



Consensus

International expert consensus on hospital intelligent pharmacy



Cao Li^{a,i}, Wenshuo Jiang^{a,b,i}, Aizong Shen^c, Yilei Li^d, Junyan Wu^e, Hua Tao^f,
Yongqiang Tang^g, Xiaolin Yue^{h,*}, Alice Hao^{i,**}, Zhigang Zhao^{a,b,***}

^a Department of Pharmacy, Beijing Tiantan Hospital, Capital Medical University, Beijing, China

^b School of Pharmaceutical Sciences, Capital Medical University, Beijing, China

^c Department of Pharmacy, The First Affiliated Hospital of USTC, Division of Life Sciences and Medicine, University of Science and Technology of China, Hefei, Anhui, China

^d Department of Pharmacy, Nanfang Hospital, Southern Medical University, Guangzhou, China

^e Department of Pharmacy, Sun Yat-Sen Memorial Hospital, Sun Yat-sen University, 107 Yanjiang West Road, Guangzhou, China

^f Department of Pharmacy, Beijing United Family Hospital, Beijing, China

^g State Key Laboratory of Multimodal Artificial Intelligence Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, China

^h Party Committee Office, Beijing Tiantan Hospital, Capital Medical University, China

ⁱ Mount Carmel West St., Ann's Hospital, Ohio, USA

ARTICLE INFO

Keywords:

Intelligent pharmacy
Hospital pharmacy
Clinical pharmacist
Rational drug use
Consensus

ABSTRACT

As the rapid advancements in medical technology and increasing demands for personalized medication, Hospital Intelligent Pharmacy (HIP) integrates artificial intelligence, large-scale health data analytics, the Internet of Things (IoT), and other cutting-edge technologies to optimize end-to-end pharmaceutical supply chain processes, management, and clinical processes. In recent years, regulatory agencies such as the European Medicines Agency (EMA), the Medicines and Healthcare products Regulatory Agency (MHRA), China's National Medical Products Administration (NMPA), and the U.S. Food and Drug Administration (USFDA) have issued policies to promote intelligent pharmacy development. However, HIP still faces challenges including ambiguous definitions, absence of standardized technical protocols, and incomplete evaluation frameworks. To address these issues, international and domestic academic organizations collaboratively developed the International Expert Consensus on Hospital Intelligent Pharmacy. This consensus clarifies HIP's definition, core components, and systematic framework, providing scientific guidance for standardized implementation and clinical application of intelligent pharmacy in hospitals. Utilizing a Delphi method process, expert opinions will be collected, analyzed, and refined. The current consensus defines HIP's scope and principles, outlining a framework with 10 components: intelligent drug supply chain management, drug dispensing, prescription review, pharmacovigilance, medication therapy management, therapeutic drug monitoring, telepharmacy services, pharmacy administration, science popularization, and clinical trials. Future directions focus on 5 key areas: AI-augmented pharmacist competency development, advancing pharmaceutical scientific research, fostering intelligent pharmaceutical publications and journals, addressing ethical and legal challenges, and promoting international harmonization in pharmacy. The consensus offers critical references and exploratory pathways for HIP's global advancement.

1. Introduction

Hospital pharmacy plays a critical role in medical services, aiming to integrate pharmaceutical expertise to enhance the scientific foundation

of drug therapy and ensure optimal outcomes under safe conditions (see Fig. 1).

With the continuous advancement of medical technologies and the growing variety of drugs, patients now face increasingly complex

* Corresponding author. Party Committee Office, Beijing Tiantan Hospital, Capital Medical University, Beijing, China.

** Corresponding author. Mount Carmel West St. Ann's Hospital in Ohio, USA.

*** Corresponding author. Department of Pharmacy, Beijing Tiantan Hospital, Capital Medical University, Beijing, China.

E-mail addresses: yxl@xwh.ccmu.edu.cn (X. Yue), alice.hao@gmail.com (A. Hao), 1022zzg@sina.com (Z. Zhao).

Peer review under the responsibility of Editorial Board of Intelligent Pharmacy.

ⁱ Li C, and Jiang WS contributed equally.

<https://doi.org/10.1016/j.ipha.2025.06.001>

Received 10 June 2025; Accepted 17 June 2025

Available online 18 June 2025

2949-866X/© 2025 The Authors. Publishing services by Elsevier B.V. on behalf of Higher Education Press and KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

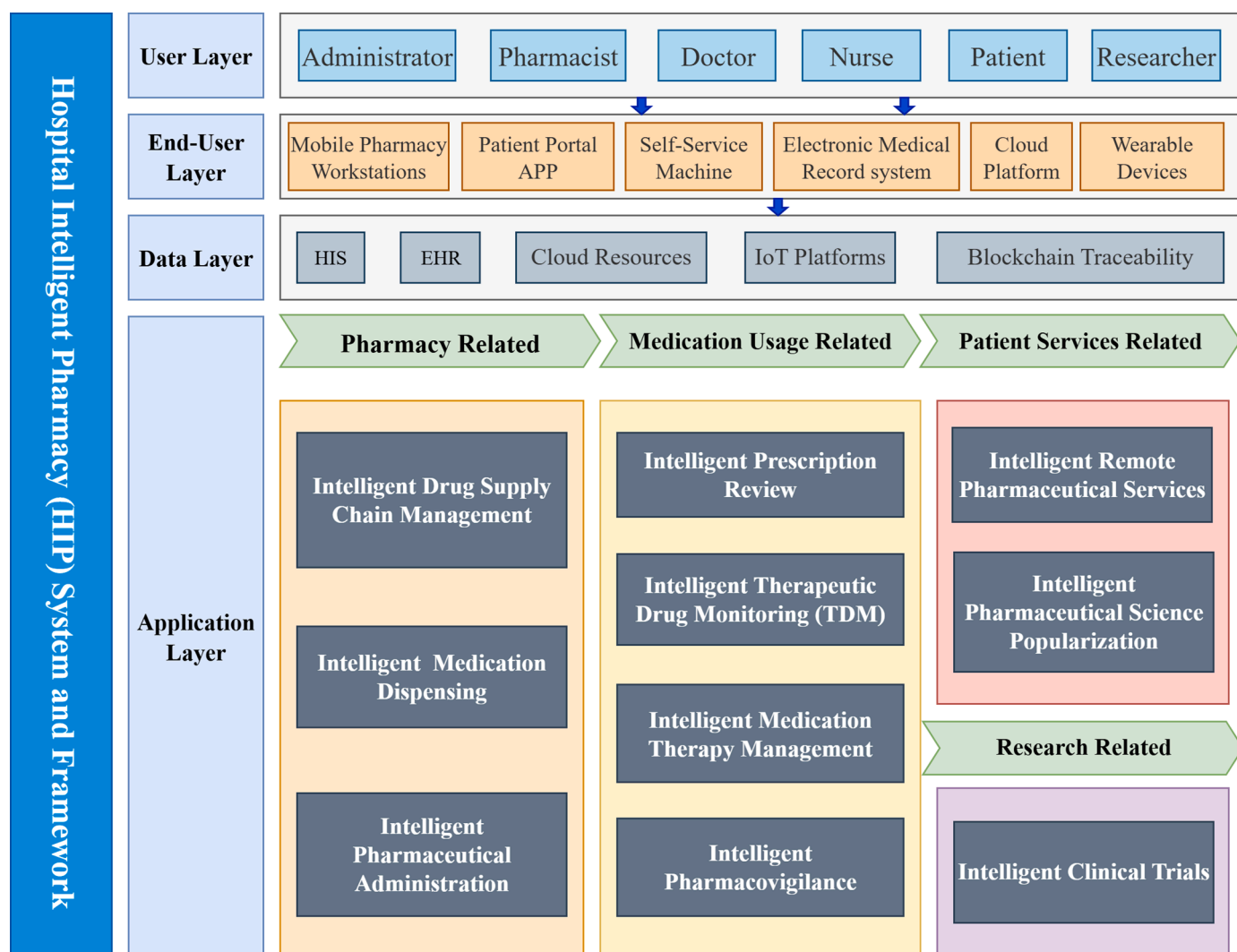


Fig. 1. Hospital intelligent pharmacy (HIP) system and framework.

treatment regimens. This complexity has led to more frequent occurrences of adverse drug reactions (ADR) and medication errors (ME), while the efficiency of pharmaceutical supply chain management remains inadequate. Simultaneously, rising patient volumes and shortages in healthcare personnel have exacerbated challenges in providing individualized drug therapy. Against this backdrop, Hospital Intelligent Pharmacy (HIP) has gained prominence.^{1,2}

Intelligent Pharmacy is based on the integration of pharmacy, computer science, bioinformatics, and other interdisciplinary fields. It explores how advanced technologies such as artificial intelligence (AI), large-scale health data analytics, and the Internet of Things (IoT) can be applied to optimize the entire process of drug development, production, distribution, and usage. From an application perspective, IP includes four major domains: intelligent drug research, intelligent drug production and circulation, intelligent drug management and dispensing, and intelligent drug use. HIP primarily focuses on the management, dispensing, and use of medications.³⁻⁶

In recent years, multiple policies and initiatives have established a robust framework for the development of Intelligent Pharmacy.⁷⁻¹⁰ In December 2023, the European Medicines Agency (EMA) released its Artificial Intelligence Work Plan (2023–2028), emphasizing the application of AI across the entire drug lifecycle.¹¹ In 2024, the UK's Medicines and Healthcare products Regulatory Agency (MHRA) issued the policy paper “Impact of AI on the Regulation of Medical Products”,

outlining strategic directions for AI in drug development, production, and post-market surveillance, highlighting the importance of algorithm transparency and clinical validation.¹² In November 2024, China raised “Reference Guide for AI Application Scenarios in the Health Industry,” providing specific guidance for the application of AI in hospital pharmacy.¹³ In January 2025, the U.S. Food and Drug Administration (FDA) released its first AI guideline, establishing standards for AI application in drug safety, efficacy, and quality evaluations.¹⁴

Despite its significant potential, HIP still faces multiple challenges. First, there remains no unified consensus regarding the definition and scope of HIP, resulting in a lack of clear development direction. Second, the absence of standardized guidance in areas such as technology selection, data management, and system integration has restricted the effectiveness of implementation. Lastly, the lack of a quality evaluation system has made it difficult to quantify HIP's clinical value and economic benefits.¹⁵⁻¹⁹ In response to these challenges, Clinical Pharmacy Committee of the Chinese Pharmaceutical Association, the Intelligent Pharmacy Committee of the China Association for Promotion of Human Health Science and Technology, Pharmacovigilance Committee of China Society for Drug Regulation, Clinical Toxicology Committee of Chinese Society of Toxicology, Drug Induced Disease Committee of Chinese Pharmacological Society, and Home Based Pharmaceutical Care Committee of Chinese Pharmacist Association, has collaboratively formulated the International Expert Consensus on Hospital Intelligent

Pharmacy. This consensus aims to provide scientific and systematic guidance for the development of HIP by clearly defining its scope and core components, proposing a comprehensive framework, and promoting the sustainable advancement of hospital intelligent pharmacy.

2. Methodology

Through a comprehensive survey of global policy guidance documents and a literature review of databases including Web of Science (WOS), embase and Pubmed, the secretariat board drafted an initial list of recommendations. Subsequently, in the first round of the Delphi method, relevant suggestions were solicited and discussed from 20 experts. The secretariat members revised the drafted recommendation list based on these suggestions. After that, in the second round of the Delphi method, 50 experts from 10 countries and regions were invited to score and provide suggestions according to the revised recommendation list. The secretariat members analyzed the results of the second - round consultation and modified the consensus. Based on the results of the two-round Delphi method consultations, 16 items were determined and finalized.

A 5-point Likert scale was utilized to assess the definitions and subcomponents of HIP. The scale included: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. Items that received an average score below 3 required experts to submit comments or revision suggestions. For both the definitions and secondary framework items, experts were also encouraged to provide additional feedback at the end of the consultation form.²⁰ The inclusion criteria for consensus required meeting all three conditions simultaneously: a mean score ≥ 4.5 , an approval rate $\geq 90\%$, and a coefficient of variation ≤ 0.25 . The approval rate was calculated as the proportion of experts giving a score of 4 or 5 out of the total number of responses for that item. Items that failed to meet these criteria after two rounds of consultation were excluded.²¹

The reliability of the consensus process was evaluated based on three parameters: expert authority, engagement level, and the coordination of expert opinions. Expert authority was quantified by calculating the authority coefficient (Cr), defined as $Cr = (Cs + Ca)/2$. Cs represented the expert's self-rated familiarity with 15 secondary items and ranged from 0 (not familiar) to 1 (very familiar). Ca was based on the influence of four factors on expert judgment: practical experience (0.5, 0.4, 0.3, or 0), theoretical analysis (0.3, 0.2, 0.1, or 0), reference literature (0.15, 0.15, 0.15, or 0), and intuitive judgement (fixed at 0.05). The engagement level was measured by the response rate, calculated as the number of valid consultation forms returned divided by the total number distributed. The coordination of opinions was assessed using Kendall's coefficient of concordance (W)²² This consensus has been registered with the Practice guideline Registration for transparency (PREPARE) platform, Registration No. PREPARE-2025CN183.

3. Definition and connotation of HIP

Hospital Intelligent Pharmacy (HIP) is both a discipline and practice model driven by next-generation information technologies such as artificial intelligence (AI), large-scale health data analytics, cloud computing, the Internet of Things (IoT), and blockchain. Through deep integration of intelligent hardware and software systems, HIP promotes the digital transformation and intelligent upgrading of pharmaceutical supply, pharmacy administration, pharmaceutical care, medication safety and pharmacist education.

HIP has the following key characteristics.

1. Data-driven proactive intervention: Leveraging real-time data analytics to anticipate medication risks—such as drug–drug interactions (DDI) and allergy conflicts—HIP transforms pharmaceutical care from reactive error correction to proactive risk prevention.²³
 2. Closed-loop full-process management: HIP manages the complete medication lifecycle—procurement, storage, prescribing, dispensing, administration, monitoring and evaluation—ensuring traceability and accountability throughout.²⁴
 3. Human-AI collaborative decision-making: AI provides quantitative recommendations, such as dosage calculations and therapeutic alternatives, while pharmacists and physicians retain final decision-making authority. This creates a synergistic “AI-assisted + human-reviewed” model.²⁵
 4. Service model expansion: HIP extends pharmaceutical care from in-hospital to home settings. For example, intelligent pillboxes and remote medication therapy management (MTM) services could enhance patient adherence and safety in home settings.²⁶
- HIP is underpinned by a diverse range of technologies that form a coordinated ecosystem:
- Artificial Intelligence:** Acts as the core engine for decision support.⁶ Natural language processing (NLP) facilitates the creation of knowledge graphs from massive clinical text data.²⁷ Machine learning enables continuous optimization of personalized medication strategies, while deep learning enhances the accuracy of ADR predictions, creating a loop of “analysis–optimization–warning–recommendation”.^{28,29}
 - Large-scale health data analytics:** Provides the digital foundation for precise pharmaceutical services. It integrates heterogeneous data from hospital information systems (HIS), electronic medical records (EMR), laboratory information systems (LIS), and wearable devices to construct a 360-degree medication profile. This multidimensional data fusion not only eliminates data silos but also uncovers hidden patterns in medication use for dynamic clinical decision support.^{30,31}
 - The Internet of Things (IoT):** Reconstructs the full-cycle pharmaceutical management system. Intelligent medicine cabinets ensure precise inventory tracking, automated dispensing machines improve prescription fulfillment efficiency, and intelligent cold chain systems monitor temperature-sensitive drugs. Digital traceability across the medication chain strengthens quality and safety.
 - Blockchain:** Establishes a trust mechanism in drug circulation. Under the **Separation of Prescription and Dispensing (SPD)** policy, blockchain technique ensures the immutability of prescription data and protects patient privacy. It also provides transparent and auditable oversight channels for regulators, addressing trust deficits in traditional supply chains.^{32,33}
- ## 4. HIP System and Framework
- ### 4.1. Intelligent drug supply chain management
- Intelligent drug supply chain management refers to the application of IoT, AI, and other technologies to optimize procurement, inventory, distribution, and storage of pharmaceuticals, enabling intelligent and data-driven management.
- Description:** The objective of intelligent drug supply chain management is to enhance efficiency, quality, and safety in drug supply, ensuring that medications move from manufacturers to hospital pharmacies and clinical departments in an optimized, traceable, and responsive manner, meeting patient needs in a timely and accurate way.³⁴
1. Intelligent procurement: Digital supplier management, intelligent invoice archiving, online drug selection and approval, multi-channel purchasing, and real-time order tracking ensure traceability and reliability of medication sources.
 2. Inventory optimization: Machine learning models are employed along with location monitoring, seasonal trends, and historical consumption data to predict shortages, automated restocking, and optimize shelf placement. Return-to-stock reconciliation and synchronization of hospital and supplier inventories help maintain access while reducing financial pressure.³⁵

3. Traceability systems: Integration of drug barcoding with cloud-based platforms enables real-time tracking, especially for controlled substances. Batch verification and warehouse labeling technologies support compliance and minimize relabeling burdens.
4. Drug storage: For special drugs requiring cold chains, light avoidance, or restricted access (e.g., narcotics), intelligent cabinets, temperature control systems, surveillance, IoT platforms, and cloud integration allow for dual-factor authentication and permissions-based access. These systems perform real-time audits and alerts while supporting data-driven management and ensuring safety compliance.

4.2. Intelligent drug dispensing

Intelligent drug dispensing involves the use of automation and digital technology to execute preparation, packaging, verification, and delivery of medications to patients efficiently and safely.

Description: Pharmacies include outpatient, emergency, inpatient, IV admixture services (PIVAS), clinical trial pharmacies, operating room, satellite pharmacies, and TCM dispensaries.

Automated dispensing tools include robotic dispensers, packaging machines, intelligent shelving, checking machines, sorting systems, delivery robots, pneumatic or track logistics systems, temperature controls, cabinets, sterilizers, and electronic queueing systems. Each type of pharmacy uses appropriate technology tailored to its operational needs.^{7,23}

Outpatient and emergency pharmacies, dealing with high patient volume yet unorganized, may benefit from dispensers, checking devices, and electronic queueing systems to improve safety and flow. Inpatient pharmacies and PIVAS may employ repackaging machines, verification machines, controlled drug cabinets, delivery robots, pneumatic tubes, and labeling machines for accuracy and efficiency.^{7,23}

Through the application of computer vision algorithms, barcode technology, and related methods, automated drug identification and classification can be achieved³⁶; queuing and call systems enable real-time patient tracking, flexible staffing; intelligent logistics algorithms support optimized delivery routing, automated recognition, and staggered scheduling to reduce peak-time congestion, with integration of electronic health records.

4.3. Intelligent prescription review

Intelligent prescription/medical order review refers to integrating drug package inserts, clinical pathways, treatment guidelines, and medication safety databases, combined with artificial intelligence (AI) technologies and iterative updates, to build a prescription review rules engine. Based on patient disease information and drug characteristics, intelligent algorithms evaluate the rationality, safety, and effectiveness of prescriptions at the time of prescribing. The system provides recommendations or warnings to physicians, helping reduce medical errors, ensure medication safety, and improve therapeutic outcomes.

Description: Hospitals of various levels, both domestically and internationally, use pharmacy service centers to implement standardized and homogenized intelligent review systems within a region. This has improved the rational use of medications in both large hospitals and primary care institutions.

By introducing large language model (LLM) technology and integrating clinical guidelines, drug package inserts, and real-world data, hospitals can build dynamic prescription review knowledge bases that support a “warning–correction–feedback” closed-loop optimization process.³⁷ Additionally, hospitals can develop AI-powered prescription review systems that automatically analyze and assess prescription risks. These systems integrate clinical guidelines, drug interaction databases, and individual patient data to scan for potential risks such as dosing

errors, contraindications, and duplicate medications. They also process multimodal data to evaluate the appropriateness of treatment plans and continuously update the rule base according to the latest medical literature and drug information. Finally, pharmacists are involved in manually reviewing high-risk prescriptions, providing evidence-based references to enhance the efficiency and accuracy of the review process.^{38,39}

4.4. Intelligent pharmacovigilance

Intelligent pharmacovigilance refers to the use of public databases, machine learning, natural language processing (NLP), and hospital electronic medical records, combined with patient-specific data, to identify high-risk drugs, drug interactions, and adverse reactions. It enables early warnings, integrated evaluation, real-time intervention, full-cycle tracking, and automated ADR reporting.

Description: Intelligent pharmacovigilance integrates multi-source data (clinical data, patient reports, adverse event databases, social media, EMRs, drug labels, etc.) and applies automation and intelligent analysis to provide deep insights and early warnings regarding drug safety.⁴⁰ With large-scale databases, AI tools can detect patterns in adverse reactions far exceeding manual methods, allowing quicker responses to risks and enhancing patient safety.^{41,42} AI simplifies the process of collecting and analyzing safety data from clinical trials, medical records, and patient feedback.⁴³ NLP is crucial in extracting valuable safety information hidden in unstructured natural language, revealing unexpected drug events or risks.⁴⁴ By analyzing real-world patient experiences, AI plays a key role in ensuring post-marketing drug safety.⁴⁵

4.5. Intelligent medication therapy management

Intelligent medication therapy management (MTM) involves using patient demographics, medical records, and test results, combined with digital systems, to create a comprehensive management framework based on knowledge bases, clinical guidelines, and pharmacists' experience. This includes forming rational drug use strategies, adjusting treatment plans, educating patients, monitoring medications, evaluating treatment outcomes, and follow-ups.

Description: MTM encompasses everything from creating drug therapy plans and identifying/intervening with medication-related problems (MRPs), to pharmaceutical consultations, patient education, therapeutic evaluations, and follow-ups. Intelligent MTM utilizes data analysis tools and patient health/genetic information to assess treatment plans, identify MRPs, and provide personalized treatment recommendations using decision support systems.^{46,47}

Real-Time Monitoring and Intervention: By applying telemedicine technologies and AI algorithms, patients' medication usage can be monitored in real time. Clinical pharmacists use the system analyzing the effectiveness and adverse reactions of drugs, promptly detects and intervenes in issues such as drug interactions or inappropriate dosing, thereby reducing medication-related risks.^{48,49}

Personalized Medication Optimization: This refers to using large-scale health data analytics to design personalized treatment plans based on patients' health status, lifestyle, and genetic traits, while dynamically adjusting treatment strategies to optimize drug dosage and therapeutic effects.⁵⁰

Intelligent Patient Education and Guidance: Through technologies such as virtual health assistants and online education platforms, patients receive real-time guidance and education on medication use. These tools help patients understand how to take their medications properly, recognize adverse effects, and adhere to treatment plans, ultimately improving medication compliance.⁵¹ AI-integrated virtual pharmacist assistants (e.g., intelligent dialogue systems based on Deepseek) provide personalized medication guidance.⁵² For instance,

based on the patient's disease-related information and medication history, the system can generate customized medication reminders, dietary recommendations, and adverse reaction management plans. Multimodal interaction (voice, text, images) further enhances patient compliance.⁵³

4.6. Intelligent therapeutic drug monitoring (TDM)

Intelligent TDM refers to using advanced information technologies and data analytics to collect patient health data, genetic information, and pharmacokinetic data to build comprehensive medication profiles. Based on pharmacokinetic principles and computational models, it determines optimal individualized dosing regimens, including drug dosage, timing, and route of administration, to achieve precise and personalized therapy.

Description: This system, through standardization and data interoperability, integrates tightly with hospital information systems, allowing direct access to patient characteristics, orders, and lab results. This supports clinicians and pharmacists in generating scientifically sound dosing suggestions and regimen adjustments. AI/ML and PBPK (Physiologically Based Pharmacokinetic) modeling can be combined to predict difficult-to-obtain parameters. AI/ML accelerates PBPK model development, shortens modeling time,⁵⁴ and improves prediction of pharmacokinetics under special administration conditions. AI/ML can also be embedded into PBPK models and combined with pharmacodynamic (PD) models to predict drug effects. These methods support toxicokinetics by predicting critical metabolic parameters. Model-Informed Precision Dosing (MIPD) has applications in anti-infective therapy, post-transplant immunosuppression, antiepileptics, antipsychotics, oncology, and antithrombotic treatments.⁵⁵

4.7. Intelligent telepharmacy services

Intelligent Telepharmacy Services refer to comprehensive pharmaceutical care services—such as medication therapy management, medication consultation, pharmaceutical education, and patient follow-up—delivered remotely by pharmacy professionals through the integration of modern information technologies, including artificial intelligence (AI), the internet, wearable devices, and cloud computing.

Description: Intelligent telepharmacy services utilize technologies such as the Internet of Things (IoT) and intelligent wearable devices to monitor patients' health data in real time (e.g., drug concentration, blood glucose, blood pressure). Based on patient feedback, medication regimens can be automatically adjusted. Leveraging cloud platforms, pharmacy professionals can remotely track treatment progress and provide timely interventions and guidance.⁵⁶ With access to patients' historical data and intelligent analytics, these services can deeply assess the effectiveness of drug therapy and identify potential medication-related issues (such as adverse drug reactions or risk of misuse) using predictive models.⁵⁷ Through virtual assistants and voice recognition technology, patients can receive educational services like medication usage guidance and early warnings of adverse drug reactions. Intelligent tools can provide personalized medication recommendations and reminders based on a patient's medication regimen and lifestyle habits, thereby enhancing medication adherence.⁵¹

Telepharmacy services also include **medication distribution and management**, involving the integration of drug distribution systems with intelligent medicine cabinets (such as automated dispensing machines) to enable intelligent medication delivery. Patients can complete consultations online and select delivery methods. At the same time, the system sends automatic reminders to ensure timely pickup and medication adherence. By integrating electronic health records, patient health profiles, and multidisciplinary healthcare team platforms, intelligent telepharmacy services facilitate **information sharing and collaborative decision-making** among pharmacists, doctors, nurses, and other healthcare providers. This ensures coordinated, continuously optimized medication plans and disease management strategies for patients.⁵⁸

4.8. Intelligent pharmaceutical administration

Intelligent pharmaceutical administration refers to the use of intelligent technologies and data analytics to monitor, assess, and optimize key performance indicators (KPIs) in pharmaceutical services within healthcare institutions. These KPIs include antimicrobial drug intensity (measured in DDDs), essential drug usage, DRG/DIP-related data, controlled substances, volume-based procurement drugs, average drug cost, intravenous infusion practices, and more. The goal is to enhance the scientific rigor, precision, and efficiency of pharmaceutical management.

Description: Through intelligent systems, data on drug usage and policy implementation within medical institutions can be collected and analyzed in real time, enabling dynamic performance evaluation of pharmaceutical management.⁵⁹ These systems can quickly detect potential issues in medication usage and offer decision support. By leveraging data analytics and machine learning, KPIs related to pharmaceutical management can be comprehensively assessed to identify shortcomings in the process. Improvement plans can then be formulated based on intelligent analysis, allowing for continuous optimization of pharmaceutical workflows and strategies. Key components include.

1. **Intelligent Drug Supervision:** Utilizing large-scale health data analytics and AI technologies to monitor all stages of drug production, distribution, and usage. These tools help identify and mitigate potential drug safety risks in a timely manner.⁶⁰
2. **Rational Medication Use Management:** Applying large-scale health data analytics to evaluate DDDs, essential drug usage, and the appropriateness of intravenous infusions. Intelligent alert and decision support systems can guide physicians in rational prescribing, preventing overuse and ensuring both medication safety and cost-effectiveness for patient.⁶¹
3. **Management of Special and Volume-Based Procurement Drugs:** Controlled substances (such as narcotics and psychotropics) are managed through technologies like intelligent access control and electronic tagging, ensuring strict regulation of storage, dispensing, and use. For volume-based procurement drugs, large-scale health data is used to analyze supply and clinical outcomes. Information is shared with suppliers to ensure stable supply and product quality.⁶²
4. **Medical Insurance Payment and Cost Control:** Under DRG/DIP payment models, intelligent pharmaceutical management systems analyze the composition of drug expenses and interface with insurance data to prevent inappropriate billing. At the same time, they comprehensively analyze patient medication data and optimize prescriptions through intelligent systems to reduce the average drug cost.

4.9. Intelligent pharmaceutical science popularization

Intelligent pharmaceutical science popularization refers to the use of digital technologies such as AI, large-scale health data, and the Internet of Things (IoT) to deliver pharmaceutical knowledge, medication safety information, and drug development updates to the public in innovative and diverse ways. The goal is to enhance public pharmaceutical literacy and promote rational drug use.

Description: With AI's natural language processing capabilities, complex and technical pharmaceutical knowledge can be transformed into simple, engaging, and easy-to-understand content. For instance, information can be presented through animations, short videos, or interactive H5 pages, making it accessible to people of all ages and educational backgrounds. Large-scale health data allows for the analysis of public browsing behavior and search histories, helping to identify their informational needs and enabling personalized delivery of educational content. Generative AI (e.g., AI-generated images and videos) can assist in creating science popularization videos and interactive Q&A content, reducing production costs. Furthermore, intelligent Q&A

systems based on large language models can respond to public medication inquiries in real time, offering accurate and easy-to-understand answers.⁶³

IoT technology breaks the limitations of time and space in science education. Intelligent pillboxes and wearable devices can send real-time medication reminders and drug information to users, allowing patients to receive pharmaceutical education as part of their daily routines. Online platforms—such as social media and science outreach websites—can further extend the reach of pharmaceutical knowledge, covering broader geographic areas and populations.³

With AI-powered Q&A systems, the public can ask questions about medication anytime and receive immediate answers. Live streams and online forums also allow real-time interactions between pharmacists, experts, and the public, enhancing the effectiveness of science popularization. Critically, AI-generated pharmaceutical content must undergo evidence-based validation and expert human review prior to dissemination to ensure clinical validity and patient safety.

4.10. Intelligent clinical trials

Intelligent clinical trials refer to the application of AI technologies such as machine learning, deep learning, and natural language processing to optimize various stages of clinical trials—such as patient recruitment, monitoring and follow-up, data analysis, and regulatory compliance—in order to accelerate drug development and improve patient outcomes.⁶⁴

Description: Intelligent clinical trials have the potential to address major issues in current clinical research, such as uneven participant recruitment, geographic constraints, and resource inefficiencies. By shifting the focus of research to patients' everyday environments, researchers can obtain more representative and diverse data, increasing the generalizability of study results. Additionally, patients can participate more flexibly without frequent hospital visits, which significantly enhances their willingness to take part.

Implementing intelligent clinical trials requires overcoming several challenges, including protecting data privacy, building robust technical infrastructure, and increasing acceptance of new technologies. For instance, when collecting data through wearables and mobile apps, it's essential to ensure patient data security and prevent leaks. Research institutions and regulatory bodies must work together to develop policies and guidelines that ensure the compliance and scientific integrity of intelligent clinical trials.

The successful promotion of intelligent clinical trials depends on collaboration among multiple stakeholders, including pharmaceutical companies, healthcare providers, regulators, and patients themselves. Establishing effective communication channels and cooperative mechanisms can facilitate resource sharing and information flow, creating a healthy and sustainable ecosystem. This transformation not only improves the efficiency and transparency of clinical research, but also offers patients more personalized and convenient treatment options—ultimately achieving a patient-centered model of care.

5. Future outlook of HIP development

5.1. Specialized training for intelligent pharmacists

Specialized training for Intelligent Pharmacists is designed to meet the current needs of digital and intelligent transformation in the pharmacy field. It aims to address the limitations of traditional pharmacy education by cultivating pharmacists who are proficient in applying advanced digital and intelligent technologies. By integrating digital intelligence into educational content, combined with hands-on training and continuous learning mechanisms, pharmacists can develop essential skills such as data analysis and the use of intelligent tools—enhancing patient medication services and driving innovation and advancement in pharmacy practice models.⁶⁵

Description: Currently, most pharmacy education remains centered on traditional curricula and lacks systematic instruction in digital and intelligent technologies. Many pharmacists are not yet proficient in data analysis or intelligent tool usage, which limits their ability to apply these capabilities in clinical practice. Effective mechanisms for personalized development and ongoing knowledge updates are also not well established. Therefore, training for Intelligent Pharmacists should prioritize digital intelligence as the core, driving reform in both pharmacy education and career development pathways.

Academic institutions should redesign their curricula by introducing forward-looking courses such as *Artificial Intelligence in Pharmacy* and *Big Data in Drug Analytics*, and deeply integrate technologies like AI-driven drug screening and blockchain-based drug traceability into instruction. Practical competencies should be strengthened through “AI + Pharmacy” joint laboratories and virtual simulation platforms. Interdisciplinary dual-degree programs (e.g., Pharmacy and Computer Science) can produce well-rounded professionals with both algorithm development and pharmaceutical expertise—for example, through training with blockchain-based drug supply chain simulation systems.

For practicing pharmacists, a tiered lifelong learning system should be established. Foundational training should focus on skills such as Python-based data analysis and operation of medical AI tools. Advanced modules should address complex applications like AI-assisted signal detection in pharmacovigilance, utilizing platforms such as the “digital twin hospital pharmacy” to enhance skills in intelligent prescription review and medication dispensing. A professional certification system should define standards for Intelligent Pharmacists. These should include proficiency in tools such as electronic prescription transmission and AI-powered adverse drug reaction monitoring, reinforced through practical assessments like machine learning model interpretation—ensuring effective integration of intelligent technologies in pharmacy practice.

5.2. Research in Intelligent Pharmacy

Research in Intelligent Pharmacy refers to the use of advanced digital and intelligent technologies, integrated with specialized knowledge and practical experience in hospital pharmacy, to conduct innovative pharmaceutical research and applied exploration. Building on the foundation of Intelligent Pharmacist training, this research promotes interdisciplinary collaboration across pharmacy, information technology, and data science—fostering integrated and innovative research teams to advance the depth and breadth of scientific inquiry.

Description: Currently, research in Intelligent Pharmacy is still in its early stages and lacks a systematic research framework. The translation of research findings into clinical applications remains slow. Moreover, interdisciplinary collaboration is limited, and deeper integration between pharmacy and information science is insufficient. As a result, many promising studies have yet to reach their full potential. To drive the development of Intelligent Pharmacy, active research efforts should be pursued, focusing on several key areas.

- **AI-Driven Multi-Omics Analysis Systems:** Develop systems capable of comprehensively analyzing various biological data—such as genomics, metabolomics, and microbiomics—using artificial intelligence. These systems can provide insights into patients' drug sensitivity and toxicity risk, offering precise guidance for physicians in selecting targeted oncology therapies, psychiatric medications, and other treatments to achieve personalized medicine.
- **Generative AI in Drug Development:** Explore the use of generative AI in pharmaceutical R&D, including molecular structure generation based on diffusion models and AI-assisted optimization of clinical trial designs.
- **Real-Time Drug Interaction Query Systems:** Build systems that support real-time drug interaction checks with voice and image input capabilities. These systems should cover interactions among Western

medicines, traditional Chinese medicines, dietary supplements, and foods—offering timely alerts for potential interactions and supporting medication guidance in community pharmacies as well as risk prevention in polypharmacy scenarios.⁶⁶

- **Blockchain-Based Drug Lifecycle Management:** Implement blockchain technology to construct systems that track the full lifecycle of medications—from manufacturing to patient use. This facilitates regulatory oversight and therapeutic outcome tracking, ensuring drug quality and safety.
- **Intelligent Medical Resource Allocation Systems:** Design intelligent systems that optimize the allocation of medical resources by accurately forecasting drug demand. These systems ensure timely supply of emergency medications and enhance the overall efficiency of healthcare services.

5.3. Publications and journals in intelligent pharmacy

Publications and journals in Intelligent Pharmacy focus on showcasing research achievements and disseminating specialized knowledge related to the application of digital and intelligent technologies across various aspects of pharmacy. They serve as communication platforms for pharmacy professionals and learners, driving the development of the discipline.

Description: These academic publications cover cutting-edge research and practical applications in pharmacy, medicine, artificial intelligence, large-scale health data analytics, and related fields. They aim to provide a high-level platform for academic exchange among pharmacy professionals, healthcare institutions, and researchers, promoting the integration of pharmacy with modern technologies and advancing intelligent pharmaceutical service systems.

Comprehensive and forward-looking monographs authored by leading experts in the field help expand professional resources and enrich the depth and breadth of industry knowledge. Existing journals such as *Intelligent Pharmacy* are already dedicated to this domain. Building on this foundation, further collaboration between academia and industry should be encouraged to explore and apply frontier technologies, thereby fostering innovation and a thriving ecosystem in Intelligent Pharmacy.

5.4. Ethics in Intelligent Pharmacy

Ethics in Intelligent Pharmacy refers to a system of principles formed through the integration of current pharmaceutical ethics with the emerging ethical norms of digital and intelligent technology applications. It aims to guide pharmacy professionals in making ethically sound decisions during intelligent pharmacy practice, balancing technological advancement with humanistic care, and promoting healthy, orderly, and sustainable development in the field—ultimately safeguarding the interests of patients and the public. Particular attention must be paid to the risks associated with generative AI, such as "hallucinations" in drug recommendation outputs. A dual-validation mechanism—consisting of pharmacist review and algorithmic explainability—should be established to ensure accuracy and safety.

Description: Ethical considerations in Intelligent Pharmacy focus on data privacy and security, traceability and transparency of technologies, and the responsible use of AI to enhance patient outcomes while safeguarding individual privacy. These principles also emphasize accountability, fairness, and transparency in technology applications to harmonize innovation with ethical responsibility.⁶⁷ Practitioners must uphold informed consent, data protection, and technological reliability, ensuring patient autonomy and awareness. When using clinical decision-support systems in pharmacy, the attribution of responsibility must be clearly defined, and systems must be accurate and unbiased to prevent harm caused by technical errors or misuse.⁶⁸

Ethics in this field also considers the impact of technology on the roles of pharmacy professionals, advocating for collaboration rather

than replacement. The goal is for technology to enhance, not diminish, the quality of pharmaceutical care. Moreover, ethical frameworks should address the societal impacts of AI, such as preventing unjust data usage and algorithmic bias, ensuring equitable access to intelligent pharmacy services for all patients. And patients must have been informed that digital tools or AI are used in the decision making and not widen health inequalities.

5.5. International harmonization of intelligent pharmacy

International harmonization of Intelligent Pharmacy refers to a unified set of standards and protocols developed to support its worldwide development. The aim is to improve the safety, efficacy, and sustainability of pharmaceutical practices while promoting international cooperation and data sharing. This standardized framework enables different countries and regions to manage data and monitor patients in a consistent and interoperable manner.

Description: International harmonization efforts focus on defining data formats, technical specifications, and process protocols to ensure seamless cross-border integration of pharmaceutical information. It emphasizes interoperability in drug research and development, facilitating global collaboration and building a more transparent and efficient pharmaceutical ecosystem. Standardization also supports drug quality, safety, and regulatory compliance across jurisdictions. While global harmonization of pharmaceutical standards remains constrained by divergent insurance payment systems, localization imperatives, clinical practice variations, and evidence-based frameworks—acknowledging operational realities require context-specific adaptation.

In practice, global standards in Intelligent Pharmacy should cover all stages of clinical medication use—including drug preparation, prescription review, and adverse drug reaction monitoring—to ensure consistency throughout the process. Patient participation and feedback must be prioritized to ensure equitable access and high-quality care. Additionally, international harmonization must address the challenges posed by emerging technologies, such as the ethical implications of AI, ensuring that innovation does not compromise fairness or patient rights. This advancement requires coordinated efforts from the global pharmaceutical community, regulatory agencies, academia, and industry to ensure that Intelligent Pharmacy progresses safely, effectively, and sustainably—ultimately benefiting people worldwide.

6. Conclusion

This consensus clarifies the definition and connotation of HIP, emphasizing its importance within intelligent hospitals. It establishes a comprehensive framework encompassing specific scenarios such as intelligent drug supply, intelligent medication review and regulation, intelligent medication decision support systems, full-cycle intelligent pharmaceutical care, and the digital empowerment of pharmacists' competencies. Future development will focus on strengthening talent cultivation and continuing education for intelligent pharmacists, promoting interdisciplinary collaboration, enhancing innovation and research capabilities, and establishing high-impact academic monographs and journals, thereby driving continuous innovation and advancement in the field of intelligent pharmacy.

CRediT authorship contribution statement

Cao Li: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Wenshuo Jiang:** Formal analysis, Investigation, Writing – original draft. **Aizong Shen:** Methodology, Validation, Writing – review & editing. **Yilei Li:** Investigation, Methodology, Writing – review & editing. **Junyan Wu:** Formal analysis, Investigation, Writing – review & editing. **Hua Tao:** Data curation, Investigation, Writing – review & editing. **Yongqiang Tang:** Investigation, Methodology, Writing – review & editing. **Xiaolin Yue:** Conceptualization,

Supervision, Writing – review & editing. **Alice Hao:** Conceptualization, Supervision, Writing – review & editing. **Zhigang Zhao:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

Data availability

Not applicable.

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.

Acknowledgement

Not applicable.

List of Abbreviations

AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
IoT	Internet of Things
PIVAS	Pharmacy IntraVenous Admixture Services
ADR	Adverse Drug Reaction
ME	Medication Error
DDD	Defined Daily Dose
DDI	Drug–drug Interaction
TDM	Therapeutic Drug Monitoring
DIP	Disease Intervention Plan
DRG	Diagnosis-Related Group
PBPK	Physiologically Based Pharmacokinetics
GDPR	General Data Protection Regulation
HIPAA	Health Insurance Portability and Accountability Act

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ipha.2025.06.001>.

References

- Bu F, Sun H, Li L, et al. Artificial intelligence-based internet hospital pharmacy services in China: perspective based on a case study. *Front Pharmacol.* 2022;13:1027808.
- Jaber D, Hasan HE, Abutaima R, Sawan HM, Al TS. The impact of artificial intelligence on the knowledge, attitude, and practice of pharmacists across diverse settings: a cross-sectional study. *Int J Med Inform.* 2024;192:105656.
- Aungst TD. Beyond the fill: navigating pharmacy's technological future in 2050. *J Am Pharmaceut Assoc : J Am Pharm Assoc JAPhA.* 2024;102285.
- Smoke S. The two dimensions of pharmacy artificial intelligence tools. *Am J Health Syst Pharm.* 2024;82(3):e113–e116.
- Schutz N, Olsen CA, McLaughlin AJ, et al. ASHP statement on the use of artificial intelligence in pharmacy. *Am J Health Syst Pharm.* 2020;77(23):2015–2018.
- Jarab AS, Abu HS, Al MA. Artificial intelligence (AI) in pharmacy: an overview of innovations. *J Med Econ.* 2023;26(1):1261–1265.
- Dipiro JT, Hoffman JM, Schweitzer P, et al. ASHP and ASHP foundation pharmacy forecast 2024: strategic planning guidance for pharmacy departments in hospitals and health systems. *Am J Health Syst Pharm.* 2024;81(2):5–36.
- Schneider PJ, Pedersen CA, Ganio MC, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: operations and technology - 2023. *Am J Health Syst Pharm.* 2024;81(16):684–705.
- Fernández DGE, Tortajada-Goitia B, Corte-García JJ, et al. Hospital pharmacy towards 2030. *Farm Hosp.* 2024;48(Suppl 1):S52–S58.
- Jessica H, Britney R, Sarira ED, Parisa A, Joe Z, Betty BC. Applications of artificial intelligence in current pharmacy practice: a scoping review. *Res Social Adm Pharm.* 2024;S1551–S7411.
- HMA-EMA Big Data Steering Group. Multi-annual AI workplan 2023-2028 [cited 2025-3-31]. 2023
- Medicines and Healthcare products Regulatory Agency. Impact of AI on the regulation of medical products [cited 2025-3-31]. 2024
- Food and Drug Administration. Considerations for the use of artificial intelligence to support regulatory decision-making for drug and biological products [cited 2025-3-31]. 2025
- General Office of the National Health Commission. Comprehensive department of the national administration of traditional Chinese medicine, comprehensive department of the national disease control and prevention administration. Notice of the general office of the national health commission on issuing the reference guidelines for artificial intelligence application scenarios in the health industry.
- Nelson SD, Walsh CG, Olsen CA, et al. Demystifying artificial intelligence in pharmacy. *Am J Health Syst Pharm.* 2020;77(19):1556–1570.
- Dentzer S. Creating the future of artificial intelligence in health-system pharmacy. *Am J Health Syst Pharm.* 2019;76(24):1995–1996.
- Abu-Shraie N. Could human pharmacy and therapeutics committees be replaced with artificial intelligence systems? *Am J Health Syst Pharm;* 2025. zxae413. Advance online publication. <https://doi.org/10.1093/ajhp/zxae413>
- Smoke S. Artificial intelligence in pharmacy: a guide for clinicians. *Am J Health Syst Pharm.* 2024;81(14):641–646.
- Nelson SD. Artificial intelligence and the future of pharmacy. *Am J Health Syst Pharm.* 2024;81(4):83–84.
- Senerth E, Whaley P, Akl E, et al. Development of a framework to structure decision-making in environmental and occupational health: a systematic review and delphi study. *Environ Int.* 2025;195:109209.
- Rodgers M, Thomas S, Harden M, Parker G, Street A, Eastwood A. *Developing a Methodological Framework for Organisational Case Studies: A Rapid Review and Consensus Development Process.* Southampton (UK): NIHR Journals Library; 2016.
- International Pharmaceutical Federation. A global competency framework for services provided by pharmacy workforce [cited 2025-5-5]. 2012
- Executive summary of the 2019. ASHP commission on goals: impact of artificial intelligence on healthcare and pharmacy practice. *Am J Health Syst Pharm.* 2019;76(24):2087–2092.
- Cobaugh DJ, Thompson KK. Embracing the role of artificial intelligence in the medication-use process. *Am J Health Syst Pharm.* 2020;77(23):1915–1916.
- Worrall C, Shirley D, Bullard J, Dao A, Morrisette T. Impact of a clinical pharmacist-led, artificial intelligence-supported medication adherence program on medication adherence performance, chronic disease control measures, and cost savings. *J Am Pharm Assoc.* 2003;65(1):102271, 2025.
- Worrall C, Shirley D, Bullard J, Dao A, Morrisette T. Impact of a clinical pharmacist-led, artificial intelligence-supported medication adherence program on medication adherence performance, chronic disease control measures, and cost savings. *J Am Pharmaceut Assoc : J Am Pharm Assoc JAPhA.* 2024:102271.
- Chaichulee S, Promchai C, Kaewkamon T, Kongkamol C, Ingviya T, Sangsupawanich P. Multi-label classification of symptom terms from free-text bilingual adverse drug reaction reports using natural language processing. *PLoS One.* 2022;17(8):e0270595.
- Alqahtani T, Badreldin HA, Alrashed M, et al. The emergent role of artificial intelligence, natural learning processing, and large language models in higher education and research. *Res Social Adm Pharm.* 2023;19(8):1236–1242.
- Ranchon F, Chanoine S, Lambert-Lacroix S, Bosson JL, Moreau-Gaudry A, Bedouch P. Development of artificial intelligence powered apps and tools for clinical pharmacy services: a systematic review. *Int J Med Inform.* 2023;172:104983.
- Imai S. Data-driven clinical pharmacy research: utilizing machine learning and medical big data. *Biol Pharm Bull.* 2024;47(10):1594–1599.
- Frestel J, Teoh SWK, Broderick C, Dao A, Sajogo M. A health integrated platform for pharmacy clinical intervention data management and intelligent visual analytics and reporting. *Explor Res Clin Soc Pharm.* 2023;12:100332.
- Van Antwerp GJ. Pharmacy 2050: a new clinical and patient experience. *J Am Pharmaceut Assoc : J Am Pharm Assoc JAPhA.* 2024:102290.
- Roosan D, Wu Y, Tatla V, et al. Framework to enable pharmacist access to health care data using blockchain technology and artificial intelligence. *J Am Pharmaceut Assoc : J Am Pharm Assoc JAPhA.* 2022;62(4):1124–1132.
- Shen J, Bu F, Ye Z, et al. Management of drug supply chain information based on "artificial intelligence + vendor managed inventory" in China: perspective based on a case study. *Front Pharmacol.* 2024;15:1373642.
- Pall R, Gauthier Y, Auer S, Mowaswes W. Predicting drug shortages using pharmacy data and machine learning. *Health Care Manag Sci.* 2023;26(3):395–411.
- Ashraf AR, Somogyi-Végh A, Merczel S, Gyimesi N, Fittler A. Leveraging code-free deep learning for pill recognition in clinical settings: a multicenter, real-world study of performance across multiple platforms. *Artif Intell Med.* 2024;150:102844.
- Corny J, Rajkumar A, Martin O, et al. A machine learning-based clinical decision support system to identify prescriptions with a high risk of medication error. *J Am Med Inform Assoc.* 2020;27(11):1688–1694.
- Chen CY, Chen YL, Scholl J, Yang HC, Li YJ. Ability of machine-learning based clinical decision support system to reduce alert fatigue, wrong-drug errors, and alert users about look alike, sound alike medication. *Comput Methods Programs Biomed.* 2024;243:107869.
- Hogue SC, Chen F, Brassard G, et al. Pharmacists' perceptions of a machine learning model for the identification of atypical medication orders. *J Am Med Inform Assoc.* 2021;28(8):1712–1718.
- Anderson AB, Grazal CF, Balazs GC, Potter BK, Dickens JF, Forsberg JA. Can predictive modeling tools identify patients at high risk of prolonged opioid use after ACL reconstruction? *Clin Orthop Relat Res.* 2020;478(7):1618.
- Longato E, Fadini GP, Sparacino G, Avogaro A, Tramontan L, Di Camillo B. A deep learning approach to predict diabetes' cardiovascular complications from administrative claims. *IEEE J Biomed Health Inform.* 2021;25(9):3608–3617.

42. Potier A, Dufay E, Dony A, et al. Pharmaceutical algorithms set in a real time clinical decision support targeting high-alert medications applied to pharmaceutical analysis. *Int J Med Inform.* 2022;160:104708.
43. McMaster C, Liew D, Keith C, Aminian P, Frauman A. A machine-learning algorithm to optimise automated adverse drug reaction detection from clinical coding. *Drug Saf.* 2019;42(6):721–725.
44. Fong A, Harriott N, Walters DM, Foley H, Morrissey R, Ratwani RR. Integrating natural language processing expertise with patient safety event review committees to improve the analysis of medication events. *Int J Med Inform.* 2017;104:120–125.
45. Cho J, Ra LA, Koo D, et al. Development of machine-learning models using pharmacy inquiry database for predicting dose-related inquiries in a tertiary teaching hospital. *Int J Med Inform.* 2024;185:105398.
46. Beaudoin M, Kabanza F, Nault V, Valiquette L. Evaluation of a machine learning capability for a clinical decision support system to enhance antimicrobial stewardship programs. *Artif Intell Med.* 2016;68:29–36.
47. Liu X, Barreto EF, Dong Y, et al. Discrepancy between perceptions and acceptance of clinical decision support systems: implementation of artificial intelligence for vancomycin dosing. *BMC Med Inform Decis Mak.* 2023;23(1):157.
48. Herrin J, Abraham NS, Yao X, et al. Comparative effectiveness of machine learning approaches for predicting gastrointestinal bleeds in patients receiving antithrombotic treatment. *JAMA Netw Open.* 2021;4(5):e2110703.
49. Wang NN, Wang XG, Xiong GL, et al. Machine learning to predict metabolic drug interactions related to cytochrome p450 isozymes. *J Cheminform.* 2022;14(1):23.
50. Chi CL, Wang J, Ying YP, et al. Producing personalized statin treatment plans to optimize clinical outcomes using big data and machine learning. *J Biomed Inform.* 2022;128:104029.
51. Bulaj G, Clark J, Ebrahimi M, Bald E. From precision metapharmacology to patient empowerment: delivery of self-care practices for epilepsy, pain, depression and cancer using digital health technologies. *Front Pharmacol.* 2021;12:612602.
52. Roosan D, Padua P, Khan R, Khan H, Verzosa C, Wu Y. Effectiveness of ChatGPT in clinical pharmacy and the role of artificial intelligence in medication therapy management. *J Am Pharmaceut Assoc : J Am Pharm Assoc JAPhA.* 2024;64(2): 422–428.
53. Li X, Guo H, Li D, Zheng Y. Engine of innovation in hospital pharmacy: applications and reflections of ChatGPT. *J Med Internet Res.* 2024;26:e51635.
54. Chou W, Lin Z. Machine learning and artificial intelligence in physiologically based pharmacokinetic modeling. *Toxicol Sci.* 2023;191(1):1–14.
55. Swierczek A, Batko D, Wyska E. The role of pharmacometrics in advancing the therapies for autoimmune diseases. *Pharmaceutics.* 2024;16(12).
56. Haas K, Ben MZ, Mahoui M. Medication adherence prediction through online social forums: a case study of fibromyalgia. *JMIR Med Inform.* 2019;7(2):e12561.
57. Usui M, Aramaki E, Iwao T, Wakamiya S, Sakamoto T, Mochizuki M. Extraction and standardization of patient complaints from electronic medication histories for pharmacovigilance: natural language processing analysis in Japanese. *JMIR Med Inform.* 2018;6(3):e11021.
58. Bottacin WE, Luquetta A, Gomes-Jr L, de Souza TT, Reis W, Melchioris AC. Sentiment analysis in medication adherence: using ruled-based and artificial intelligence-driven algorithms to understand patient medication experiences. *Int J Clin Pharm.* 2024.
59. Thibault M, Tanguay C. Development and evaluation of a model to identify publications on the clinical impact of pharmacist interventions. *Res Social Adm Pharm.* 2024;20:1134–1141.
60. Fu L, Jia G, Liu Z, Pang X, Cui Y. The applications and advances of artificial intelligence in drug regulation: a global perspective. *Acta Pharm Sin B.* 2025;15(1): 1–14.
61. Del RC, Medrano IH, Yebe L, Poveda JL. Towards a symbiotic relationship between big data, artificial intelligence, and hospital pharmacy. *J Pharm Policy Pract.* 2020; 13(1):75.
62. Molokhia M, Majeed A. Current and future perspectives on the management of polypharmacy. *BMC Fam Pract.* 2017;18(1):70.
63. Kufel WD, Hanrahan KD, Seabury RW, et al. Let's have a chat: how well does an artificial intelligence chatbot answer clinical infectious diseases pharmacotherapy questions? *Open Forum Infect Dis.* 2024;11(11):ofae641.
64. Grothen AE, Tennant B, Wang C, et al. Application of artificial intelligence methods to pharmacy data for cancer surveillance and epidemiology research: a systematic review. *JCO Clin Cancer Inform.* 2020;4:1051–1058.
65. Aldughayfiq B, Sampalli S. Patients', pharmacists', and prescribers' attitude toward using blockchain and machine learning in a proposed eprescription system: online survey. *JAMIA Open.* 2022;5(1):ooab115.
66. Sirois C, Khoury R, Durand A, et al. Exploring polypharmacy with artificial intelligence: data analysis protocol. *BMC Med Inform Decis Mak.* 2021;21(1):219.
67. Hasan HE, Jaber D, Khabour OF, Alzoubi KH. Ethical considerations and concerns in the implementation of AI in pharmacy practice: a cross-sectional study. *BMC Med Ethics.* 2024;25(1):55.
68. Da SM, Horsley T, Singh D, et al. Legal concerns in health-related artificial intelligence: a scoping review protocol. *Syst Rev.* 2022;11(1):123.