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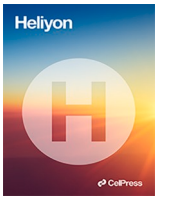

Effect of an automated dispensing cabinet system on drug distribution effectiveness in a surgical unit

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ABSTRACT

The use of the automated dispensing cabinet (ADC) for drug distribution in hospitals has become increasingly common and has numerous benefits.

This retrospective study assessed the effectiveness of an ADC that uses integrated information technology in the drug distribution process in a surgical unit as part of a smart medical process improvement project at Taichung Veterans General Hospital in 2019. The outcomes include medicine delivery time, working time of healthcare professionals, transportation manpower, dispensing errors, and satisfaction of nursing staff with the medication distribution process. After ADC implementation, the average waiting time of standing orders decreased significantly for both on and off duty periods (40.0 ± 27.6 to 3.0 ± 3.9 min, $P < 0.001$; 45.2 ± 25.8 to 2.9 ± 2.9 min, $P < 0.001$; respectively). Similar results were observed with immediate or temporary medication orders (54.4 ± 31.5 to 2.0 ± 3.0 min, $P < 0.001$; 64.0 ± 47.5 to 1.5 ± 1.8 min, $P < 0.001$; respectively). The average time spent by operation room and post-operation room (OR/POR) nurses on communicating with ward nurses for medication delivery to OR/POR was shortened by 46.9 ± 4.4 h per month, and the average time pharmacists spent on dispensing immediate or temporary medication orders was shortened by 5.6 ± 0.2 h per month. The satisfaction of nursing staff with the OR/POR drug delivery process was significantly improved after ADC implementation (3.2 ± 0.8 vs 4.2 ± 0.7, $P < 0.001$).

Our results showed that ADC implementation in surgical units simplified drug delivery processes, shortened drug delivery time, improved drug delivery timeliness for surgical patients, decreased dispensing errors, and increased nursing staff satisfaction. In conclusion, the implementation of ADC was beneficial for surgical units. To the best of our knowledge, there have been no studies on a similar ADC system.

1. Introduction

Improving medical efficiency and patient safety is a major concern for hospitals. Most hospitals in the United States use automated dispensing cabinets (ADC) for dose distribution. The use of ADCs in hospitals increased from 22.3 % in 2002 to 74.5 % in 2020 [1]. ADCs provide a number of benefits, such as improved efficiency among pharmacy and nursing staff, cost containment, and reduced

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medication errors [2–10]. In 2017, an ADC (TouchPoint Medical Inc, Odessa, Florida, USA) was implemented for the first time in a pilot surgical intensive care unit in our hospital, Taichung Veterans General Hospital (TCVGH), in Taiwan [11]. The ADC markedly shortened the average waiting time of nursing staff (from 83.1 ± 39.6 to 4.0 ± 11.2 min per prescription), reduced erroneous delivery events, and unused drug returns [11]. This ADC was the first real-time medication management system implemented in Taiwan. It consists of an intelligent medicine cabinet, which integrates the doctor's instructions, prescription evaluation, drug dispensation, and administration in the surgical intensive care unit [11]. It effectively reduced delivery errors caused by prescription changes, shortened the waiting time for emergency medication, and increased nurse satisfaction. Inspired by the implementation of an ADC in our hospital, other hospitals in Taiwan gradually introduced ADCs and have published related studies [6,7]. Owing to this successful experience, nursing staff requested to have an ADC set up in the surgical unit to facilitate drug delivery to patients and prevent errors.

TCVGH is a public medical center in central Taiwan with 1600 beds. The surgical unit includes an operation room (OR) and a post-operation room (POR). The OR has 24 suites, and a multidisciplinary team provides patient care during surgical interventions. In 2019, the average number of operations was 140 per working day. The surgical unit within the hospital requires urgent drug administration. Prior to the use of an ADC, when a patient was transferred from the ward to the OR and to the POR after surgery, medications were sent to the OR/POR from the pharmacy or wards before the patient returned to the ward. This process was time- and labor-consuming and caused quality-related problems, such as drug damage during transportation, which affected the immediacy and safety of the patients'

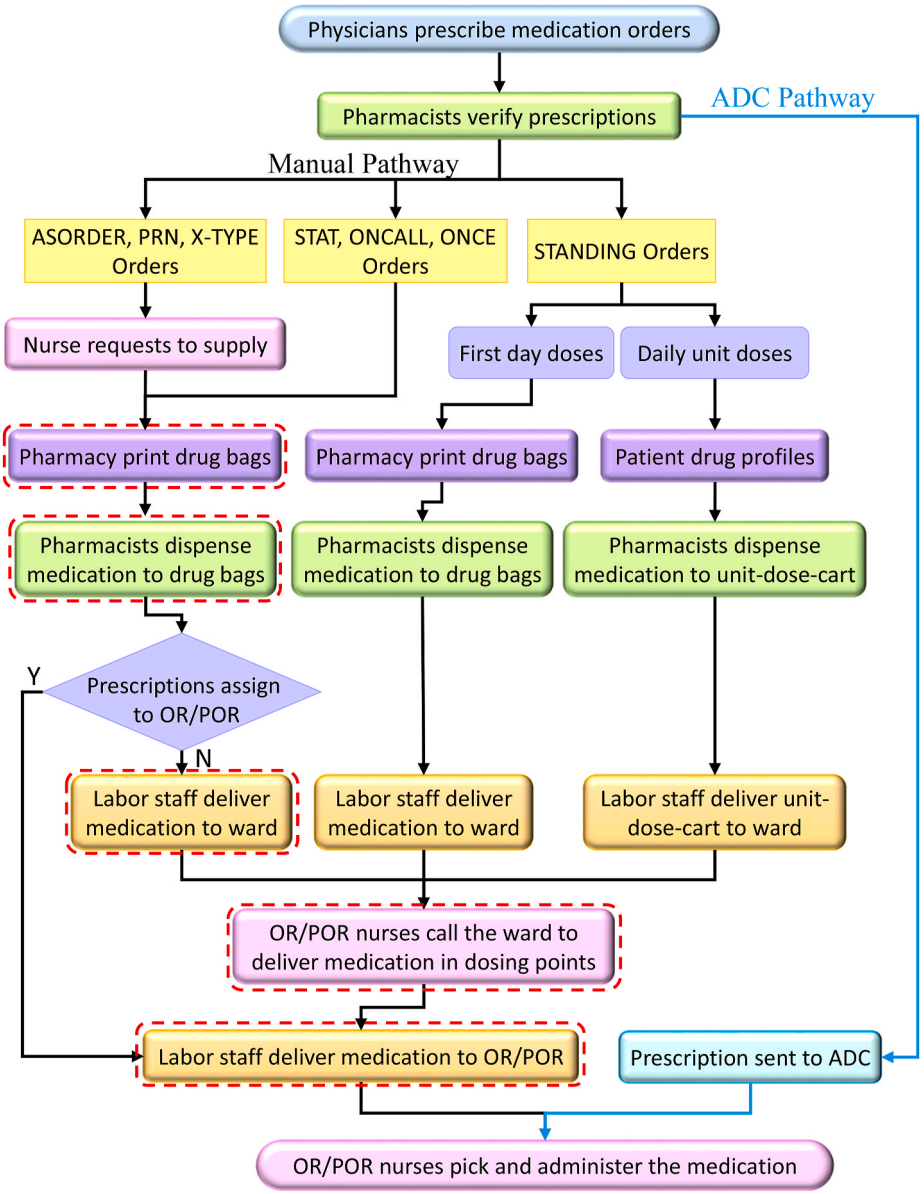

Fig. 1. Drug delivery processes in the surgical unit: Manual Pathway vs. ADC Pathway.

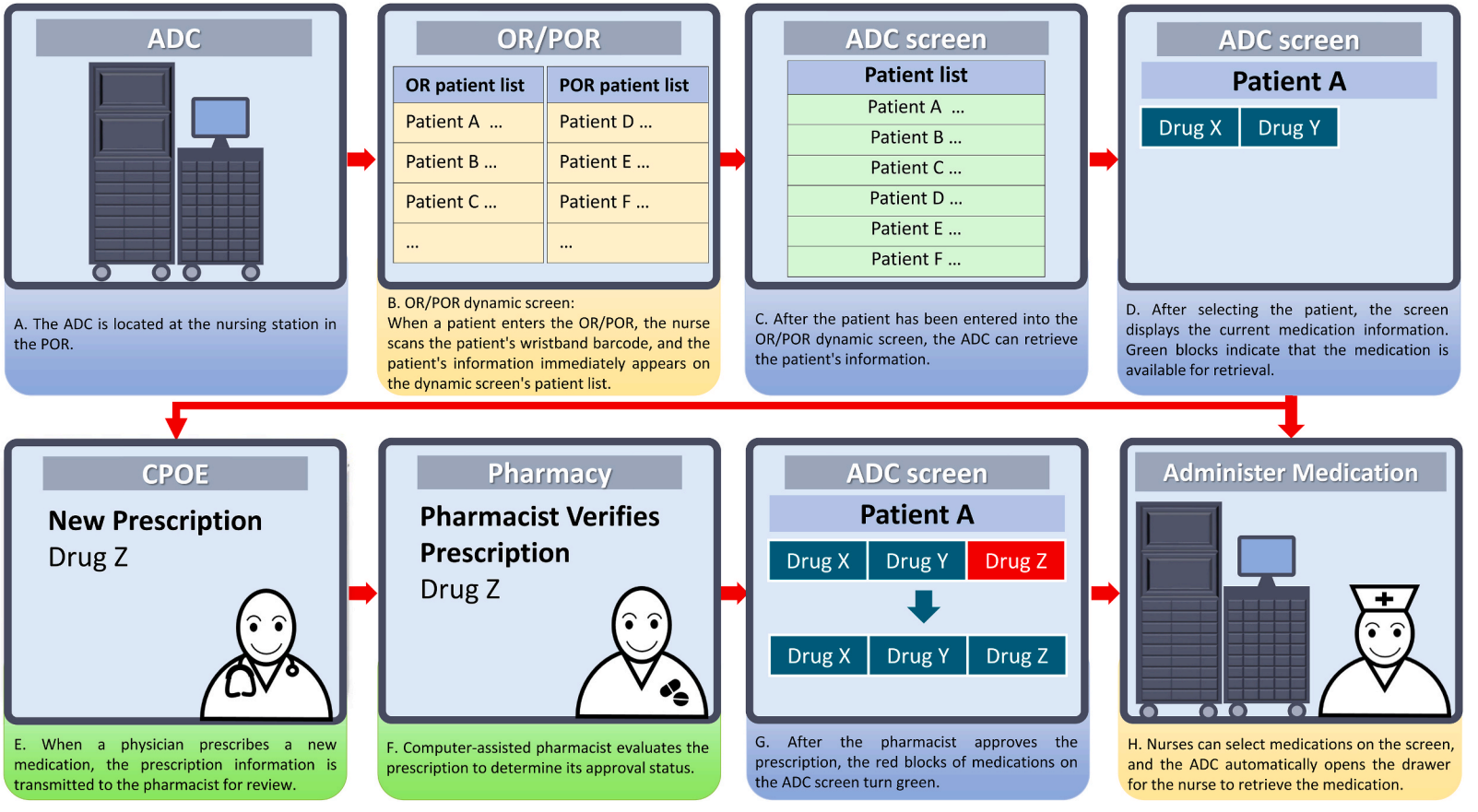

Fig. 2. The operational workflow of ADC in the OR/POR.

medications. Therefore, a project aimed at improving the smart medication system in surgical units was carried out between October 2018 and March 2020 using the lean thinking method [12].

The American Society of Health-System Pharmacists (ASHP) recommended [13] that ADCs in nursing units be profiled to address safety concerns. However, profiling medications in the perioperative unit may be challenging owing to the high patient turnover. Although ADC application is widespread in hospitals in the United States, its implementation in Taiwan is still in its early stages. Taiwanese hospitals usually have ADCs installed in intensive care units, general wards, emergency rooms, and chemotherapy rooms. Few studies have focused on its implementation in Taiwan hospitals [6,7], particularly in surgical units. This study aimed to evaluate the impact of ADC implementation on the medication distribution process in surgical units.

2. Materials and methods

2.1. Data source and ethical considerations

This was a retrospective study that analyzed the effectiveness of the smart medical process improvement project implemented by the Department of Pharmacy at TCVGH in 2019. It was approved by the Institutional Review Board of TCVGH and met the criteria for review exemption according to the human subject protection regulation (CW21271A).

2.2. Lean thinking application

The OR/POR is a complicated and dynamic time-critical environment. The OR has a pharmacy from which narcotics and anesthesia trays are obtained for each surgical operation. Apart from medications provided by the OR satellite pharmacy, when patients in OR/POR need other medications, they are divided into several categories based on the type of prescription: (a) immediate medication orders, (b) temporary medication orders, and (c) standing orders. The delivery process (manual pathway) is shown in Fig. 1; this pathway is clearly time-consuming.

The project utilized the Elimination-Combination-Rearrangement-Simplification method, which is based on a lean thinking approach to identify and remove unnecessary operational steps. The steps were then simplified in the future distribution process, as shown in Fig. 1. In total, five steps related to pharmacist dispensing, nurse calling, and labor staff delivery were deleted.

2.3. Automatic dispensing cabinet implementation process

A team constituting the departments of pharmacy, nursing, and information technology was recruited to implement the ADC project starting in August 2018. The process consisted of program writing, program rule confirmation, and drug item analysis. The ADC system was officially posted online in July 2019.

The TouchPoint ADC system was deployed at the POR station, with a stock of 72 drug items, accounting for approximately 95 % of the prescription medications for surgery patients during their stay in the OR/POR. After patient information is inputted into the OR/POR dynamic screen, the system assigns each patient a virtual and dynamic bed number. The ADC integrates the inpatient and outpatient information systems to accurately determine the patient's status and then initiates the relevant medication access rules.

The ADC system was also integrated into the computerized physician order entry (CPOE) system. Whenever a new prescription was issued, it was transmitted to ADC for the nursing staff to promptly retrieve the medication. To ensure medication safety, pharmacists reviewed and approved all medication orders before a nurse retrieved the medication from the ADC system. The workflow of the ADC is shown in Fig. 2.

2.4. Data collection

The study assessed the effectiveness of ADC implementation with respect to several outcomes, including the waiting time of medicine delivery, working time of healthcare professionals, manpower transportation, patient safety, and satisfaction of nursing staff with the medication distribution process. Drug delivery time was measured before (March 5 to 18, 2019) and after (July 23 to August 5, 2019) ADC implementation. Before ADC implementation, the average time required for drug delivery from the wards to the OR/POR and for immediate or temporary medication assigned to the surgical unit was estimated, as was the time required for delivery from the pharmacy to the OR/POR. After the implementation of ADC, the average time it took for pharmacists to verify prescriptions was estimated.

The time spent by healthcare professionals on dispensing and communicating drug delivery processes of the care unit was evaluated by measuring the work time of each activity performed by healthcare professionals from October to December 2019.

The number of prescription medications taken by the OR/POR nurses from the ADC between October and December 2019 was determined and reflected reduced transportation manpower costs. Patient safety events were obtained from the patient safety reporting system in 2019.

A questionnaire was developed to evaluate the satisfaction of nursing staff with the surgical medication distribution process. The questionnaire comprised 11 items measured on a 5-point Likert scale with scores 5 to 1 representing very satisfied, satisfied, fair, dissatisfied, and very dissatisfied, respectively. The questionnaire was validated by five experts: two pharmacy directors, a pharmacy team leader, the head of nursing, and the nursing supervisor. The questionnaire was revised based on the comments received to reach a consensus in the final version. The validity indicator Scale-Level Content Validity Index was 1.0. The reliability of Cronbach's α was

0.96. The questionnaire was distributed twice to the nursing staff of surgical related wards using Google Forms: before (April 2019) and after (February 2020) the ADC implementation. The questionnaire survey was completed anonymously by the nurses after appropriate oral explanations during the project implementation.

2.5. Statistical analyses

Categorical data were expressed as absolute (n) and relative (%) frequencies. Continuous variables were presented as mean and standard deviation. The Mann–Whitney *U* test was used to compare continuous variables with non-normal distributions. The significance level was set at $P < 0.05$ for all tests. Data analyses were performed using SPSS version 22 (SPSS Inc. Chicago, Illinois, USA).

3. Results

3.1. Reduction in waiting time for medications

We observed a significant reduction in drug delivery time (Table 1). The average waiting time for standing medication was significantly reduced during both on-duty time and off-duty time (40.0 ± 27.6 to 3.0 ± 3.9 min, $P < 0.001$; 45.2 ± 25.8 to 2.9 ± 2.9 min, $P < 0.001$; respectively). The immediate or temporary medications assigned to the surgical unit showed similar results (54.4 ± 31.5 to 2.0 ± 3.0 min, $P < 0.001$; 64.0 ± 47.5 to 1.5 ± 1.8 min, $P < 0.001$; respectively).

3.2. Reduction in working time of healthcare professionals

ADC resulted in reduced working time for nurses and pharmacists (Table 2). The time spent by the OR/POR nurses on communicating with the ward nurses for medication delivery to OR/POR dropped by 46.9 ± 4.4 h per month, and the time spent by pharmacists on dispensing immediate or temporary medications assigned to the surgical unit dropped by 5.6 ± 0.2 h per month.

3.3. Reduction of transporting manpower

From October to December 2019, for drug items taken by nurses from the ADC after pharmacist verification, the frequency of medication delivery for labor staff decreased by an average of 1245 ± 105 standing prescriptions per month and by 1335 ± 50 immediate and temporary prescriptions per month. This reduced the labor cost of transportation significantly (Table 2).

3.4. Dispensing error events

In 2019, TCVGH's patient safety report system recorded 67 adverse drug events. Two of these events (9.1 %) related to the OR/POR occurred before ADC implementation, including one transporting and one dispensing error. After the implementation of ADC in the OR/POR, there were no transporting or dispensing errors.

3.5. Satisfaction with medication distribution process

The numbers of average scores for each question are presented in Table 3. The overall satisfaction of nursing staff with the OR/POR drug delivery process was significantly higher after the ADC placement (item 11, 3.2 ± 0.8 vs. 4.2 ± 0.7 on the 5-point Likert scale, $P < 0.001$), particularly in the delivery of immediate drugs not assigned to the surgical unit and standing order (items 6 and 7, 2.9 ± 1.0 vs. 4.0 ± 0.8, $P < 0.001$; 3.2 ± 0.9 vs. 4.1 ± 0.8, $P < 0.001$ respectively). The score of satisfaction upon reducing the frequency to initiate manual delivery of medicines to the OR/POR was 4.2 ± 0.8. The satisfaction with drug delivery immediacy during both on-work and off-work times increased (items 9 and 10, 3.4 ± 0.8 vs. 4.2 ± 0.7, $P < 0.001$; 3.3 ± 0.8 vs. 4.1 ± 0.7, $P < 0.001$, respectively). Satisfaction was significantly higher in terms of drug dispensing correctness, quality integrity, and delivery. Although patients taking

Table 1
Drug delivery time before and after ADC implementation.

Drug delivery time	On duty time			Off duty time		
	Before	After	*P* value	Before	After	*P* value
Standing medication						
No. of patients	101	308		23	144	
Time from notifying wards by OR/POR nurse to receiving medication, minute, Mean (SD)	40.0 (27.6)	3.0 (3.9)	<0.001	45.2 (25.8)	2.9 (2.9)	<0.001
Immediate or temporary medication						
No. of orders	152	508		215	396	
Time from physician prescribing to OR/POR nurse receiving medication, minute, Mean (SD)	54.4 (31.5)	2.0 (3.0)	<0.001	64.0 (47.5)	1.5 (1.8)	<0.001

Abbreviations: ADC, automatic dispensing cabinet; OR/POR, operation room and post-operation room.
Mann–Whitney *U* Test.

Table 2
Benefits for healthcare professionals after ADC implementation.

Type of healthcare professionals and activities	ADC Mean (SD)	Manual work Mean (SD)	Total Mean (SD)
Nurse			
No. of standing prescriptions per month	1245 (105)	127 (30)	1373 (96)
No. of patients per month	617 (50)	76 (16)	638 (42)
No. of patients whose medicines were all processed by ADC per month	562 (53)	–	562 (53)
Communication time saved in medicine delivery from the ward to the OR/POR[a], h/month	46.9 (4.4)	–	46.9 (4.4)
Pharmacist			
No. of immediate or temporary prescriptions per month	1335 (50)	208 (25)	1543 (35)
Time required for pharmacist to verify ADC prescriptions, h/month	5.6 (0.2)	–	5.6 (0.2)
Time required for medicine dispensation by pharmacist[c], h/month	–	1.7 (0.2)	1.7 (0.2)
Medicine dispensation time saved by pharmacists[d], h/month	5.6 (0.2)	–	5.6 (0.2)
Delivery person			
No. of prescriptions saved on delivery of standing orders per month	1245 (105)	–	1245 (105)
No. of prescriptions saved on delivery of immediate or temporary orders per month	1335 (50)	–	1335 (50)

a: Calculated based on the average communication time of nurses: 5 min.
b: Calculated based on the average verification time of pharmacists: 15 s.
c: Calculated based on the average dispensing time of pharmacists: 30 s.
d: Calculated based on the average saved dispensation time: 30–15 = 15 s, for pharmacists.
Abbreviations: ADC, automated dispensing cabinet; OR/POR, operation room and post operation room.

Table 3
Nursing staff satisfaction with medication distribution process before and after ADC implementation.

#	Statements	Mean (SD)		*P* value
		Before (n = 53)	After (n = 174)	
1	How satisfied are you with the process of delivering "immediate drug prescription assigned to surgical unit" to the OR/POR?	4.0 (0.8)	4.2 (0.8)	0.09
2	How satisfied are you with the "drug return process" of the OR/POR?	3.5 (0.7)	4.0 (0.8)	<0.001
3	How satisfied are you with the accuracy of "drug dispensation" for the OR/POR prescriptions?	3.5 (0.8)	4.1 (0.7)	<0.001
4	How satisfied are you with "drug delivery accuracy" for the OR/POR prescriptions?	3.6 (0.8)	4.1 (0.8)	<0.001
5	How satisfied are you with the "drug quality (without damage)" of the OR/POR prescriptions?	3.7 (0.7)	4.1 (0.8)	<0.001
6	How satisfied are you with the process of delivering "immediate drug prescription not assigned to the surgical unit" for the OR/POR?	2.9 (1.0)	4.0 (0.8)	<0.001
7	How satisfied are you with the process of delivering "regular drug prescription" for the OR/POR?	3.2 (0.9)	4.1 (0.8)	<0.001
8	How satisfied are you with reducing the frequency to initiate manual delivery of medicines to the OR/POR after ADC implementation?	NA	4.2 (0.8)	NA
9	How satisfied are you with the timeliness of medicine delivery to the OR/POR during on duty time?	3.4 (0.8)	4.2 (0.7)	<0.001
10	How satisfied are you with the timeliness of medicine delivery to the OR/POR during off duty time?	3.3 (0.8)	4.1 (0.7)	<0.001
11	Overall, how satisfied are you with the drug delivery process for surgical patients?	3.2 (0.8)	4.2 (0.7)	<0.001

11 statements on the ADC with a 5-point Likert scale (5 = very satisfied, 4 = satisfied, 3 = fair, 2 = dissatisfied, 1 = very dissatisfied).
Abbreviations: ADC, automated dispensing cabinet; OR/POR, operation room and post-operation room.
Mann–Whitney *U* Test.

medication in the OR/POR led to an increase in the number of drug withdrawals in the unit-dose cart of the ward, nurses' satisfaction with the drug return process improved (item 2, 3.5 ± 0.7 vs. 4.0 ± 0.8, $P < 0.001$). The percentage of satisfaction scores that were ≥ 4 increased from 35.2 % to 80.5 % after ADC implementation.

4. Discussion

Implementing ADC in the OR/POR simplified the drug delivery process. The nurses' waiting time for medication decreased from approximately 1 h for manual delivery to approximately 3 min, a significant improvement, thereby meeting the purpose of immediate administration. The communication time for drug delivery between the OR/POR nurses and the ward staff was reduced by 47 h per month; the dispensing time by pharmacists for immediate or temporary orders was reduced by 5.6 h per month; and the duty load of delivery by labor staff was reduced by approximately 2600 medications per month. The printing of drug bags was reduced by 1335 pieces per month, and the cost of each piece was NT$ 0.72, resulting in a cost-saving of approximately NT$ 960 per month. Our findings on these improvements are consistent with those of previous reports [3–6].

The greatest challenge in regard to this ADC system was the design of information technology (IT). When inpatients or outpatients entered the OR/POR, there was no exclusive OR/POR bed number. The information system could not identify the patients that were in the OR/POR according to their corresponding bed number in the original ward. Instead, we used the virtual and dynamic bed numbers in our operating procedure. The ADC program needed to integrate the inpatient, outpatient, and emergency patient information

systems to accurately determine each patient's status, and then initiate correct medication access rules. When a patient entered the OR/POR, the nurse inputted them into the OR/POR real-time dynamic screen. The ADC then displayed the patient's previous prescription in the ward.

Hence, nurses directly picked medications from ADC at the point of administering medications, and no longer needed to inform the ward to prepare, deliver, and wait for the medications. If physicians needed to prescribe medications other than those provided by the OR pharmacy drug tray, they placed new prescriptions through the CPOE system. The nurse only needed to wait for the pharmacist to verify the prescription on the CPOE and then go to the ADC to pick up the medication. There was no need to go through procedures such as dispensing by pharmacists in the central pharmacy and order delivery by the service personnel. The overall process was based on the Elimination-Combination-Rearrangement-Simplification method to simplify the five steps.

When a patient was transferred out of the OR/POR to return to the ward, the OR/POR nurse removed the patient out of the real-time dynamic screen, and the medication for this patient in the OR/POR ADC ended. If the patient was transferred to a ward fitted with the ADC, information on drug administration continued. If they were transferred to a ward without the ADC, the traditional mode of drug administration was resumed. Because patient medications were from the ADCs during the OR/POR stay, drugs that were originally delivered to the ward by the unit-dose cart in the traditional way were returned to the central pharmacy along with the cart, and the system automatically generated a drug return report for the pharmacist to check. The establishment of this system was patient-centered. When the patient was in the special environment of the OR/POR, both new and old prescriptions were guaranteed to provide the required medications in the shortest time possible. To the best of our knowledge, there have been no studies on a similar ADC system.

Many studies have reported that ADCs reduce drug errors, but other studies indicate otherwise. This difference can be partly attributed to nurses taking medicines in an override manner. In emergency situations, certain facilities can approve nursing retrieval of medications prior to pharmacy review by overriding the ADC. However, retrieving medications by an override mechanism and administering them before pharmacy review increases the risk of medication errors [2,14,15]. Consultations between the Pharmacy and Nursing Departments revealed that our system design did not allow ADC medications to be overridden.

According to the ASHP guidelines [13,16], our ADC is a patient-specific system that is also linked to the CPOE system. All prescriptions must be prescribed by a physician and verified by a pharmacist before nursing staff can take medicines from ADCs. To reduce the occurrence of medication errors, the override mechanism is not allowed. In emergency situations, emergency medication can be taken from the OR/POR emergency cart without a time limit. After the introduction of the ADC in July 2019, we identified no additional dispensing errors or incidents of wrong delivery of medication. The most common problem encountered by the ADC was drug shortage, and pharmacists needed to regularly review drug items to address this problem and adjust safety stocks.

The nursing staff's satisfaction with the OR/POR drug delivery process was significantly improved after the establishment of the ADC, increasing from 35.2 % to 80.5 %. Metsamuuronen et al. [17] found that 84 % of the nurses were satisfied with ADCs. Moreover, 80 % of the ICU nurses and 42 % of the OR nurses reported that ADC made their work easier, reduced the time spent on dispensing and preparing medications, and increased the time spent on direct patient care. Zaidan et al. [18] showed that the overall satisfaction rate was 91 %. Ninety-four percent of the nurses agreed that ADC allowed them to work more safely, and 90 % agreed that they spent less time waiting for medication from the pharmacy after ADC implementation. The results of a questionnaire conducted by Wang et al. [6] indicated that the majority of nurses agreed that they could do their job more safely using the ADC system and that it made their job easier. Our study results are consistent with those of previous studies on the effects of ADC.

This study has several limitations. First, we did not calculate the time it took for pharmacists to process drug returns for medicines taken from the OR/POR ADC. Because pharmacists had to deal with drug returns from the unit-dose cart in the ward every day, the increased time for processing this activity was almost negligible. Second, data on nurses' administration time before and after ADC were not collected. We assumed that the nurses' tasks of administering medication to patients were the same before and after ADC, except those delivered manually or taken from the ADC. Therefore, only a nurse's waiting time for medication was calculated. Third, while the number of prescriptions delivered by labor staff was reduced by 2600 prescriptions per month, calculating the actual reduced delivery time was difficult. Because the calculation of time depended on the location of the ward and the number of prescriptions delivered each time, the manpower time saved was not calculated. Finally, the limited data are insufficient to confirm that ADC can improve the accuracy of OR/POR nurses' drug administration. Medication errors for OR/POR are inherently rare and require a longer duration of data collection. Further research is needed to confirm our findings.

5. Conclusions

A program was designed to virtually and dynamically assign bed numbers for patients in the OR/POR. The program successfully integrated the inpatient and outpatient information systems to accurately identify the patient's status and initiate the correct medication access rules. Our results showed that ADC implementation in surgical units simplified the drug delivery processes, improved the drug delivery timeliness for surgical patients, reduced the labor time of delivery, decreased dispensing errors, and increased nursing staff satisfaction. In conclusion, the implementation of ADC was beneficial for surgical units.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jaw-Horng Liou: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Shuw-Chuan Wang:** Software, Investigation, Data curation. **Yu-Chi Hou:** Methodology. **Chih-Ho Yen:** Resources, Project administration. **Hsiu-Mei Chen:** Resources, Project administration. **Wen-Shyong Liou:** Supervision, Conceptualization. **Ming-Fen Wu:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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