs and ADCs combined with drug trolleys[23 24] Positive opinions by healthcare staff on the ADCs, ADCs combined with drug trolleys and ward-based MVS[13 16 22 24 35] Decentralised automated dispensing devices and ADCs combined with drug trolleys was related with technical problems[14 24] Other technologies recommended (eg, eMAR, BCMA) to be combined with the decentralised dispensing system[8]

ADC, automated dispensing cabinet; ADDS, automated drug dispensing system; ADE, adverse drug event; ADM, automated dispensing machine; BC, barcode; BCMA, barcode medication administration; CDT, carousel dispensing technology; CPOE, computerised physician order entry; MAE, medication administration error; ME, medication error; MVS, medicines vending system; UDS, unit-dose system; eMAR, electronic medication administration record.

RESULTS

Of 3136 citations found, 30 studies met the inclusion criteria (figure 1). The USA was the country with the highest number of published studies (n=7), followed by the UK (n=5), Canada (n=4), France (n=4), Spain (n=3), Australia (n=2), Qatar (n=1), Palestinian Territory (n=1), Saudia Arabia (n=1), Ghana (n=1) and Finland (n=1) (see online Appendix 1). The included studies applied a variety of research methodologies comprising systematic reviews (n=2), before-and-after studies (n=9), observational studies (n=6), cross-sectional studies (n=4), surveys (n=3) and other studies. The quality of the included systematic reviews (n=2) was graded as high, whereas the other articles were graded as moderate (n=10), low (n=17) or very low (n=1) in quality because of the absence of a controlled study design or other major limitations in study design or methodology.[20] Studies included a description of the DDS explored (Appendix 2).

Drug distribution systems

The studies (n=30) concerned three different kind of automated or semi-automated DDSs: decentralised (n=19), centralised (n=6) and hybrid systems (n=5).[1–3 8 13 14 16–18 21–41] The key outcomes and recommendations of the included studies are shown in tables 3 and 4. Most of the studies (n=19) considered decentralised ward-based ADDSs, such as ADCs (n=18). Six of the studies investigated pharmacy-based centralised DDSs, such as unit-dose DDSs (n=5).[1 21 28 34 40 41] Studies on hybrid systems (n=5) combined features of both centralised and decentralised DDSs.[3 17 18 26 33] More detailed information about DDSs is presented in online Appendix 1 and 2.

Safety

Safety of the medication-use process in hospitals was the most reported outcome of the assessed automated and semi-automated DDSs (table 3). Safety was mainly assessed through the incidence of MEs and changes in clinical pharmacy practices, such as pharmacists' enhanced involvement in the medication-use process in the study sites.[1–3 13 14 16 17 21–38 40 41]

Medication errors

Many studies reported that patient safety improved with automation (n=27/30).[2 13 14 16 22 23 25 29–32 35–38] Reduction in MEs was found in all three DDSs.[3 13 14 16 17 24–27 29 30 35 39 41] Accuracy of drug dispensing also improved when systems such as CDT and unit-dose system (UDS) combined with pharmacy-based ADC were combined with BC scanning and CPOE.[17 34 40] The frequency and severity of reduced errors varied in all three systems; some studies showed that all error types reduced in hybrid and decentralised systems, whereas in some studies effects on error severity or type were not found in centralised or decentralised systems.[26 28 29 36]

In a centralised system, selection errors were not reduced by a UDS as the wrong medication could also be selected from the touch-screen monitors of ADDSs; also, the medication carts alone did not reduce the MEs (table 4).[1 34 40] The hybrid system did not reduce some error types such as prescribing errors or missing medications.[26] In decentralised systems, some studies (n=6) showed a reduction in MEs (eg, from 18.6TOE% (total opportunities for error) to 13.5TOE%, 1.96% to 0.69%), medication administration errors (MAEs, from 7.0% to 4.3%; from 6.4% to 2.3%) and adverse drug events (ADEs, −27%).[13 14 27 29–31 35] One study showed no significant effect on MAEs and another study even demonstrated an increase in MAEs (+33%) resulting from the wrong time or route of administration.[2 27] Automation did not affect the most frequent ME types described in the literature, such as wrong administration techniques; also, picking errors remained for medicines not dispensed by ADDS.[13 29 36]

Reallocation of pharmacists' tasks

Automation in both centralised and decentralised systems supported clinical pharmacy practice development in hospitals. Pharmacists had a better chance to perform clinical pharmacy tasks, such as to review prescriptions and control the use of medicines, due to a reduction in logistic tasks and MEs which were detected before reaching the patient, improving the safe and rational use of medicines.[13 16 24 27 28 30 41]

Table 4 Key conclusions and recommendations of the studies on centralised, decentralised and hybrid medication distribution systems in hospitals

	Centralised medication distribution system	Hybrid medication distribution system and others	Decentralised medication distribution system
Medication errors	Unit-dose DDS seems safer than the traditional ward-stock DDS[41] Medication carts alone did not reduce the risk of MEs[1] Unit-dose distribution using CDT with BC scanning seems to improve accuracy of dispensing and may be even less costly and equally effective without carts[40] More attention should be paid to reduce MEs in centralised DDS[41] No change was identified in the incidence of technical (selection) errors in UDS in comparison to pharmacy-based ADCs[34]	Automated dispensing technology reduces MEs[3 17 26] All error types reduced in the unit-dose drug distribution system[26] Hybrid system reduces MAEs compared with WSS. The system does not affect prescribing errors[26] Hybrid system does not prevent errors caused by missing medications[26] Strategies to prevent MEs must be based on changes to the systems rather than individuals[3] BC scanning was found to prevent errors[17]	Decentralised medication distribution system reduces MEs: prescribing, administration, picking/selection, preparation, missing medications and wrong dose errors[13 14 16 24 25 27 29 30 35 39] ADCs and CPOE reduces prescription and dispensing errors[8] ADCs improve the efficiency of medicines administration but have little effect on the rate of MEs[2] An increase in MAEs and decrease in ADEs was found[27] Decentralised dispensing system could not prevent all MEs, for example, wrong-technique errors and picking errors still remain for non-ADDS medicines[13 29 36] Risks are found in subprocesses other than administration itself[8]
Clinical pharmacy	Gives pharmacists a better chance of performing clinical pharmacy activities[41] Automation has a positive impact on medication management process[21] More visits to the wards are needed to stregthen clinical pharmacy-related activities[41]	Not reported	Pharmacists have a better chance to review prescriptions and control the usage of medicines. More errors are avoided and safety is improved[16 24 30]
Patient safety	Unit-dose DDS improves patient safety[41] Improved quality management enables better patient safety[28] Nursing staff were satisfied with the use of technology and believed it facilitated their work and contributed to safe healthcare[1]	Technology improves the quality of patient care itself by controls and alerts and by freeing up healthcare professionals to perform tasks that improve patient care in other ways[3 17] Medications are ready to dispense after pharmacist's verification[17] The risk of an unnecessary medication being administered was reduced due to redesigned cartfill process[33]	Decentralised system may improve safety and quality of care[13 16 27] Electronic systems can have benefits in drug administration and safety aspects[31] BCs increased confirmation of patient identity before administration[30 31 39] Nurses believed that safety improved and system helped to reduce medication incidents[35] Collaboration is essential to ensure safe patient experiences[32] New technologies may compromise patient safety or create a false sense of security[23 35] System increased documentation discrepancies[31]
Time	Cart-fill process was faster before implementation[40]	Hybrid system saves time compared with decentralised system[18] The cart-fill redesign had positive impact on lead times[33]	Time spent on medication-related tasks inrceased after implementation[24 30] Technican spent more time managing the stocks with ADDS[25 30 32] Pharmacists' time spent performing technical distribution activities was decreased while time spent on clinical work appeared to increase[14] Nusing time dedicated to medications reduced[2 25 30] Faster medication process: the automated medication dispensing systems outside patient rooms resulted in fewer episodes waiting to access the system and allowed nurses more time at the bedside. ADCs enabled fast ADE reports, improved timelines and security of administration[16 31 32 38] The time taken to retrieve narcotics and other controlled drugs improved[14 16 37] Pharmacists and nurses spend less time dispensing drugs. Pharmacists have more time to collaborate with their nursing colleagues, check physicians' orders against patients' drug profiles, reconcile patient medication, participate in patient care rounds and provide patient education. Nurses have more time to observe patients[16 25 31] With ADM the medication retrieval process was slower than before[37]
Work/workload	Centralised dispensing systems create additional workload in pharmacies, especially for pharmacy technicians[28 40] Reduction in labour required to perform first-dose dispensing enabled reallocation of technician staff to other areas[40]	Automation eases pharmacists' distributive responsibilities. It also frees up technicians to do other duties[17 33] Transition from hybrid system to decentralised system would result in decreased technician labour requirements and greater increase in nursing staff workload, which inreases costs[18]	Technology implementations need additional work compared with traditional system[23] The automated dispensing systems improved the productivity of pharmacists and nurses.[25 27] ADCs reduced pharmacists' dispensing time[16] Nurses believed that the system made their work easier[35] To improve nurses' working conditions and knowledge about medications will reduce MEs[13 16]
Cost	Carousels seem to reduce inventory costs and increase the inventory turn rate[40]	Has best total human resource utilisation and employee skill mix. Decentralised is more expensive compared with hybrid system[18]	With ADDS, costs are easier to control or are even reduced[14 25 27]

Continued

Table 4 Continued

	Centralised medication distribution system	Hybrid medication distribution system and others	Decentralised medication distribution system
Stocking	Better tools would be needed to manage medication inventories, generate usage reports and monitor workflow in the future[40]	Gives better tools to manage medication inventories, evaluate charging, decrease returns to pharmacy, reduce waste and enable just-in-time delivery[17 33] Better stocking enables improved safety: system stores and controls medications, fewer unnecessary medicines are stored in the ward[17 33]	Automation improved storage, stock control and security[22 27 29 31 37] Less time is spent searching for medicines[37] ADDS decreased storage errors[13 14] Narcotics management has been improved with ADC. It eliminates the manual count and provides secure medication storage supported by electronic tracking[16 35] Automated dispensing increases the accuracy of inventory levels and decreases time spent on billing[14]
Technology	Healthcare leaders must understand the impact a technology solution has at individual group and organisational levels to achieve maximum benefit and to minimise unnecessary consequences[40] Some individual problems are found in centralised systems concerning technology: no alerts combined with BC scanning, computers' touch-screen selection enables look-alike, sound-alike medication-related mistakes, problems passing the information on stat medications[34 40]	Complementary solutions are needed in technology to prevent MEs and optimise medication management[26] Some individual problems are found in hybrid systems concerning technology: robots do not handle all the medications (large bottles and cold storage) and errors are still observed, labelling and preparing processes are also prone to errors[17 26]	Nurses were satisfied with the decentralised dispensing system[13 16 22 24 32 35 37] Proper integration into an institution's distribution process is needed to achieve positive results[14] Technical systems will require time and effort to improve safety[24] Some individual problems are found in decentralised systems concerning technology: Manufacturers do not provide medication in unit-dose packages and repackaging is needed, which is costly. Formulation and allergy alerts are needed[8 29 35] Decentralised medication distribution system cannot prevent all ME types. Additional solutions and new technological enhancements are needed to reduce errors and improve safety: electronic prescribing, CPOE, BCed patient identification (with photographs), user identification, eMAR, pop-up alerts, clinical warnings, clinical decision support tool[2 8 13 16 25 29 30 36 39]
Education, information and general guidelines	Individual and general group trainings for healthcare staff are needed to minimise change resistance towards the new technologies and to improve accuracy in medication administration[21 34] Patient infomation and communication between healthcare professionals must be intensified to improve patient safety in a centralised medication distribution process[28] Common guidelines on the optimal use of the carts, reducing the interruptions and reviewing the filling policies are needed to improve processes[1]	Education on the new system helped personnel overcome initial resistance to the changes[33] Despite the use of various methods for communication and education, it was not as successful as desired[33] With the thrice-daily cart-fill process, nurses had fewer opportunities than before to contact pharmacists or pharmacy technicans directly[33] Drug information about brand names and availability is needed to prevent errors caused by missing medications[26]	Good planning and communication is needed to ensure successful implementation[2 23] Nurses' better knowledge about drugs is needed to reduce errors[36] System improved communication between nurses and pharmaceutical staff[25] Employees were satisfied with training and felt system easy to use[22]

ADC, automated dispensing cabinet; ADDS, automated drug dispensing system; ADE, adverse drug event; BC, barcode; CDT, carousel dispensing technology; CPOE, computerised physician order entry;DDS, drug dispensing system; MAE, medication administration error; ME, medication error; UDS, unit-dose system; WSS, ward-stock system; eMAR, electronic medication administration record.

Medication-use process

Automation seemed to improve the medication-use process (n=12).[2 14 16 17 21 23 24 27 32 33 39 40] Medication management and dispensing itself improved in the centralised system.[21 40] In a decentralised system efficiency and accuracy improved, processes were standardised and quality of medical care was improved.[2 14 16 23 24 27 32 39] Prescriptions (n=2) improved with a closed-loop system (eg, electronic prescribing, automated dispensing, BC patient identification and electronic medication administration record (eMAR)).[24 30] It also helped to indicate risk factors (n=3) in the medication-use process, such as patient identification, risk medicines and wrong techniques of IV drug dilution.[8 23 36] After noticing problems it was possible to improve nurses' working procedures and knowledge of drugs or implement a BC technology to improve patient identification and documentation in the administration phase.[8 36]

Time

The effects of the DDS on time, such as labour time, staffing workload or changes in process, were explored in most of the studies (n=24/30).[1 2 8 13 14 16–18 21 23–25 27 28 30–33 35–37 39–41] There were mixed findings about the staff time needed for automation in the drug distribution process. Although changes in process were not always supported by staff in the beginning, nurses thought that the workload was easier and that work conditions improved with the automation in centralised and decentralised systems.[1 13 28 35]

Centralised dispensing systems created an additional workload for pharmacy technicians (eg, 2.6 full-time equivalents) (table 4).[28 40] The cart-fill process was faster before implementation of a CDT in a hospital pharmacy. However, reduction in some activities was seen, which enabled reallocation of technicians to other tasks.[40]

The decentralised DDSs improved productivity of pharmacists and nurses (table 4).[25 27] Pharmacists had more time to collaborate with nurses, check physicians' orders against patients' drug profiles, reconcile medications, participate in rounds and counsel patients, and nurses had more time to monitor patients.[16 25 31] ADCs enabled faster ADE reports, reduced pharmacists' dispensing time and improved timelines, such as the time needed to retrieve narcotics and other controlled drugs (36 s; 59 s).[14 16 31 32 37 38] In some studies (n=5) more staff were needed to complete the drug distribution process than before the implementation (table 3).[14 25 30 32 39] Usually extra pharmacy staff, mainly technicians, were needed to fill machines and manage the stocks.[14 25 30 32 39] Some studies reported that

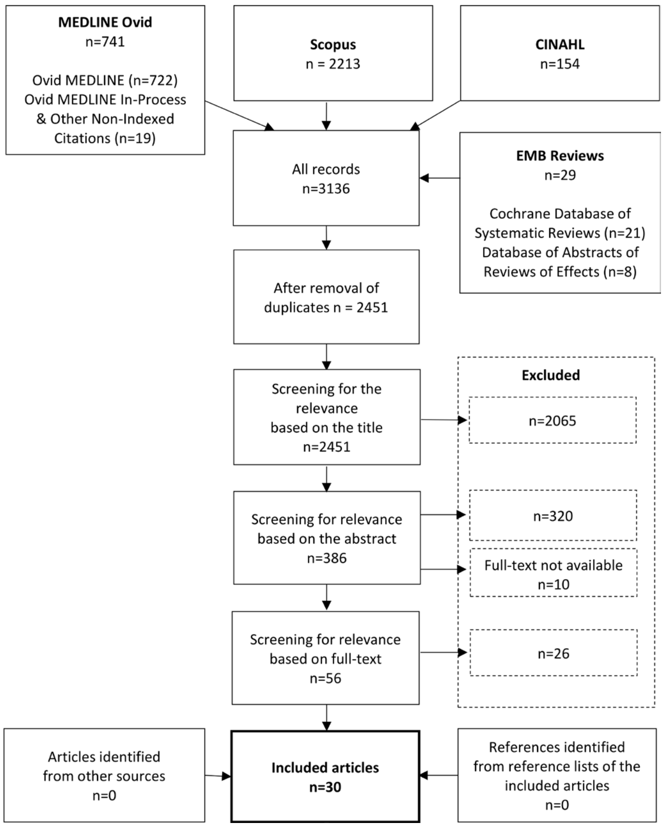

Figure 1 Flow chart of the article selection of the study.

time dedicated to medication-related tasks increased (n=3) or decreased (n=3).[2 16 24 25 30 37]

A hybrid system was found to save more time compared with a decentralised system as technicians spent more time managing the stocks with ADDS.[18 25 30 32] In a hybrid system automation was also found to ease pharmacists' distributive responsibilities and to free up technicians to do other tasks (table 4).[17 33]

Costs

Six studies explored the costs and economic savings related to the DDSs (table 3).[14 18 21 25 27 28] In centralised systems better cost control and savings were found, or at least the costs stayed at the same level as before implementation.[21 28] Carousels were found to reduce inventory costs ($25 059) and increase the inventory turn rate.[40] In the decentralised system, costs were easier to control (n=1) or even reduce (n=2; eg, €44 298; $9932/month) with ADDS.[14 25 27] Chapuis *et al*[25] showed that ADDS implementation was financially profitable especially in intensive care units due to savings in nursing time and reduction in medication-related costs (global cash flow €148 229). A hybrid system was found to possess the best total human resource utilisation and employee skill mix, and was therefore considered less expensive ($229 691/year) than a decentralised system.[18]

Other outcomes

Great advantages were found in medication storing (n=9).[13 14 17 18 21 22 25 40 41] Smaller warehouses, improved stock control and decreased errors in storage were reported as positive outcomes.[13 14 21 22 25] Degree of medicine waste and expired drugs decreased as unused drugs were returned to the pharmacy.[25 33 41] Moreover, the inventory and security of drug storage improved by improved control due to automation.[1 22 26 31 40 41] ADCs supported by electronic tracking improved narcotics management; storage errors decreased, it eliminated the manual count and improved security.[16 35]

Technical usability brought some advantages, and also some problems to the drug distribution (n=13).[1 8 13 14 16 17 22–24 28 34 35 41] Technical problems were found usually in the implementation phase of the decentralised system.[14 30] Technology improved the quality of patient care by controls and alerts and by freeing up healthcare professionals to perform patient care tasks (table 4).[3 17] In all dispensing systems other technological solutions (eg, BC medication administration, eMAR) were recommended to be combined with an ADDS to improve safety of medication distribution.[8 17 34]

Authors' key conclusions and recommendations

The key conclusions and recommendations of the studies are collected in table 4. In addition to the previously presented findings, a proper risk management assessment of implementing a new DDS was recommended together with educating and informing the staff of the new technologies and changes in the distribution process. To improve medication safety and the right use of technology, nurses' knowledge needs to be increased.[21 34 36] Different systems may ease or complicate communication between healthcare professionals, and communication must be intensified to improve patient safety in the implementation of the new system.[25 28 33]

The most recent evidence (2016 to January 2019)

The later literature search found 848 articles (duplicates not removed), of which four new articles were evaluated more closely. Studies were performed in Denmark (n=2, decentralised system), Thailand (n=1, centralised system) and Brazil (n=1, hybrid system).[42–45] Safety (n=2), time (n=2) and cost-effectiveness (n=2) were studied. In the hybrid study, personnel savings were found of 6.5 hours/day.[45] In the centralised model, the ADM system decreased the workload of pharmacy technicians but required more time from pharmacists as a result of the redesigned work process.[44] The decentralised study showed reductions in MEs.[42] Another study compared three different types of complex automated dispensing systems.[43] This study found that a patient-specific automated medication system and a non-patient-specific automated medication system were more cost-effective than the system which included ADC (15 times more expensive per avoided clinical error).

DISCUSSION

The decentralised DDS is the most studied distribution type in terms of its impact on medication safety, time and costs of medication care. Decentralised ward-based ADDSs are more recent innovations than traditional centralised systems, which may explain the greater research interest towards them. In the USA, 97% of the hospitals used ADCs in their medication distribution systems in 2015 whereas, in the UK, only 7% of the hospitals reported usage of cabinets in 2014.[46 47]

The benefits of decentralised dispensing compared with hybrid and centralised systems are not clear. Most of the studies concentrated on medication safety outcomes; however, the DDSs did not differ in their impact on safety. Automation, such as UDSs, CDTs, ADCs and BC scanning improved medication safety by reducing MEs, and would be recommended to be implemented as part of the distribution systems to manage medication safety risks.

The hybrid DDS seemed to possess advantages in terms of studied outcomes. In hybrid systems, safety increased and the medication management process became faster due to automation. Also, cost-effectiveness of human resources was rated optimal from the staffing point of view.[18] However, it should be noted that hybrid systems and their study designs varied, affecting comparability.[3 18 26 33] Consequently, the presented findings may not be generalisable for all hybrid systems and more research is needed to demonstrate their benefits.

Effects of drug distribution systems on medication safety

The findings indicate that automation in the dispensing process mainly decreases dispensing and storage errors of medicines that are suitable for an ADDS but does not affect other error types such as prescribing errors, which tend to occur before the dispensing phase.[9 30 48] To safeguard the entire medication-use process, other automated solutions are needed—such as computerisation of patients' files, prescriptions, CPOE and BC verification—to complete the safe dispensing process.[4 5 17 35 49] Moreover, in addition to new technological solutions, education of nurses about medication treatment and management was also found to improve patient safety by improving accuracy of dispensing and reducing MEs.[3 17 21 24 30 34 36 39] Most importantly, the strategies to prevent MEs must be based on changes to the systems and the medication-use process.[3]

Effects of drug distribution systems on time

Centralised and hybrid dispensing systems seem to save nursing time by localising logistic phases of drug distribution to pharmacies.[2 18 25] However, in a decentralised system, extra staff were usually needed, mainly technicians managing the stocks with ADDS.[14 25 30 32 39] In centralised and decentralised systems, nurses perceived that workloads were easier with automation.[1 13 28 35] This may be explained by technicians mainly being the ones who manage the stocks. Moreover, in hybrid and decentralised systems, drug stocking on wards was improved.[17 22 27 29 31 33 37] This saved nurses' time from handling restricted medicines and improved security of narcotic drugs management.

The review of the evidence indicates that all three DDSs accompanied by automation improved the quality of patient care by shifting pharmacists' time from technical distributive activities to clinical work.[2 14 18 25] Pharmacists had more time to review prescriptions and errors were more commonly detected before medication administration.[16 24 30] When introducing new ADDSs, hospitals would be recommended to create strategies for reallocating pharmacist resources from dispensing to clinical work to optimise their use of time, skills and efforts on medication safety.

Effects of drug distribution systems on costs of care

Few studies that concerned economic aspects suggested that medication costs were easier to control or even reduced with ADDSs.[18 25 27 28] There was no clear evidence that the studied DDSs differed in their impact on costs of care. This may indicate that cost reduction is primarily associated with medication dispensing automation, not a single type of DDS. Studies on financial savings of the DDSs were the least studied area, representing a central target for future studies.

A hybrid system with ADCs was found to save costs in staff resources.[18 45] Also, decentralised ADDSs showed financial savings because of smaller drug storage costs and a reduction in medication in intensive care units and haemodialysis.[25 27] In some studies no evidence of cost reduction was found related to centralised and decentralised ADDSs.[14 21] Despite the unclear cost effects, the achieved improvements in quality of care have led to accepting ADDSs over traditional manual systems in many countries. To find the most efficient system for hospital drug distribution, it is important to customise the ADDS.

Recommendations for risk management in implementing drug distribution systems

ADDSs are designed to provide medication safety and increased efficiency in drug distribution.[10] However, it should be noted that their implementation in the hospital medication-use process may produce new safety risks due to changes in distribution processes and daily work.[1 8 13 23 24 35 36] Balka *et al* and Rochais *et al* found that new technologies, such as decentralised DDSs, may compromise patient safety or even create a false sense of security among care providers.[23 35] These risks need to be recognised in developing and implementing a new automated distribution process so that new errors can be prospectively prevented.[50] If the risks are not identified proactively, the system may generate new errors, causing additional costs by, for example, increasing inpatient time or adding extra work in reorganising the medication-use process. Consequently, it is important to invest in implementation of a new ADDS, train all users, ensure communication between healthcare professionals to avoid lack of knowledge and allocate sufficient staffing at the beginning of the implementation.[2 46 50]

Limitations of the systematic review

The main limitation of the present study was the relatively low quality of the published evidence. Most of the included studies were graded as low or very low in quality as they applied mainly observational methodologies. However, no studies were excluded because of their quality. More research with rigorous study designs, such as controlled studies, are urgently needed to be able to reliably compare costs, time and safety benefits of the systems, especially the effects of centralised and hybrid systems.

The included studies applied different study designs and outcome measures, so quantitative analysis was not peformed. Moreover, some of the results were contradictory. Dispensing systems and their integration in different types of medication processes in hospital organisations and the pharmacists' role varied, which may indicate that the outcomes were institution-specific, adding to the difficulty of generalising or transferring the results between healthcare institutions. Exploring the cost-effectiveness of dispensing automation in small and medium sized hospitals (<500 beds) represents a special target for future studies.

CONCLUSIONS

Medication safety and quality of care improved with implemented ADDSs. However, there seemed to be no major differences between the DDSs in terms of their impact on safety. MEs were decreased, but automation did not reduce all error types (eg, prescription errors). Changes in processes may also create new risks for errors.

ADDSs improved quality of patient care by shifting pharmacists' time from technical distributive activities to clinical work.[2 14 18 25] Still, implementation of automation was found to require time. Centralised and hybrid systems saved more time than a decentralised system.

No clear evidence was found on cost differences between the studied DDSs. Costs were reduced in decentralised systems mainly in high-expense units, but no evidence was available to indicate whether the implementation would lead to savings in smaller units. The benefits and costs of decentralised systems compared with hybrid systems should be evaluated further.

Key messages

What is already known on this subject

- There are three different types of automated and semi-automated drug distribution systems to increase the safety and effectiveness in the medication-use process in hospitals: (1) decentralised ward-based automated drug dispensing systems; (2) centralised pharmacy-based systems; and (3) hybrid systems where centralised and decentralised features are combined.
- In the USA, most of the hospitals are using decentralised ADCs in their medication distribution systems whereas, in the UK, only some hospitals have reported usage.

What this study adds

- Medication safety and quality of care improved with implemented automation but did not reduce all error types; changes in processes may also create new sources of errors.
- Automation shifted pharmacists' time from technical distributive activities to clinical work, and centralised and hybrid systems saved more time than decentralised systems.
- From the financial point of view, costs were reduced in decentralised systems mainly in high-expense units, but there is no evidence that implementation would cause any savings in smaller units.

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