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Research Article

Effectiveness of the Clinical Decision Support System Upgrade in the Automated Unit Dose Drug Dispensing System

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Abstract

Objective: This study aims to evaluate the effectiveness of the clinical decision support system (CDSS) upgrade in the automated unit-dose drug dispensing system (AUDDS), which comprises both the pre-review CDSS software of the automated drug unit-dose dispensing machine (ADDM) and the pre-verify CDSS software of the medication detection machine (MDM). The ultimate goal of these coordinated enhancements is to improve the overall dispensing efficiency of the AUDDS. **Methods:** A multidisciplinary collaboration involving pharmacists and the AUDDS engineer was established to implement two upgrades: the rule-based pre-review CDSS software in ADDM and the pre-verify CDSS software in MDM. The upgraded CDSS software of ADDM was configured to automatically identify and intercept three categories of clinically inappropriate inpatient medication orders (IMOs) based on real-time patient data from the hospital information system: duplicate IMOs, IMOs of excessive doses, and non-splittable IMOs. Upon detection, the CDSS software in ADDM generates an alert to notify the managing pharmacist, who conducts a telephone consultation with the prescribing doctor for timely resolution. The pre-verify CDSS software in MDM was upgraded to improve image acquisition and recognition accuracy and reduce the error rate in automatically identifying mismatched unit-dose medication bags (UMBs). **Results:** Pre-post comparisons revealed improvements in both workload and efficiency metrics and safety metrics. After the upgrade, total order volume (TOV) and order volume per pharmacist (OVP) showed a 7.54% mean increase, and the monthly total number of pre-verified unit-dose medication bags (MTN) revealed a 31.84% mean increase. The monthly volume of duplicate IMOs (MVDI) displayed a 11.62% mean reduction, and the ratio of duplicate IMOs (RDI) displayed a 19.32% mean reduction. The monthly volume of IMOs with excessive doses (MVIE) revealed a 35.20% mean reduction, and the ratio of IMOs with excessive doses (RIE) displayed a 41.78% mean reduction. The monthly true-positive error rate (MTER) displayed a 16.29% mean reduction. However, the monthly false-positive error rate (MFER) was higher after the upgrade. Non-splittable IMOs were rare in the study, so they were excluded from the comparison. **Conclusion:** This study demonstrates that the upgrade was associated with improvement of the appropriateness of long-term IMOs and the dispensing efficiency of AUDDS, thereby enhancing medication safety in hospital pharmacies.

Keywords: decision support systems, clinical; medication errors; medication systems; pharmaceutical services

1. Introduction

Hospital medication management involves a complex, multi-step workflow including prescribing, medication order verification, dispensing, administration, and monitoring. Each step of the workflow is susceptible to medication errors (MEs) [1,2]. ME, defined as preventable events that may lead to patient harm, increased healthcare costs, and mortality, represents a persistent and major challenge in inpatient care. The research from Norway links MEs to demanding nursing workloads and gaps in pharmacy competency in nurses [3]. Moreover, medication-related incidents account for the highest proportion of preventable patient harm [4]. Substantial evidence supports that the use of clinical decision support systems (CDSS), alerts within CDSS, automated unit dose drug dispensing system (AUDDS), and feedback on prescribing errors are critical strategies to mitigate MEs [1,5,6,7].

CDSS extends to provide interactive support that systematically empowers health professionals, thereby facilitating superior clinical decisions and yielding multiple gains in decision-making efficiency, patient safety, and cost-effectiveness through workflow optimization [8,9]. A key application in medication safety is the use of AUDDS to produce ready-to-administer, patient-specific unit doses, which represents a promising strategy to prevent MEs when dispensing. This approach prepackages multiple medications into a patient-specific bag for specific administration time, which provides convenience for medication management of nursing staff and increases medication adherence of inpatients [1,10,11]. The consolidation of AUDDS and CDSS can enhance efficiency, but it also underscores the critical need for robust pre-verification mechanisms to ensure the accuracy of medication orders before dispensing.

To address this critical need, this study implemented an upgrade to the pre-review CDSS software of the auto-

Table 1. The timetable for the upgrade.

Subsystem	Pre-intervention cohort	Upgrade period		Post-intervention cohort
		Implementation period	Stabilization period	
ADDM	January to March 2025	April 2025	May 2025	June to August 2025
MDM	February to April 2025	May and June 2025	July 2025	August to October 2025

ADDM, automated drug unit-dose dispensing machine; MDM, medication detection machine.

mated drug unit-dose dispensing machine (ADDM), alongside an upgrade to the pre-verify CDSS software of the medication detection machine (MDM), with the overarching goal of enhancing the efficiency of AUDDS and medication safety.

2. Materials and Methods

2.1 Study Establishment and Data Source

This study was conducted in the inpatient pharmacy department of a tertiary A hospital. All oral inpatient medication orders (IMOs) from the inpatient wards processed through the AUDDS during the study periods were included. IMOs of oral solid medications can be automatically processed by ADDM (Xana-U4002W, TOSHO Inc., Japan) and dispensed into unit-dose medication; IMOs of other oral medications are pre-reviewed by the CDSS software of ADDM, then manually dispensed by the managing pharmacist and reviewed by another pharmacist for final dispensing.

An upgrade to the CDSS software (AP software V4.0, XYDY Medical Technology (Beijing) Co., Ltd.) in ADDM was implemented by the AUDDS engineer in April-May 2025, based on the demand of pharmacists. To evaluate the effectiveness of this upgrade in ADDM, a pre-post comparison was employed. IMOs from January to March 2025 constituted the pre-upgrade cohort, while those from June to August 2025 formed the post-upgrade cohort. The period for the upgrade of CDSS in ADDM includes the implementation period (April 2025) and the stabilization period (May 2025).

The upgrade to the pre-verify software of MDM (MDM 2.0, Global Factories BV, Gravenhage, Netherlands) was implemented by the AUDDS engineer in May-July 2025, based on the demand of pharmacists. A pre-post comparison was employed to evaluate the impact of the upgrade. The period from February to April 2025 served as the pre-upgrade cohort, and the period from August to October 2025 served as the post-upgrade cohort. The period for the upgrade of CDSS in MDM includes the implementation period (May and June 2025) and the stabilization period (July 2025). Both stabilization periods for ADDM and MDM undergo small revisions. The timetable for the upgrade is shown in the Table 1.

For a systematic comparative evaluation, monthly aggregate data from the AUDDS were analyzed during the study. The metrics are categorized as follows:

2.1.1 Workload and Efficiency Metrics

Total order volume (TOV): The total number of IMOs processed by ADDM per month.

Order volume per pharmacist (OVP): The average number of IMOs processed by ADDM per working pharmacist per month, calculated based on a standard daily staffing of four pharmacists.

Monthly total number of pre-verified unit-dose medication bags (UMBs) (MTN): the UMBs pre-verified by MDM per month.

2.1.2 Safety Metrics (Derived From Long-Term IMOs)

Monthly volume of duplicate IMOs (MVDI): Monthly volume of duplicate IMOs pre-reviewed by upgraded CDSS software in ADDM.

Monthly volume of IMOs with excessive doses (MVIE): Monthly volume of IMOs with excessive doses pre-reviewed by upgraded CDSS software in ADDM.

Monthly true-positive error rate (MTER): the ratio of error UMBs correctly identified by MDM to the total number of UMBs pre-verified by MDM per month.

Monthly false-positive error rate (MFER): the ratio of error UMBs falsely identified by MDM to the total number of UMBs pre-verified by MDM per month.

The following metrics are derived from the monthly proportion relative to the initial long-term IMOs:

Ratio of duplicate IMOs (RDI): the ratio of duplicate IMOs to initial long-term IMOs.

Ratio of IMOs with excessive doses (RIE): the ratio of IMOs with excessive doses to initial long-term IMOs.

2.2 Upgrade of CDSS Software Within ADDM for Pre-Review

The upgraded CDSS software of ADDM is a rule-based screening tool that pre-reviews all IMOs processed by AUDDS. Any IMO that fails automated pre-review triggers an alert in the CDSS of ADDM, which prompts the managing pharmacist to intervene before dispensing. This alert initiates a structured workflow in which the managing pharmacist directly consults the prescribing doctor by telephone. This consultation intends to review the clinical rationale for the IMO that failed pre-review and collaboratively determine whether to dispense the IMO or not. In most cases, this consultation persuades the prescribing doctor to correct the IMO as suggested by the managing pharmacist. If the prescribing doctor decides that the original IMO should be dispensed despite the alert, the managing pharmacist would ensure that the prescribing doctor provides a formal prescription for further dispensing.

Construction of the rule bank in the pre-review CDSS software of ADDM is carried out by the pharmacists and the AUDDS engineer based on the drug instructions and up-to-date clinical guidelines. After the initial construction, 2 pharmacists were responsible for the accuracy verification by reviewing the up-to-date drug instructions and clinical guidelines. The rule-bank is mostly created based on the drug instructions, which have legal effect.

Ongoing maintenance of the rule bank in the pre-review CDSS software of ADDM is carried out by the managing pharmacist every day. The update of drug instructions sent from the manufacturer will notify every pharmacist, especially the managing pharmacist of AUDDS, to facilitate the revision of the rule bank immediately. Pharmacists in the inpatient pharmacy department revise the rule bank in ADDM according to the changes in clinical guidelines per quarter. However, the changes in clinical guidelines are mostly learned from the prescribing doctor, since they will prescribe IMOs according to up-to-date clinical guidelines. These IMOs refer to the up-to-date clinical guidelines that may be alerted by the CDSS of ADDM, leading to the managing pharmacist learning the up-to-date clinical guidelines and revising the database after a careful discussion with the chief of the inpatient pharmacy department. If the IMO refers to the up-to-date clinical guidelines is proven correct, the rule bank in ADDM will be revised, and the IMO will be appropriate in the CDSS of ADDM.

By those steps above, the CDSS of ADDM acquired the ability to pre-review IMOs and identify the inappropriate IMOs. The upgraded rule-based CDSS software in ADDM can automatically pre-review and generate alerts for inappropriate IMOs based on real-time data from the hospital information system (HIS), which can be divided into three types: duplicate IMOs, IMOs of excessive doses, and non-splittable IMOs.

2.2.1 Settings for Pre-Review of the Duplicate IMOs

The upgraded rule-based CDSS software in ADDM is programmed to identify IMOs as duplicates if two or more IMOs for a patient share the same HIS drug code and medication frequency. Upon detecting such duplication, an alert is generated in the CDSS software before the automated dispensing, pending mandatory review by the managing pharmacist. The managing pharmacist can find the precise information about the alerted IMOs by clicking on the alerted inpatient ward and the "duplicate IMOs" button, which is necessary for the pharmacist-doctor consultation. The managing pharmacist can access a contextual decision menu by right-clicking on the alert in the CDSS interface. This menu presents the managing pharmacist with a binary choice to either authorize or cancel the dispensing of the duplicate IMO, ensuring that no duplicate IMOs are dispensed without explicit clinical oversight. The long-term duplicate inpatient medication orders are constrained, while the stat duplicate inpatient medication orders can be manually allowed by the managing pharmacist for automatic dispensing.

2.2.2 Settings for Pre-Review of the IMOs of Excessive Doses

The upgraded CDSS software in ADDM is programmed to screen all IMOs against a predefined maximum single-dose limit. This limit is configured in the CDSS rule bank by the managing pharmacist based on official manufacturer drug instructions and clinical guidelines, daily maintained by the managing pharmacist. Upon detecting an IMO that exceeds the maximum single-dose limit, the CDSS software generates an alert before dispensing, which prompts the managing pharmacist to review the IMO. The managing pharmacist can find the precise information about the alerted IMOs by clicking on the alerted inpatient ward and the "IMOs of excessive doses" button for the pharmacist-doctor consultation. The managing pharmacist can then access a contextual decision menu by right-clicking the alerted IMOs. This menu presents a binary choice to authorize or cancel the dispensing of the alerted IMO, ensuring that no IMOs of excessive doses are dispensed without explicit clinical oversight.

2.2.3 Settings for Pre-Verification of the Non-Splittable IMOs

The upgraded CDSS software in ADDM contains the pre-review rules for non-splittable IMOs in the rule bank. The CDSS rule bank identifies specific drugs as non-splittable upon their entry into the ADDM. An alert is triggered before dispensing when an IMO contains a non-splittable drug, and its dosage deviates from the standard package size, specifically when the prescribed dosage does not align with the available package size (e.g., a prescription for half a tablet). The managing pharmacist can find the precise information about the alerted IMOs by clicking on the alerted inpatient ward and the "non-splittable IMOs" button, which is necessary for the pharmacist-doctor consultation. The managing pharmacist can access a contextual decision menu by right-clicking on the alert in the CDSS interface to authorize or cancel the dispensing of the non-splittable IMO.

2.3 Upgrade of the Automated Verification Software of MDM

MDM pre-verifies the UMBs by capturing color, grayscale, and color pictures of the drugs. These pictures are compared in real time against reference medication images stored in the MDM database, using the barcode printed on each UMB generated by the ADDM for picture identification.

When a mismatch is detected between the captured picture and the MDM database, the MDM generates an alert. The pharmacist can review the mismatched UMB in the MDM verification software (MDC, Medicine Detection Checkout Client, V1.9.8.5, Global Factories BV, Gravenhage, Netherlands) after the automatic pre-verification of all UMBs of an inpatient ward is finished. The pharmacist can perform a real-time visual comparison between the captured color picture and the stored reference picture in the MDC software. If the pharmacist is unable to confirm the match through this verification process, a manual comparison is mandatory to identify the mismatched UMBs and implement appropriate corrective actions before final dispensing.

To enhance the accuracy of image acquisition and automated pre-verification, an upgrade for the image capture function and pre-verify CDSS software (MDM-Detection, V1.8.2.1, Global Factories BV, Gravenhage, Netherlands) in MDM was implemented. The upgrade involved recalibration of the camera in MDM to improve the accuracy of captured color, grayscale, and color pictures. Additionally, the algorithm in automated verification software was optimized to enhance MDM's ability to recognize drug color, texture, and imprint, with particular attention to contrast and color variation, thereby improving overall verification accuracy.

2.4 Statistical Analysis

All statistical analyses were conducted using GraphPad Prism Software (V8.0.2, San Diego, California, USA). Data is presented as line plots and mean ± standard deviation (SD). Comparisons of continuous variables between the pre-upgrade and post-upgrade cohorts were performed using descriptive statistics analysis. Results of statistics analysis are shown in Table 2.

3. Results

3.1 Enhanced Automated Dispensing Efficiency of ADDM After Upgrade

Despite an overall increase in hospital workload, the ADDM demonstrated enhanced dispensing efficiency after the upgrade. Under equivalent operation time, both key workload metrics improved in the post-upgrade cohort.

Specifically, TOV increased from 343,065 ± 45,136 in the pre-upgrade cohort to 368,947 ± 7859 in the post-upgrade cohort, representing a 7.54% increase in the average monthly volume. OVP increased from 85,766 ± 11,284 in the pre-upgrade cohort to 92,237 ± 1965 in the post-upgrade cohort, corresponding to a 7.54% mean increase (Fig. 1A). These findings indicate that the upgrade was associated with the improved efficiency of the ADDM under the same working conditions, which contributes to the overall efficiency improvement of AUDDS.

3.2 Volume and Ratio of Inappropriate IMOs in Long-Term IMOs Reduced After CDSS Pre-Review Upgrade

Both the volume and the rate of duplicate long-term IMOs decreased in the post-upgrade cohort. MVDI decreased from 261.70 ± 21.03 (pre-upgrade cohort) to 231.3 ± 27.30 (post-upgrade cohort), displaying a 11.62% reduction in average (Fig. 1B). RDI decreased from 0.647 ± 0.091% (pre-upgrade cohort) to 0.522 ± 0.076% (post-upgrade cohort), indicating a 19.32% mean reduction (Fig. 1C). These results indicate that the upgraded CDSS software is related to the reduction of duplicate IMOs.

A similar reduction was observed for IMOs with excessive doses in the post-upgrade cohort. MVIE decreased from 83.33 ± 8.505 (pre-upgrade cohort) to 54.00 ± 12.53 (post-upgrade cohort), revealing a 35.20% mean reduction (Fig. 1B). RIE decreased from 0.2073 ± 0.0404% (pre-upgrade cohort) to 0.1207 ± 0.024% (post-upgrade cohort), which displayed a 41.78% mean reduction (Fig. 1C). These results demonstrate that the reduction of inappropriate IMOs is related to the pre-review CDSS software upgrade.

However, non-splittable IMOs were infrequently observed among overall IMOs. Because of their low occurrence, non-splittable IMOs were not suitable for statistical analysis and were therefore excluded from the comparison.

3.3 Effectiveness of Upgraded Pre-Verify CDSS Software on MDM and Improved Throughput of MDM After Upgrade

Under equivalent operation time, the MTN increased following the pre-verify CDSS software upgrade. Specifically, the MTN increased from 94,526 ± 63,059 in the pre-upgrade cohort to 124,624 ± 5588 in the post-upgrade cohort, corresponding to a 31.84% increase in average (Fig. 2A). These findings demonstrate that the enhanced pre-verify CDSS software improved the throughput of MDM, which contributes to the overall efficiency gain of the AUDDS.

Following the upgrade, the MTER decreased from 0.1633 ± 0.01528% (pre-upgrade cohort) to 0.1367 ± 0.02309% (post-upgrade cohort), corresponding to a 16.29% mean reduction (Fig. 2B). However, the MFER was higher after the upgrade. MFER is 7.067 ± 0.6616% in the pre-upgrade cohort, while the MFER in the post-upgrade cohort is 8.593 ± 0.8819% (Fig. 2C).

4. Discussion

In this study, the CDSS software of the AUDDS was upgraded to improve the overall efficiency and enhance medical safety. Upgrade of CDSS software in ADDM reduced the volume and proportional rate (relative to initial long-term IMOs) of clinically inappropriate IMOs (the duplicate IMOs and the IMOs of excessive doses), and increased the efficiency. In the post-upgrade cohort, RDI displayed a 19.32% mean reduction, and RIE displayed a 41.78% mean reduction. Similar trends were found in the MVDI and MVIE. These findings suggest that IMOs' prescribing is more appropriate with the pharmacist-doctor consultation and the upgraded CDSS software in ADDM

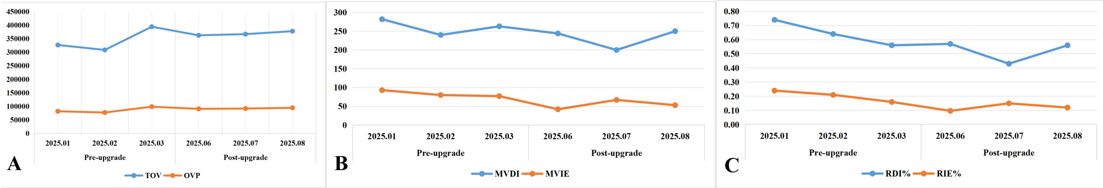

Fig. 1. Effectiveness of the CDSS software upgrade on ADDM. (A) Line plots of the TOV and OVP of the pre-upgrade cohort and the post-upgrade cohort. Blue line: TOV; Orange line: OVP. (B) Line plots of the MVDI and MVIE in the pre- and post- upgrade cohort. Blue line: MVDI; Orange line: MVIE. (C) Line plots of the RDI and RIE in the pre- and post- upgrade cohort, unit: %. Blue line: RDI; Orange line: RIE. CDSS, clinical decision support system; ADDM, automated drug unit-dose dispensing machine; TOV, Total order volume; OVP, Order volume per pharmacist; MVDI, Monthly volume of duplicate IMOs; MVIE, Monthly volume of IMOs with excessive doses; RDI, Ratio of duplicate IMOs; RIE, Ratio of IMOs with excessive doses.

Table 2. The result of the descriptive statistics analysis.

	Mean		Range		SD		SEM		CV	
Metrics	Pre-upgrade	Post-upgrade	Pre-upgrade	Post-upgrade	Pre-upgrade	Post-upgrade	Pre-upgrade	Post-upgrade	Pre-upgrade	Post-upgrade
TOV	343,065	368,947	308,394–394,100	362,389–377,658	45,136	7859	26,059	4537	13.16%	2.130%
OVP	85,766	92,237	77,099–98,525	90,597-94,415	11,284	1965	6515	1134	13.16%	2.130%
MVDI	261.7	231.3	240–282	200–250	21.03	27.3	12.14	15.76	8.038%	11.80%
MVIE	83.33	54	77–93	42–67	8.505	12.53	4.91	7.234	10.21%	23.20%
RDI (%)	0.6467	0.5217	0.5590–0.7400	0.4340–0.5660	0.09063	0.07592	0.05233	0.04383	14.02%	14.55%
RIE (%)	0.2073	0.1207	0.1640–0.2440	0.0970–0.1450	0.04041	0.02401	0.02333	0.01386	19.49%	19.90%
MTN	94,526	124,624	21,877–135,103	118,701–129,803	63,059	5588	36,407	3226	66.71%	4.484%
MTER (%)	0.1633	0.1367	0.15–0.18	0.11–0.15	0.01528	0.02309	0.008819	0.01333	9.352%	16.90%
MFER (%)	7.067	8.593	6.380–7.700	7.680–9.440	0.6616	0.8819	0.382	0.5092	9.362%	10.26%

SD, standard deviation; MTN, monthly total number of pre-verified UMBs; MTER, Monthly true-positive error rate; MFER, Monthly false-positive error rate; SEM, Standard error of the mean; CV, coefficient of variation.

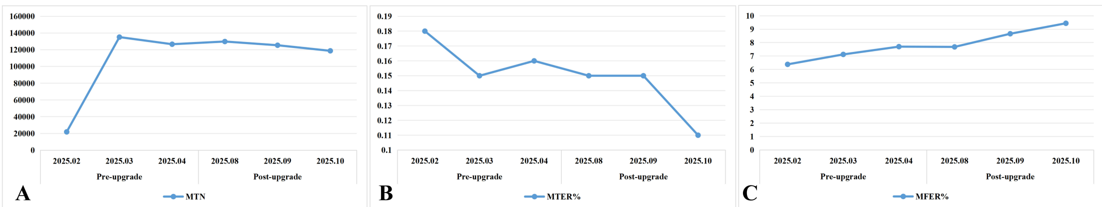

Fig. 2. Effectiveness of the CDSS software upgrade on MDM. (A) Line plots of the MTN of the pre-upgrade cohort and the post-upgrade cohort. Blue line: MTN. (B) Line plots of the MTER in the pre-post comparative analysis. Blue line: MTER, Unit: %. (C) Line plots of the MFER in the pre- and post-upgrade cohorts. Blue line: MFER, Unit: %. CDSS, clinical decision support system; MDM, medication detection machine; MTER, Monthly true-positive error rate; MFER, Monthly false-positive error rate; MTN, Monthly total number of pre-verified UMBs.

for IMO pre-review. Moreover, due to the increased hospital workload, the TOV and OVP of ADDM are increased under the same work conditions after the upgrade, which indicates the time saving for pharmacists by simplifying the workflow of the inappropriate IMO resolution. As to the MDM, the upgrade also increased the MTN, reducing the MTER. Conversely, the MFER increased after the upgrade.

CDSS is widely recognized as the essential tool for enhancing medication safety, preventing dispensing errors, and reducing overall MEs in hospitals [11,12]. The preventable nature of a substantial proportion of MEs is underscored by data from the European spontaneous reporting system (EudraVigilance database): of 1750 reported medication errors, 1300 (74%) were identified as preventable drug-related problems [13]. The reduction of inappropriate IMOs in our study lends indirect support to this conclusion. AUDDS, constituted by ADDM and MDM, is designed for convenient medication distribution. AUDDS is widely recognized as an intelligent technology for safer, more efficient, and traceable drug administration in hospitals [14]. AUDDS can enhance patient safety by preventing drug dispensing errors while simultaneously offering convenience for pharmacists and nurses [15,16,17]. In addition, the involvement of pharmacists has proven to be a highly effective strategy for improving medication safety. Pharmacist-led interventions have been associated with a 32% reduction in potentially inappropriate prescriptions [18]. Pharmacist-involved disease management can improve medication adherence and reduce adverse drug reactions (ADRs) [19,20,21]. Based on these studies, this study constitutes a pharmacist-doctor consultation along with the pre-review CDSS software of ADDM for a stricter IMOs review, which improved the appropriateness of IMOs and the efficiency of ADDM. While the upgrade of the pre-verify CDSS software of MDM is not that successful. The improved efficiency of the MDM is revealed by the increased MTN and the reduced MTER after the upgrade. The reasons we conclude for the increased MFER after the upgrade are the frequent drug replacement resulting from the National Drug Centralized Procurement Policy in the post-upgrade cohort, and the increase in hospital workload. The upgrade of MDM offsets these disturbances and achieves a stable running state.

This study provides a reachable approach for improving the appropriateness of IMOs by constituting a rule-based pre-review CDSS software in ADDM before the automatic dispensing. The appropriateness of IMOs can be improved by forming the CDSS software-pharmacists-doctors axis in the hospital pharmacy workflow. The inappropriate IMOs were hard to find in the overall IMOs before the upgrade, which consumed more time of the pharmacist and may cause MEs. And if the inappropriate IMO is found out by the pharmacist who is responsible for final dispensing, this IMO has been packaged by ADDM as a single-unit dose drug. It takes more time to correct it and put the drugs back in ADDM, or discard these drugs for safety, which causes drug waste. Upgraded CDSS software of ADDM can save time for pharmacists, reduce the drug waste and MEs resulting from inappropriate IMOs.

In the future, we will still work on the upgrade of the AUDDS to further upgrade the CDSS software in ADDM for better pre-review of the IMOs and reduce the MFER in MDM. The rule bank in the CDSS software of ADDM will be more specific for pre-review, and the AUDDS will complete pre-review together with other CDSS software or novel technology in the future. Moreover, the pre-verify CDSS software in MDM will be upgraded to improve the pre-verify function targets for the drugs with high false-positive alerts to reduce the manual workload of the pharmacist.

5. Limitations

The study is carried out as a monocentric study in a tertiary A hospital with 3060 beds and over 80 wards. The IMOs processed by the AUDDS and the inpatient numbers are massive, so the CDSS software for IMO pre-review and UMB pre-verification is necessary to reduce the manual workload of pharmacists. The initial time investment of the upgrade consumes 3 weeks, and the ongoing data maintenance is carried out by the managing pharmacist every day. Most updates of guidelines are learned from the prescribing doctor, and the rule bank of the CDSS software in ADDM is updated quarterly. The AUDDS is supervised by a managing pharmacist during daily work. Although the study provides an effective workflow to reduce the inappropriate IMOs, the workload of hospital and the time investment limited the generalizability of the study.

The unequal upgrade periods for the ADDM and MDM may affect the precision of the ADDM post-upgrade datasets since the post-upgrade cohort of ADDM contains the upgrade periods of MDM. But this influence is slight. Because the ADDM and MDM work independently, the upgrade of one subsystem had little influence on the working condition of the other system. Besides, the metrics in the study can be divided into metrics of ADDM, including TOV, OVP, MVDI, MVIE, RDI, RIE, and metrics of MDM: MTN, MTER, and MFER. These metrics belong to each subsystem and remain unrelated to those of the other subsystem.

During the study, the hospital workload increases rapidly, which leads to an increase in IMOs and UMBs. While the seasonality of workload during the study is controlled, as the pre-upgrade cohort and the post-upgrade cohort both contain national vacation, the workload remains fluctuant. The difference and seasonality of workload are the cofounding factors of the study. The results of the statistical analysis reveal that the upgrade is effective, but the periods for the study are short and are influenced by many disturbances, such as increased hospital workloads and frequent drug replacement. As a study for the AUDDS efficiency assessment based on a small number of monthly observations, it also lacks patient-level outcome data and external validation, which limits the effectiveness of the findings. Thus, the upgrade is associated with the improvements of the IMO quality and overall efficiency of the AUDDS, rather than a strong correlation. The generalizability of the study is limited.

6. Conclusions

In this study, the upgrade of the pre-review CDSS software in ADDM and the pre-verify CDSS software in MDM, along with the pharmacist-doctor consultation workflow, contributes to the improvement of the IMO quality and overall efficiency of the AUDDS. The upgrades are related to the time saving of the inappropriate IMO resolution workflow and the reduction of the proportion of inappropriate IMOs in the long-term IMOs, enhancing medical safety.

Availability of Data and Materials

Data from the study are available from the corresponding author upon reasonable request.

Author Contributions

Conceptualization & Writing—Review & Editing: LC; Writing—Original Draft & Methodology: KZ; Funding Acquisition&Conceptualization: JL; Data Curation: MC; Formal Analysis: XZ. All authors contributed to the study conception and design. All authors read and approved the final manuscript. All authors contributed to editorial changes in the manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the principles of the Declaration of Helsinki and complied with the institutional ethical guidelines. No patient-specific data were collected, ensuring compliance with the data protection standards. As an efficiency improvement study of AUDDS, it involves no direct patient contact or intervention, and no personally identifiable patient information was collected or recorded. Therefore, no patient consent was required. All data in this study were aggregated and anonymized, with metrics treated as secondary data contain no information that can identify individuals. Based on the relevant national regulation, ethical approval is exempt.

If an ME reaches a patient during the study, the ME will be formally documented in accordance with the established safety protocols of the hospital. The relevant nursing staff and pharmacist will be immediately notified to facilitate prompt clinical review and corrective action, thereby ensuring that patient safety remains the highest priority. The MEs in this study are those that happened in the inpatient pharmacy department, including inappropriate IMOs and error UMBs, which were corrected by the pharmacists and the AUDDS before reaching patients. As all data analyzed in this study consisted of aggregated and anonymized metrics, any ME reaching patients was excluded from the final dataset to maintain the integrity of the pre-post comparative analysis. However, no ME reached patients in the study.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used DeepSeek for language editing, grammar checking, and improving readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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