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Review

Use of robotics and AI to transform dispensing and drug therapy as well as shaping the future of pharmacy education in Japan

Tomoki Takase, Nobuyuki Muroi and Tohru Hashida*

Department of Pharmacy, Kobe City Medical Center General Hospital, Hyogo, Japan

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*Corresponding author
Department of Pharmacy, Kobe City Medical Center General Hospital, 2-2-1, Minatojima Minamimachi, Chuo-ku, Kobe-city, Hyogo 650-0047, Japan
E-mail: tohru@kcho.jp

ABSTRACT

In Japan, dispensing is a key responsibility of pharmacists and continues to evolve with advancements in robotics and artificial intelligence (AI). This review examines the integration of robotics and AI into pharmaceutical practice, presents supporting evidence for their effectiveness, and explores future directions for teaching dispensing in pharmacy education in Japan. Dispensing robots, such as automated dispensing systems and robotic aseptic preparation units, have been introduced in hospitals and pharmacies to enhance efficiency, reduce dispensing errors, and optimize medication management (Takase, 2022). AI-driven systems assist pharmacists in decision-making and personalized pharmacotherapy, enhancing medication safety, predicting adverse reactions, and optimizing individualized drug therapy (Chow, 2023). Although the initial implementation costs are high, the integration of robotics and AI is expected to expand, particularly in areas such as medication safety monitoring and AI-assisted drug therapy management. Dispensing plays a crucial role in individualized drug therapy and requires technological literacy along with clinical expertise. To adapt to these advancements, pharmacy education reforms are required to incorporate AI-driven decision support systems, robotics training, and interdisciplinary collaboration. Equipping future pharmacists with these skills will ensure that they can effectively integrate robotic and AI technologies, while maintaining patient safety and quality of care. As pharmacy practices continue to evolve, pharmacists must adapt to technological advancements and collaborate with robotics and AI to optimize pharmacotherapy outcomes.

Key words: pharmacist, dispensing, robot, artificial intelligence (AI), pharmacy education

1. Introduction

Dispensing is one of the most important responsibilities of pharmacists in Japan. Article 19 of the Japanese Pharmacist Act states that “No person who is not a pharmacist shall dispense drugs to sell or give away.” In contrast, in other countries, including the United States (U.S.), pharmacy technicians are utilized to perform drug dispensing (Mattingly and Mattingly, 2018). However, such systems do not exist in Japan, making pharmacists solely responsible for dispensing. Dispensing is also a fundamental component of pharmacy education. The Objective Structured Clinical Examination (OSCE), which undergraduate students must pass before beginning practical training, evaluates dispensing techniques using dedicated equipment. Furthermore, hands-on experience in dispensing is a major part of subsequent practical training in hospitals and pharmacies. Nontheless, recent advances in robotic technology and artificial intelligence (AI) have significantly transformed the field of pharmacy, particularly in drug dispensing. Robotic dispensing systems have demonstrated potential in improving accuracy and efficiency. In addition, automated aseptic preparation of anticancer drugs, another crucial responsibility of pharmacists, is becoming increasingly common with the introduction of robotic systems. AI-driven decision-support systems are being developed to optimize medication safety, reduce errors, and personalize drug therapy. Given these advancements, pharmacy education must evolve to incorporate AI and robotics, ensuring that future pharmacists are equipped with the necessary knowledge and skills to work effectively in a technology-driven healthcare environment. In this review, we explore the current state of robotic and AI implementation in pharmaceutical practices, including in our institution, and discuss the future directions for integrating robotics and AI into pharmacy education in Japan.

2. Utilization of dispensing robots for oral medicines

Recent technological advances have increased the utilization of dispensing robots worldwide. In Japan, dispensing robots are gradually being introduced into hospitals and community pharmacies. The Japan Municipal Hospital Association conducted a survey to determine the rate of introduction of these devices in public hospitals in Japan. According to the survey, the introduction rates of automatic tablet packaging machines, automatic injection drug dispensing machines, and robots for preparing anticancer drug mixtures were 94.2%, 43.4%, and 0.9%, respectively, in 2022. Dispensing robots are used to increase efficiency, reduce errors, prevent staff exposure to hazardous drugs, and reduce labor costs. The functions of these robots vary among different countries because of the differences in how medicines are packaged and dispensed. The main forms of packaging for tablets and capsules in the USA, Europe, and Japan are bottles; blister packages and boxes; and press-through packages (PTP, also known as blister packs), respectively (Roullet and Droulers, 2005). Facilities across the world have reported the efficacy of utilizing dispensing robots into the workflow of these packaging methods (Hamada et al., 2014; Tabata et al., 2018; Takase et al., 2022; Lin et al., 2007; Ruhle et al., 2009; Rodriguez-Gonzalez et al., 2019). Table 1 presents the findings of such studies across the world. Since 2014, there have been reports on the effectiveness of domestic robots dispensing PTP sheets of tablets and capsules in hospitals and community pharmacies in Japan (Hamada et al., 2014; Tabata et al., 2018; Takase et al., 2022). These effects include reductions in the number of dispensing errors, the duration of patient waiting times, and time spent dispensing or preparing medicines.

At our hospital (Kobe City Medical Center General Hospital, Japan), we implemented two types of dispensing robots for packaged and powdered medicines and a bar-coded medication dispensing support system with personal digital assistance (PDA). The dispensing robot for packaged medicines (Drug Station®, Yuyama Co., Ltd., Osaka, Japan, Fig. 1a) stores a maximum of 1,200 single-unit packages of oral medicines, such as tablets, capsules, powders, liquids, and topical medications. Pharmacists or pharmacy support staff without a pharmacist's license could pick up the ordered quantity of medicines according to the instructions on the screen from the storage bins, which automatically move to the handling slots of Drug Station® using ordered prescription

Table 1. Work and efficacy of dispensing robots introduced in hospital and community pharmacy.

Author, Year	Country	Setting	Name of robot	Medicines handled by robots	Work of robots	Outcomes following the introduction of robots
Hamada et al., 2014	Japan	Community pharmacy	Robo-Pick	PTP sheets of tablets or capsules	Automatically prepares PTP sheets in prescribed quantities	Reduction in the number of dispensing errors
Tabata et al., 2018	Japan	Hospital	DimeRo	Powdered medicines	Automatically weighs and packs powdered medicines	Reduction in the length of patient waiting time for dispensing
Takase et al., 2022	Japan	Hospital	Drug Station, Mini DimeRo	Drug Station: Single unit packages of oral medicines, such as tablets, capsules, powders, liquids, and topical medications Mini DimeRo: Powdered medicines	Drug Station: Automatically moves storage bins to the handling slots and confirms ordered quantity Mini DimeRo: Automatically weighs and packs powdered medicines	1) Reduction in the number of dispensing errors 2) Reduction in the length of dispensing time 3) Shifting of responsibilities from pharmacists to pharmacy support staff
Lin et al., 2007	U.S.	Community pharmacy	Script-Pro SP-200	Tablets and capsules	Automatically obtains appropriate size vials, collects medicines and labels vials	1) Reduction in the length of dispensing time 2) Shifting of responsibilities from pharmacists to technicians
Ruhle et al., 2009	Germany	Community pharmacy	ROWA robotic dispensing machines	Packaged medicines in box	Picks out packaged medicines	1) Reduction in personnel costs 2) Increase in the number of sales of over-the-counter drugs
Rodriguez-Gonzalez et al., 2019	Spain	Hospital	ROWA Vmax	Packaged medicines in box	Automatically stores and picks out packaged medicines	1) Reduction in the number of dispensing errors 2) Reduction in time required for stock management

PTP: press-through package

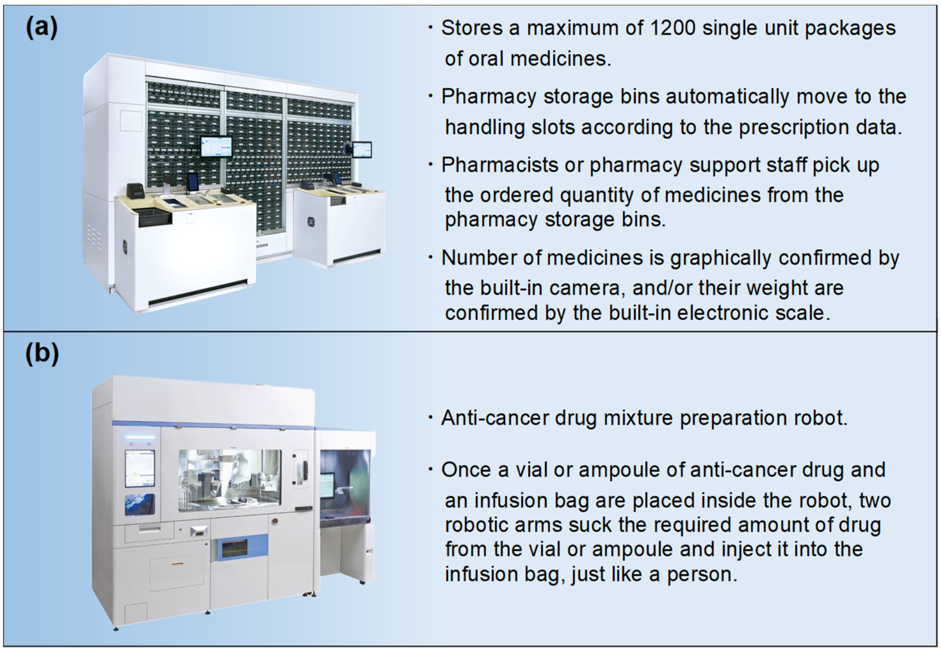

Figure 1. Automated dispensing robot and sterile preparation robot for cancer chemotherapy in Kobe City Medical Center General Hospital. (a) Drug Station®. (b) ChemoRo®.

data in the computerized physician order entry system (HOPE/EGMAIN-GX®, Fujitsu, Ltd., Tokyo, Japan). After a pharmacist or pharmacy support staff picked up the medicines from the storage bins, the number of medicines was graphically confirmed using a built-in camera and their weight was confirmed using a built-in electronic scale. The dispensing robot for powdered medicines (Mini DimeRo®, Yuyama Co., Ltd., Osaka, Japan) automatically weighs and packs powdered medicines according to prescriptions written by physicians. The barcoded medication-dispensing support system with a PDA uses barcodes to check for prescriptions and medication packs that cannot be stored in the dispensing robot. The system checks whether medicines have been correctly selected according to their prescriptions. These robots and systems covered approximately 90% of the total number of medication orders per prescription dispensed, reducing dispensing errors by approximately 80% and pharmacist dispensing time by approximately 60% (Takase et al., 2022). Thus, dispensing robots reduce dispensing errors and manpower required by pharmacists, thereby improving the efficiency of pharmaceutical operations. Considering the cost of their introduction, they are expected to be increasingly introduced into pharmacy practices in the future.

3. Utilization of robots in chemotherapy compounding

Sterile preparation robots in cancer chemotherapy have significant potential for improving operational efficiency and accuracy and protecting employees from exposure to anticancer agents. Traditionally, PPE and exposure control devices have been used to ensure employee safety. However, they are considerably expensive. Although the initial cost of introducing a robot is high, some facilities consider it operationally superior when considering the ongoing cost of the required exposure control devices and pharmacist labor costs. In Japan, these robots are currently being introduced in facilities specializing in cancer treatment. Although early robots were convenient, several problems were identified. Nurgat et al. (2015) reported on the compounding accuracy, days of operation, and downtime of a first-generation chemotherapy compounding robot (CytoCare, Health Robotics). It was found to have various challenges, including mechanical failures, such as robotic arm clamping and needle positioning errors, which occasionally disrupted the workflow. Despite these issues, the robot enhanced safety by reducing the staff's exposure to cytotoxic agents. This study emphasizes the need for regular maintenance and operator training to optimize system reliability and efficiency (Nurgat et al., 2015). Iwamoto et al. reported on the improved dosing accuracy and sterility of another chemotherapy compounding robot (APOTECA, Loccioni) compared with those of manual methods. The robot also reduced occupational exposure to hazardous drugs, thereby contributing to a safer working environment (Iwamoto et al., 2017). The productivity of robotic systems for compounding chemotherapy (KIRO Oncology, Grifols) has been investigated across multiple healthcare centers, and findings indicate that these systems result in significant time savings and consistent preparation quality, with fewer errors compared to manual processes. However, various challenges have been identified, such as high initial costs and the need for specialized staff. This study supports the integration of robotics into pharmacy operations, emphasizing their role in improving workflow efficiency and ensuring patient safety (Riestra et al., 2022).

At our hospital, a sterile preparation robot for cancer chemotherapy (ChemoRo®, Yuyama Co., Ltd., Osaka, Japan, Fig. 1b) was introduced in 2017 and used in combination with mixing and preparation by pharmacists. Prescriptions for the cancer drugs to be prepared are sent to the satellite pharmacy department system of the outpatient chemotherapy center by the physician who selects the cancer chemotherapy regimen registered in the electronic medical record in advance. The pharmacist audits the medication history of the patient and the results of the current day's tests and then sends the necessary data and instructions for starting the preparation. The robot is operated by an assistant who is not a licensed pharmacist. In our hospital, the number of anticancer drug preparations is increasing annually, and by 2023, the number of robotic preparations will account for 12,276 (41%) of 30,266 preparations, increasing operational efficiency while ensuring safety. The introduction of an anticancer drug preparation robot at our facility enabled tasks that previously required two pharmacists to be performed.

In the introduction of this paper, we stated that under Japanese law, dispensing is the exclusive job of pharmacists and that there is no pharmacy technician system that qualifies persons with a certain level of education in dispensing practices to perform dispensing tasks in Japan. On the other hand, Japan's Ministry of Health, Labour, and Welfare (MHLW) has recently expressed the view that effective approaches to improve operational efficiency, including the use of dispensing equipment and information technology, should be considered (MHLW, 2019). The basic concept of operations that can be performed by non-pharmacists is based on the premise that pharmacists have the ultimate responsibility for dispensing. Among them, the robot assistance tasks in the overall dispensing process under the supervision of a pharmacist, which were performed at our hospital, can be interpreted as tasks that can be performed by assistants who are not qualified as pharmacists. By shifting the task of dispensing drugs to the robot and the assistant, which used to take up much of the pharmacist's time, we believe that the pharmacist can benefit from this effort in the optimization of drug treatment, which should be focused on more intensively.

4. Impact of artificial intelligence on pharmacy practices

AI, including robotics, has emerged as a transformative strategy across various industries, including healthcare and pharmacy. Its potential to revolutionize pharmacy practices and education is widely acknowledged, as evidenced by a growing body of research. AI is reshaping daily life and pharmacy practices, emphasizing the need for its adaptation and integration in professional and educational settings. As AI technologies continue to develop, their impact on pharmacy will become even more profound, necessitating proactive measures to harness their benefits while addressing associated challenges (Chow, 2023). In addition to dispensing, AI-powered tools are enhancing medication management. In particular, AI algorithms analyze patient data to identify potential drug interactions, optimize dosing, and predict adverse reactions. These tools assist pharmacists in tailoring treatments to individual patients, enhancing precision medicine (Poweleit et al., 2023). Additionally, chatbots and virtual assistants, powered by natural language processing, provide 24/7 support for patient queries, making pharmacy services more accessible and user-friendly. AI also plays a crucial role in pharmaceutical research and development. Machine learning models expedite drug discovery by analyzing vast datasets to identify promising compounds and predict their efficacy and safety profiles (Iwata, 2020). This reduces the time and cost associated with bringing new drugs to market, ultimately benefiting patients by improving access to innovative therapies.

5. Impact of the development of robots and AI on pharmacy education

Reconstructing pharmaceutical dispensing education prepares future pharmacists to meet evolving healthcare demands. The 2022 revision of the Model Core Curriculum for Pharmacy education in Japan (MEXT, 2022) shifted focus from facility-specific practical training to equip students with the ability to address public needs and solve societal issues (Fig. 2). This emphasized the need to train pharmacists to be capable of preventing diseases and providing personalized pharmacotherapy from the beginning of their academic journey. The curriculum includes the statements "Clinical Pharmacy", which integrates educational experiences between universities and clinical settings as well as "Medical pharmacy" in which students are trained in prescription-based dispensing, understanding pharmaceutical regulations, and the science of drug formulation. These courses aim to teach students a comprehensive flow of dispensing activities such as ensuring prescription accuracy, evaluating dosage forms, and determining the appropriateness of drug administration methods. By engaging in activities, such as prescription auditing, dispensing, patient education, and monitoring, students can develop the skills needed to optimize pharmacotherapy, reduce risks, and enhance patient outcomes. Dispensing is not only a procedural task but also a central component of individualized pharmacotherapy, connecting basic pharmaceutical sciences with clinical practice. Additionally, the development of dispensing robots is linked to this change in pharmacy education. With the development of dispensing robots in systems engineering, AI and machine learning will also be used in clinical practice in the near future. Currently in Japan, pharmacists ultimately bear the responsibility for dispensing errors, including errors

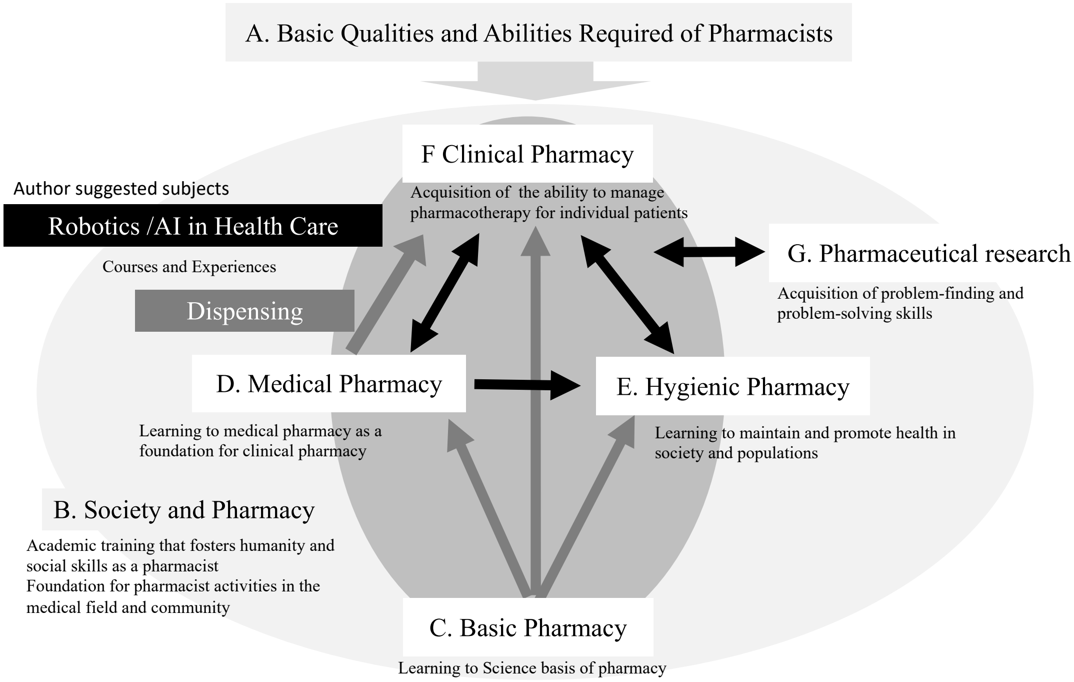

Figure 2. Concepts included in the Model Core Curriculum for Pharmacy Education in Japan.
(Based on the Model Core Curriculum for Pharmacy Education, 2022, MEXT). By incorporating advanced technologies, such as robotics, AI, and system engineering, into pharmacy education, future pharmacists will be better equipped to meet the evolving demands of healthcare.

caused by system errors, therefore pharmacists need to become familiar with these systems. In order for pharmacists to become familiar with more advanced dispensing systems in the future, acquisition of advanced technologies such as AI should be introduced into pharmacy education. To fully leverage AI while addressing its challenges, pharmacy education must evolve. In Japan and Asia, pharmacy programs should shift from traditional knowledge-based curricula to those that emphasize interdisciplinary learning and technological skills, including AI, data science, and digital health. Students must understand machine learning, natural language processing, and robotic automation, along with their applications in pharmacies. Courses like "AI in Healthcare" should cover predictive analytics, decision-support systems, and AI ethics. Moreover, hands-on experiences are crucial. Pharmacy schools should partner with healthcare institutions and technology companies to provide students with access to AI tools. Simulation laboratories can help bridge the gap between theoretical learning and practical applications, allowing students to work with robotic dispensing systems and AI-driven clinical tools. AI integration into pharmacies requires collaboration across disciplines. Pharmacy students should work with their computer science and engineering peers on AI-related projects to foster technological understanding, teamwork, and the problem-solving skills necessary for interdisciplinary innovation.

In addition to dispensing education, research has also played a significant role in improving Japanese pharmacy education. Under "Pharmaceutical Research," students identify clinical and practical challenges, develop research plans, and execute them independently. Through this process, students acquire critical problem-solving skills and the ability to conduct scientific inquiries. This approach underscores the importance of dispensing as a core practice in pharmacies and bridges education, clinical application, and innovation, thereby contributing to the advancement of both the pharmaceutical field and overall healthcare.

6. Conclusion

The integration of robots and AI into pharmaceutical practice marks a significant advancement in the field, improving efficiency, safety, and operational workflows while reducing the number of dispensing errors and exposure to hazardous substances, tailoring treatments to individual patients. These developments underscore the importance of aligning pharmacy education with technological innovation in Japan. The revised Model Core Curriculum for Pharmacy education in Japan emphasizes the critical role of dispensing in individualized pharmacotherapy, recognizing it as more than a procedural task but as a central component of optimizing patient care. By incorporating advanced technologies, such as robotics, AI, and system engineering, into pharmacy education, future pharmacists will be better equipped to meet the evolving demands of healthcare. The emphasis on research in pharmacy education highlights the need for pharmacists to develop problem-solving and analytical skills. This approach bridges the gap between theoretical knowledge and practical application, ensuring that pharmacists contribute to both innovation and patient safety. Collaboration between human expertise and robotics and AI is vital for advancing pharmacy practice and education, ultimately enhancing the quality and outcomes of pharmacotherapy.

Conflict of Interest

The authors declare no conflicts of interest associated with this study. This study was conducted in the absence of any conflicting commercial or financial relationships.

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