

REVIEW

Decentralized Automated Dispensing Devices: Systematic Review of Clinical and Economic Impacts in Hospitals

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ABSTRACT

Background: Technologies have been developed over the past 20 years to automate the stages of drug distribution in hospitals, including ordering, dispensing, delivery, and administration of medications, in attempts to decrease medication error rates. Decentralized automated dispensing devices (ADDs) represent one such technology that is being adopted by hospitals across Canada, but the touted benefits, in terms of improved patient safety and cost savings, are increasingly being questioned.

Objective: To summarize and evaluate the existing literature reporting the clinical and economic impacts of using decentralized ADDs in hospitals.

Data Sources: A literature search was conducted in MEDLINE, Embase, and all evidence-based medicine databases for the years 1992 to 2012 to identify English-language articles reporting on the use of ADDs in hospital wards.

Study Selection and Data Extraction: All randomized controlled trials, observational studies, before-and-after studies, time series analyses, cost-effectiveness and cost-benefit analyses, and review articles were considered for inclusion. Studies evaluating pharmacy-based ADDs, such as bar code-based medication dispensing carousels, automated dispensing shelves, and combinations of various dispensing modalities, were excluded.

Data Synthesis: Of 175 studies initially identified, 8 were retained for evidence synthesis. It appears that ADDs were effective in reducing medication storage errors and the time that nurses spent taking inventory of narcotics and controlled substances. There was no definitive evidence that using ADDs increased the time that nurses or pharmacists spent with patients, reduced medication errors resulting in patient harm, or reduced costs in Canadian hospitals. However, pharmacy technicians spent more time stocking the machines.

Conclusion: ADDs have limited potential to decrease medication errors and increase efficiencies, but their impact is highly institution-specific, and use of this technology requires proper integration into an institution's medication distribution process. Before deploying this technology, it is recommended that Canadian hospitals carefully examine their current systems and the benefits they hope to gain with the changes.

Keywords: automated dispensing device, medication errors, costs

RÉSUMÉ

Contexte : Au cours des vingt dernières années, des technologies ont été développées afin d'automatiser les étapes de la distribution des médicaments dans les hôpitaux, notamment pour ce qui est de l'émission d'ordonnances et de la dispensation, de la délivrance et de l'administration des médicaments, le tout dans le but de réduire le nombre d'erreurs de médication. Les cabinets automatisés décentralisés (CAD) font partie de ces technologies qui sont adoptées par les hôpitaux du Canada, mais leurs bienfaits très publicisés, en ce qui a trait à l'amélioration de la sécurité des patients et aux économies pouvant être réalisées, sont de plus en plus remis en question.

Objectif : Résumer et évaluer la littérature faisant état des retombées cliniques et économiques de l'utilisation de CAD dans les hôpitaux.

Sources des données : Une recherche documentaire a été effectuée dans MEDLINE, Embase ainsi que dans l'ensemble des bases de données médicales fondées sur des preuves pour la période allant de 1992 à 2012 afin de trouver les articles rédigés en anglais qui font état de l'utilisation des CAD dans les services d'hôpitaux.

Sélection des études et extraction des données : Cette revue a pris en considération toutes les études cliniques aléatoires, les études observationnelles, les études avant-après, les analyses de séries chronologiques, les analyses coût-avantage et coût-efficacité, et les articles de synthèse. Les études évaluant les CAD en usage dans les pharmacies, robots parmi lesquels on compte les carrousels de distribution de médicaments utilisant des codes-barres, les rayonnages de distribution automatisés et les combinaisons de différents moyens de distribution, n'ont pas été retenues.

Synthèse des données : Des 175 études d'abord recensées, huit ont été retenues pour la synthèse des données probantes. Les CAD semblent avoir été utiles pour réduire le nombre d'erreurs d'entreposage de médicaments ainsi que le temps nécessaire au personnel infirmier pour faire l'inventaire des narcotiques et des substances contrôlées. Aucune donnée probante ne permet d'affirmer que le temps passé par le personnel infirmier et les pharmaciens auprès des patients a augmenté, que le nombre d'erreurs de médication causant du tort aux patients a baissé ou que les coûts des hôpitaux canadiens ont chuté grâce à l'utilisation des CAD. Par contre, les techniciens en pharmacie ont passé plus de temps à remplir les machines.

Conclusion : Les CAD présentent un faible potentiel de réduction du nombre d'erreurs de médication et d'augmentation de l'efficacité des ressources. Cependant, leur incidence est propre à chaque établissement

et l'utilisation de cette technologie nécessite une intégration réfléchie dans le processus de distribution des médicaments d'un établissement. Avant de mettre en place cette technologie, il est recommandé aux hôpitaux canadiens de bien étudier leurs systèmes actuels et de réfléchir aux avantages qu'ils espèrent obtenir par ce changement.

Mots clés : cabinet automatisé décentralisé, erreurs de médication, coûts

[Traduction par l'éditeur]

INTRODUCTION

Since the Institute of Medicine published *To Err is Human* in 1999,¹ health care institutions have recognized the need to make systemic changes and find innovative solutions to improve quality related to patient safety. Yet more than a decade later, preventable medication-related errors continue to be a major cause of morbidity and mortality in Canada. In 2011, Hohl and others² estimated that the Canadian burden associated with in-hospital adverse drug events was more than 1.5 million hospital days, leading to hospitalization costs of \$2.2 billion to \$5.6 billion annually (in 2008 Canadian dollars).

With the desire to improve quality, the pressure to reduce costs, and the pharmacy profession's transition to direct patient care, pharmacy departments have looked to automation to expand their distribution capabilities and to improve efficiency. One such technology that is increasingly being used in Canadian hospitals is referred to by various terms, including automated dispensing cabinets and automated dispensing devices (ADDs). Recent surveys have indicated that by 2009/2010, ADDs were being used in at least 53% of Canadian hospitals (Hospital Pharmacy in Canada survey)³ and 89% of US hospitals (American Society of Health-System Pharmacists survey).⁴

The higher uptake of ADDs in the United States has not necessarily been the result of a drive for safer systems. They were initially employed in US hospitals to help capture all patient-specific financial charges, to ensure that a complete bill would be available on discharge, and to track narcotics and controlled substances in response to a federal monitoring system.⁵ Given that these benefits cannot be realized in the Canadian setting, it is unclear whether the uptake of expensive technology such as ADDs in Canadian hospitals (by 47% between 2007/2008 and 2009/2010) was cost-effective.³

A systematic review of technologies intended to reduce errors in dispensing and administration of medications in hospitals, published by the Canadian Agency for Drugs and Technology in Health in 2009, showed that implementation of a hospital ward-based (decentralized) ADD could reduce costs and error rates in medical and surgical patient care units but would increase costs in intensive care units (ICUs).⁶ Detailed

review of this report indicates that this conclusion was driven largely by unpublished data (cited as "Baker 2008") from Cardinal Health, which at the time owned Pyxis, a pioneer and manufacturer of ADD technology.⁶

The objective of the current systematic review was to facilitate evidenced-based decision-making regarding the use of ADDs in Canadian hospitals by providing an unbiased assessment of the clinical and economic impacts of using decentralized ADDs relative to traditional, centralized processes for manual dispensing of medications.

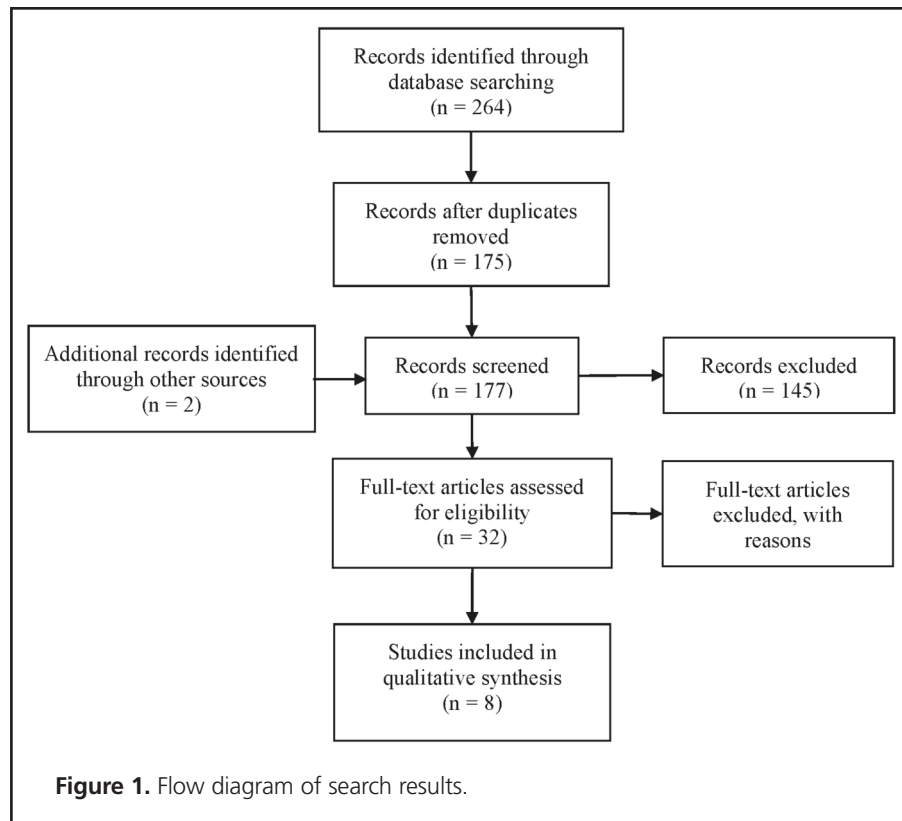
METHODS

Literature Search

A literature search for the period 1992 to 2012 was conducted within MEDLINE (1946 to present with daily update), Embase (1974 to 2012 week 26), the Cochrane Database of Systematic Reviews (2005 to May 2012), ACP Journal Club (1991 to June 2012), the Database of Abstracts of Reviews of Effects (second quarter 2012), Cochrane Central Register of Controlled Trials (June 2012), Health Technology Assessment (second quarter 2012), and National Health Service Economic Evaluation Database (second quarter 2012) with the following search terms: "automated dispensing device", "automated dispensing cabinet", "automated dispensing machine", "automated dispensing system", "drug distribution system", "Pyxis", "Omniceil", and "Medstation" (see Appendix 1 for MEDLINE search strategy). The search was limited to English-language articles because the authors did not have the resources to translate or interpret publications in other languages. The reference lists of relevant articles identified by these searches were reviewed manually for additional studies.

Inclusion Criteria

Articles reporting on the use of ward-based (i.e., decentralized) ADDs, including all published randomized controlled trials, observational studies (cohort and case-control), before-and-after studies, time series analyses, cost-effectiveness or cost-benefit analyses, and review articles, were considered for inclusion. Unpublished studies were not considered, as these



have not undergone peer review or review of any kind. Studies must have investigated and reported on one or more of the following outcomes of interest: medication error rates, efficiency (time, staffing, workload, etc.), or costs.

Exclusion Criteria

Because the objective of this analysis was to evaluate the benefit of ward-based ADDs relative to traditional manual medication-dispensing processes (including centralized unit-dose systems), studies evaluating pharmacy-based ADDs, such as bar code-based medication dispensing carousels, automated dispensing shelves, and combinations of various automated dispensing modalities, were excluded. Studies comparing one type of ADD with another were excluded, as were those evaluating the same ADD implemented on different hospital wards.

Analysis

Two reviewers (N.W.T., C.L.) independently screened all relevant abstracts and full-text articles for inclusion, resolving any disagreements by discussion. For each full-text study included in the analysis, the same 2 reviewers independently extracted data for the following variables: title, authors, and year of publication; study type; sample size; inclusion and exclusion criteria; interventions; outcomes; and results. Results were categorized according to the outcomes of interest (medication error rates, efficiency, and cost). We were unable to

contact the authors of any of the studies for additional data. All included studies were critically appraised for internal validity and generalizability; any issues affecting the results are considered in the Discussion section, below.

RESULTS

A total of 175 unique records were identified, of which 145 were excluded at the abstract review stage (Figure 1). Two studies identified through manual searching of other articles' reference lists were included for full-text review. In total, 32 full-text articles were reviewed, 24 of which were subsequently excluded. Therefore, a total of 8 studies were included for evidence synthesis: 6 prospective before-and-after studies, 1 time flow study, and 1 randomized controlled trial (RCT). Characteristics of the included studies are summarized in Table 1.⁷⁻¹⁴ ADDs had been implemented in ICUs, general medicine wards, surgical units, or a combination of these locations within the study hospitals. All studies were conducted in the United States, except for one study that was performed in France. The duration of the studies ranged from 14 days to 9 months, and all were published between 1992 and 2010.

Medication Error Rates

Five of the 8 included studies examined differences in medication error rates, albeit with various approaches and

Table 1. Characteristics of Studies Included in a Systematic Review of ADDs (part 1 of 2)

Reference	Design	Duration	Population and Inclusion/Exclusion Criteria	Intervention
Lee et al. ⁷ (1992, United States)	Prospective before- and-after study	6 months	2 nursing stations (general medicine and surgical unit) at Riverside Methodist Hospital (1000-bed tertiary care referral hospital) Exclusion criteria not stated	Traditional distribution system with locked narcotic cabinets (accessible with key) versus ADDs (Pyxis Medstation Rx) containing controlled and uncontrolled medications, as well as IV solutions (dextrose and saline)
Borel and Rascati ⁸ (1995, United States)	Prospective before- and-after study	About 2 months before and 2 months after implementation (total duration 4 months)	3 units at Baylor Medical Center, Garland, Texas (600-bed teaching hospital) Unit A: orthopedic unit with 2 ADDs and full-time pharmacist Unit B: medical-surgical unit with ADDs in 2 small medication rooms with order entry from central pharmacy Unit C: medical-surgical unit with decentralized order entry (pharmacist entered orders from room near nurses' station) Exclusion criteria not stated	Traditional unit-dose exchange carts and ADDs for narcotics and ward stock (phase 1) versus ADD (Pyxis Medstation Rx) containing most medications (phase 2) Override function available for drugs needed immediately (new orders)
Ray et al. ⁹ (1995, United States)	Prospective before- and-after study	1.5 months before and 1.5 months after implementation (total duration 3 months)	1 adult medicine unit at UCSD Medical Center Exclusion criteria not stated	Traditional centralized unit-dose system with 24-h cassette exchange versus ADD (Pyxis Medstation Rx) containing as many medications as possible (95% of most commonly prescribed drugs)
Schwarz and Brodowy ¹⁰ (1995, United States)	Prospective before- and-after study	Medication errors: 6 months before and 3 months after implementation (total duration 9 months) Missing doses: 2 months before and 2 months after implementation (total duration 4 months)	560-bed teaching hospital Exclusion criteria not stated	ADD (Pyxis Medstation) implemented first in emergency department (October 1992), then in PACU, two 36-bed surgical units, and one 8-bed ICU (April 1993) In emergency department and PACU, ADD contained all medications; in other units ADD was used for narcotics and PRN drugs only UCSF was also beta test site of a second-generation Pyxis machine called Medstation Rx (implemented in 36-bed SICU and 8-bed CICU) Nurses were initially allowed to use override function Pharmacists dispensed 12-h supply of drugs not available in ADD and report was run every 12 h to determine drugs required but not stocked versus Unit-dose cassette system

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Table 1. Characteristics of Studies Included in a Systematic Review of ADDs (part 2 of 2)

Reference	Design	Duration	Population and Inclusion/Exclusion Criteria	Intervention
Guerrero et al. ¹¹ (1996, United States)	Prospective before-and-after study	7 days before and 7 days after implementation (total duration 14 days)	Two nursing units (SICU and general medicine) at University of Utah Health Sciences Center, Salt Lake City (400-bed teaching hospital) Exclusion criteria not stated	Unit-dose cart filling and centralized IV admixture service with decentralized pharmacies Centralized pharmacy with ADDs (Baxter Sure-Med system) dispensing all scheduled medications on the patient's profile
Wise et al. ¹² (1996, United States)	Time flow study	Unclear (2–3 months before and after implementation)	Two 26-bed medical units at Stanford Health Center Exclusion criteria not stated	Two ADDs (Pyxis Medstation) implemented in each unit, carrying 90% of all medications; medical units already had 3 years' experience with ADDs for dispensing narcotics
Shirley ¹³ (1999, United States)	Prospective single-blind, before-and-after study	2 weeks before and 1 month after implementation (total duration 1.5 months)	First medication ordered and administered after patient's admission to 1 of 11 nursing units (obstetrics, pediatrics, hospice, progressive care, 2 critical care and medical–surgical care units) at Mercy Hospital, Scranton, Pennsylvania (270-bed tertiary care facility) Inclusion criteria: data available for patient number, patient room number, admission date and time, time order was written, medication administration schedule, and time of administration Exclusion criteria: omitted oral medications other than first medication given, IV medications, single-dose medications (not stored in ADD), all medication courses that did not fully meet the inclusion criteria, medications administered late because of pharmacotherapy change	Traditional unit-dose cassette exchange and pneumatic tube system ADD (Pyxis Medstation Rx 1000) storing all unit-dose medications and highly used premixed IV drugs; medications not stored in ADD were delivered via pneumatic tube
Chapuis et al. ¹⁴ (2010, France)	Randomized controlled trial	4 months	68 nurses caring for 115 patients in 2 medical ICUs (8 and 10 beds, respectively) in same department, covered by same staff, at Grenoble University Hospital (2000-bed university hospital) Exclusion criteria not stated	ADD (Omnnicell) was implemented in one ICU; other ICU used traditional floor stock distribution system (control) ADD reloaded daily, except on weekends, when drugs were dispensed conventionally

ADD = automated dispensing device; CICU = cardiac intensive care unit; ICU = intensive care unit; PACU = post-anesthesia care unit; PRN = as needed; SICU = surgical intensive care unit; UCSD = University of California, San Diego; UCSF = University of California, San Francisco.

definitions.^{8,9,10,13,14} Four of these studies employed a prospective before-and-after design, whereby data were collected for a specified period before and after ADD implementation.^{8,9,10,13} The fifth study was a 4-month RCT reporting the impact of ADDs on medication error rates at a university hospital in France.¹⁴ This was the only study comparing error rates of ADDs with error rates for a traditional floor stock drug distribution system. All other studies took place at hospitals that used unit-dose cassette systems.

Borel and Rascati⁸ conducted a prospective before-and-after study at a teaching hospital in Garland, Texas. They implemented ADDs in 3 units of the hospital and compared ADDs with the existing unit-dose cassette system via direct observation. Observers watched nurses enter data on the ADD screens and remove the medication doses; observers also verified whether the correct drug was selected for the correct patient and whether the drug was given. Observers also checked the medication administration records (MARs) to verify that the correct dose was given and recorded the time of administration. Omission errors were recorded if examination of the MAR revealed that a prescribed drug had been missed. The overall error rate, defined as the number of errors divided by the number of observations, was reduced following implementation of the ADDs, from 17.0% (148/873) to 10.4% (97/929) ($p = 0.001$). This reduction was driven by a 73% relative reduction in omission errors, from 4.1% (36/873) to 1.1% (10/929). However, it is not known whether errors classified as omission errors actually represented delayed doses, with the medication being given at a time when the nurses were not being observed. Wrong-time errors were most prevalent, at 10.4% (91/873) before and 8.4% (78/929) after ADD implementation. Mean deviations from scheduled medication administration times were 34.5 min (standard deviation [SD] 48.9 min) before and 30.1 min (SD 31.6 min) after ADD implementation ($p = 0.03$). Little difference was found for errors related to wrong dose, wrong dosage form, unauthorized drug, wrong route, wrong rate, wrong preparation, or extra doses.

Ray and others⁹ conducted the only study examining error rates for stocking of medications by pharmacy technicians before and after implementation of ADDs at a medical centre in San Diego, California. For 6 weeks before conversion to ADDs, pharmacists checked unit-dose cassettes after technicians had filled them and recorded the number of errors found. Then, for 6 weeks after ADD implementation, pharmacists similarly checked medications in the ADDs after technicians had stocked them and recorded the number of errors found. Error rates, in terms of percentage of doses dispensed, were significantly lower with ADDs than with unit-dose cassettes (0.61% versus 0.89%, $p = 0.04$).

Schwarz and Brodowy¹⁰ studied the impact of implementing ADDs in a surgical ICU and a cardiac ICU at the University of

California, San Francisco Medical Center, relative to unit-dose cassette systems. They analyzed the type and frequency of medication errors from incident reports for 6 months before and 3 months after ADD implementation. They found that the mean number of errors per month decreased in the surgical ICU, from 6.5 (SD 2.6) before to 4.3 (SD 2.3) after ADD implementation, but increased in the cardiac ICU, from 1.0 (SD 1.3) to 1.7 (SD 0.6). Schwarz and Brodowy¹⁰ noted that their results were not interpretable because of data contamination introduced by a new pilot error-reporting form, which increased medication errors by 30% in 7 nursing units (including the surgical and cardiac ICUs). They did find that ADDs were associated with a reduction in the mean rate of missing doses, from 13.8/day (SD 7.1) to 3.3/day (SD 3.4) in the surgical ICU and from 33.8/day (SD 3.0) to 1.2/day (SD 1.5) in the cardiac ICU ($p < 0.05$ for both).

Shirley¹³ investigated 11 nursing units in a tertiary care hospital in Pennsylvania that switched from unit-dose cassette systems to ADDs. Data were collected on medication administration time for the first orally administered medication after each patient's admission to a nursing unit. The author found that after ADD implementation, the proportion of medications administered on schedule increased from 59% to 77%. Mean deviation between scheduled and actual medication administration times improved from 129.84 min to 101 min, but this change was not statistically significant ($p = 0.157$). In an attempt to conduct a single-blind study, the author obtained actual medication administration times from a chart review, not by direct observation.

Chapuis and others¹⁴ conducted a 4-month RCT involving implementation of an ADD in one ICU and usual practice (traditional floor stock drug distribution system) in another ICU (control) within the same department of a 2000-bed university hospital. The primary outcome of this study was total error rate, defined as percent total opportunities for error (calculated by dividing the number of drugs associated with one or more errors by the number of drugs ordered). Secondary outcomes included percent of detailed opportunities for error and percent of storage errors. Detailed opportunities for errors were defined as any gesture or action by a nurse that could result in the following types of errors: (1) picking errors (wrong name, dosage, or pharmaceutical form); (2) preparation errors (wrong dose, solvent type, or volume for reconstitution, or wrong mixtures); (3) administration errors (wrong technique, route, rate, or administration time more than 1 h before or 1 h after the expected time; physicochemical incompatibility); (4) omissions; and (5) extra doses. These authors found that total error rates differed significantly between the control and study units after implementation of the ADD (18.6% versus 13.5%, $p < 0.05$), whereas no difference was found before ADD implementation. Total error rates in the intervention unit were

20.4% before and 13.5% after implementation ($p < 0.01$), a decrease of 6.9 percentage points (compared with a decrease of 0.7 percentage points in the control unit). Wrong-dose errors declined from 3.8% to 0.5% ($p = 0.017$); however, no difference was found in picking and administration errors, including wrong-time errors, omission errors, or extra doses given. There were 14.4% fewer storage errors in the study unit than in the control unit ($p < 0.01$).

Efficiency

Five of the 8 studies investigated the impact of ADDs on various efficiency outcomes.^{7,9,10-12} Most of the studies looked at differences in the time that pharmacists, pharmacy technicians, and nurses spent performing medication-related activities. The methods of measurement were relatively consistent among the studies, with all but one study collecting data by direct observation of time spent on defined activities by various personnel.

Nurses' Time

Implementing ADDs for narcotics and controlled substances clearly resulted in a reduction in nurses' time for certain activities. For example, Schwarz and Brodowy¹⁰ found that implementation of ADDs reduced the mean time that nurses spent on acquisition of a single narcotic dose from 107 s (SD 106 s) to 48 s (SD 23 s). Time spent taking inventory of controlled substances also decreased, from 5.04 h/week to 0.36 h/week.¹⁰ However, the results were less clear with respect to all other medications. Lee and others⁷ documented the time that nurses spent on various activities before and after ADD implementation, specifically medication-related activities (including preparation of medications stored as floor stock, controlled substances, unit-dose medications, and IV admixtures); charting or documentation; interaction with patients; interaction with other personnel; and miscellaneous activities. After implementation of ADDs, the proportion of nurses' time spent on medication-related activities decreased from 10.2% to 5.6% ($p < 0.05$) and time spent on charting or documentation decreased from 28.0% to 16.9% ($p < 0.05$).⁷ Conversely, time spent on interaction with patients increased from 20.0% to 28.6% ($p < 0.05$). There was no change in time spent interacting with other personnel (20.5% versus 22.5%). The results of 2 other studies^{11,12} were conflicting. Wise and others¹² observed that nurses' time required to gather medications increased by an average of 2.3 min/day, with this increase being offset by a decrease in medication administration time of 6.7 min/day. They also found that nurses' total travel time during a shift was reduced from 20.2 min to 6.34 min as a result of ADD implementation. However, in a self-report work sampling study, Guerrero and others¹¹ found that ADDs had no impact on the time that nurses spent performing medication-related activities.

Pharmacy Technicians' Time

In the study by Lee and others,⁷ the time that pharmacy technicians spent stocking all medications other than narcotics increased significantly after ADD implementation, from a mean of 7.17 min (SD 1.63 min) to a mean of 48.96 min (SD 8.77 min) per nursing unit. However, there was no change in the time required to stock narcotic drugs. Wise and others¹² found that ADD implementation resulted in an average increase of 5 min/day in the time required for technicians to fill the ADDs. Any post-implementation efficiencies for technicians' time were related to time spent on billing. Lee and others⁷ reported a decrease in time spent on billing for controlled substances, from a mean of 7.15 min (SD 6.97 min) to a mean of 1.36 min (SD 0.64 min). Schwarz and Brodowy¹⁰ corroborated this result, reporting that ADDs completely eliminated time spent on billing by pharmacy technicians (reductions of 13 min [SD 16.1 min] in the surgical ICU and 8.6 min [SD 2.2 min] in the cardiac ICU).

Pharmacists' Time

Three studies examined changes in time that pharmacists spent on various activities after ADD implementation. Wise and others¹² found a reduction of 40 min/day in pharmacists' time required to check unit-dose cassettes or ADDs. Guerrero and others¹¹ reported no change in pharmacists' time spent performing distribution activities that, by law, only a pharmacist can do; however, they observed an increase in time spent on clinical activities because of a reduction in time spent on technical functions. Ray and others⁹ reported that a year before ADD implementation, 25% of clinical pharmacists' time was spent resolving drug distribution problems, whereas 3 years after implementation, this activity occupied only 5% of their time.

Ray and others,⁹ whose study was sponsored by an ADD vendor, described a separate study in which they found that the average waiting time for the first dose of a new medication declined from 45 min with the traditional system to 1 min with the ADD; in addition, the number of phone calls to the pharmacy was reduced by 90%. However, Ray and others⁹ provided no details as to how the study was conducted or whether the data were reliable.

Costs

All 3 of the studies that examined "cost-effectiveness" or cost offsets after ADD implementation reported positive results.^{7,10,12} It appeared that increases in charge capture rates and overall decreases in personnel time were the factors primarily responsible for cost offsets in implementing ADDs. Improved charge capture allows the hospital to bill for a larger proportion of medications used, thus increasing revenues.

Lee and others⁷ found that ADD implementation increased the mean charge capture rate from 63% to 97% for floor stock medications, IV solutions, and IV sets in patient care units. These authors estimated that an additional \$250 000 annually would be generated as a result of the ADDs; when the costs of implementation, maintenance, and technician time (total of about \$215 000 annually) were taken into account, a net of \$35 000 was expected (in 1992 US dollars). Schwarz and Brodowy¹⁰ determined that the economic benefits of ADDs over unit-dose cassette systems stemmed from the ability of ADDs to reduce overall personnel time. They estimated reductions of 0.8 pharmacist full-time equivalents (FTEs), 2.6 pharmacy technician FTEs, 1.2 pharmacy billing technician FTEs, and 3.0 nurse FTEs, for a total savings of \$2.08 million over 5 years (1994 US dollars). Wise and others¹² estimated that a net gain of 230 h/year of nurses' time attributable to ADDs would generate cost savings of \$8053/year (1994 US dollars). The per-shift reduction in total travel time for nurses equated to savings of \$25 471/year, and the reduction of pharmacists' time equated to savings of \$8807/year.¹² Along with the increase in charge capture rates, these authors concluded that an annual net saving of \$80 910 could be realized, after the rental costs of ADDs (about \$27 780 annually) were taken into account.¹²

DISCUSSION

To the authors' knowledge, this is the first systematic literature review to summarize the clinical and economic evidence comparing decentralized ADDs with traditional manual medication dispensing processes in the hospital setting. Because of heterogeneity in study designs and outcomes reported, it was not possible to perform a quantitative synthesis of the evidence. Also, many of the studies employed a before-and-after design with direct observation of time that personnel spent on various activities (work sampling), but this type of design has potential biases, such as the Hawthorne effect,¹⁵ the extent of which could not be ascertained.

Table 2 summarizes the overall impact of ADDs on medication errors. In particular, ADDs were effective in reducing storage errors. Pharmacy technician's errors in filling the ADDs were also reduced relative to errors in filling automated unit-dose cassettes.^{9,14} However, this outcome is highly institution-specific; for example, it may depend on the number and types of medications that an institution decides to store in the ADDs or on the drug distribution process used at the institution before ADD implementation. Furthermore, Chapuis and others¹⁴ were the only authors who assessed the severity of medication errors observed. They found no difference in errors causing harm or death, although this finding was likely due to a sample size that was insufficient to reject the null hypothesis.¹⁴

The ability of ADDs to reduce nurses' time with respect to distribution of narcotics and controlled drugs was evident and

generally accepted. However, results were inconclusive with respect to other medications. Lee and others⁷ and Schwarz and Brodowy¹⁰ reported that nurses' time was reduced; Wise and others¹² found that time to gather medications was offset by decreased time for medication administration; and Guerrero and others¹¹ found no changes. It remains unclear why ADDs would have any effect on the time taken by nurses for medication administration. Additionally, the number of ADDs implemented in each ward would directly affect nurses' time; ideally, enough machines should be installed to avoid a bottleneck in the overall workflow. Pharmacists' time spent performing technical distribution activities was decreased, while time spent in clinical work appeared to increase, though the strength of this evidence was questionable, with little detail being reported about the magnitude and statistical significance of these differences.^{9,11,12} In addition, the potential benefit of this observation may no longer be applicable in today's practice setting and the future, as the scope of practice for pharmacy technicians continues to increase.

ADDs were very effective in increasing charge capture rates and decreasing the time that pharmacy technicians spent on billing.^{7,12} As such, this technology was reported to be cost-effective or cost-saving. It appears that ADDs increase the accuracy of tracking inventory levels and medication usage per patient, which allows hospitals to accurately bill patients or payers for reimbursement.¹⁶ This particular aspect of the hospital system does not exist in the Canadian setting, and these economic findings are therefore not generalizable to Canadian hospitals. In a recent systematic review, CADTH looked at all automation technologies intended to reduce errors in dispensing and administration of medications in hospitals.⁶ Except for the inclusion of unpublished data from one ADD vendor, the clinical and cost outcomes in the CADTH review were taken from studies included in the current review and were used to inform an economic model with 2008 Canadian prices applied.⁶ In its base-case analysis, CADTH determined that ADDs in medical and surgical units resulted in cost savings of \$128 000 to \$152 000 over 5 years, whereas ADDs in ICUs led to cost increases ranging from \$76 000 to \$100 000 over 5 years.⁶ According to this analysis, the cost savings associated with ADDs were driven largely by reductions in nurses' and pharmacists' time. Because ICUs had fewer patients taking fewer medications, the scale of cost savings from reduced personnel time were not enough to offset the costs of implementation, planning, and equipment related to the ADDs.⁶ CADTH made an effort to extrapolate evidence from the literature to the Canadian setting; however, lack of reliable data remained a caveat.⁶ Because the current study included only published, peer-reviewed literature, we were unable to confirm the data that CADTH used in its economic analysis.

The current study had a few limitations. We were unable to assess publication bias in the literature, as most of the studies

Table 2. Summary of Impact of ADDs on Medication Errors (part 1 of 2)

Type of Error	Study Results	Interpretation	Overall Conclusion
Omission	Borel and Rascati ⁸ : decrease from 4.1% (36/873) to 1.1% (10/929); relative reduction 73% Chapuis et al. ¹⁴ : no effect	In Borel and Rascati study, ⁸ omission errors were recorded if administration had not been documented by the time observers checked medication administration records; not known if these drugs were given at a later time	ADDs have no impact on omission errors.
Wrong time	Borel and Rascati ⁸ : mean deviation from scheduled administration times 34.5 min (SD 48.9) before and 30.1 min (SD 31.6) after implementation ($p = 0.03$) Shirley ¹³ : mean deviation between actual and scheduled administration times improved from 129.84 min to 101 min ($p = 0.157$) Chapuis et al. ¹⁴ : no effect	Mean reduction in wrong-time errors of 4.4 min in the Borel and Rascati study ⁸ was statistically significant but not clinically significant. Shirley ¹³ found a mean difference of 28.84 min, but this was not statistically significant. A time difference of this magnitude also would not have been clinically significant in the majority of cases. Chapuis et al. ¹⁴ found that ADDs had no impact on timing errors in the ICU.	ADDs have no impact on wrong-time errors.
Wrong dose	Borel and Rascati ⁸ : no effect	No interpretation required	ADDs have no impact on wrong-dose errors.
Wrong preparation or dosage form	Borel and Rascati ⁸ : no effect Chapuis et al. ¹⁴ : no effect	No interpretation required	ADDs have no impact on wrong-preparation or wrong-dosage-form errors.
Unauthorized drug	Borel and Rascati ⁸ : no effect	No interpretation required	ADDs have no impact on unauthorized-drug errors.
Wrong route	Borel and Rascati ⁸ : no effect	No interpretation required	ADDs have no impact on wrong-route errors.
Extra dose	Borel and Rascati ⁸ : no effect Chapuis et al. ¹⁴ : no effect	No interpretation required	ADDs have no impact on extra-dose errors.
Missing doses	Schwarz and Brodowy ¹⁰ : decrease in mean number of missing doses from 13.8/day (SD 7.1) to 3.3/day (SD 3.4) in surgical ICU and from 33.8/day (SD 3.0) to 1.2/day (SD 1.5) in cardiac ICU	Error rate determined by review of missing-medication forms sent to pharmacy; pharmacy would then send medications to unit, resulting in no patient harm.	Implementation of ADDs containing all medications will reduce the number of missing-medication forms being sent to pharmacy.
Pharmacy technician filling error	Ray et al. ⁹ : decrease relative to unit-dose cassettes (0.61% versus 0.89%, $p = 0.04$)	Reduction was believed to be a result of fewer medications from which technicians had to select when stocking ADDs, since type of medications in ADDs does not change (whereas any medication might be required when preparing unit-dose cassettes).	Technician filling errors may be reduced, depending on system design before and after ADD implementation; this result will be institution-specific.

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Table 2. Summary of Impact of ADDs on Medication Errors (part 2 of 2)

Type of Error	Study Results	Interpretation	Overall Conclusion
Preparation error	Chapuis et al. ¹⁴ : decrease from 3.8% to 0.5% ($p = 0.017$) in a medical ICU	During direct observation, Chapuis et al. ¹⁴ found a reduction in errors related to the preparation of medications after implementation of ADDs. Exact definition of preparation errors was not given, but there is no reason that ADDs should influence nurses' preparation of medications, especially given that the same study showed no difference in picking errors.	Inconclusive
Storage error	Chapuis et al. ¹⁴ : decrease by 14.4% ($p < 0.01$)	This was the only study that assessed storage errors; although it was conducted in the ICU, there is no reason to think this benefit would not be seen in other patient care units.	The use of ADDs will reduce storage errors.

ADD = automated dispensing device; ICU = intensive care unit; SD = standard deviation.

pertaining to the research question were small, unregistered observational studies. In addition, no studies were excluded on the basis of quality. Because only 8 publications were relevant to the research question and most were published in the 1990s, excluding studies because of quality would have rendered insufficient data for evidence synthesis. Nevertheless, studies of new technologies rarely involve randomized controlled trials but are usually observational, akin to the majority of studies included in this review. Finally, we were unable to contact the authors of included studies for clarification or additional data. Nevertheless, the literature search was thorough and robust, and detailed data were extracted from each study and then synthesized to arrive at the most appropriate conclusions.

CONCLUSION

This review has shown that ADDs have the potential to decrease storage errors and pharmacy technician filling errors, while increasing the amount of time that technicians spend on stocking activities. The ability of ADDs to reduce nurses' time spent on distribution of narcotics and controlled drugs was evident and generally accepted. However, results were inconclusive with respect to other medications. There was no definitive evidence that ADDs increased the time that nurses or pharmacists spent with patients, reduced medication errors resulting in patient harm, or reduced costs in Canadian hospitals. Before deploying this technology, it is recommended that Canadian hospitals carefully examine their current systems and the benefits they hope to gain with the change.¹⁷ Until evidence exists, hospitals must make institution-specific decisions on how to properly configure and integrate ADDs into their workflow.^{5,17} With the rapid uptake of ADDs, this area requires additional study, since the improper management of ADDs is believed to jeopardize patient safety.^{5,17} Also, more longitudinal studies are required to capture less common medication errors causing patient harm or death. Finally, the downstream costs and implications of medication errors avoided as a result of ADDs should be investigated and used to inform a more robust economic analysis.

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Appendix 1. Search Strategy for Ovid MEDLINE In-Process and Other Non-Indexed Citations and Ovid MEDLINE, 1946 to present

Search	Search Term	No. of Items Returned
1	automated dispensing device.mp.	3
2	automated dispensing cabinet.mp.	12
3	automated dispensing machine.mp.	3
4	drug distribution system.mp.	132
5	(Pyxis or Medstation).mp.	24
6	Omniceil.mp.	0
7	1 or 2 or 3 or 4 or 5	173
8	limit 7 to (english language and yr="1992 – 2012")	71