

An Overview of Recent Trends in Pharmaco-Cybernetics

Sravanthi Mulagada*, Sowmya. Ch, Yernamma. D, Sri Hari Priya. K, Asha
Jyothi. M, Pavan Kumar. M, Shravya Bhavana. P, Mounika. B

Assistant professor, Department of Pharmaceutical Technology, St. Ann's college of pharmacy, cantonment,
Vizianagaram, AP, India-535003*

Date of Submission: 14-09-2026

Date of Acceptance: 26-09-2026

ABSTRACT

Pharmaco-cybernetics is a new field that supports our use of medicines and drugs through the combined use of computational technologies with the human-computer-environment interactions to decrease or prevent drug-related problems. The advantage of pharmaco-cybernetics has led to the development of various software, tools and internet applications that can be used by health care professionals to deliver optimum pharmaceutical care and health-related problems. Patients are becoming more informed through health information on the internet, which empowers them to better participate in the management of their own conditions. This moves beyond "Pharmacokinetic and Pharmacodynamic" to feedback control, non-linear interactions, as well as data-driven decision-making about the best outcome of drug efficacy and the safety. Particular emphasis is placed on the integration of pharmaco-cybernetic systems with the Ayushman Bharath Digital Mission (ABDM), using the Ayushman Bharath Health Account (ABHA) as a unique digital patient identifier to securely link prescriptions, dispensing data and clinical outcomes. To design, develop, apply and assess technological innovations that enhance drug and medication management as well as prevent or resolve drug-related issues.

KEY WORDS

Pharmaco-cybernetics, Artificial Intelligence, Ayushman Bharath Health Account (ABHA), Machine Learning, Human-computer-environment interactions.

I. INTRODUCTION

Cybernetics

Cybernetics looks at how humans and machines interact. It's based on the idea that very different kinds of systems can all be understood using the same ideas of feedback, Control and Communication. This field was started by NORBERT WIENER with his 1948 book Cybernetics or Control and Communication in the animal and the machine. In it, he connected the ideas

of Communication and Control, which inspired engineers, system theorists, and tech thinkers for years to come. Since then, Cybernetics has influenced many different areas of study around the world. Even so, it played a big role in shaping other systems sciences that are important today, and it helped create a way of thinking about technology that is still part of our modern culture. ^[1]

Pharmaco- cybernetics

Pharmaco-cybernetics uses that concept to explain by the same medicine can work differently for different people. With the help of computer simulations and algorithms, this approach can predict how a medicine will act inside your body instead of just in an average person. As a result, we get more accurate doses, fewer side effects, and better results overall. This is especially useful for personalized medicine, where treatment is tailored to the individual. Pharmaco-cybernetics is based on the ideas of Norbert Wiener and is field of cybernetics, which examines how control and communication work in both machines and living beings. ^[1]

Pharmaco-cybernetics is an area that mixes pharmacology with systems theory, cybernetics, and computer modelling. It studies how drugs interact with complex biological systems overtime, including feedback loops and unpredictable, non-linear reactions. One of the core ideas in pharmaco-cybernetics is human-computer synergy. This means digital systems are not meant to replace doctors, but to assist them. Computers can handle large amounts of data, spot potential risks and send quick alerts. This tool connects complicated drug information with real-time clinical decision making. ^[2]

Pharmaco-cybernetics supports personalized medicine by looking at a patient's unique body, drug response and other diseases. Rather than average doses, it allows doctors to design and adjust therapies dynamically based on real-time feedback. ^[3]

II. METHODOLOGY

Digital tools

In these systems, different digital tools work together. Examples include Electronic Health Records (EHRs), Computerized Physician Order Entry (CPOE), Pharmacy Information Systems (PIS), Clinical Decision Support Systems (CDSS), Tele pharmacy Platforms and Mobile Health apps. [4],[5]

These digital systems also help with accurate record-keeping, automatic safety checks and ongoing patient monitoring. This reduces human mistakes and supports care that's truly focused on the patient. [6],[7]

Software and Hard ware systems of Pharmaco-cybernetics

Electronic Health Records (EHR):

Electronic Health Records are complete digital data bases that store all key patient details. This includes past prescriptions, lab test results, allergies, diagnosis and doctor's notes. EHRs give pharmacists up-to-date and accurate information during patient care. This helps them review medication properly and avoid giving the same treatment twice. [14]

Pharmacy Information Systems (PIS):

The Pharmacy Information System is the main software used to run day-to-day pharmacy operations. It handles computerized prescription entry checks for drug interactions, verifies medications and manages the dispensing process. PIS also monitors how drugs are being used, automates stock management and maintains records for audits. These features help improve accuracy, reduce mistakes during dispensing and make the overall pharmacy workflow more efficient. [15]

Clinical Decision Support Systems (CDSS):

CDSS provides instant clinical alerts through smart modules integrated into Pharmacy Information Systems or Electronic Health Records. These alerts warn about potential issues like drug interactions, duplicate therapies, contraindications, wrong doses and dose adjustments needed for patients with liver or kidney problems. By doing this, CDSS helps increase patient safety, promotes appropriate medication use and supports health care professionals in making informed treatment choices based on clinical evidence.

Tele pharmacy and Communication Platforms:

Tele pharmacy provides remote services such as consultations, help with prescription, medication verification and follow-up monitoring. These services are delivered using tools like Zoom,

Microsoft Teams or dedicated portals that connect pharmacists with patients. [18]

Mobile Medication Apps:

It supports drug education and adherence. Main features are dose reminders, pill tracking, drug ID tools, education, secure patient-pharmacist chat. The benefits of mobile medication apps are enables remote monitoring by pharmacists, increases patient involvement in care. [16]

Database Management Systems (MySQL, Oracle, MS Access):

The purpose of data base management is to store structured clinical and pharmacy data. Its functions are Centralized storage, custom data retrieval, report generation, performance monitoring. [17]

Hardware systems

Workstation Computers:

High-performance desktops and laptops form the backbone of pharmaco-cybernetics systems. They act as the main processing units for running key software. These work stations are essential for operating Electronic Health Records (EHR), Clinical Decision Support Systems (CDSS) and Pharmacy Information Systems (PIS). [19]



Fig.No.1 Workstation Computers

Mobile Devices [Smartphones/Tablets]:

Mobile phones support mobile health or mHealth, apps that help patients stick to their medication, allow remote monitoring and enable digital communication. These devices also give pharmacists the ability to do tele pharmacy consultations, conduct online medication reviews and check drug details during patient care. [10]



Fig.No.2 Mobile Devices

Barcode scanners and RFID [Radio Frequency Identification Readers]:

Barcode and RFID technologies are key parts of

Barcode Medication Administration (BCMA) and automated inventory systems. Barcode scanners are used to check medication labels when drugs are dispensed and given to patients. This helps ensure the “five rights” of medication safety: right patient, right drug, right dose, right route and right time. RFID readers on the other hand, track medications in real-time as they move around the pharmacy. They also help maintain accurate stock records. Together, these tools cut down on human mistakes and make the process of distributing medications safer and more dependable.^[11]



Fig.No.3 Barcode Scanner

Automated Dispensing Cabinets [ADC]:

Automated Dispensing Cabinets are secure, computer-based systems used to store and retrieve medications. They help make the dispensing process faster and more efficient. ADCs ensure that prescription transactions are recorded accurately, prevent mismatches in inventory and reduce the chances of unauthorized access.



Fig.No.4 Automated Dispensing Cabinets

They also improve audit tracking and support safer, more effective medication management. When connected with Pharmacy Information Systems (PIS) and Electronic Health Records (EHR), ADCs can automatically update stock levels in real times.^[12]

Server Infrastructure or Cloud-Based Computing Systems:

Large data bases, patient profile, medical record and system applications are kept on servers or cloud platforms. These systems allow for centralized storage, secure backups and quick access to health information across different pharmacy departments

and health care facilities.

This makes them important for tele pharmacy hospital networks with multiple branches and team-based care, since they let many uses access and work on real-time data at the same time.^[13]



Fig.No.5 Cloud-based computing systems

APPLICATIONS

➤ Human- Computer Synergy in Pharmacotherapy:

Human- computer synergy in pharmacotherapy means professionals work together with intelligent systems- like AI, machine learning, and smart devices- to improve how we monitor, prescribe, and manage drugs. The goal isn't to replace clinicians. Instead, technology supports them with data- driven insights, real-time tracking, and predictive analysis to make better decisions.^[22]

➤ Clinical Decision Support Systems (CDSS): CDSS are interactive software tools that help healthcare providers make clinical decisions based on evidence. They pull together EHRs and pharmacology databases, then use rule-based logic or ML models to give recommendations or alerts.

➤ Smart Medication Technologies:

Smart technology in drug therapy provides real-time feedback, improves patient adherence, and lets healthcare teams monitor how well a drug is working – all remotely.

Smart Pills

These are capsules with tiny ingestible sensors. Once swallowed, they send data about:

1. When the dose was taken
2. GI transit time
3. Pharmacokinetic profile^[19]

Wearable Biosensors

These devices track vital signs like blood pressure, heart rate, and glucose-all important for monitoring drugs and adjusting doses.

Examples:

- Freestyle Libre by Abbott:
For continuous glucose monitoring in diabetes
- Smart inhalers for asthma:
Track usage patterns and send reminders to patients.
- Artificial Intelligence in Drug Therapy Optimization
AI uses patient data and clinical guidelines to forecast outcomes, cutdown errors, and personalize treatment plans.^[20]

CASE STUDIES

Case-I (2007)

Patient Details:

200 adult ICU patients receiving IV medications, critically ill with polypharmacy.

Case summary:

simultaneous IV incompatible pairs (E.g. midazolam +hydrocortisone, cefepime combinations) accounted for 40.9% of drug-related problems, risking precipitation, occlusion and therapeutic failure.

Solution:

EHR -integrated IV – compatibility CDSS for automated detection and alternatives.^[21]

EMERGING TRENDS IN PHARMACO-CYBERNETICS

Artificial intelligence and Machine Learning

AI and ML are set to transform pharmacy practice. These technologies can process huge amounts of health data to spot patterns, forecast patient outcomes, and catch medication – related issues early. AI systems can also make routine tasks faster, like medication reconciliation, by automatically checking prescriptions against a patient's history to find mismatches. Additionally, ML algorithms help move toward personalized medicine by recommending drug therapies based on a patient's genetics, medical history, and how they respond to treatment.^[23]

Blockchain Technology

Blockchain provides a secure, transparent way to handle medication - related information. Because blockchain records are decentralized and hard to alter, they help protect patient data from tampering and unauthorized access. This is useful for maintaining accurate medical records, confirming that medications are genuine, and making the drug

supply chain safer. By tracking medicines from manufacturer to pharmacy, blockchain can also reduce counterfeit drugs and build more trust in how medications are distributed.^[24]

Health Card Systems

Health Card Systems are moving toward becoming universal digital health passports. They would store a patient's full medication history, allergies, pharmacogenomic data and current prescriptions.



Fig. No. 6 Smart Health Card

Accessed through NFC or smartphones, these cards would allow smooth prescribing and medication management across different hospitals and clinics.

Pharmacogenomics Integration

Pharmacogenomics looks at how your genes affect your response to medicines. It will soon become a normal part of health care. By combining a patient's genetic data with health records. Pharmacists can choose the right drug and dose for each person. This personalized approach makes treatment more effective, safer and reduces side effects.

Advanced Telehealth Services

Telehealth is expected to expand a lot, giving pharmacists new ways to care for patients remotely. Using advanced tele pharmacy tools, they will be able to manage treatments, do virtual consults and tracked chronic conditions in real life. Wearables and digital tools can send patient data directly to the pharmacist, so they can respond faster to issues. This will improve on going care and help reach people who have limited access to pharmacy services.

Robotics and Smart Hospitals

Robotics and Smart Hospital technology will upgrade how medicines are prepared and delivered. Future robots can make sterile drugs, manage stock and dispense medications with high accuracy. Smart systems with automated vehicles, sensors and connected data platforms will also streamline pharmacy work and cut down on mistakes.^[25]

Emerging Role of Pharmaco-cybernetics in India's Digital Health Ecosystem

Pharmaco-cybernetics in India should connect with the Ayushman Bharath Digital Machines (ABDM) to make healthcare more secure, connected and focused on patients. Using the Ayushman Bharath Health Account (ABHA) number as a unique ID, prescriptions, dispensing records and treatment results can all be linked.

With ABDM's digital setup, hospitals, pharmacies, labs and regulators can share data instantly. This helps track medicines better, reduces prescription mistakes, stop duplicate treatments and keeps patient care consistent.

These systems also support large scale drug safety monitoring using anonymous data on drug use and side effects. This strengthens oversight by agencies like CDSCO. At the same time, patient get access to their own medication records, which helps doctors make better clinical decisions.^[26]

EXPECTED OUTCOMES OF PHARMACO-CYBERNETICS

Medication Safety

The main goal of pharmaco-cybernetics is to cutdown medication errors. Tools like barcode scanning, automatic alerts and e-prescription help make sure patients receive the correct medicine in correct dose. Standardized digital workflows also reduce mistakes from miscommunication or bad hand writing, plus, better digital tracking makes it easier to check a patient's past reactions, allergies and prescription history. This helps prevent serious health problems.

Improved Clinical Decision-Making

Pharmacists can make better and safer treatment choices by using Electronic Health Records (EHRs). EHRs give the instant access to key patient details like allergies, medical history, current medicines and lab reports.

Decision support systems can also flag potential drug interactions or wrong dosages. This helps pharmacists track how patients respond to treatment and recommend the most suitable care plan.

Enhanced Efficiency

Automation makes pharmacy work more efficient. With technology like robotics, automated dispensing cabinets and e-ordering, pharmacists spend less time on repetitive manual tasks.

Instead, they can focus more on patient care – like counselling, reviewing treatments and working with other healthcare staff. This shift leads to faster service

and smoother overall pharmacy operations.

Better Patient Engagement

Digital tools help patients take a bigger role in their healthcare. Apps for reminders, text alerts and tele pharmacy let patients get notifications for visits, refills and doses.

They can also talk to pharmacists online, which is really helpful for people in remote areas. This setup encourages patients to ask questions and follow their prescriptions properly, so they stay more involve in their treatment.

Population Health Management

Informatics helps healthcare teams focus on the health of entire communities, not just individual patients. Pharmacists can use data from EHRs, pharmacy records and public health systems to spot prescription trend, find groups at risk for certain illnesses and track chronic disease patterns.

This information helps in planning health programs, improving treatment guidelines and deciding which medicines to include in a formulary.

REGULATORY, ETHICAL AND STANDARDIZATION FRAME WORKS

As pharmaco-cybernetic systems become more integrated into healthcare, we need clear regulations, strong ethical guidelines and consistent standards. These are essential to protect patient safety, ensure data accuracy and maintain public trust in the technology.

I. Regulatory Considerations

- Approval pathways for digital therapeutics: Agencies like the FDA in the US and EMA in Europe are starting to create rules for approving digital health tools such as AI systems and smart pills. But the guidelines are evolving and not fully clear.

- Post-Market surveillance:

Even after approval, products must be monitored in real-world use. This helps catch side effects, system failures or bias in algorithms that weren't seen during testing.^[27]

II. Ethical and Social Implications

- Privacy and Data Security:

These systems handle sensitive health data, so their must follow laws like HIPAA in the US and GDPR in the EU, plus use strong cybersecurity to protect patient information.

- Algorithmic Transparency and Bias

AI systems should be explainable and fair. This is

especially important because biased algorithms can negatively impact certain communities or backgrounds.

- Patient autonomy

There needs to be a balance. AI can recommend treatments but patients should still have the final say and make informed decisions about their own care.

- Equity and Access

Digital health tools should be available to everyone, including people in low-resource areas and under represented groups, so no one is left behind.^[28]

III. Need for Standardization

- Interoperability

Without common data standards like FHIR, HL7, DICOM and SNOMED-CT different systems can't communicate well. That breaks the feedback loops that make pharmaco-cybernetic systems work.^[29]

- Validation Protocols

We need common guidelines to test and validate AI algorithms, sensor accuracy and real-time feedback systems. Having shared standards makes it possible to compare results across different studies and systems.

- Performance Metrics

Standard measures need to be set to judge how well these systems work. Key metrics include:

- Responsiveness – how quickly the system reacts
- Safety – risk to patients
- Accuracy – correctness of data and decisions
- Patient adherence – whether patients follow the treatment plan These metrics help evaluate overall system effectiveness.^[30]

III. CONCLUSION

Pharmaco-cybernetics is a promising step forward in combining digital technology with pharmaceutical care. It has the potential to bring major benefits to India's growing healthcare system. This will help modernize and make pharmacy practice in India more sustainable. By supporting accurate prescription processing, live drug monitoring and better clinical decision-making, these systems can greatly improve medication safety and treatment results. Linking pharmaco-cybernetics with national programs like the Ayushman Bharat Digital Machine can make these systems even stronger. It helps with data sharing between systems, protects patient data, and ensures continuous care through ABHA- linked digital health records.

Also, adding pharmaco-cybernetics to drug safety monitoring systems can improve how adverse drug reactions are detected and reported. This supports regulators like CDSCO in keeping a closer watch on drug safety. Even though there are challenges with infrastructure, standardization, and data privacy, continued government support, new technology, and proper training for professionals can help these systems reach more people.

Pharmaco- cybernetics combines cybernetic systems with pharmacology to make giving medications safer, smarter, and more personalized. With use of ML, AL, and digital monitoring tools, drug therapy is becoming more precise and adaptable. But to make this work, we need strong rules and regulations to handle ethical concerns, legal issues, and data privacy. Ultimately, combining human expertise with intelligent systems has the power to transform how we use drugs. It can make healthcare more responsive, self-improving, and patients-focused, while setting new standards for modern medicine.

REFERENCES

- [1]. Wiener N, von Neumann J. Cybernetics or Control and Communication in the Animal and the Machine. Physics Today. 1949 May 1;2(5):33-4.
- [2]. Phansalkar S, Edworthy J, Hellier E, Seger DL, Schedlbauer A, Avery AJ, Bates DW. A review of human factors principles for the design and implementation of medication safety alerts in clinical information systems. Journal of the American Medical Informatics Association. 2010 Sep 1;17(5):493-501.
- [3]. Topol E. Deep medicine: how artificial intelligence can make healthcare human again. Hachette UK; 2019 Mar 12.
- [4]. Eggerth A, Hayn D, Schreier G. Medication management needs information and communications technology-based approaches, including telehealth and artificial intelligence. British Journal of clinical pharmacology. 2020 Oct;86(10):2000-7.
- [5]. Sutton RT, Pincock D, Baumgart DC, Sadowski DC, Fedorak RN, Kroeker KI. An overview of clinical decision support systems: benefits, risks, and strategies for success. NPJ digital medicine. 2020 Feb 6;3(1):17.
- [6]. Kawamoto K, Houlihan CA, Balas EA, Lobach DF. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to

- success. *Bmj*. 2005 Apr 2;330(7494):765.
- [7]. Kane-Gill SL, Achanta A, Kellum JA, Handler SM. Clinical decision support for drug related events: moving towards better prevention. *World Journal of Critical Care Medicine*. 2016 Nov 4;5(4):204.
 - [8]. Ye J, Bronstein S. Using shared clinical decision support to reduce adverse drug events and improve patient safety. *Frontiers in Digital Health*. 2025 Dec 4;7:1703141.
 - [9]. Sittig DF, Singh H. Electronic health records and national patient-safety goals. *New England Journal of Medicine*. 2012 Nov 8;367(19):1854-60.
 - [10]. Free C, Phillips G, Watson L, Galli L, Felix L, Edwards P, Patel V, Haines A. The effectiveness of mobile-health technologies to improve health care service delivery processes: a systematic review and meta-analysis. *PLoS medicine*. 2013 Jan 15;10(1):e1001363.
 - [11]. Poon EG, Keohane CA, Yoon CS, Dittmore M, Bane A, Levzion-Korach O, Moniz T, Rothschild JM, Kachalia AB, Hayes J, Churchill WW. Effect of bar-code technology on the safety of medication administration. *New England Journal of Medicine*. 2010 May 6;362(18):1698-707.
 - [12]. Zheng WY, Lichtner V, Van Dort BA, Baysari MT. The impact of introducing automated dispensing cabinets, barcode medication administration, and closed-loop electronic medication management systems on work processes and safety of controlled medications in hospitals: A systematic review. *Research in Social and Administrative Pharmacy*. 2021 May 1;17(5):832-41.
 - [13]. Pedersen CA, Schneider PJ, Ganio MC, Scheckelhoff DJ. ASHP national survey of pharmacy practice in hospital settings: dispensing and administration—2020. *American Journal of Health-System Pharmacy*. 2021 Jun 15;78(12):1074-93.
 - [14]. Menachemi N, Collum TH. Benefits and drawbacks of electronic health record systems. *Risk management and healthcare policy*. 2011 May 11:47-55.
 - [15]. Adler-Milstein J, Jha AK. HITECH Act drove large gains in hospital electronic health record adoption. *Health affairs*. 2017 Aug 1;36(8):1416-22.
 - [16]. Kaushal R, Shojania KG, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. *Archives of internal medicine*. 2003 Jun 23;163(12):1409-16.
 - [17]. Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. *Journal of the American Medical Informatics Association*. 2001 Jul 1;8(4):299-308.
 - [18]. Santo K, Richtering SS, Chalmers J, Thiagalingam A, Chow CK, Redfern J. Mobile phone apps to improve medication adherence: a systematic stepwise process to identify high-quality apps. *JMIR mHealth and uHealth*. 2016 Dec 2;4(4):e6742.
 - [20]. Hafezi H, Robertson TL, Moon GD, Au-Yeung KY, Zdeblick MJ, Savage GM. An ingestible sensor for measuring medication adherence. *IEEE Transactions on Biomedical Engineering*. 2014 Jul 21;62(1):99-109.
 - [21]. Yap KY, Lim KJ. Merging the old with the new: a cybermedicine marriage for oncology interactions with traditional herbal therapies and complementary medicines. *Tang Humanitas Medicine*. 2012 May;2(2):18-1.
 - [22]. Preciado B. Pharmaco-pornographic politics: Towards a new gender ecology. *parallax*. 2008 Jan 1;14(1):105-17.
 - [23]. Hafezi H, Robertson TL, Moon GD, Au-Yeung KY, Zdeblick MJ, Savage GM. An ingestible sensor for measuring medication adherence. *IEEE Transactions on Biomedical Engineering*. 2014 Jul 21;62(1):99-109.
 - [24]. Rammal DS, Alomar M, Palaian S. AI-Driven pharmacy practice: Unleashing the revolutionary potential in medication management, pharmacy *Pharmacy Practice (Granada)*. 2024;22(2):9.
 - [25]. Casino F, Dasaklis TK, Patsakis C. A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and informatics*. 2019 Mar 1;36:55-81.
 - [26]. Henriksen K, Battles JB, Keyes MA, Grady ML. Advances in patient safety: new directions and alternative approaches. *AHRQ Publication*. 2008 Aug(08-0034).
 - [27]. Kruse CS, Smith B, Vanderlinden H, Nealand A. Security techniques for the electronic health records. *Journal of medical systems*. 2017 Aug;41(8):127.
 - [28]. Mittelstadt BD, Allo P, Taddeo M, Wachter S, Floridi L. The ethics of algorithms: Mapping the debate. *Big data & society*. 2016 Nov;3(2):2053951716679679.

-
- [29]. Floridi L, Cowls J. A unified framework of five principles for AI in society. Machine learning and the city: Applications in architecture and urban design. 2022 May 21:535-45.
- [30]. Mandel JC, Kreda DA, Mandl KD, Kohane IS, Ramoni RB. SMART on FHIR: a standards-based, interoperable apps platform for electronic health records. Journal of the american medical informatics association. 2016 Sep 1;23(5):899-908.
- [31]. Topol E. Deep medicine: how artificial intelligence can make healthcare human again. Hachette UK; 2019 Mar 12.