

TECHNOLOGICAL INNOVATIONS IN THE PREVENTION OF MEDICATION DISPENSING ERRORS IN THE HOSPITAL SETTING

*Inovações tecnológicas na prevenção de erros de dispensação
medicamentosa no ambiente hospitalar*

*Innovaciones tecnológicas en la prevención de errores de dispensación
medicamentosa hospitalaria*

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ABSTRACT

The high production pressures of hospital pharmacies make medication dispensing a process prone to errors and, therefore, unfavorable clinical outcomes. Given this, the objective is to map the main technological measures under development in the context of medication dispensing for hospitalized patients. This is an integrative review of studies published between 2020 and 2025 in the following databases: PubMed, Lilacs, Virtual Health Library, and ScienceDirect. The dispensing technologies addressed were automated dispensing cabinets, robotic picking and storage systems, image capture systems, mobile applications for bedside validation, and inventory management platforms. These have shown good integration into the hospital pharmacy workflow, with high adoption and satisfaction among professionals. However, further understanding of the effectiveness and usability, as well as the limitations and improvements proposed for such technological interventions, is still necessary.

Keywords: Medication Errors. Biomedical Technology. Pharmacy Service, Hospital.

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RESUMO

A pressão produtiva da farmácia hospitalar torna a dispensação medicamentosa um processo propício para a ocorrência de erros e, portanto, para desfechos clínicos desfavoráveis. Diante disso, objetiva-se mapear as principais medidas tecnológicas em desenvolvimento no contexto da dispensação medicamentosa para pacientes hospitalizados. Trata-se de uma revisão integrativa de estudos publicados entre 2020 e 2025 nas bases de dados: PubMed, Lilacs, Biblioteca Virtual em Saúde (BVS) e ScienceDirect. As tecnologias dispensadoras abordadas foram armários de dispensação automatizada, sistemas robóticos de separação e armazenamento, sistemas de captura de imagem, aplicativos móveis para validação à beira leito e plataformas de gestão de estoque. Estas têm evidenciado boa integração ao fluxo de trabalho da farmácia hospitalar, com alta adesão e satisfação por parte dos profissionais. Contudo, ainda é necessário aprofundar a compreensão sobre a efetividade e usabilidade, bem como sobre as limitações e aprimoramentos propostos para tais intervenções tecnológicas.

Palavras-chave: Erros de Medicação. Tecnologia Biomédica. Serviço de Farmácia Hospitalar.

RESUMEN

La presión productiva en la farmacia hospitalaria convierte la dispensación de medicamentos en un proceso propenso a errores y a desenlaces clínicos desfavorables. Ante esto, el objetivo es mapear las principales medidas tecnológicas en desarrollo en el contexto de la dispensación de medicamentos hospitalarios. Se trata de una revisión integrativa de estudios publicados entre 2020 y 2025 en las bases: PubMed, LILACS, Biblioteca Virtual en Salud (BVS) y ScienceDirect. Las tecnologías abordadas fueron armarios de dispensación automatizada, sistemas robóticos de selección y almacenamiento, sistemas de captura de imágenes, aplicaciones móviles para validación al pie de la cama y plataformas de gestión de inventario. Estas han demostrado buena integración en el flujo de trabajo, con alta adhesión y satisfacción por parte de los profesionales. Sin embargo, aún es necesario profundizar en la comprensión de su efectividad y usabilidad, así como en las limitaciones y mejoras propuestas para tales intervenciones tecnológicas.

Palabras clave: Errores de Medicación. Tecnología Biomédica. Servicio de Farmacia en Hospital.

INTRODUCTION

It is estimated that, globally, medication errors can affect up to 25% of patients, and it is speculated that most of these could be avoided through efficient pharmacovigilance policies¹. Furthermore, Brazil exceeds this rate, since, according to the National Health Surveillance Agency (Anvisa), on average, three out of every ten medications administered contain some kind of error².

As a consequence, the patient may experience adverse reactions, drug interactions, prolonged hospital stays, and even death³. Adverse events related to healthcare affect up to 10% of hospitalized patients, and a large proportion of these can be attributed to medications⁴. According to the World Health Organization (WHO), annual global spending on medication errors reaches US\$42 billion, which corresponds to 1% of total health investments⁵.

To understand the weaknesses of the current process, it is essential to list the steps that govern it: management of hospital medications, prescription, transcription, verification, dispensing, administration and, finally, therapeutic monitoring⁶. These steps are subject to errors, which can culminate in the substitution, omission, repetition or addition of medications, as well as non-compliance with the recommended dose, frequency, time or route⁷.

In this context, technological measures have emerged as ways to automate hospital pharmacy, minimizing the risk of human error. The benefits can be obtained both through direct intervention in the steps governing safe medication and indirectly, through the completion of mechanical tasks, consequently freeing up professionals for tasks that require a greater cognitive load. This second aspect is especially important, since up to 55% of

pharmacist's time is spent on infrastructure services⁸. Therefore, the role that technological measures can play is evident from optimizing workflows and computerized therapeutic decisions to medication verification⁹⁻¹³.

The main objective of this review was to map the main technological measures under development in the context of medication dispensing for hospitalized patients. The secondary objectives were: to understand the effectiveness, usability, and impact of dispensing technologies on the daily routine of healthcare professionals; to identify the challenges to their implementation; and to recognize proposals for improvement.

METHOD

This is an integrative literature review, whose advantages stand out due to the approach of different methodological designs, mapping of gaps in the literature and basis for future studies. This study was conducted according to the following steps: identification of the problem, systematic literature search, critical evaluation of the included studies, data analysis and synthesis, and presentation of results¹⁴.

The research question was "What technologies are being used to reduce medication dispensing errors in hospitals and what are their impacts?". The elements of the question were decomposed according to the PICO acronym (population, intervention, comparison and outcome) (Table 1).

Table 1 - Definition of the PICO acronym

Acronym PICO	Research question element
Population	Hospitalized patients using medication
Intervention	Innovative technologies focused on the medication dispensing process.
Comparison	Traditional medication dispensing protocols
Outcome	Reducing medication errors

Source: Prepared by the authors, 2025

The databases used were *PubMed*, *Lilacs*, *Virtual Health Library*, and *ScienceDirect*, each with a search strategy that was duly adapted (Table 2).

Table 2 - Search strategies adapted for the databases

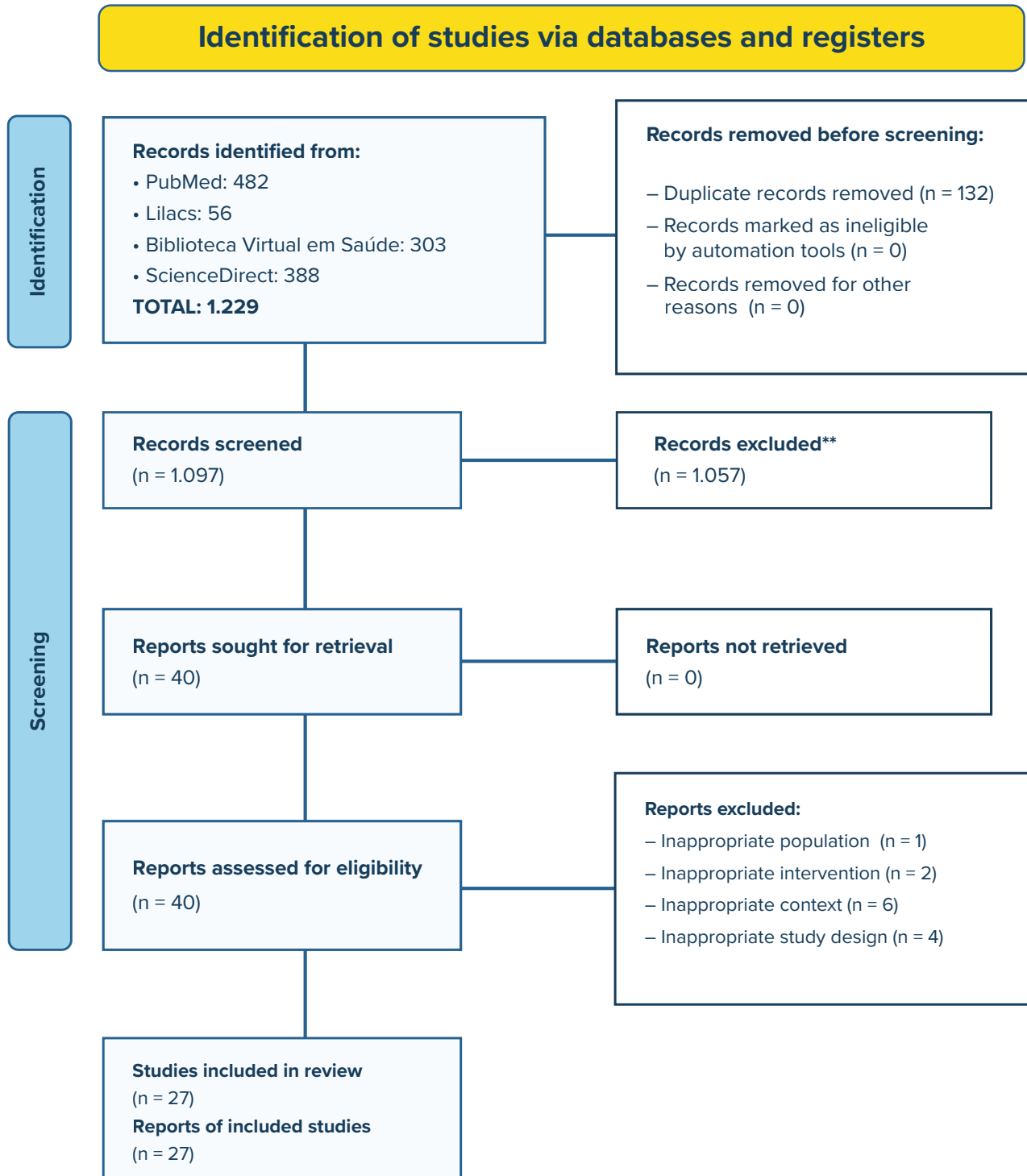
Base	Search strategy
PubMed	("medication error*") OR ("drug use error*") AND ((automation) OR (technology) OR ("medical system*")) AND ((patient*) OR (inpatient*) OR (hospital*))
Lilacs	(medication errors) AND (automation OR medical technology) AND (patient OR hospital)
Virtual Health Library	(medication errors) AND (automation OR medical technology) AND (patient OR hospital)
ScienceDirect	("medication errors" OR "drug use error") AND (automation OR "medical systems") AND (patient OR hospital)

Source: prepared by the authors, 2025

The inclusion criteria were: original articles, published between 2020 and 2025, and addressing technological interventions aimed at medication dispensing. The exclusion criteria were: duplicates; reviews, case studies, operational research, conference proceedings, letters to the editor, editorials, book chapters, and epidemiological bulletins; articles addressing process innovations, technologies already well-established in the market (electronic prescribing systems, barcodes, and infusion pumps), outpatient care, or other medication stages; and articles unavailable for full-text reading.

The selection of publications was carried out using *Rayyan software (AI-Powered Systematic Review Management Platform)*. The initial number of exported articles was 1,229. First, duplicates were excluded, prioritizing those with the most recent publication. This left a total of 1,097 articles. Subsequently, titles and abstracts were read, selecting based on inclusion and exclusion criteria, in order to reach 40 studies. Finally, the remaining articles were read in full and, again, those that did not demonstrate a relationship with the research question were excluded. Thus, 27 articles were included for analysis (Figure 1).

Figure 1 - PRISMA 2020 flowchart for new systematic reviews that included only database and registry searches.



Source: adapted from PRISMA, 2020

The articles were analyzed descriptively, ensuring the identification of patterns, trends, particularities, and gaps in the literature. The extracted data included: authors, type of study, and summary. A spreadsheet was created in *Microsoft Excel* to organize this data.

RESULTS

The main data extracted from the analyzed studies were compiled in Table 1. Among the 27 articles selected for full-text reading, there was a heterogeneous distribution regarding the country of publication. The main center was the Asian continent, concentrating 33.3% of the articles, followed by the European (29.6%) and North American (25.9%) continents. There were no Latin American literatures in the selected sample.

Regarding the type of technology addressed, the prominence gained by *Automated Dispensing Cabinets (ADCs) in the context of the hospital medication supply chain was notable. The majority of studies (70.37%) referred to this type of technology. However, tools complementary to ADCs* were also discussed: automated medication dispensing systems, drug detection *software* using image capture, medication verification applications, and intelligent inventory management systems.

Finally, various hospital care settings were included, from the emergency room to general and specialized wards, the surgical center, and the Intensive Care Unit (ICU).

Table 1 - Main data extracted from the reviewed articles

Authors	Type of study	Synthesis
Aldughayfiq ²²	Methodological study	Identification tokens for cross-checking medication and patient information. - Advantages: ease of use and error identification.
Heo ¹⁷	Technological development study	Visual identification of tablets from a database. - Advantage: good accuracy in uncontrolled real-world environments.
Wooten ³⁹	Retrospective observational study	ADC issues warning for the withdrawal of Remifentanyl. Advantages: reduced waste, conscious use, cost savings, and optimized workflow.
Hsia ¹⁹	Retrospective observational study	Intravenous medication administration system using image capture. - Advantages: greater job satisfaction, improved traceability and security. - Limitations: false alerts and a slight increase in preparation time.
Patterson ³²	Retrospective observational study	ADCs - Limitations of <i>overrides</i> : they do not accelerate medication administration and leave room for errors. ADC systems should require more careful use of <i>overrides</i> .
Jefrey ³⁶	Retrospective observational study	ADCs - Limitation: did not reduce the rate of antimicrobial omission due to stock unavailability. - Challenges: inventory management and excessive reliance of professionals on ADCs.
Chiu ¹⁶	Technological development study	Image-based identification system - Advantages: time saving - Limitations: Inability to identify large loads, forced classification of unrecognized items, and difficulty differentiating them from nearby medications.
Jeffrey ²⁹	Prospective observational study	ADC - Advantages: time savings, reduced travel, and less manual labor. - Limitation: maintaining high rates of task interruption and medication rounds time (which decreased only in the surgical ward)

Jessurun ³³	Economic evaluation	Automated and centralized dispensing system - Advantage: Reduction in the quantity and severity of administrative errors. Factors that led to better cost-effectiveness included oral formulations, pharmacies with high dispensing volume, and no negative impact on workload.
Zheng ²¹	Qualitative study	Ideal AI prototype Issuing alerts with solutions and justifications. - “Adaptive automation”: adapting the degree of automation according to the complexity of dispensing and the capacity of the system. Reference images for comparison of visual aspects of the medication.
Line ¹⁵	Retrospective observational study	- Carousel System : a system that stores medications in rotating compartments. - XR2 Robot : identifies, selects, and dispenses prescribed medications. - Advantages: Reduction of medication errors and workload, especially with the XR2.
Mutair ²⁷	Qualitative study	ADC - Advantages: time savings, reduced workload, reduced stress, increased safety, and inventory control. - Limitations: technical failures, proximity between <i>bins</i> , poor lighting, incomplete integration, overload of restocking professionals, and notification overload.
Ruutiainen ³⁷	Cross-sectional observational study	ADC - 16% of LASAs were stored close together, and of those, 4% were high-surveillance. - Suggestions: distant compartments, eye-catching labels, alerts, integration with the electronic prescription system, and staff training.
Jumeau ³¹	Prospective observational study	ADC - Advantages: accelerated medication preparation, minimized task interruptions, and a five-fold reduction in dispensing errors.
Alanzani ²⁴	Qualitative study	ADC - Advantages: Time savings in dispensing and labeling, with greater focus on reviewing the prescription and preparations. - Challenge: adaptation regarding inventory counting
Wang ³⁴	Prospective and qualitative observational study	ADC - Advantage: Reduction of medication errors. - Limitations: formation of queues, incomplete stock, increased preparation and return time of medications, confusing instructions, and multiple medications per compartment.
Almalki ¹¹	Prospective observational study	ADC - Advantages: faster medication administration, financial savings, reduction of medication errors, and increased pharmacist productivity.
Baraka ³⁵	Retrospective and prospective observational study	ADC - Advantages: Reduced waste and optimized inventory control. - Limitations: overestimation of inventory and lack of familiarity of the team.
Deng ²⁰	Technological development study	Image recognition system that identifies the drug and dose aspirated by the syringe. - Advantages: reduction of manual labor and dispensing errors.
Ashraf ¹⁸	Methodological study	Image capture conferencing system - Advantage: Good accuracy and sensitivity even in uncontrolled real-world environments. - Limitations - Lower effectiveness on mobile devices, poor image quality, inability to identify medications simultaneously.
Wai ³⁸	Quasi-experimental before-and-after study	Smart inventory control panel Advantages: reduction of inventory, stockouts, and operational costs.

Farsi ²⁶	Quasi-experimental before-and-after study	ADC - Advantages: increased efficiency, optimized performance, cost savings, responsible use of controlled medications, and enhanced safety and traceability of medications. - Limitations: Incomplete integration with the prescription system and inability to refrigerate.
Tu ¹²	Retrospective observational study	ADC - Advantages: Reduction in the number and severity of errors, both in relation to medications included in the ADCs and to external medications. - Limitations: little impact on administration errors related to incorrect timing or unauthorized medication.
Craswell ²⁵	Cross-sectional observational study	ADC - Advantages: Reduction of medication errors and workload. - Limitations: longer travel time for pharmacists, delays in restocking, interruption of tasks, queues, and lack of alerts.
Ramachandram ²³	Cross-sectional observational study	Automated tablet dispensing and packaging system - Advantages: pharmacists more focused on clinical tasks and pharmacy assistants on operational tasks, reduction of errors and greater patient satisfaction.
Korhonen ⁴⁰	Qualitative study	ADC - Advantages: optimized inventory management, traceability, and ease of use. - Limitations: delays in dispensing medications, limited physical space, lack of familiarity among professionals, and incomplete integration with the prescription system.

Source: Reviewed articles, 2025

DISCUSSION

Medication preparation

Firstly, the medication preparation stage can benefit from the introduction of the Carousel System, a type of cabinet with rotating shelves. This device works in such a way that the medication goes to the professional, instead of the other way around. Complementarily, there are automated devices integrated into the electronic prescription system. Tasks such as searching, scanning, packaging, labeling, and recording the dispensing of medication are performed by robotic parts, thus replacing an extremely manual and repetitive process. In an implementation study with one of these models (the XR2), the error rate reached 0%, an achievement that can be explained both by the identification of medications and by the reduction in workload. After all, the technology saved the equivalent of 77% of a pharmacist's working time and 176% of a pharmacy technician's time¹⁵.

Medication conference

With regard to the conference, artificial intelligence (AI) has been gaining increasing prominence. In this context, applications have been developed in which a camera is coupled to a neural network, for checking both drugs and their doses¹⁶⁻²⁰.

Validation studies of this type of technology have revealed good accuracy. In an assessment of healthcare professionals' perception, up to 92% considered the measure as helpful in patient safety¹⁹.

On the other hand, studies still diverge regarding the potential of this technology to decrease or increase preparation and verification time. Furthermore, it is suggested that its accuracy decreases when applied to large volumes of medication, low-quality photographs, or mobile devices¹⁶⁻¹⁹. Additionally, there is the problem of forced classification, in which even unrecognized medications are randomly classified¹⁶.

One of the proposed solutions was to conduct practical training sessions with the healthcare team on the correct technique for capturing images¹⁸. When asked about what an ideal AI prototype would be, the pharmacists referred to transparency as an important principle. Thus, an “adaptive automation” could be built, in which there would be a balance between automation and human intervention, which would lean more to one side or the other depending on contextual factors, such as the risk of the drug in question or the degree of accuracy achieved by the system²¹.

Image identification technologies have been discussed regarding their application in *bins* or in automated dispensing cabinets¹⁶. Furthermore, their applicability at the home level is discussed, where patients with visual impairments or low levels of health literacy can benefit from the use of automated systems for the recognition of their medications¹⁸.

Another supporting technology for the conference is the mobile application based on *Near Field Communication (NFC)*. The proposal is that medications be labeled with an identifying NFC *tag*. Thus, before administering the medication, the nurse must use an application to “read” the information on the *tag* and check if it matches that contained in the prescription²².

In usability tests, the technology was well-received by professionals, perceived as easy to use and as a positive intervention in favor of patient safety. One study revealed that, while 62% of participants successfully identified a medication as incorrect through manual checking, 90% did so when supported by the NFC app²².

Storage, release and registration

Finally, when discussing the stages of medication storage, release, and registration, one cannot fail to mention *Automated Dispensing Cabinets (ADCs)*, which contribute to the closed-loop management of medications.

ADCs have brought profound transformations to the workflow of pharmacists, pharmacy technicians, and nurses, as well as to patient safety and inventory management.

When questioned, the healthcare team demonstrated good receptiveness, reduced occupational stress, and optimism regarding patient safety^{11,23-27}. Most reported a reduction in the time elapsed between medication request and administration, a reduction that reached 83% in one of the studies²⁸. This can be explained by factors such as: concentration of supplies in a single environment, decreased manual searching for medications, and minimization of task interruptions²⁹⁻³¹.

Workflows have been shown to be impacted in various ways across different hospital sectors. The surgical ward, for example, proved to be the most affected. Among the clinical wards, general wards were more impacted than specialized wards. In the emergency room, in particular, there is an important peculiarity in the functioning of ADCs, the *overrides*, in which medications are dispensed even without a prescription or prior verification^{29,32}.

Since they issue alerts when incorrect medication is being dispensed, automated cabinets also significantly reduce medication errors, reaching a 5-fold decrease in one study^{12,31-33}. Furthermore, residual errors have shown lower severity and less involvement of high-alert medications. Even prescription, administration, or medication-related errors not under the control of ADCs have decreased, due to more time being dedicated to clinical tasks¹².

Finally, ADCs have their own inventory management system, optimizing demand control and medication requests. In this way, there is a reduction in waste rates, linked to expiration, returns or indiscriminate and unauthorized use^{11,26-27}.

However, some studies have also raised limitations in the use of these cabinets. Regarding workflow, for example, while some studies report a streamlining of the dispensing process, others show just the opposite^{32,34},

discussing as main causes the unavailability of stock, the formation of queues in the *ADCs*, the need for pharmacists and pharmacy technicians to travel to the wards and lack of familiarity with the technology^{25,30-31,35}.

Furthermore, some pharmacy professionals have found themselves overburdened with extra tasks: that of replenishing the stock of *ADCs* and that of counting their medications daily, in those hospitals where this task has not yet been automated^{27,30}.

As for patient safety, while *ADCs* have reduced medication, dosage, or patient-related errors, they have also shown the potential to increase errors due to omission or delay in administration, whether due to medication unavailability or delays in equipment handling^{12,32,36}.

Furthermore, such devices are not completely immune to other types of errors. One publication revealed that 16% of *look-alike, sound-alike* (LASA) medications were stored dangerously close together and that 4% of these were high-alert devices³⁷. The risk also persists in tasks of human responsibility: depositing the medication in the correct compartment, correct typing, and selecting the correct drug from those stored in the same compartment^{27,29}.

As mentioned above, stock unavailability is a common challenge in managing dispensing cabinets. There is a fragile balance between shortages and surpluses of medications^{26,29,36}. Furthermore, constant updates to guidelines, intersectoral variations, and the seasonality of clinical conditions challenge the creation of an efficient management system³⁶.

Although *ADCs* have such limitations, they have also been the subject of adaptations in some articles. Initiatives that seek to further streamline the dispensing process include remote medication requests and prioritization of orders³⁰⁻³¹. Regarding safety, it has been suggested that alerts be issued in cases of high-alert medications, LASA, drug interactions, or contraindications^{26,34,37}.

One example of inventory optimization is the creation of computerized management systems that monitor inventory surpluses and shortages, as well as key demands, and generate *dashboards* to facilitate logistics³⁸.

The literature discusses that the implementation of a system such as *ADCs* must be well supported by a continuing education program, whether through *workshops*, training, simulations or physical guides. Furthermore, there must be rigorous monitoring, through the provision of *feedback*, the generation of reports and an interprofessional team responsible for the dynamics of the *ADCs*^{12,27,30,35}.

Furthermore, when innovation in healthcare is on the agenda, one issue that deserves special attention is the balance between human judgment and automated tasks. The literature argues, on the one hand, for a lack of trust among professionals in the implemented technologies and, on the other hand, for the possibility of excessive dependence and consequent susceptibility to errors.

However, it is certain that human judgment should still prevail as the driving force in the dispensing process, with automation acting as a facilitator. It was from this perspective that the *Institute for Safe Medication Practices (ISMP)* recommended that automated dispensing cabinets incorporate alerts that require user interaction, thus encouraging critical thinking and not just "autopilot." After all, *ADCs* only fulfill their objectives if they are fed correct information by people. Incorrect counting or typing of supplies, for example, generates a discrepancy between the actual stock and the inventory recorded in the system. As a consequence, the equipment fails to issue automatic replenishment alerts³⁹⁻⁴⁰.

CONCLUSIONS

Based on this review, it is possible to see how much pharmaceutical technologies have already advanced in the field of in-hospital dispensing and how much they can still be enhanced. These technologies can be divided according to the stage of dispensing in which they intervene: medication preparation (automated

robots and *Carousel System*), verification (image capture recognition systems and mobile applications based on proximity communication systems), storage, release, and recording (automated dispensing cabinets).

Most studies have reported the effectiveness of technological interventions in saving time, reducing task interruptions, minimizing manual and repetitive work, improving patient safety, and managing inventory. Furthermore, these innovations have shown good adoption by healthcare professionals.

On the other hand, some challenges regarding its implementation were also identified, including the need for technical, organizational, and interpersonal adaptations. Some of the suggestions made were intelligent management systems, alert generation, report building, integration between different technologies, and the creation of a favorable institutional culture for its adoption.

Finally, there is an expectation that future studies will focus on the long-term functioning and areas for improvement of these technologies, in order to provide a basis for standardized protocols for the implementation of dispensing technologies.

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