TITLE: Automated Medication Dispensing Systems: A Review of the Clinical Benefits, Harms, and Cost-Effectiveness

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CONTEXT AND POLICY ISSUES:

Large volumes of medications are dispensed in Canadian hospitals on a daily basis. Medication errors, even at low rates, can have serious consequences in terms of adverse drug events, with potential impacts on patient morbidity and mortality.[1,2] Automated dispensing devices (ADDs) are used in an effort to decrease errors in the medication distribution process, before medications reach the patient. These devices are intended to reduced errors by packaging, dispensing, and identifying medications using bar codes.[1] ADDs may also reduce costs, not only through reductions in medication errors and their consequences, but also through reduced staffing requirements and improved inventory management.

A 2003 survey of 78 Canadian hospitals[3] reported that 56% of hospitals used some form of automated dispensing, with this technology servicing an average of 35% of their hospital beds. In the same survey, 33% of respondents chose automated dispensing as their hospital's next investment. A more recent survey of Canadian hospitals[4] reported that 75% of 102 respondents used automation in their centralized unit dose systems. High rates of use (83%) have also been reported in the United States.[5]

While ADDs and other related technologies are intended and perceived[6] to reduce medication errors, improve patient outcomes, and improve efficiencies, it is unclear that these outcomes are always achieved.[1,7]

The decision to adopt medication dispensing systems in hospitals should be informed by the evidence for their clinical benefit, and their impact on resource use and costs. The current review was conducted with the objective of summarizing the available clinical and cost effectiveness evidence related to ADDs.

RESEARCH QUESTIONS:

1. What are the clinical benefits and harms of automated medication dispensing systems in hospitals?

2. What is the cost-effectiveness of automated medication dispensing systems in hospitals?

METHODS:

A limited literature search was conducted on key health technology assessment resources, including Ovid Medline, EBSCOhost CINAHL, The Cochrane Library (Issue 8, 2010), University of York Centre for Reviews and Dissemination (CRD) databases, ECRI (Health Devices Gold), EuroScan, international health technology agencies, and a focused Internet search. The search was limited to English language articles published between January 1, 2005 and August 30, 2010. No filters were applied to limit the retrieval by study type. The types of studies considered for inclusion included health technology assessments (HTAs), systematic reviews, meta-analyses, randomized controlled trials, non-randomized studies, and economic evaluations.

This review updates a CADTH health technology assessment on this topic that was published in 2009,[2] and as such, primary studies were only considered for inclusion if they were published in 2009 or 2010 and were not included in the CADTH publication.

SUMMARY OF FINDINGS:

The literature search yielded 149 citations, 20 of which were selected and retrieved for further screening. The screening process resulted in the exclusion of 18 reports. Reasons for exclusion were: report published prior to 2009 (n=12), not a comparative study (n=2), not the intervention of interest (n=2), assessment done in outpatient setting (n=1), and impact of dispensing device could not be properly assessed due to concurrent interventions (n=1). The two remaining reports included a health technology assessment[2], and a non-randomized study[8] which considered health outcomes as well as economic impacts. The health technology assessment included clinical and economic literature reviews, as well as a primary economic evaluation. No randomized studies were identified.

HTIS reports are organized so that the higher quality evidence is presented first. Therefore, the health technology assessment report is presented first, followed by the non-randomized study reporting clinical and economic outcomes.

Health technology assessments

In 2009, CADTH published a health technology assessment[2] on technologies used to reduce dispensing and medication administration errors in hospitals. The report included a systematic review of the clinical literature that was conducted for the purpose of assessing the clinical effectiveness of using these technologies in preventing medication errors, adverse drug events, morbidity, and mortality. Papers published between 1992 and 2008 were included. Other inclusion criteria were: systematic reviews, health technology assessments, and clinical studies with comparison groups; studies of hospital inpatient populations (i.e., acute care, critical care, rehabilitation, long-term care, emergency rooms); technologies relating to medication

dispensing or medication administration in hospitals that were commercially available, customized, or developed in-house. A total of 30 studies were included in the clinical review, 16 of which were relevant to automated drug dispensing (see Appendix 1). None of the studies were conducted in a Canadian setting.

The 16 studies varied with respect to design; none were randomized trials. Study designs included prospective (n=11), cohort (n=1), before-and-after with time series (n=1), and time series (n=1). Two studies did not specify if they had been done prospectively or retrospectively. The systems evaluated included ADDs (11 studies) and bar code medication dispensing (BCMD) (4 studies). ADDs were also considered in combination with bar code medication administration (BCMA) and electronic medication administration record (eMAR) (2 studies). Seven of the studies on ADDs were on pharmacy-based systems and four were on ward-based systems. The authors differentiated between profiled and unprofiled ADDs. In profiled systems, a nurse's access to medications is limited through specification of a patient's profile in a computerized system, whereas nurses may access any medication in a cabinet with an unprofiled system.

Among the comparators in these studies were manual or traditional drug distribution systems. Outcomes evaluated included medication errors (ME), medication administration errors, dispensing errors, adverse drug events (ADEs), near misses or potential ADEs, and preventable ADEs. The definitions for these outcomes were obtained from the Canadian Patient Safety Dictionary[9], the US Agency for Healthcare Research and Quality[10], and the Institute of Medicine[11], and are given in Appendix 2. Studies varied with respect to the methods used to ascertain errors, some of which may have resulted in underestimation of error rates. Due to the variability in study design and heterogeneity in study characteristics, study results were not meta-analyzed and a descriptive analysis of the studies was performed. The authors of the health technology assessment summarized the relative risks for dispensing errors, medication errors, filling errors, and adverse drug events as reported in the included studies, and their summary of results is given in Table 1.

Table 1: Summary of clinical findings from 30 studies reviewed for CADTH HTA: Technologies to Reduce Errors in Dispensing and Administration of Medication in Hospitals[2]

Technology	Outcome	Number of studies	RRR or RRI
Profiled, ward-based (decentralized) ADD	Dispensing errors	1	↓28.7%*
	Total MEs	1	↓38.4%*
	MEs in surgical unit	1	↓33.8%
	MEs in ICU	1	↑70.0%
	Medication-related events	1	↓36.6%*
Pharmacy-based (centralized) ADD	Dispensing errors using ATC-212™	1	↓22.3%†
	Cart-filling errors using ATC-212™	1	↓99.7%*
	Dispensing errors using original-pack dispensing systems	5	↓16.0% to ↓61.3%
BCMD (carousels)	Filling errors for first dose or missing dose	1	↓15.2%†
	Filling errors for automated dispensing cabinet fill	1	↓74.7%*

Table 1: Summary of clinical findings from 30 studies reviewed for CADTH HTA: Technologies to Reduce Errors in Dispensing and Administration of Medication in Hospitals[2]

Technology	Outcome	Number of studies	RRR or RRI
	Dispensing errors for first dose or missing dose	1	↑9.0%†
	Dispensing errors for automated dispensing cabinet fill	1	↓28.9%†
	Dispensing errors	2	↓36% and ↓96%
	Potential ADE	1	↓63%
Ward-based ADD and BCMA	Dispensing errors	1	↓99.0%
	MEs	1	↓9.8%
Ward-based ADD, BCMA, and eMAR	Medication administration errors	1	↓47.5%*

HTA: Health technology assessment; ADD=automatic dispensing device; ADE=adverse drug event; BCMA=bar code medication administration; BCMD=bar code medication dispensing; eMAR=electronic medication administration record; ICU=intensive care unit; ME=medication error; RRI=relative risk increase; RRR=relative risk reduction

*met an investigator-defined threshold of statistical significance; †did not meet an investigator-defined threshold for statistical significance

Among ward-based automated dispensing systems, dispensing errors, medication errors and medication-related events were decreased by approximately 30-40%. However, one study conducted in an intensive care unit (ICU) reported a 70% increase in the rate of medication errors. Dispensing errors and cart-filling errors were reduced with centralized, pharmacy-based ADDs, however the authors noted that the ATC-212™ is an older technology that is no longer available for purchase, and that original-pack dispensing systems are only available in Europe. With BCMD, relative risk reductions in filling and dispensing errors ranged from 15% to 96%, although one study reported a 9% increase in the relative risk of dispensing errors for first dose or missing dose. While all potential ADEs were reported to decrease by 63% with BCMDs in one study, this same study reported a 2.8-fold increase in life-threatening ADEs due to dispensing errors. Studies of ward-based ADDs combined with other technologies such as BCMA or eMAR also reported reductions in error rates.

The authors of the health technology assessment concluded that the use of ward-based ADDs, BCMD, and combined technologies, reduced the risk of dispensing or medication errors in hospitals. However, the impact on potential adverse drug events, adverse drug events, morbidity, and mortality could not be assessed as these outcomes were not measured in most studies. No evidence was available for currently available centralized, pharmacy-based ADDs.

The CADTH health technology assessment[2] also addressed the cost-effectiveness of technologies intended to reduce medication errors in hospitals. The literature search for the systematic review of the economic literature was performed together with the clinical literature search, and yielded 14 relevant reports (see Appendix 3). Nine studies were on ward-based ADDs, three were on pharmacy-based ADDs, and two were on BCMDs. Two of the studies on ward-based ADDs, and all three of the studies on pharmacy-based ADDs, had also been included in the systematic review of the clinical literature. As in the clinical review, the three

studies on pharmacy-based ADDs were on technologies that are not currently available in Canada. None of the 14 studies were conducted in a Canadian setting. Most studies reported an incremental analysis, and four included all relevant resources in their analyses. The authors summarized the findings of the fourteen reports according to technology and resources measured, and the results of this summary are given in Table 2.

Table 2: Summary of economic findings from 15 studies reviewed for CADTH HTA: Technologies to Reduce Errors in Dispensing and Administration of Medication in Hospitals[2]

Technology	Resources measured	Number of studies	Range of findings
Profiled, ward-based ADD	Nurse time allocation	3	↓18% to ↓45%
	Pharmacy time allocation	5	↓88% to ↑42%
	Inventory management	3	Costs greater with manual system
	Captured charges*	2	Gains in captured charges
	Economic efficiency and financial analysis	4	Benefits exceed costs
Pharmacy-based ADD	Pharmacy time allocation	3	Reduction in staff time
	Allocation of space	2	Reduction in space
BCMD (carousels)	Cost-benefit analyses	2	Net benefit over 5 years US$3.49 million

HTA: Health technology assessment; ADD=automatic dispensing device; BCMD=bar code medication dispensing.
*Captured charges are financial benefits of a technology that are accrued to the hospital instead of the patient.

Among ward-based automated dispensing systems, three studies reported reductions in nurse time allocation, while one reported no change in nurse time spent on drug administration. Results for pharmacy time allocation varied. Three studies of inventory management suggested greater costs with manual systems. Two studies reported gains in captured charges accruing to the hospital. Four studies reported aggregate financial analyses conducted from the perspective of the hospital, and all reported that benefits exceeded costs. Studies of pharmacy-based ADDs reported reductions in staff time and space requirements. Two studies of BCMD, both conducted in the same 735-bed tertiary hospital, reported that this technology was associated with an estimated net benefit of US$3.49 million over 5 years.

Given a lack of comprehensive data on the financial impact of automation, the authors of the CADTH health technology assessment[2] conducted a primary economic evaluation of ward-based ADDs (with or without patient medication profiles) compared with a manual drug distribution system (with medication cassettes), from the perspective of a Canadian hospital over a time horizon of five years. This model-based cost-consequences analysis used results from the clinical review to estimate the impact of ward-based ADDs on outcomes. The target population for the analysis was a "representative" hospital, and the model had a hospital unit component. A hospital unit was a patient care unit (20 beds) or an intensive care unit (ICU) (8 beds). Equipment life was assumed to be five years. Estimates of nursing, pharmacist, and pharmacy technician time were obtained from unpublished data. Differences in inventory turnover between the two systems were obtained from the literature. Sensitivity analyses were conducted on the capital equipment costs, nursing costs, pharmacists and pharmacy technician

time, and inventory and planning costs. The five-year drug distribution costs estimated in the base case analysis are given in Table 3.

Table 3: Five-year drug distribution costs from base-case of primary economic evaluation in CADTH HTA: Technologies to Reduce Errors in Dispensing and Administration of Medication in Hospitals[2]

Unit	Technology	Costs
Patient care unit	Manual	$968,000
	Unprofiled ADD	$816,000
	Profiled ADD	$840,000
Intensive care unit	Manual	$353,000
	Unprofiled ADD	$429,000
	Profiled ADD	$453,000

ADD: automatic dispensing device

Unprofiled ADDs were less costly than manual systems in patient care units ($816,000 vs. $968,000, difference=$152,000), but more costly than manual systems in the ICU ($429,000 vs. $353,000, difference=$76,000). Profiled ADDs were also less costly than manual systems in the patient care units ($840,000 vs. $968,000, difference=$128,000) and more costly than manual systems in an ICU ($453,000 vs. $353,000, difference=$100,000). Better outcomes for ADDs with profiling (i.e., reduction in dispensing errors and MEs, as reported in the clinical section), and lower costs in patient care units suggested that this was a dominant strategy over manual systems. No clinical data were available for unprofiled ADDs. Nursing costs in the manual and automated systems represented 68% and 50% of total costs, respectively. Pharmacy technician costs in the manual and automated systems represented 26% and 13% of total costs, respectively. Equipment costs and planning costs were approximately 14% and 6% (respectively) of the total costs of the automated systems. Sensitivity analyses showed five-year costs of both profiled and unprofiled ADDs to be sensitive to changes in nursing and pharmacy technician time.

The authors concluded that the implementation of a ward-based ADD in a hospital patient care unit can reduce costs while reducing error rates. In contrast, implementation of this technology in intensive care units results in a net increase in costs. The reason given for this latter finding is the large capital expenditure required to implement ADD systems for a relatively small number of patients. Furthermore, there is uncertainty regarding the clinical impact of ADDs in ICU wards. The authors noted that it was difficult to assess the economic impact of other technologies due to gaps in the available evidence.

Non-randomized studies

Temple et al.[8] (2010) reported on the implementation and evaluation of a carousel dispensing technology (CDT) in an American university medical centre pharmacy. The CDT under evaluation was the MedCarousel, supplied by McKesson Automation Solutions (Cranberry Township, PA). The authors compared accuracy rates of technician dispensing for automated dispensing cart (ADC) refills, first-dose requests, and cart-fill requests during the pre-implementation and post-implementation phases. Data were collected over a six-month period. Attempts were made to reduce observation bias by not making technicians aware that accuracy

was being assessed. Accuracy rates in the pre- and post-implementation stages are provided in Table 4.

Table 4: Accuracy rates before and after implementation of a carousel dispensing technology (CDT) in Temple et al.[8]

Refill type	Pre-implementation	Post-implementation	Difference
Automated dispensing cart refills	99.84%	99.99%	0.15%
First-dose requests	98.51%	99.53%	1.02%
Cart-fill requests	98.73%	98.94%	0.21%
All refills (pooled)	99.02%	99.48%	0.46%

Given their average daily number of ADC refills (n=2200), first doses dispensed (n=2000), and cart refills (n=500), the authors estimated that the decrease in error rates attributed to the CDT would reduce the annual number of dispensing errors at their centre by 7,783, decreasing potential adverse drug events by 47%. The authors concluded that the CDT improved the accuracy of medication dispensing at their centre.

Economic evaluations

Temple et al.[8] also included an assessment of resource use efficiency, specifically, turnaround times and labour requirements for the dispensation and procurement of medications, and medication inventory turnover. Turnaround times decreased in the post-implementation stage for ADC refills (62 minutes vs. 53 minutes) and first-dose requests (56 seconds vs. 24.6 seconds), and increased for cart-fill requests (18.06 seconds vs. 25.7 seconds). Using time studies, the authors estimated that CDT was associated with 2.6 full-time equivalents (FTEs) in labour savings, and that departmental staff was reduced by 2.0 FTEs. Inventory carrying costs were reduced from $343,502/year to $318,443/ year (difference: $25,509) while annualized purchases increased from $5.4 million/year to $5.9 million/year, and inventory turns increased from 16.1/year to 18.5/year (a 15% increase). The authors concluded that overall efficiency was improved by the CDT.

Limitations

The authors of the CADTH health technology assessment noted that the strength of evidence was limited as none of the included studies were randomized, few adjusted for confounders which could have impacted the observed reductions in error rate, and detection or performance bias may have been introduced. The use of relative risks as a measure of effect did not permit an assessment of absolute differences, and baseline risks of study participants were not taken into account. Furthermore, error rates in clinical studies were used as proxies for clinical outcomes, which were not directly assessed.

Temple et al. noted that their study was based on direct observation of staff, which may have resulted in performance bias.[8] They also noted that the impact of CDT on inventory management may have been confounded by concurrent implementation of purchasing software. In addition, the authors acknowledged that other factors such as formulary changes, price changes, and medication shortages, could have affected assessments of inventory differences.

None of the studies reviewed were conducted in a Canadian setting. There was no evidence for centralized pharmacy-based ADDs that are currently available in Canada. With regard to hospital settings, while some wards were considered by the studies reviewed (i.e., general/medical, cardiac, surgical, ICU), information on the effectiveness of automated dispensing units in other important hospital areas (e.g., emergency rooms) was not available.

The authors of the health technology assessment noted that most of the economic studies reviewed had limitations such as the omission of some relevant costs, lack of assessment of the clinical significance of MEs, and incomplete accounting of downstream costs.[2] The primary economic evaluation reported in the CADTH HTA was limited by the poor quality of resource use and cost data available in the literature.

CONCLUSIONS AND IMPLICATIONS FOR DECISION OR POLICY MAKING:

Compared with manual or traditional systems, automated dispensing devices may reduce dispensing and medication errors, as well as costs, in some hospital units. A notable exception is the ICU setting, where ADDs may actually incur higher costs than manual dispensing, and their benefit in terms of reduced medication errors are uncertain. It should be noted that these results have important limitations. Most studies had important methodological shortcomings, and impacts on adverse drug events, potential adverse drug events, morbidity, and mortality were not assessed by any of the studies reviewed. Furthermore, resource use and cost data related to ADDs were of limited quality. Hence, adoption of automated dispensing technology does not automatically ensure better patient outcomes or greater efficiency. If ADDs are implemented, strategies to optimize their use such as those described in the literature[7] should be considered.

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APPENDIX 1: Studies on automated dispensing systems (ADDs and BCMDs) included in systematic review of clinical literature in CADTH HTA[2]

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APPENDIX 2: Definition of outcomes considered in CADTH HTA[2]

The Canadian Patient Safety Dictionary[9]

Medication error: the failure to complete a planned action as it was intended, or when an incorrect plan is used, at any point in the process of providing medications to patients. (p31)[9]

Adverse event: i) an unexpected and undesired incident directly associated with the care or services provided to the patient; ii) an incident that occurs during the process of providing health care and results in patient injury or death; iii) an adverse outcome for a patient, including an injury or complication (p40)[9]

The US Agency for Healthcare Research and Quality Patient Safety Network Glossary[10]

Adverse event: an injury caused by medical care.

Adverse drug event**:** an adverse event involving medication use.

Potential adverse drug event: a medication error or other drug-related mishap that reached the patient but happened not to produce harm (e.g., the penicillin-allergic patient receives penicillin but happens not to have an adverse reaction). It can also refer to errors or other problems that, if not intercepted, would be expected to cause harm.

Near miss: an event or situation that did not produce patient injury, but only because of chance. This good fortune might reflect the robustness of the patient (e.g., a patient with penicillin allergy receives penicillin, but has no reaction) or a fortuitous, timely intervention (e.g., a nurse happens to realize that a physician wrote an order in the wrong chart). This definition is identical to that for close call.

Adverse drug reaction: an adverse effect produced by the use of a medication in the recommended manner. These effects range from "nuisance effects" (e.g., dry mouth with anticholinergic medications) to severe reactions, such as anaphylaxis to penicillin.

The Institute of Medicine Key Definitions[11]

Error*:* the failure of a planned action to be completed as intended (error of execution) or the use of a wrong plan to achieve an aim (error in planning). An error may be an act of commission or an act of omission. (p360)[11]

Medication error**:** an error occurring in the medication-use process. (p360)[11] *(Examples include wrong dosage prescribed, wrong dosage administered for a prescribed medication, or a failure to give (by the provider) or take (by the patient) a medication.)*

Adverse drug event: any injury due to medication. (p359)[11] *(Examples include a wrong dosage leading to injury (e.g., rash, confusion, or loss of function) or an allergic reaction occurring in a patient not known to be allergic to a given medication.)*

APPENDIX 3: Studies on automated dispensing systems (ADDs and BCMDs) included in systematic review of economic literature in CADTH HTA[2]

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