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Review Article

A Pathway Toward AI and Digitalised Pharmacy

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ABSTRACT

Artificial intelligence (AI) and digital technologies are transforming pharmacy from traditional, manual work into a fast, safe, and patient focused service. It traces the evolution of pharmacy through four main stages: ancient and empiric practices using natural remedies, the industrial era of mass-produced medicines, the patient care era where pharmacists became active healthcare partners, and the current digital era. Modern digital pharmacy uses tools like electronic health records, e prescriptions, automated dispensing, telepharmacy, mobile health apps, and cloud systems to improve accuracy, reduce errors, and make medicines more accessible. AI adds advanced capabilities such as analysing large datasets, predicting drug interactions, designing new medicines, and personalising patient care. AI supports every stage of the pharmaceutical process from drug discovery, preclinical research, and clinical trials to manufacturing, supply chain management, and post marketing safety monitoring. Companies and startups using AI for faster drug design, quality control, and patient engagement. Ethical issues such as privacy, bias, transparency, accountability, and equal access are discussed, along with the need for strong regulations and cybersecurity. The future of pharmacy is expected to be highly automated, with smart factories, digital twins, and AI driven precision medicine, but will still require human oversight to ensure safety and fairness. Overall, the topic shows that digitalisation and AI are not just improving efficiency they are reshaping pharmacy into a connected, data driven, and patient centred system that can deliver safer, faster, and more personalized healthcare worldwide.

INTRODUCTION

Artificial Intelligence (AI) and digital pharmacy systems are changing how pharmacy works, bringing in a new age where advanced technology works closely with healthcare. This change has grown from many decades of progress and innovation.[1] They are reshaping how medicines are discovered, managed, and delivered by combining advanced computer systems with modern healthcare services. AI refers to computer

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programs and machines that can learn, reason, and make decisions in ways like humans, allowing them to analyse substantial amounts of medical and drug-related data, find patterns, predict outcomes, and support pharmacists in making better treatment choices. Digital pharmacy, on the other hand, uses online platforms, electronic prescriptions, automated dispensing systems, telepharmacy, and mobile health tools to provide pharmacy services remotely and efficiently, making it easier for patients to access medicines, receive reminders, and consult pharmacists without always visiting in person. Together, AI and digital pharmacy aim to make healthcare faster, safer, and more personalized, building on decades of technological progress and innovation in pharmacy practice.[2] The way pharmacy is practiced has changed greatly with the growth of digital pharmacy systems. This change began in the early 1980s, when computers were first used to manage basic pharmacy tasks. Soon, these tools developed into integrated pharmacy management systems (PMS) that could manage prescription processing, billing, electronic health records (EHR), and inventory control. A major step forward came with the spread of electronic prescribing (e-prescribing) and secure messaging systems, which made it easier for doctors and pharmacists to communicate, reduced mistakes caused by manual work, and helped patients take their medicines on time through automated reminders and built-in decision support tools. By the 2010s, digital pharmacy had grown to include cloud-based systems, mobile health apps, and remote access features, allowing pharmacists, patients, and healthcare providers to work together in connected digital health networks. The move toward digital care became even faster during the COVID-19 pandemic, when telepharmacy and online pharmacy services became essential for keeping medication management, virtual consultations, and home delivery running smoothly, helping to overcome distance and access problems.[3] An ideal digital pharmacy must ensure high accuracy and patient safety at every stage of the medication process. This means the system should have built in checks to prevent errors, such as verifying prescriptions through barcode scanning, flagging potential drug interactions, and alerting pharmacists to allergies or incorrect dosages. These safety features reduce the risk of harm and improve trust in the service.[4] A strong digital pharmacy should be able to connect seamlessly with other healthcare systems, such as electronic health records (EHRs), hospital information systems, and telehealth platforms. This integration allows pharmacists, doctors, and nurses to share up-to-date patient information instantly, improving coordination of care.[5] An ideal digital pharmacy must be easy to use for both healthcare professionals and patients. For pharmacists, the interface should be intuitive, with clear workflows that reduce training time and prevent confusion. For patients, mobile apps or web portals should be simple to navigate, offering features like prescription tracking, refill requests, and medication reminders.[6] An ideal digital pharmacy must protect patient privacy and comply with all relevant healthcare regulations, such as HIPAA in the US or GDPR in Europe. Strong encryption, secure logins, and regular system audits are essential to keep sensitive health data safe. At the same time, the system should be adaptable, able to update with new medical guidelines, integrate emerging technologies like artificial intelligence, and scale to meet growing patient demand.[7] Online pharmacies allow patients to order prescription and over-the-counter medicines through secure websites or mobile apps. These platforms often provide home delivery, making it easier for people with mobility issues or those living far from a physical pharmacy to access medicines. Many also offer features like price comparison, refill reminders, and access to pharmacists via chat or email. Studies show that online pharmacies improve convenience and can help patients maintain better adherence to treatment plans when combined with professional guidance [3] Telepharmacy is a type of digital pharmacy that uses video calls, secure messages, and other online tools to connect patients with pharmacists, so people can get pharmacy services without visiting in person. It is especially helpful for people living in rural, remote, or underserved areas where there may be no nearby pharmacy or limited healthcare services. Through telepharmacy, patients can get many services from home, such as medicine counselling, prescription checks, treatment monitoring, and follow-up advice. This saves time, reduces travel costs, and ensures patients get quick help from trained pharmacists. Telepharmacy systems are often linked to electronic health records (EHRs) and pharmacy software, so pharmacists can see a patient's medical history, check for drug interactions, and update records instantly. These systems can also include tools like medicine reminders, refill alerts, and educational materials to help patients take their medicines correctly. For healthcare providers, telepharmacy makes it possible to serve more patients, work more efficiently, and share information securely with doctors and nurses. Studies show that telepharmacy is just as safe and effective as in-person pharmacy services, with high patient satisfaction and good health results. During the COVID-19 pandemic, it became an essential service, keeping medicine supply and consultations going when people could not visit pharmacies, and its success has made it a lasting part of healthcare.[2] Automated dispensing systems are advanced machines used in hospitals, clinics, and community pharmacies to store, package, and give out medicines in a safe and organised way. These systems are connected to pharmacy software and use barcode scanning to make sure the right medicine and the correct dose are given to the right patient every time. When a prescription is entered into the system, it automatically selects the medicine from its secure storage, measures the correct amount, and prepares it for the patient. This process greatly reduces the chances of mistakes that can happen with manual handling, such as giving the wrong drug or the wrong dose. Because the machine handles much of the repetitive work, pharmacists can spend more time on important clinical tasks like counselling patients, checking for drug interactions, and collaborating with doctors to improve treatment plans. Automated dispensing systems also help keep track of medicine stock in real time, alerting staff when supplies are low or when medicines are close to their expiry date, which reduces waste and ensures that essential drugs are always available. In busy healthcare settings, these systems speed up the dispensing process, reduce waiting times for patients, and improve overall workflow efficiency. Research has shown that using automation in medicine dispensing not only improves accuracy but also increases patient safety and satisfaction, making it an important part of modern digital pharmacy practice.[8] Integrated PMS platforms combine multiple pharmacy functions such as prescription processing, billing, inventory tracking, and patient record management into one digital system. This integration allows for better coordination between pharmacists, doctors, and nurses, as everyone can access the same up-to-date patient information. PMS also supports regulatory compliance and reporting, making it a backbone of modern digital pharmacy operations.[2] Mobile health apps designed for pharmacy services allow patients to manage their prescriptions, receive medication reminders, track doses, and even access educational content about their medicines. Some apps integrate with wearable devices to check health indicators, which can be shared with pharmacists for personalised advice. Studies show that mHealth tools can improve medication adherence and patient engagement when used alongside professional support.[3] Cloud-based systems store pharmacy data securely online, allowing authorised users to access it from anywhere. This is particularly useful for large healthcare networks, chain pharmacies, or telepharmacy services, as it enables real-time updates and collaboration. Cloud solutions also make it easier to scale services, integrate modern technologies, and keep data backups for disaster recovery.[2] E-prescribing systems allow doctors to send prescriptions directly to pharmacies electronically, eliminating paper scripts. This reduces errors from illegible handwriting, speeds up processing, and ensures that prescriptions are stored securely in a patient's digital record. E-prescribing also supports automated checks for allergies, drug interactions, and dosage accuracy, improving overall medication safety.[3] Pharmacy has moved from paper records to computer systems, then to online services, mobile apps, and telepharmacy, making medicine access, communication, and patient care faster. Pharmacy has changed a lot over time, moving step by step from using paper records to using modern digital systems that make healthcare faster, safer, and easier for patients. In the past, pharmacists wrote prescriptions by hand and kept records manually, which took more time and sometimes caused mistakes. When computers were introduced, pharmacies could store prescription details, medicine stock, and patient information electronically, which reduced errors and saved time. As technology improved, pharmacies started offering online services where people could order medicines, check availability, and even get home delivery. Mobile apps made these services even easier to use, letting patients manage prescriptions, get reminders, and track their medicines from their phones. More recently, telepharmacy has allowed patients to talk to pharmacists through video calls or secure messages without having to travel. All these digital tools together have made it simpler to get medicines, improved communication between patients and healthcare providers, and helped deliver care more quickly, safely, and conveniently.

Importance of digitalised Pharmacy: Digitalised pharmacy is important because it has completely changed how medicines are prescribed, prepared, given to patients, and watched, making healthcare safer, faster, and easier for people everywhere. In the past, pharmacists worked with handwritten prescriptions and paper records, which could be slow, hard to read, and sometimes lead to mistakes that affected patient safety. With digital systems, all prescription details, patient histories, and stock information are stored electronically, which means pharmacists can quickly check the correct medicine, dose, and instructions, and see if there are any possible drug interactions or allergies before giving the medicine. This reduces errors, saves time, and keeps records organised for future use. Digital pharmacy also makes life easier for patients they can order medicines online, track their prescriptions, get reminders to take their doses, and even speak to pharmacists through video calls or secure messages without leaving home. This is especially helpful for people in rural or remote areas who may not have a local pharmacy nearby. In hospitals, automated dispensing systems use barcode scanning and smart software to make sure the right medicine goes to the right patient at the right time, reducing human error and speeding up the process. These systems also update stock levels in real time, helping pharmacies know exactly what medicines are available, when to reorder, and how to prevent waste from expired drugs. Digital pharmacy also plays a significant role in public health by collecting and analysing prescription data, it can help track disease trends, check antibiotic use, detect shortages early, and support faster responses to health emergencies. During the COVID-19 pandemic, digital pharmacy proved its value by keeping medicine supply and consultations going through online ordering, home delivery, and virtual counselling, even when people could not visit pharmacies in person. It also improves teamwork in healthcare pharmacists, doctors, and nurses can share patient information securely through connected systems, ensuring everyone has the same up-to-date details for better decision-making. Digital tools also support pharmacovigilance by making it easier to report and study side effects, which improves medicine safety. Mobile health apps linked to pharmacy systems give patients easy access to their prescription history, dosage instructions, and educational materials, empowering them to take an active role in their health. On a global scale, digital pharmacy helps create a more connected and efficient healthcare system, where data can be shared securely between countries to improve medicine safety and access. Digital pharmacy is now a core part of healthcare delivery, not just a convenience, because it combines technology with professional expertise to improve patient outcomes.[5] Digitalisation increases efficiency, reduces workload stress, and allows pharmacists to focus more on clinical care rather than repetitive paperwork.[9] Digital systems help achieve key goals such as quality improvement, cost control, and compliance with regulations. Together, these benefits show that digitalised pharmacy is not just about using computers it is about creating a connected, patient-centred healthcare system where medicines are managed more accurately, services are more accessible, and care is delivered more efficiently. It helps patients by making it easier to get medicines, understand how to use them, and stay on track with treatment. It helps pharmacists by giving them better tools to work safely, save time, and provide more personalised care. And it helps healthcare systems by improving safety, reducing waste, and making better use of data to plan and respond to health needs.[4] As technology continues to advance with artificial intelligence, mobile health, cloud systems, and real-time data analytics digital pharmacy will keep growing in importance, becoming an essential part of how healthcare is delivered everywhere, from big cities to the most remote villages, ensuring that no patient is left behind and that every medicine is delivered in the safest, fastest, and most effective way possible.

Evolution of pharmaceutical industry: Understanding the history and evolution of pharmacy is important because it shows us how the profession has grown from traditional methods to modern digital systems. By looking at past changes such as the move from handwritten prescriptions to computerised records, and from in-person services to online and telepharmacy we can better predict and prepare for future trends, technologies, and challenges in pharmacy practice. The pharmaceutical industry has changed a lot over time. In ancient pharmacy, medicines were made from plants and minerals, using traditional knowledge and trial and error. This was called empiric pharmacy, where treatments were based on experience, not scientific testing. Later, in the 19th and 20th centuries, industrial pharmacy began, with factories making medicines in enormous amounts and with better quality control. Over time, the role of pharmacists grew to focus more on patient care, such as giving advice, checking treatments, and making sure medicines are used safely. In recent years, automated pharmacy has been introduced, where machines and digital systems help store, prepare, and give out medicines faster and more accurately. In the future, experts talk about dark pharmacy fully automated, staff-free pharmacies that work all day and night, where robots and AI manage the entire medicine supply process.

1.Ancient era: Ancient pharmacy means the earliest ways people found, made, and used medicines to treat sickness, long before modern science and technology. In the beginning, healing was linked to religion, magic, and nature. People watched plants, minerals, and animal products around them and learned often by trial and error which ones could help reduce pain, heal wounds, or cure illness. This early stage is called empiric pharmacy because treatments were based on experience, not scientific testing. In Mesopotamia around 2600 BCE, clay tablets written in cuneiform listed hundreds of medicine recipes made from plants like thyme, licorice, and mustard, mixed with honey, beer, or milk. The people who prepared these medicines were often priests or healers who also used prayers and rituals.[10] In ancient Egypt, pharmacy was well developed and closely tied to religion. The famous Ebers Papyrus (c. 1550 BCE) listed over 800 prescriptions using ingredients like aloe, castor oil, and frankincense. Egyptian pharmacists, called "pastors," collaborated with doctors to prepare remedies, grinding ingredients on stone mortars and storing them in clay jars.[11] In ancient India, the Ayurveda system described in books like the Charaka Samhita and Sushruta Samhita gave detailed lists of medicinal plants, minerals, and animal products, along with methods for making powders, herbal drinks, and ointments. Indian pharmacists, called "Vaidyas," focused on keeping the body in balance and preventing disease.[12] In ancient China, the Shennong Bencao Jing (c. 1st century CE) listed 365 medicines from herbs, minerals, and animal sources, forming the base of Traditional Chinese Medicine. Chinese pharmacists used methods like drying, fermenting, and mixing herbs to make them more effective.[13] In ancient Greece, pharmacy started to move away from religion and became more scientific. Hippocrates (460–370 BCE) promoted careful observation and reasoning, while Dioscorides (c. 40–90 CE) wrote De Materia Medica, a five-volume book describing over 600 medicinal plants and their uses a guide followed for more than 1,500 years.[14] The Romans built on Greek knowledge, creating public pharmacies and using advanced jars, sieves, and scales to prepare medicines. During the Islamic Golden Age (8th–13th centuries), scholars translated Greek, Roman, Indian, and Persian medical books into Arabic, keeping and improving this knowledge. They set up some of the first regulated pharmacies called saydalas, where trained pharmacists made medicines under government rules.[15] Across all these cultures, ancient pharmacy involved careful work grinding, boiling, fermenting, filtering and measuring ingredients accurately, even without modern tools. Medicines were stored in jars, boxes, or animal skins, often with labels or symbols. Some remedies worked because of active ingredients, while others worked mainly because people believed in them. Most importantly, ancient pharmacy created the first organised systems for finding, preparing, and giving medicines the foundation of modern pharmacy. "The roots of today's pharmacy lie deep in the soil of ancient civilizations, where observation, tradition, and experimentation combined to create the earliest healing arts." [16]. In the ancient world, one of the most valued natural medicines was willow bark, known for its ability to reduce pain and fever, and its preparation shows how early pharmacists worked with plants to make effective remedies.[17], the process began with careful plant selection healers would choose young branches from the white willow tree Salix alba during spring or early summer, when the sap was rising and the bark contained the highest amount of the healing substance. The bark was stripped from the branches using simple knives or sharpened stones, then cut into thin strips to increase the surface area for drying. These strips were laid out in the sun or in warm, airy places to dry slowly, which helped preserve their medicinal strength. Once dried, the bark could be stored in clay jars, woven baskets, or animal-skin pouches to protect it from moisture. When a patient needed treatment for pain, fever, or inflammation, the ancient pharmacist would take a measured amount of dried bark and crush it into small pieces using a stone mortar and pestle. The crushed bark was then boiled gently in water over a clay or bronze pot for a long time sometimes up to an hour to draw out the active compounds into the liquid. This boiling process created a bitter-tasting tea or decoction, which was strained through cloth or fine reeds to remove solid pieces. The patient would drink the warm liquid in tiny amounts, often several times a day, depending on the severity of the illness. In some traditions, such as in ancient Greece, the crushed bark was also mixed with wine or honey to improve the taste and make it easier to swallow. Egyptian healers sometimes combined willow bark with other herbs like myrrh or frankincense to create multi-herb remedies, believing that combining plants increased their healing power. The knowledge of willow bark's effects was passed down through generations, and ancient healers noticed that it could ease headaches, joint pain, and fevers conditions we now know are linked to inflammation. Although they did not understand the chemical science, they saw its consistent results and refined their preparation methods over centuries. In some cultures, the bark was also chewed fresh for quick relief, especially by soldiers or travellers who could not prepare a full decoction. The preparation process was not only about extracting the medicine but also about ensuring purity and correct dosage too much bark could cause stomach upset, so experienced healers learned to balance strength with safety. This careful observation and adjustment over time is what made ancient pharmacy both an art and a science. The making of willow bark medicine shows how early pharmacists combined practical skills like plant identification, harvesting, drying, grinding, boiling, and straining with patient care, ensuring that the remedy was effective, safe, and suited to the individual's needs. It also shows how ancient pharmacy laid the foundation for modern drug development: the active ingredient in willow bark, salicin, was later studied, purified, and transformed into acetylsalicylic acid the basis of modern aspirin. But in its ancient form, willow bark tea was a simple, natural, and widely trusted remedy, prepared with tools no more complex than knives, mortars, pestles, pots, and cloth strainers, yet capable of delivering real relief. This example captures the essence of ancient drug-making a blend of nature, observation, and human skill and reminds us that even without modern laboratories, early pharmacists developed effective treatments that have lasted thousands of years in medical tradition. [17]

2. Industrial era: The Industrial Era of pharmacy was the time, starting in the late 1700s and continuing through the 1800s and early 1900s, when making medicines changed from being a small, manual job in local pharmacies to a large-scale process in factories. Before this, pharmacists made medicines by hand, grinding, mixing, and measuring ingredients for each patient. The Industrial Revolution in Britain brought new machines, steam power, and better chemical manufacturing methods, which turned pharmacy into a modern industry. Factories could now make massive amounts of medicines in standard doses, making them cheaper, easier to get, and more dependable in quality. This period saw the growth of industrial pharmacy the part of pharmacy focused on mass-producing medicines, packaging them, labelling them, and sending them across the country and even to other countries.[18]

Advances in chemistry meant scientists could take out the active parts of plants, like morphine from opium in 1804, quinine from cinchona bark in 1820, and salicylic acid from willow bark in 1828, and make them in pure form. New inventions like the pill-making machine in the mid-1800s and gelatine capsules in the 1870s made it easier to produce medicines in neat, ready-to-use forms.[19] Big companies such as Merck Germany, Burroughs Welcome, UK, and Parke-Davis, USA grew quickly, building research labs and large factories. This era also brought the first important pharmacy laws to protect people, like the UK Pharmacy Act of 1868, which said only trained pharmacists could sell dangerous drugs, and the US Pure Food and Drug Act of 1906, which required correct labelling and banned unsafe or fake medicines.[20] The job of the pharmacist began to change instead of making most medicines from scratch, they started giving out ready-made products from factories and spent more time advising patients. New types of medicines appeared, such as compressed tablets, ointments in tubes, and sterile injections, made possible by better machines and knowledge about germs. The discovery of synthetic dyes in the 1850s led to the modern chemical industry, which soon made synthetic drugs like aspirin in 1899 and barbiturates in 1903. Mass production meant medicines could be sent all over the world, creating a global market for the first time. There were problems too in some places, weak rules meant unsafe products were sold, and some companies promoted unproven remedies just to make money. Over time, stronger laws, better professional standards, and scientific testing improved safety and public trust. By the early 1900s, industrial pharmacy had built the base for today's pharmaceutical industry with large-scale manufacturing, research-based product development, quality control labs, and worldwide distribution. "The Industrial Era transformed pharmacy from a craft based on individual skill to a science-based industry capable of supplying safe, effective medicines to millions."[21] In short, this was the time when pharmacy moved from the pharmacist's workbench to the factory floor from hand-made remedies for a few people to machine-made medicines for the whole world creating the systems, companies, and rules that still guide pharmacy today.

[Raw Materials]
↓
[Chemical Synthesis]
↓
[Mass Production]
↓
[Quality Control]
↓
[Packaging & Distribution]

Figure 1.1 Concept chart of making drug in industrial era.

As shown in fig 1.1 during the Industrial Era, drug manufacturing became a large-scale, mechanized process. It began with raw materials, either extracted from plants, animals, or mined minerals, which were purified to remove unwanted substances. These materials then underwent chemical synthesis, where controlled chemical reactions produced the active pharmaceutical ingredient (API) in bulk. The API was then moved into mass production, where it was mixed with inactive ingredients (excipients) and processed into tablets, capsules, or liquid forms using machines like granulators, tablet presses, and coating pans. Throughout production, quality control teams tested samples for purity, potency, uniformity, and safety, ensuring they met pharmacopeial standards. Finally, the finished drugs were packaged and distributed, with proper labelling and storage to maintain stability until they reached pharmacies and hospitals.[22] During the Industrial Era, pharmacy changed from making small batches of herbal remedies to producing large amounts of pure medicines from plants and animals. This became possible because of new advances in chemistry, steam-powered machines, and better ways to extract substances using solvents. One of the first plant-based medicines made on a large scale was morphine, taken from the opium poppy (Papaver somniferum). It was discovered in 1804 by Friedrich Sertürner, and by the 1820s it was being made in factories to relieve pain. Soon after, quinine from the bark of the cinchona tree (Cinchona officinalis) became an important treatment for malaria, with industrial production starting in Europe in the 1820s. Another important discovery was salicin from willow bark (Salix alba), which led to the creation of aspirin (acetylsalicylic acid) in 1897 by scientists at Bayer. Medicines from animals were also important. Heparin, a drug that prevents blood clots, was first found in 1916 in dog liver, but by the 1930s it was being made from pig intestines and cow lungs. Insulin, discovered in 1921 from dog pancreas, was soon produced from pig and cow pancreases to treat diabetes. Urokinase, an enzyme that helps dissolve blood clots, was first taken from human urine in the 1940s, but the methods used were based on earlier enzyme extraction techniques from the late Industrial Era. These discoveries where a turning point medicine were no longer just crude plant or animal extracts. They became purified, measured, and mass-produced, laying the groundwork for today's modern pharmaceutical industry.[23]

Table 1.1 Extraction of important drug during industrial era

Year	Drug/Enzyme	Extracted from	Scientist name
1804	Morphine	Opium poppy (Papaver somniferum)	Friedrich Sertürner
1820	Quinine	Cinchona tree (Cinchona officinalis)	Pierre Joseph Pelletier
1828	Salicin	Willow bark (Salix alba)	Johann Andreas Buchner
1897	Aspirin	Willow bark (Salix alba)	Felix Hoffmann
1901	Adrenaline	from adrenal glands of animals	Jokichi Takamine
1916	Heparin	First from dog liver; later from pig intestines and cow lungs	Jay McLean
1921	Insulin	Pancreas of dogs, later pigs and cows	Frederick Banting, Charles
1928	Penicillin	Mold Penicillium notatum	Alexander Fleming
1935	Sulfonamides	Synthetic (inspired by dyes)	Gerhard Domagk
1943	Streptomycin	Bacterium streptomyces griseus	Selman Waksman, Albert Schatz

3. Patient care era: The Patient Care Era is the modern stage of pharmacy history. It started in the 1970s and is still going on today. In earlier times, pharmacists mainly made and gave out medicines. Their main job was to prepare the right product and make sure it was safe. In the Patient Care Era, the focus changed now the main goal is to help patients get the best results from their medicines. This means pharmacists are not just medicine suppliers, but also healthcare providers who work directly with patients. This change happened for many reasons. First, there were many new medicines developed in the mid-1900s. People often had to take several medicines at the same time, which could cause side effects or dangerous drug combinations. Second, people started living longer but with long-term illnesses like diabetes, high blood pressure, asthma, and arthritis. These conditions need careful, ongoing medicine management. Third, pharmacists began working in hospitals with doctors and nurses, where they could see patients directly and help prevent medicine related problems. A big turning point came in 1990, when two pharmacy experts, Charles Hepler and Linda Strand, introduced the idea of pharmaceutical care. They said pharmacists should take responsibility for making sure medicines are used in a way that improves a patient's quality of life. This idea became the heart of the Patient Care Era. In this era, pharmacists do much more than before. They review all the medicines a patient is taking, check if the doses are correct, look for harmful combinations, and work with doctors to fix any problems. This process is called Medication Therapy Management (MTM). Pharmacists also teach patients how to take their medicines properly, explain possible side effects, and answer questions. Another big change is that pharmacists now focus on the whole patient, not just the medicine. They think about the patient's health history, lifestyle, culture, language, and even whether they can afford the medicine. They also help prevent illness by giving vaccines, checking blood pressure and sugar levels, and giving advice on healthy living. Pharmacists now work closely with other healthcare professionals' doctors, nurses, dietitians as part of a team. This teamwork helps patients get better care. Over time, there have been important milestones: The benefits of the Patient Care Era are clear. Patients get better results from their medicines, there are fewer mistakes, and healthcare costs go down because problems are prevented early. Patients also understand their medicines better and can get help more easily because pharmacists are often more available than doctors. There are still challenges. Pharmacists have heavy workloads and must balance dispensing medicines with patient care. In some places, they are not paid for clinical services, which makes it harder to provide them. They also need ongoing training to keep up with new medicines and technology. Technology is now a big part of patient care. Electronic health records help pharmacists see a patient's full medical history. Computer systems can warn about dangerous drug combinations. Telepharmacy allows pharmacists to help patients in remote areas. Mobile apps remind patients to take their medicines and track their progress. The Patient Care Era is happening all over the world, but at different speeds. In the UK, pharmacists run clinics for asthma, high blood pressure, and diabetes. In Canada, they can prescribe for minor illnesses. In India, clinical pharmacy is growing in hospitals, and pharmacists are becoming more involved in-patient counselling. Looking ahead, pharmacy will move towards precision medicine, where treatments are chosen based on a patient's genes. Pharmacists may be able to prescribe more medicines and will be even more involved in public health. The main idea will stay the same pharmacists will keep working to make sure every patient gets the safest and most effective use of their medicines. In short, the Patient Care Era changed pharmacy from a job focused on products to a profession focused on people. Pharmacists are now medicine experts, educators, and partners in healthcare, helping patients live healthier, better lives.[24]

Table 1.2 Various events in decades of patient care era

Year	Events or changes in era
1970s	Pharmacists start working directly with patients in hospitals.
1980s	More pharmacists work in clinics for patients who are not in hospital.
1990s	The term "Pharmaceutical care" is defined.
2000s	Pharmacists start giving vaccines in many countries.
2010s	Technology like electronic health records and telehealth becomes common.
2020s	During COVID-19, pharmacists play a key role in testing, vaccination, and patient education.

Digitalisation in Patient care era: In the Patient Care Era, digital technology has changed the way pharmacists help patients, making care faster, safer, and more personal. Electronic health records

(EHRs) let pharmacists quickly see a patient's full medical history, so they can choose the right medicine and avoid dangerous drug combinations. E-prescriptions remove problems caused by unclear handwriting and make it quicker to prepare medicines. Telepharmacy allows pharmacists to give advice and check on patients from a distance, which is very helpful for people in rural areas. A major new development is Generative AI — a type of artificial intelligence that can create new information and solutions. In pharmacy, it can make personalised medicine guides for patients, write hospital discharge notes, and suggest the best medicine plans based on a patient's health data. It can study large amounts of information to predict side effects, design custom treatment plans, and even create fake (but realistic) patient data for research without breaking privacy rules. Generative AI can also be used for training by creating realistic patient cases, and it can work with decision-support tools to give quick advice during patient consultations. By using these digital tools, especially generative AI, pharmacists spend less time on paperwork and more time talking to patients. This makes pharmacy work more efficient, proactive, and focused on the patient, leading to better health and safer medicine use.[25] A digitalised pharmacy works through six main pillars electronic health records for complete patient data, e-prescriptions for error-free orders, telepharmacy for remote care, AI and machine learning for smart decisions, mobile tools for patient reminders, all improving safety, speed, and personalised care

Pillars for digitalisation in pharmacy: The Five main pillars of digitalised pharmacy work together to make the Patient Care Era more convenient by speeding up services, reducing errors, enabling remote consultations, giving personalised treatment, keeping patients engaged with reminders, and protecting health data all leading to safer, faster, and more patient-focused healthcare.

1.Electronic Health Record (EHF) and Data Integration: Electronic Health Records, or EHR**s**, are safe, computer-based versions of a patient's complete medical history. Instead of keeping information in paper files, EHRs store it digitally so it can be shared quickly with authorised healthcare providers. In pharmacy, EHRs are very important because they give pharmacists fast and reliable access to the details, they need to make sure medicines are safe and effective. EHRs are now a key part of modern pharmacy, helping pharmacists focus more on patients than just on dispensing medicines. An EHR contains much more than a list of medicines. It usually includes personal details, medical history, allergies, vaccination records, lab test results, hospital discharge notes, and comments from doctors, nurses, and other healthcare workers. This means pharmacists can see the full picture of a patient's health, not just the prescription in front of them.[26][27] This complete view helps prevent mistakes and improves safety. Data integration means connecting information from different healthcare systems, so it appears together in one place. Without integration, a patient's details might be scattered across hospitals, clinics, and pharmacies, making it hard to get a complete view. With integration, all this data flows into the EHR, so the pharmacist can see it in real time. This requires "interoperability" the ability of different systems to work together which can be a big challenge.[28]. In the Patient Care Era, EHRs and data integration have changed pharmacy practice. In the past, pharmacists often relied only on the prescription slip and what the patient could remember. This sometimes-caused errors, like giving a medicine that reacted badly with another drug the patient was already taking. Now, with EHRs, pharmacists can check the full medication list, see recent lab results, and even read the doctor's notes explaining why a medicine was prescribed. this access to complete, up-to-date information is essential for safe, personalised care.[29]. EHRs improve medication safety. For example, if a patient is allergic to penicillin, this will be clearly marked in their EHR. If a doctor prescribes a penicillin-based antibiotic by mistake, the pharmacy's system can alert the pharmacist, who can then contact the doctor to change it. They also make **c**ommunication between healthcare professionals easier. Doctors, pharmacists, nurses, and specialists can all see the same information, reducing the need for repeated tests or phone calls. In India and globally, startups are helping make EHRs more accessible. PharmEasy integrates e-pharmacy, diagnostics, and teleconsultation with patient records. Tata 1mg links its services with India's Ayushman Bharat Digital Health Mission (ABHA) to create unified health IDs. Netmeds **i**s building a connected system for prescriptions and lab results. CureBay combines physical health centres with digital records for rural areas. Globally, Redox in the U.S. connects healthcare apps to EHR systems, and SimplePractice offers cloud-based EHR tools for smaller providers.

2. E. prescribing and Automated dispensing: E-prescribing means sending a prescription from a doctor to a pharmacy using a computer or secure online system instead of writing it on paper. This makes the process faster and safer. Handwritten prescriptions can be hard to read, which sometimes causes mistakes. With e-prescribing, the medicine name, dose, and instructions are typed clearly, so there is less chance of confusion. It also allows the pharmacist to check the patient's medical history, allergies, and other medicines before giving out the prescription. This helps prevent harmful drug interactions 'prescribing also saves time for patients because the pharmacy can start preparing the medicine before the patient arrives. It reduces the risk of losing prescriptions and makes it harder for anyone to create fake ones e-prescribing improves accuracy, reduces errors, and strengthens communication between doctors and pharmacists.[30] Automated dispensing is when machines or computer-controlled cabinets store and give out medicines. These machines are often used in hospitals, clinics, and some community pharmacies. They keep medicines in secure compartments and release the correct drug and dose only when authorised by a pharmacist or healthcare worker. Automated dispensing systems can be connected to e-prescribing and electronic health record systems, so they only give out medicines that have been properly prescribed and checked. automated dispensing reduces mistakes, improves stock control, and saves time for healthcare staff. This means pharmacists and nurses can spend more time with patients instead of searching for medicines.[31] When e-prescribing and automated dispensing work together, the process becomes even smoother. For example, in a hospital, a doctor can enter a prescription into the computer. The pharmacy system checks it for safety, and then the automated cabinet in the ward releases the medicine for the nurse to give to the patient. This reduces delays, ensures the right medicine reaches the right person, and keeps a digital record of every step. These systems also help with inventory management. Automated machines track how much medicine is used and can alert staff when stock is low or close to expiry. This reduces waste and ensures important medicines are always available. In busy community pharmacies, dispensing robots can prepare prescriptions in advance, giving pharmacists more time to explain medicines to patients. There are some challenges. These systems need reliable internet, secure data storage, and trained staff. The machines and software can be expensive to buy and maintain. Data privacy is also important as strong security is needed to protect patient information.[32] In short, e-prescribing and automated dispensing make pharmacy work faster, safer, and more accurate. They reduce mistakes, save time, and allow pharmacists to focus more on patient care — which is the main goal of the Patient Care Era.

3.Telepharmacy and Remote care: Telepharmacy means giving pharmacy services to patients from far away using technology like phone calls, video chats, mobile apps, or secure websites. It allows pharmacists to help people even if they are not in the same place. This is very useful for patients in villages, small towns, or areas without a nearby pharmacy. telepharmacy can include checking prescriptions, giving advice on how to take medicines, watching how treatment is going, and even guiding medicine preparation from a distance.[33]. Remote care is a bigger idea it means any way pharmacists help patients without meeting them face-to-face. This includes telepharmacy, follow-up phone calls, sending reminders to take medicines, and checking health data online. remote care saves travel time, improves access to medicines, and still gives patients expert advice when they can't visit a pharmacy.[34] Telepharmacy became very important during COVID-19, when people could not easily visit hospitals or pharmacies. Telepharmacy helped patients take medicines correctly, reduced mistakes, and kept care going during lockdowns. Most patients were happy with the service, especially when they got clear instructions and follow-up support.[35] The main benefits are better access to care, safer medicine use, and more personal attention. For example, a patient in a remote village can have their prescription checked by a pharmacist in a city, making sure the medicine is safe and right for them. There are some challenges. Telepharmacy needs good internet, secure systems to protect patient information, and trained staff. Rules about telepharmacy are different in each country, which can limit how it is used.as working of telepharmacy

4. Mobile health and Patient engagement: Mobile health (mHealth) means using mobile phones, tablets, wearable devices, and health apps to give healthcare services and information. It helps people track their health, get medicine reminders, consult doctors online, and learn about healthy living — all from their devices. Because smartphones are common, mHealth is an easy and low-cost way to reach people, even in rural areas. Patient engagement means patients take an active role in their own care — making decisions, following treatment plans, and checking their health regularly. mHealth makes this easier by giving patients constant access to their health data and advice. For example, apps can remind them to take medicines, record blood sugar readings, or track exercise, helping them stay committed to treatment. Studies, such as show that most mHealth users report better medicine adherence, improved health knowledge, and better disease control.[36] In India, the government supports mHealth through programs like the Ayushman Bharat Digital Mission (ABDM), which gives every citizen a unique health ID and links their health records; eSanjeevani, a telemedicine platform for online consultations; mDiabetes, which sends tips on diabetes prevention; and mobile apps for maternal and child health tracking. Startups are also driving change Practo offers online consultations and digital health records, mfine uses AI for teleconsultations and health monitoring, HealthifyMe provides nutrition and fitness coaching, BeatO focuses on diabetes care with connected glucometers, and Tata 1mg combines e-pharmacy, diagnostics, and health information linked to ABDM. Globally, companies like MySugr, Babylon Health, and Ada Health are showing how mHealth can transform patient engagement. The benefits include better access to care, early detection of problems, improved health awareness, and less travel for patients, while also helping healthcare providers monitor patients remotely. Challenges include protecting patient data, making apps easy for older adults, and ensuring access for people without smartphones or internet. Overall, mHealth and patient engagement work together to make healthcare more personal, proactive, and accessible, with strong support from both government programs and innovative startups.[37][38]

5. Generative AI: Generative Artificial Intelligence (Generative AI) is a smart computer technology that can create new content — like text, summaries, images, or reports by learning from large amounts of data. In a digitalised pharmacy, where systems like electronic health records (EHRs), e-prescriptions, and automated dispensing are already used, generative AI adds extra intelligence. It can not only read and process information but also produce useful outputs for pharmacists, doctors, and patients. One major use is personalised patient communication. Instead of giving the same leaflet to everyone, AI can create medicine instructions in simple language, in the patient's preferred language, and suited to their health condition. It can also prepare discharge summaries and treatment plans quickly, saving pharmacists time. In drug discovery, generative AI can study huge research databases to suggest new drug molecules, predict side effects, and estimate how well a medicine might work. In clinical decision support, it can check a patient's history, lab results, and current medicines to suggest safer or more effective options. Generative AI is also useful for training. It can create realistic patient cases for pharmacy students or staff to practise problem-solving. Startups like Insilico Medicine use it for drug discovery, Ada Health for personalised symptom checks, and Indian platforms like PharmEasy are exploring AI-driven patient counselling. While it offers faster work, fewer errors, and more personalised care, challenges include protecting patient data, avoiding over-reliance on AI, and ensuring human experts review all AI suggestions. Used responsibly, generative AI can make pharmacy safer, smarter, and more patient-focused.[39][40] As further we discuss about AI in detail.

AI in pharmaceutical industry: Artificial Intelligence (AI) in pharmacy means using smart computer systems that can learn from data and help in making better decisions about medicines and patient care. Unlike normal computer programs that only follow fixed instructions, AI can study large amounts of medical and pharmacy information, find patterns, and give useful suggestions. In modern pharmacies, AI can help in many ways such as finding the best medicine for a patient, checking for harmful drug combinations, and helping to design new medicines faster. It can also take over routine jobs like checking prescriptions, managing stock, and preparing patient information, so pharmacists have more time to talk to patients and give advice. AI tools like machine learning (learning from data), natural language processing (understanding human language), and generative AI (creating new content) are already being used to make personalised medicine guides, summarise patient records, and create training cases for pharmacy students. AI is not here to replace pharmacists but to work alongside them, making pharmacy work safer, faster, and more focused on the patient. However, it must be used carefully, with strong rules for privacy, ethics, and human checking of AI suggestions. As more pharmacies go digital, AI is becoming an important part of the Patient Care Era, helping to make healthcare more accurate, quick, and personalised for each patient.[41]

1. What is AI? Artificial Intelligence (AI) is a field of computer science that focuses on creating systems capable of performing tasks that normally require human intelligence. In technical terms, AI involves building algorithms and models that allow machines to learn from data, recognise patterns, make decisions, and improve their performance over time without needing to be programmed for every single step. These systems can process large amounts of information, analyse it quickly, and provide outputs that help solve problems or support decision-making. AI includes areas such as machine learning (where computers learn from examples), natural language processing (understanding and responding to human language), computer vision (interpreting images and videos), and expert systems (using stored knowledge to solve specific problems). Technically, AI works by combining data inputs, mathematical models, and decision rules to produce results that mimic human reasoning. It can be designed for a single task, known as "narrow AI," or, in theory, for many tasks like a human, known as "general AI.", AI can be defined as "the study of agents that receive precepts from the environment and take actions that maximise their chances of achieving goals**."** [42]

2. Working of AI: Artificial Intelligence (AI) is a technology made by humans to help machines do tasks that usually need human thinking. It cannot work on its own people give it information, called data, and instructions on how to use that data. The AI then learns from this information and uses it to give answers, make suggestions, or perform actions. AI systems have two main parts. The frontend is the part we can see and use. This could be a chatbot screen, a mobile app, or a website where we type questions or give commands. The frontend is designed to be easy for people to interact with. The backend is the hidden part that we do not see. This is where the AI stores data, processes information, and runs algorithms (step-by-step instructions) to find answers. The backend is like the "brain" of the AI, while the frontend is like its "face" that talks to us. Both parts work together the frontend takes our input, the backend processes it, and then the frontend shows us the result. This teamwork makes AI useful in many areas, including pharmacy, healthcare, education, and daily life.

A. Frontend of AI: The frontend of AI is the part you can see and use. It is the user-facing layer that sits on top of the complex AI "brain" and data systems. Its job is to take what a person wants, turn it into instructions the AI can understand, and then turn the AI's results into answers people can trust and use. [43] You can think of it as the "face and voice" of AI the screens, buttons, chat boxes, voice prompts, and visuals that make talking to AI feel natural and safe. A good frontend makes things easier, prevents mistakes, shows what the system is doing, and explains results clearly so people can make good decisions. [44] The frontend mainly does three things: input, interaction, and output. Input means collecting what the user wants to do typing a question, uploading a file or image, speaking into a microphone, or sharing data from a camera or wearable device. [42] Interaction means guiding the conversation or process asking follow-up questions, showing progress, giving choices, and handling mistakes politely [44] Output means showing results text answers, summaries, warnings, charts, images, or step-by-step instructions.[45] Modern AI frontends support many ways to interact chat windows, forms, dashboards, and voice. They must be accessible large, clear text, good colour contrast, captions, keyboard navigation, and screen-reader support [46] They should also support different languages, use plain words, and allow personalisation like remembering preferences or letting users choose between short or detailed answers.[45]. AI can be wrong or unsure, so the frontend should show confidence levels, explain assumptions, and give sources It should separate facts from AI-generated suggestions and use safety features like warnings for sensitive topics, alerts for risky medicine doses, or "needs human review" labels.[47] It should also make it easy to edit, approve, or send an issue to an expert Performance and privacy are also important. If a task takes time, the frontend should show progress or partial results If the internet drops, it should save your work. It should ask only for the data it needs, let you delete or download your data, and show when the microphone or camera is on In healthcare and pharmacy, the frontend has extra duties. A patient app should use simple language, big buttons, and reminders It should clearly show side-effect warnings and drug interaction alerts. A pharmacist dashboard should highlight urgent safety issues first and make it easy to contact doctors A telepharmacy portal should make identity checks and consent simple before starting a video call For chat-based AI, the frontend should break long answers into smaller parts, let you interrupt, and allow you to start a new conversation easily It should show what it remembers, let you change it, and allow you to turn memory off. If the AI makes something up, the frontend should encourage you to check the information and show sources. Finally, the frontend should learn from use. It can collect safe, privacy-friendly feedback on what works and what doesn't, test different designs, and improve over time in short, the AI frontend is the bridge between people and the AI's complex inner workings. It turns human needs into clear instructions for the AI and turns AI results into answers people can understand and trust. In pharmacy, a good frontend makes AI safer, easier to use, and more helpful for both patients and healthcare professionals.[48][49][50]. B. Backend of AI: when we use Artificial Intelligence (AI), what we see on the screen — the chat box, buttons, or dashboard is only the frontend. Behind the scenes, there is a much larger and more complex part called the backend. The backend is like the "brain and engine room" of AI. It is where all the heavy work happens storing data, processing it, running algorithms, and generating the answers or actions that the frontend shows to the user. Without the backend, the frontend would just be an empty shell The backend of AI has several important parts that work together. The first is data storage. AI systems need large amounts of data to learn and to make decisions. This data can include text, numbers, images, audio, or sensor readings. In pharmacy, for example, the backend might store drug databases, patient health records, clinical guidelines, and research papers This data is usually kept in secure databases or cloud storage systems, which are designed to handle huge volumes of information safely and quickly. The second part is data processing and cleaning. Raw data is often messy it may have errors, missing values, or inconsistent formats. The backend uses special programs to clean and organise the data so the AI can use it effectively. In healthcare, this might mean standardising drug names, convert units of measurement, or remove duplicate patient records. the third part is the AI models and algorithms. This is the true "thinking" part of the backend. AI models are built using techniques like machine learning, deep learning, or natural language processing. These models are trained on large datasets so they can recognise patterns, make predictions, or generate new content. For example, in a pharmacy AI system, a model might be trained to detect dangerous drug interactions or to suggest alternative medicines based on a patient's allergies The backend also includes the model training environment. Training an AI model means feeding it data and adjusting its internal settings (called parameters) until it performs well. This requires powerful computing resources, often using GPUs (graphics processing units) or TPUs (tensor processing units) to handle the large calculations quickly. In pharmacy research, training might involve analysing millions of chemical structures to find promising drug candidates. Once a model is trained, the backend handles model deployment making the model available for real-time use. This means setting up systems so that when a user sends a request from the frontend, the backend can quickly run the model, get the result, and send it back. This process is called inference. For example, when a pharmacist enters a prescription into an AI-powered drug interaction checker, the backend runs the trained model to check for risks and returns the result in seconds Another key part of the backend is APIs (Application Programming Interfaces). APIs are like messengers that allow the frontend and backend to talk to each other. They define how requests are sent, what data is needed, and how results are returned. In pharmacy, an API might let an AI system pull patient data from an electronic health record or send alerts to a pharmacist's dashboard. The backend also manages security and privacy. This is especially important in healthcare, where patient data is sensitive. The backend uses encryption to protect data, access controls to ensure only authorised people can use it, and audit logs to track who accessed what information and when. In India, systems must also follow rules under the Digital Personal Data Protection Act and healthcare guidelines. Scalability is another back-end responsibility. AI systems may need to handle thousands or millions of requests at the same time. The backend uses load balancing, caching, and distributed computing to make sure the system stays fast and reliable even under heavy use. For example, a national telepharmacy service might have thousands of patients connecting at once the backend ensures each request is processed without delay. In pharmacy and healthcare, the backend often integrates with specialised knowledge bases. These are curated collections of medical and pharmaceutical knowledge, such as drug formularies, treatment guidelines, and clinical trial results. The AI can query these knowledge bases to support its recommendations. For example, if a patient's blood pressure is high, the AI might check the latest hypertension guidelines before suggesting a medicine The backend also supports continuous learning and updates. Medical knowledge changes quickly new drugs are approved, guidelines are updated, and safety alerts are issued. The backend must be able to update its models and databases regularly, so the AI stays accurate. This might involve retraining models with new data or adding new rules to the system Monitoring and maintenance are ongoing back-end tasks. The system must track performance, detect errors, and fix problems quickly. In AI, this is called MLOps (Machine Learning Operations) a set of practices for managing AI models in production. In pharmacy, MLOps ensures that a drug interaction checker continues to work correctly as new medicines are added to the market. In short, the backend of AI is the hidden powerhouse that makes everything work. It stores and processes data, runs the AI models, ensures security, connects to other systems, and keeps everything up to date. In pharmacy, a strong backend means AI tools can give fast, accurate, and safe advice to pharmacists and patients. Without it, even the most beautiful frontend would be useless.[51][52][53][54] In short, the working of AI shown in figure

Fig.3.1. the working of AI

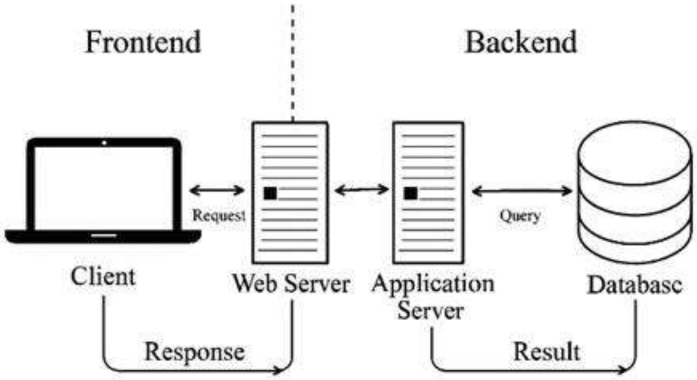

Fig.3.1 the working of AI diagram using various external references [55]

The frontend and backend of AI work together at the same time, like two connected parts of one machine. The frontend is what you see the app screen, chat box, or buttons where you type, speak, or give your request. The moment you do that the frontend sends your request to the backend. The backend is hidden and does the main work it looks at the data, runs the AI's "brain," and finds the answer. That answer is then sent back to the frontend, which shows it to you. This happens instantly, so both parts work together continuously. When making computer programs, different languages are used for the frontend and the backend because they do different jobs. The frontend is the part people see and use like the buttons, menus, colours, and text on a website or app. To make this, developers often use HTML (to build the structure), CSS (to design the look), and JavaScript (to make it interactive). The backend is the hidden part that works in the background. It stores information, processes requests, and makes sure everything runs smoothly. Common backend languages are Python, Java, PHP, Ruby, and C+. The frontend sends user actions to the backend the backend does the work and then sends the results back to the frontend to show to the user. Both parts must work together for the program to be fast, safe, and easy to use. [56].

Table.3.1 Various Computer Language for Frontend and Backend

Frontend languages	Backend languages
Html	Node.Js
Css	PHP
React.Js	Python
Vue.Js	Ruby
Angular.Js	Go

Table 3.1 Various computer language table is made by reference [56].

As shown in table 3.1 from above languages We can use many different programming languages to build both the front end and back end of an application. However, professional developers suggest certain languages work best for each. For example, HTML, CSS, and JavaScript are common for the front end, while Python, Java, and PHP are often preferred for the back end. A computer language is a special way for humans to give instructions to a computer so it can perform specific tasks. Just like people use spoken languages to communicate with each other, programmers use computer languages to communicate with machines. These languages have their own rules (called syntax) for writing instructions and meanings (called semantics) that tell the computer what to do. Without them, computers would only be able to work with raw binary code long strings of 0s and 1s which is very hard for humans to understand. Computer languages make it easier to create software, websites, mobile apps, and control systems. They can be grouped into low-level languages, which are close to machine code and work directly with hardware, and high-level languages, which are easier for humans to read and write. Examples of high-level languages include Python, Java, and C++, while low-level languages include Assembly and Machine Language. Some languages are also designed for specific purposes, like SQL for databases or HTML for web pages. In short, computer languages act as a bridge between human thinking and machine execution, making modern technology possible.[57]

Applications of AI and digitalised pharmacy: Digitalised pharmacy and artificial intelligence (AI) are transforming how medicines are discovered, developed, and delivered. In drug discovery, AI can quickly analyse huge chemical and biological datasets to find promising drug candidates, predict their safety, and suggest optimal dosages. In pre-clinical research, computer-based models and digital twins simulate how drugs behave in the body, reducing the need for animal testing. During clinical trials, AI helps select suitable patients, forecast recruitment, and monitor participants through wearable devices and mobile health apps. In pharmacy operations, automated dispensing systems, prescription verification, and stock forecasting improve accuracy and efficiency. Cloud computing enables secure data sharing between researchers, manufacturers, and healthcare providers, while AI-powered pharmacovigilance systems detect adverse drug reactions early. Together, these tools make pharmacy faster, safer, and more personalised, improving patient care and reducing costs.[58]

1. Drug Discovery & Design: Digital pharmacy and artificial intelligence (AI) are changing how new medicines are found and designed. In the past, drug discovery was slow and expensive. Scientists had to test thousands of chemicals in the lab, often taking more than 10 years to find one medicine that works. Now, AI and digital tools make this process much faster. The first step in drug discovery is finding a target usually a protein or enzyme in the body linked to a disease. AI can search huge amounts of data from genetics, lab studies, and medical papers to find these targets quickly. It can also spot patterns that humans might miss. Once a target is found, scientists look for molecules that can work on it. Instead of testing each one in the lab, AI can do virtual screening on a computer, checking millions of molecules in a short time. AI can also design brand-new molecules (de novo design) with the right shape and properties to fit the target, like a key fitting into a lock. AI tools can predict if a molecule will be safe, how it will move through the body, and whether it might cause side effects. This helps remove bad options early. Cloud computing lets researchers around the world share and analyse data together in structure-based drug design, AI works with 3D models of proteins to improve how well a drug binds to its target. Tools like AlphaFold have made it easier to know protein shapes, speeding up design. Overall, AI and digital pharmacy save time, reduce costs, and increase the chances of finding safe, effective medicines.[40][59]

2. Pre-clinical Research: Pre-clinical research is the stage after scientists discover a possible new drug but before it is tested on people. In this stage, they check if the drug is safe, how it works, and how it moves through the body. In the past, this meant a lot of slow lab work and animal testing. Now, digital pharmacy tools and artificial intelligence (AI) are making this stage faster, cheaper, and more accurate. One big change is the use of computer simulations (also called in silico models). These are like virtual experiments that can predict how a drug will behave in the body. AI can create digital twins of cells, tissues, or organs to test the drug's effects without using real animals at first. This helps find problems early, such as harmful side effects or poor absorption.AI is also very good at predicting toxicity whether a drug might damage the liver, heart, or other organs. It does this by comparing the new drug's chemical structure with huge databases of known safe and unsafe compounds. This means unsafe drugs can be redesigned before expensive lab tests. In PK/PD modelling (pharmacokinetics and pharmacodynamics), AI predicts how much of the drug will reach the target, how long it will stay active, and how it will affect the body. This helps scientists choose the best doses to test later. High-content screening uses automated microscopes and AI image analysis to study thousands of cells at once, spotting patterns that humans might miss. Omics data (like genomics and proteomics) can also be analysed by AI to understand exactly how a drug changes the body at the genetic and protein level. Cloud computing allows scientists around the world to store, share, and analyse all this data quickly and securely. In animal studies, AI can monitor behaviour automatically, reducing stress for the animals and improving accuracy. Overall, digital pharmacy and AI in pre-clinical research save time, reduce costs, cut down on animal testing, and improve the chances of success when the drug moves to human trials.[60][58]

3. Clinical Trials: Clinical trials are the stage where a new medicine is tested in people to check if it is safe, works well, and is better than current treatments. This process is very important but can take many years and cost a lot of money. Digital pharmacy tools and artificial intelligence (AI) are now helping to make clinical trials faster, cheaper, and more accurate. One big challenge is finding the right patients for a trial. AI can search through hospital records, genetic data, and other health information (with privacy protection) to quickly find people who match the trial's needs. This saves time and helps choose patients who are more likely to benefit. Once patients join, digital health tools like wearable devices, mobile apps, and remote monitoring systems can track their health in real time for example, heart rate, blood pressure, or activity levels. This means fewer hospital visits and more comfort for patients. The data is sent securely to cloud systems, where AI looks for patterns or early signs of side effects.AI also helps design better trials. It can predict how many patients are needed, how long the trial should run, and what results to measure. Some trials are now adaptive, meaning the design can change during the study if early results show a better way forward. Safety monitoring is improved too. AI can scan trial data and medical reports to quickly spot possible harmful effects, so action can be taken sooner. With decentralised trials, patients can take part from home using telemedicine and home delivery of medicines. AI coordinates these processes and keeps all the data organised. Overall, digital pharmacy and AI make clinical trials faster, more efficient, and more patient-friendly helping new medicines reach people sooner.[40][58]

4. Manufacturing & Quality Control: Manufacturing is the stage where medicines are made in large quantities, and quality control (QC) is the process of checking that every batch is safe, effective, and meets standards. In the past, this was done mostly by hand, with checks at the end of production. Now, digital tools and artificial intelligence (AI) are making the whole process faster, more accurate, and more reliable. Modern factories use sensors to measure things like temperature, pressure, mixing speed, and humidity during production. These sensors send data to AI systems, which can spot small problems early for example, if the temperature is drifting or a machine is vibrating unusually. This is called predictive monitoring, and it helps prevent waste and delays. Process Analytical Technology (PAT) is used to check the product while it's being made, not just at the end. AI analyses this live data and can approve batches in real time (Real Time Release Testing), which saves days of waiting for lab results. Digital twins virtual copies of machines or production lines let engineers test changes on a computer before trying them in real life. AI runs these simulations to find the best settings for quality and efficiency. For quality checks, AI-powered cameras inspect tablets, capsules, and vials for cracks, chips, wrong colours, or label errors. They work faster and more accurately than humans, and they don't get tired. In sterile manufacturing, AI also monitors air quality and cleanliness to prevent contamination. Predictive maintenance uses AI to tell when a machine will need servicing, so it can be fixed before it breaks down. AI also checks raw materials from suppliers to make sure they meet quality standards before use. All this data is stored securely in the cloud, making it easy to share with other sites and with regulators. Digital records are complete and traceable, which helps with audits and compliance. The result is faster production, fewer errors, lower costs, and safer medicines. While AI can't replace skilled people, it gives them better tools to make sure every patient gets high-quality treatment.[61]

5. Supply Chain & Distribution: The pharmaceutical supply chain is the journey a medicine takes from the factory to the patient. It starts with getting raw materials, then making the medicine, storing it safely, transporting it, and finally delivering it to hospitals, pharmacies, or homes. Because medicines are sensitive some need to be kept cold, handled carefully, and tracked closely managing this process is complex. Digital tools and artificial intelligence (AI) are now making this work faster, safer, and more reliable.AI helps with demand forecasting predicting how much medicine will be needed in different places. It studies past sales, disease trends, hospital data, and even weather patterns to make accurate predictions. This prevents shortages and reduces waste from expired stock. In inventory management, AI tracks stock in real time using barcodes, RFID tags, and sensors. It can automatically reorder medicines when supplies are low and make sure older stock is used first. For medicines that need cold storage, IoT sensors monitor temperature and humidity during storage and transport. AI checks this data and sends alerts if conditions change, preventing spoilage.AI also improves delivery routes. It finds the fastest, safest paths by looking at traffic, weather, and delivery deadlines, saving time and fuel. Blockchain technology adds security by recording every step of the supply chain in a tamper-proof digital log. AI can then check this data to confirm authenticity and detect fake medicines. Digital twins virtual models of the supply chain let companies test "what-if" situations, like a factory shutdown or sudden demand spike, and find the best solutions before problems happen.AI also ensures regulatory compliance by keeping complete, accurate digital records for audits. In hospitals and pharmacies, it helps decide how much stock to keep based on patient needs and prescription trends. During emergencies, like the COVID-19 pandemic, AI helped companies quickly adjust supply chains, manage shortages, and coordinate with healthcare providers.[62]

6. Post-Marketing & Pharmacovigilance: Once a medicine is approved and sold, the job isn't over. Companies and regulators must keep checking that it stays safe when used by real patients in everyday life. This ongoing safety check is called pharmacovigilance. It's important because some side effects only appear after a drug is used by large numbers of people, or in groups not fully covered in clinical trials. Digital pharmacy tools and AI now make this process faster and more accurate. First, they help collect safety information from many places doctors' reports, patient feedback, hospital records, pharmacy systems, call centres, emails, social media, and medical journals. AI tools like natural language processing (NLP) can read free-text reports and pull-out key details such as the drug name, what happened, when it happened, and the patient's details. This saves time and reduces human error.AI can also spot duplicate reports (the same case sent in by different people) and sort cases by urgency, so serious ones are handled first. It can help check if the side effect is likely caused by the medicine by looking at timing, dose, other illnesses, and known risks. Another big use is signal detection finding patterns that might mean a new side effect is emerging. AI can scan huge safety databases, medical literature, and even social media posts to look for unusual trends. For example, if more people than expected report a certain symptom after taking a drug, AI can flag it for experts to investigate. Digital tools also help with regulatory compliance. They keep complete, accurate records of every safety report, making it easier to meet strict reporting deadlines and pass audits. AI can also prepare parts of the regular safety reports that companies must send to regulators. For patients, digital systems make it easier to report side effects through online forms, mobile apps, or chatbots. AI then organises these reports and sends confirmation back to the patient, building trust and encouraging more people to report problems.[63]

Table 4.1 Various AI and digitalised tools, Companies in pharmaceutical field

Fields	Startups/Companies	Role & Tools
1. Drug Discovery & Design	BenevolentAI, Insilico Medicine, Atomwise, Exscientia	Use AI and machine learning to scan chemical libraries, predict drug–target interactions, and design new molecules faster.
2. Pre-clinical Research	Schrödinger, Cyclica, DeepMind (AlphaFold)	Apply computational chemistry, protein structure prediction, and AI-based modelling to assess safety and efficacy before animal or human trials
3. Clinical Trials	Pfizer + IBM Watson Health, Novartis + Microsoft Azure, Medidata Solutions	Use AI to optimise trial design, predict patient recruitment, and analyse trial data in real time via cloud computing.
4.Manufacturing & Quality Control	GSK, Roche, Moderna, Siemens Healthineers	Deploy digital twins, IoT sensors, and predictive analytics to monitor production, ensure compliance, and reduce waste.
5. Supply Chain & Distribution	SAP Pharma Cloud, TraceLink, Moderna	Use blockchain, AI, and cloud platforms to track medicines, prevent counterfeiting, and optimise logistics.
6.Post-Marketing&pharmacovigilance	MedWatcher, Bayer + NLP tools, ArisGlobal	Apply natural language processing and AI to detect

		adverse drug reactions from patient records, social media, and literature.

Table 4.1 Various AI and digitalised tools Companies in made using reference [40][60][58][61][62][63]

Companies, Startups in digitalised pharmacy: Many companies and startups are now using digital technology and artificial intelligence (AI) to improve different areas of pharmacy. These organisations develop tools that help in drug discovery, manufacturing, quality control, supply chain management, and patient care. For example, AI can analyse large amounts of medical data to find new medicines faster, while digital platforms can track medicines from the factory to the pharmacy to ensure safety and prevent counterfeiting. Startups also create mobile apps, telepharmacy services, and smart dispensing systems to make healthcare more accessible. Together, these innovations make pharmacy work faster, safer, and more efficient for patients and professionals.

1. BenevolentAI: BenevolentAI is a company in the UK that uses artificial intelligence (AI) to help discover and develop new medicines more quickly. It was started in 2013 and has offices in London and research labs in Cambridge. The company's AI system studies huge amounts of scientific information such as research papers, clinical trial results, and genetic data to find links between diseases, genes, and possible drug molecules. This helps scientists choose the best drug targets and design new medicines that are more likely to work. BenevolentAI works with big pharmaceutical companies like AstraZeneca and Merck. For example, with AstraZeneca it is looking for new treatments for kidney and lung diseases, and with Merck it is working on medicines for cancer and immune system problems. The company also develops its own drugs for diseases like ulcerative colitis, brain cancer, and ALS (a serious nerve disease). By using AI, BenevolentAI can save time, reduce costs, and bring new treatments to patients faster, especially for illnesses that currently have few or no good options.[64]

2. Insilico Medicine: Insilico Medicine is a biotechnology company that uses artificial intelligence (AI) to help discover and develop new medicines faster. It was founded in 2014 by Dr. Alex Zhavoronkov and has offices in the United States, Hong Kong, and other countries. The company's main tool is an AI platform called Pharma.AI, which can study huge amounts of scientific and medical information such as genetic data, research papers, and clinical trial results to find patterns and connections that humans might miss. This AI can suggest new "targets" in the body for treating diseases, design new drug molecules from scratch, and predict how these drugs will behave in the body. Insilico is known for using generative AI (which creates new ideas or designs) and reinforcement learning (where the AI improves through trial and error) to make drug discovery more efficient. The company works on its own medicines for diseases like cancer, lung fibrosis, and ageing-related illnesses. It also partners with big pharmaceutical companies to help them find new treatments. One of its major achievements was creating a drug for idiopathic pulmonary fibrosis (a serious lung disease) using AI and moving it into clinical trials in record time. By combining biology, chemistry, and AI, Insilico Medicine aims to cut the time and cost of drug development and bring new treatments to patients more quickly.[65]

3. Atomwise: Atomwise is a company in San Francisco that uses artificial intelligence (AI) to help scientists discover new medicines more quickly. It was started in 2012 by Abraham Heifets and Izhar Wallach. The company's main technology is called AtomNet, which was the first AI system to use deep learning to predict how small drug molecules will fit and work with specific proteins in the body like finding the right key for a lock. Normally, scientists must test millions of chemical compounds in the lab to find a few that might work as medicines. This takes a lot of time and money. Atomwise's AI can do this "virtual screening" on a computer, checking billions of molecules in a short time and picking the most promising ones for lab testing. Atomwise works with pharmaceutical companies, biotech firms, and research groups all over the world. It helps them in the early stages of drug discovery, especially in finding "hits" (molecules that show potential) and improving them into "leads" (stronger candidates for development). The company also works on hard-to-treat diseases by targeting proteins that were once thought to be "undruggable. "One of its major programs, called AIMS (Artificial Intelligence Molecular Screen), has supported hundreds of research projects globally. By combining AI with modern chemistry and biology, Atomwise aims to cut the time and cost of developing new medicines and bring treatments to patients faster.[66]

4. Schrödinger: Schrödinger, Inc. is a company that makes advanced computer programs to help scientists design new medicines and materials. It was started in 1990 and is based in New York, working with pharmaceutical companies, biotech firms, and research groups all over the world. The company's main skill is computational chemistry using powerful computer models, physics, and AI to predict how molecules will behave. This means scientists can test drug ideas on a computer before making them in the lab, which saves a lot of time and money. Schrödinger's software can show how a drug molecule might fit into a target protein, how strongly it will bind, how easily it will dissolve, and how it can be improved. Some of its popular tools are Live Design, which lets research teams work together online, and PyMOL, a program used worldwide to view and study molecules in 3D. Schrödinger also uses its own technology to work on new medicines and partners with big companies like Bayer and Takeda. One well-known success was its work with Nimbus Therapeutics, which led to a drug candidate later sold to Gilead Sciences in a deal worth up to $1.2 billion. By combining accurate computer simulations with AI, Schrödinger helps speed up drug discovery, lower costs, and improve the chances of finding effective treatments. This "digital-first" approach means much of the early research happens on computers before moving to the lab.[67]

5. IBM Watson Health: IBM Watson Health was a part of IBM, started in 2015, that used artificial intelligence (AI) and cloud computing to help improve healthcare. It was based on IBM's Watson technology, which became famous for winning the quiz show Jeopardy! in 2011. In healthcare, Watson's goal was to read and understand huge amounts of medical information such as research papers, clinical guidelines, and patient records and then give doctors suggestions for diagnosis and treatment based on evidence. One of its most known projects was Watson for Oncology, made with Memorial Sloan Kettering Cancer Centre. It aimed to help cancer doctors choose treatments by comparing a patient's details with medical knowledge. Watson Health also worked on drug discovery, medical imaging, and analysing health data for large groups of patients.

However, it faced problems. Some doctors felt its advice was not always accurate because it sometimes used limited or hypothetical data instead of real patient cases. It was also hard to connect Watson smoothly with hospital systems, and the way it made decisions was not always clear to users. In 2022, IBM sold much of Watson Health to another company, but some of its technology is still used. The story of Watson Health shows both the promise and the challenges of using AI in healthcare especially the need for good-quality data, clear explanations, and close teamwork between AI systems and medical experts.[68]

6. SAP Pharma Cloud: SAP Pharmaceutical Cloud is a digital system that helps pharmaceutical companies manage all their important work in one place. It is built on SAP's cloud technology and is designed especially for the needs of the pharma industry. With this system, companies can connect different parts of their business such as research, manufacturing, quality control, supply chain, and distribution so that everyone works with the same, up to date information. It helps companies follow strict rules from agencies like the FDA and EMA by keeping accurate records, tracking every batch of medicine, and making regulatory reports easier. The system also supports Good Manufacturing Practice (GMP) and ensures that medicines are made and stored correctly. For supply chain work, it can forecast demand, track inventory in real time, and monitor cold-chain conditions for temperature-sensitive products like vaccines. It also has quality management tools to check product quality during production and quickly fix problems. Because it is cloud-based, teams in different locations such as factories, research labs, and offices can work together easily and securely. It can also connect with AI, IoT sensors, and blockchain to add features like predictive maintenance, counterfeit prevention, and automated compliance checks. Overall, SAP Pharmaceutical Cloud helps companies make medicines faster, reduce costs, improve safety, and respond quickly to changes in demand or regulations.[69]

7. Bayer + NLP tools: Bayer is a global healthcare and life sciences company that uses Natural Language Processing (NLP) a type of artificial intelligence to make its work in pharmacy and medicine faster and smarter. NLP helps computers read and understand human language, which is useful because a lot of important medical information is written as text in research papers, clinical trial reports, patient records, and regulatory documents.

Normally, going through all this information by hand takes a lot of time. Bayer's NLP tools can quickly scan millions of documents and pick out useful details, such as the name of a drug, the disease it treats, results from studies, or possible side effects. In drug discovery, NLP can search scientific literature to find information about promising compounds or disease targets, helping scientists focus on the best ideas. In clinical trials, it can read patient records to find people who match the trial's requirements, making recruitment faster and more accurate. NLP can also help detect rare side effects by scanning medical reports and patient feedback. Bayer often combines NLP with other AI tools, like knowledge graphs and machine learning, to connect related information and find patterns that humans might miss. This helps in making better decisions in research, development, and safety monitoring. By using NLP, Bayer can save time, reduce costs, improve safety, and bring new medicines to patients more quickly.[70]

Impact of AI in pharmaceutical field: Artificial Intelligence (AI) is changing the way the pharmaceutical industry works. Making a new medicine has always been slow, expensive, and risky. It can take 10–15 years and cost more than $2 billion to bring a drug from an idea to the market. Even then, most drugs fail along the way only about 12% of drugs that start clinical trials are ever approved (Tufts Centre for the Study of Drug Development). This means a lot of time and money is spent on medicines that never reach patients. AI computer systems that can learn from data, find patterns, and make predictions is now helping at every stage of the drug's life, from early research to safety checks after launch. The AI in pharmaceuticals market is growing fast. Statista (2023) says it was worth $1.5 billion in 2022 and could grow to over $9 billion by 2030, with more than 25% growth each year. This is happening because computers are more powerful, more data is available, and there is a big need for faster drug development something made clear during COVID-19, when AI helped companies like Pfizer and Moderna speed up vaccine work.[71]. One of the biggest uses of AI is in drug discovery and design. In the past, scientists had to test thousands or millions of chemical compounds in the lab to find a few that might work. This was slow and costly. AI can do virtual screening, where it checks huge chemical libraries on a computer and predicts which molecules are most likely to work on a disease target, like a protein. This can cut lab testing by more than 90%. For example, Atomwise uses its AtomNet AI to screen billions of compounds in days. AI is also used for target identification, finding new proteins or genes linked to diseases. BenevolentAI uses AI to find hidden links between diseases and possible drug targets. Another big step is de novo drug design, where AI creates brand-new molecules with the right shape and properties. Insilico Medicine used AI to design a drug for idiopathic pulmonary fibrosis and moved it into clinical trials in under 18 months a process that normally takes years AI can cut early drug discovery from 4–6 years to 1–2 years, saving money and improving success rates.[71]. After discovery, drugs go through pre-clinical research lab and animal tests to check safety and how the drug behaves in the body. AI helps by predicting toxicity (whether a drug could be harmful), modelling ADME (absorption, distribution, metabolism, and excretion), and reducing the need for animal testing. AI can compare a molecule's structure with databases of known safe and unsafe compounds, spotting risks early so scientists can redesign the drug before expensive tests. Studies show AI toxicity screening can cut pre-clinical failures by up to 30%. AI can also create in silico models computer simulations of cells, tissues, or organs to test drugs without live animals. [72]. The next stage is clinical trials, where drugs are tested in humans to confirm safety and effectiveness. This is the most expensive and time-consuming stage. AI makes trials faster and smarter. One big challenge is patient recruitment finding people who meet the trial's requirements. AI can scan health records, genetic databases, and even social media (with privacy safeguards) to find suitable candidates much faster. AI can cut recruitment time by up to 50%. AI also helps design trials by simulating different scenarios to find the best sample size, length, and goals. Adaptive trials, where the design changes based on early results, are possible because AI can analyse data in real time. During trials, AI can monitor patients remotely using wearables and apps, tracking vital signs, activity, and medication use. This reduces hospital visits and improves patient participation. AI also analyses trial data quickly, spotting patterns humans might miss, which can lead to earlier detection of side effects or signs the drug is working.[72]. Once a drug is approved, it must be manufactured in large amounts while keeping quality high. AI is a key part of Pharma 4.0 the digital transformation of manufacturing. AI can monitor production lines in real time, using sensors to track temperature, pressure, and mixing speed. If something goes wrong, AI can alert staff or adjust the process automatically this is called predictive process control. AI also does predictive maintenance, checking machine data to predict when repairs are needed, cutting downtime by up to 30%. In quality control, AI-powered cameras can inspect tablets, capsules, and vials for defects faster and more accurately than humans.[75]. The pharmaceutical supply chain is also improved by AI. This chain is complex, involving raw materials, finished products, and sensitive items like vaccines that need cold storage. AI helps with demand forecasting, inventory management, and route planning. Forecasting tools look at sales data, disease trends, and even weather to predict medicine needs, reducing shortages and waste. AI tracks stock in real time and can reorder automatically. For cold-chain products, sensors monitor storage conditions, and AI spots problems early. Route planning tools find the fastest, most efficient delivery paths, cutting costs and delays. Statista says AI forecasting can reduce stockouts by up to 50%. Even after a drug is launched, it must be monitored for safety this is called pharmacovigilance. AI improves this by collecting and analysing safety data from medical reports, patient feedback, and social media. Natural Language Processing (NLP) tools can read unstructured text in safety reports and pull-out details like the drug name, side effect, and patient age. AI can detect duplicate reports and prioritise serious cases. In signal detection, AI scans large safety databases for patterns that may show new side effects, often spotting them months earlier than traditional methods. [78]. The benefits of AI in pharmacy are clear: faster drug development, lower costs, higher success rates, better safety checks, and more personalised treatments. AI also supports precision medicine, where treatments are tailored to each patient's genetics, lifestyle, and environment, improving results and reducing side effects. But there are challenges. AI needs high-quality data, and poor data leads to poor predictions. Bias is a risk if the data is biased, the results will be too. Transparency is another issue: some AI models are "black boxes" that are hard to explain, which can be a problem for regulators. There are also privacy concerns and the need to follow strict rules like GDPR. Adding AI to existing systems can be complex and costly, and skilled staff are needed who understand both AI and pharmacy. Looking ahead, experts predict that by 2030, AI will be part of over 70% of new drug development projects. We may see fully AI-designed drugs on the market, more use of digital twins of patients for virtual testing, and AI-driven personalised medicine becoming standard. If challenges like data quality, bias, and regulation are solved, AI could make drug development faster, safer, and more effective than ever before.

Ethical issues of AI in pharmaceutical industry: new medicines, check prescriptions, manage supply chains, and even give advice to patients. But while AI can make pharmacy work faster and more accurate, it also brings ethical issues questions about what is right, fair, and safe when using this technology. One big issue is privacy and data protection. AI systems need a lot of information to work well, including patient medical records, prescription history, and sometimes genetic details. This is very sensitive data. If it is not stored securely, it could be stolen, leaked, or misused. Even if names are removed, advanced technology can sometimes identify people again.*)* In BMC Medical Ethics, more than half of pharmacy professionals worry about patient privacy and cyberattacks. Patients need to know their data is safe and used only for the right reasons. Another problem is bias and fairness. AI learns from past data. If that data is incomplete or biased for example, if it has more information about one group of people than another the AI's advice may be unfair. In pharmacy, this could mean some patients get better treatment suggestions than others.[73] Developers must check AI systems regularly to make sure they work equally well for everyone. Transparency is also important. Many AI systems are like "black boxes" they give answers, but it's hard to see how they reached them. In pharmacy, where decisions affect health, pharmacists and doctors must be able to explain why the AI gave a certain recommendation. Without this, patients may not trust the system, and it will be harder to find out who is responsible if something goes wrong.[74]. That leads to the next issue: accountability. If an AI system makes a mistake for example, suggesting the wrong dose who is to blame? Is it the company that made the AI, the pharmacist who used it, or the hospital that bought it. clear rules are needed so everyone knows who is responsible for checking and approving AI decisions. Informed consent is another key point. Patients should be told when AI is being used in their care, what it does, what data it uses, and what the risks and benefits are. This way, they can decide if they are comfortable with it. In pharmacy, this might mean telling a patient that AI helped choose their medicine or dosage. Some people also worry about job loss. AI can do tasks like checking prescriptions, spotting drug interactions, or answering simple patient questions. This could reduce the need for some pharmacy jobs. 62.9% of pharmacists said they were concerned about AI replacing non-specialist roles. The solution is to train pharmacy staff to work alongside AI, focusing on tasks that need human judgement and empathy.[73]. Regulation is another challenge. In many countries, there are no specific laws for AI in pharmacy. This makes it unclear what safety checks are needed, how to handle mistakes, or how to protect patients. suggest that governments, pharmacy experts, and AI developers should work together to create clear rules covering data protection, fairness, safety testing, and ongoing monitoring. There is also the issue of equal access. AI systems can be expensive, so big companies and rich countries may benefit more than smaller pharmacies or poorer regions. This could make healthcare inequalities worse. Ethical AI should aim to help all patients, not just those in wealthy areas.[74]. Cybersecurity is a growing risk. AI systems often connect to electronic health records, supply chain systems, and even wearable devices. If hackers break in, they could change prescriptions, disrupt medicine supply, or steal patient data. Strong security systems and regular updates are essential. Finally, there are unintended consequences. AI systems can change over time as they learn from new data. This means their behaviour might shift in ways that are hard to predict. In pharmacy, this could cause unexpected errors or changes in how care is given. Continuous human oversight is needed to make sure AI stays safe and effective. In short, AI can make pharmacy faster, more accurate, and more personalised, but it also raises important ethical questions. These include protecting privacy, avoiding bias, being transparent, deciding who is responsible, getting patient consent, protecting jobs, making fair rules, ensuring equal access, keeping systems secure, and watching for long-term risks., the best way forward is to combine AI's power with strong ethical guidelines, good training, and patient involvement. This will help AI improve pharmacy while keeping patients safe and maintaining public trust.[73]

Future trend of Automatization in pharmacy:

The pharmaceutical industry is changing fast, moving towards automation and digital technology a change often called Pharma 4.0. This means using artificial intelligence (AI), robots, smart sensors, and cloud systems to make medicines faster, safer, and at lower cost. In the future, AI will help scientists in research by quickly scanning millions of chemical structures, finding the best ones for a disease, and even creating new drug molecules. This can reduce the time needed for early drug discovery from years to just months.[71] In manufacturing, "smart factories" will replace slow batch production with continuous manufacturing, where medicines are made in a steady flow. Sensors and AI will watch every step, predict problems before they happen, and keep quality high.[75] Robots will handle dangerous chemicals, pack medicines, and do repetitive lab work, while digital twins virtual copies of factories will let engineers test changes without stopping production. The supply chain will also become smarter, with AI predicting demand, tracking stock in real time, and monitoring cold-chain conditions for vaccines so they stay safe. [76] Many startups are leading this change: Insilico Medicine (AI-designed drugs), BenevolentAI (finding new disease targets), Atomwise (deep learning for molecule–protein matching), Schrödinger (AI and physics-based drug design), Exscientia (precision medicine), Valo Health (digital twins of patients), and Yseop (automated medical reports). Digital platforms like SAP Pharmaceutical Cloud and Bayer's NLP tools are also helping companies share data in real time, follow regulations, and analyse information faster. These changes will make it possible to bring medicines to patients more quickly, reduce waste, and create treatments tailored to each person. But as the industry becomes more digital, it will need strong cybersecurity, skilled workers, and clear rules to make sure AI decisions are safe and fair.[77] Overall, the future automated pharmaceutical industry will be highly connected and AI-driven, able to deliver medicines faster and more precisely than ever before, while still needing careful management to ensure technology is used responsibly.

CONCLUSION: In the end, using artificial intelligence (AI) and digital tools is changing pharmacy in a big way. Pharmacy has grown from old methods of making medicines by hand, to factories making them in large amounts, to today's smart, connected systems. Now, computers, mobile apps, and machines help pharmacists work faster, make fewer mistakes, and give better care to patients. AI can help find new medicines, check for harmful drug combinations, design treatments for each person, and keep track of medicine safety after it is sold. These changes make healthcare safer, quicker, and more personal. Patients can get medicines more easily, even from home, and pharmacists can spend more time giving advice instead of doing only manual work. But there are also challenges. We must protect patient privacy, make sure AI is fair for everyone, follow clear rules, and keep systems safe from hackers. In the future, pharmacy will use even more automation, smart factories, and AI to make and deliver medicines faster. Still, human experts will always be needed to check decisions and care for patients. By combining technology with human skill, pharmacy can give better treatments, reach more people, and improve health for everyone. This is not just about using new machines it's about creating a connected, patient-focused healthcare system for the future**.**

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