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Review Article

Artificial Intelligence in Pharmaceutical Sciences: Transforming Drug Discovery and Health Care Delivery

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ABSTRACT

The integration of artificial intelligence (AI), particularly machine learning (ML), into medicine marks a significant breakthrough in drug discovery. AI acts as a powerful tool that bridges the gap between understanding diseases and identifying potential treatments. Traditional drug development is often costly, time-consuming, and prone to high failure rates. In recent years, however, AI has emerged as a transformative approach in the pharmaceutical industry, offering innovative solutions to these challenges. This review highlights the diverse roles of AI in drug discovery, including AI-assisted drug design, the identification of new drug candidates, and the advancement of novel AI methodologies. It examines different stages of the drug discovery process—from disease identification and diagnosis to target selection, screening, and lead discovery. AI's capacity to analyze vast datasets and detect hidden patterns plays a vital role in these stages, enhancing accuracy and efficiency in disease identification, drug development, and clinical trial management. AI is particularly important in accelerating drug development by significantly reducing both time and cost. Machine learning algorithms aid in experimental design, predicting drug metabolism and toxicity, and prioritizing lead compounds. This reduces the reliance on extensive and costly animal testing. Moreover, AI supports personalized medicine by analysing real-world patient data, enabling more effective treatments and improving patient adherence. Overall, this study provides a comprehensive overview of the recent advancements in AI and its growing impact on drug discovery.

Introduction

Natural compounds represent a wide range of bioactive chemicals with diverse structures and strong therapeutic potential, making them vital to the field of drug discovery. These compounds, derived from sources such as plants, microorganisms, and marine life, continue to inspire and contribute to the creation of innovative drugs aimed at addressing various modern health challenges [1]. Over the past 15 years, the pharmaceutical industry has seen a decline in interest in natural products, largely due to a shift toward high-throughput screening of synthetic chemical libraries. This change has been linked to a reduction in new drug approvals and the imminent expiration of patents for several major medications [2]. However, there is renewed hope in discovering novel drugs from natural products through the exploration of untapped biological resources, advanced smart screening techniques, robotic separation methods combined with structural analysis, metabolic engineering, and synthetic biology

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[3]. In the 21st century, natural products have regained their importance in drug discovery, aided by advances in high-throughput screening, genomics, and artificial intelligence (AI). These technologies have significantly enhanced the identification and development of new bioactive molecules, emphasizing the continued relevance of natural sources in pharmaceutical innovation. Traditional and ethnomedicinal knowledge has also played a key role in leading to breakthrough drug discoveries from natural sources [4]. The unique properties of medicinal plants—including their side effects—have motivated scientists to create novel small molecules. Moreover, bioactive substances from human, animal, and microbial origins have become essential assets in the drug development process. Rapid technological advances have introduced new strategies for natural product-based drug discovery, with bioinformatics and AI playing a pivotal role in driving progress [5]. AI has emerged as a transformative tool in the field, using computational power to analyze vast datasets and uncover insights beyond human reach. Techniques such as natural language processing (NLP), machine learning (ML), and deep learning (DL) each contribute distinctively to pharmaceutical research. Drug discovery is widely known to be costly, time-consuming, and often marked by failure [6]. Developing a single new drug typically spans more than ten years and costs upwards of 2.6 billion USD. Furthermore, fewer than 10% of drug candidates successfully advance from Phase I clinical trials to final approval [7]. Despite these challenges, AI has made significant strides in the last decade by enhancing various phases of drug discovery—ranging from virtual screening and de novo drug design to retrosynthesis prediction and protein engineering. These AI applications fall mainly into two categories: predictive and generative [8]. Predictive models estimate molecular properties such as bioactivity and toxicity, while generative models are designed to create new molecular structures or suggest reaction pathways. Natural products are considered "privileged structures" due to their high affinity for binding with key protein targets, making them ideal for developing both small molecule drugs and macrocyclic compounds [9]. Between the 1980s and 2010s, nearly two-thirds of new human therapeutic agents were based on natural products. Among these, about 5% were unmodified compounds sourced directly from nature (unaltered PS), 28% were NP analogues—semisynthetic or derivative molecules—and 35% were NP pharmacophores, which contain key natural product-based structural features, even if they are entirely synthetic. Scientific research supports the role of health-promoting functional food ingredients (FFIs) in maintaining and improving health [10]. As public interest in nutritional benefits grows, the nutrition sector continues to expand, largely influenced by consumer demands [11]. AI offers vast potential to enhance the discovery and annotation of FFIs by systematically identifying and analysing effective bioactive ingredients. However, many companies involved in FFI production have been slow to adopt AI, resulting in inefficiencies in ingredient research and development [12]. Integrating AI into this space could revolutionize the characterization of FFI molecules and improve the availability of targeted bioactive compounds for specific health needs [12]. The traditional process of drug discovery is highly complex and challenging, often requiring up to 15 years and costing between $1 and $2 billion for each approved drug [13]. These long timelines are largely due to high failure rates and prolonged clinical trials. Despite substantial investment, nearly 90% of drug candidates fail, even after reaching phase I clinical trials [14]. Successfully advancing a representative to phase I trials after extensive preclinical optimization is therefore considered a significant milestone for both pharmaceutical companies and academic researchers. To improve the chances of success, large-scale computer-based screening and docking techniques have been employed [15]. However, these approaches often suffer from inefficiency and limited accuracy. To overcome these challenges, artificial intelligence (AI)—particularly deep learning (DL) and machine learning (ML) algorithms—has emerged as a promising solution. Beyond drug discovery, the AI integration is also transforming

pharmaceutical supply chain management by consolidating diverse AI research efforts to address operational challenges. Recent studies further identify potential directions for developing more advanced decision-making tools in this area [6]. Additionally, the lack of innovation in clinical trial models continues to hinder progress, leading to repeated and prolonged projects [16]. Critical aspects of healthcare trials—such as patient recruitment, enrolment, monitoring, retention, and adherence to medications—require special attention. Patient enrolment is often hampered by the need to travel to trial sites, and frequent visits make re-enrolment even more difficult, adding to the overall complexity of clinical trials [17].

Role of Artificial Intelligence in Herbal Formulations

Incorporating AI into herbal medicinal compositions is a potential technique for progressing the development of natural treatments. Traditional knowledge, pharmacological characteristics, botanical components, and treatment outcomes are some of the large datasets that are being analysed more and more using AI technology [13]. Discovering the molecular processes behind herbal remedies, anticipating synergistic effects, and identifying bioactive substances are all made easier with the use of methods like natural language processing, neural networks, and machine learning. Models driven by AI also accelerate the process of drug development by allowing for more thorough testing of formulations for therapeutic efficacy, bioavailability, and safety [14]. The complex interactions between phytochemicals and biological targets can be studied, and the novel therapeutic mixes can be found more quickly by combining AI with herbal medicine. Nevertheless, further study and validation are necessary due to concenrs over the reliability of algorithms, ethical implications, and data veracity. Notwithstanding these caveats, there is significant promise for advancing individualized, evidence-based treatment through the use of AI in herbal medicine [15].

Role of Artificial Intelligence in Business

This issue highlights the effect of artificial intelligence (AI) on organizational processes and management, revealing important business implications. Research in this area discusses practices such as data-driven decision-making, process mining, and automation. AI has been utilized in the development of Decision Support Systems (DSS) for several decades (Turban, 1988), demonstrating its value in transforming raw data into actionable knowledge [18]. According to Davenport, AI benefits organizations by automating administrative, financial, and bureaucratic tasks through Robotic Process Automation (RPA), assisting managers in making informed decisions, and enhancing employee or customer engagement through human-like agents such as chatbots. Another significant business application of AI is the creation of Expert Systems (ES), which can simulate human reasoning and provide explanations for the conclusions they reach [19]. Additionally, the review emphasizes the increasing importance of process mining—using AI to detect trends, patterns, and opportunities for improving business process efficiency through the analysis of log data [20].

Role of Artificial Intelligence in Human Implications

The digitalization of human resource management (HRM) in the workplace is heavily reliant on artificial intelligence (AI), which has far-reaching effects on both processes and surroundings. It positions itself as a useful adjunct to human labour by increasing the efficacy and efficiency of operations, which in turn improves the management of time, cost, and quality of the job [19]. The use of AI for big data analysis presents more possibilities, especially for the automation of service-desk business procedures. Managers face continuous hurdles in adapting to changing technology and business environments. They should prioritize knowledge generation and the development of internal skills [20]. AI's ability to increase personal productivity while decreasing the costs of project execution has made it a widely recognized business enabler. Additionally, AI is

a helpful tool for managerial decision-making as it improves human judgment in strategic planning, action, and execution. New data-centric positions such as data scientists, data analysts, analytics developers, and big data systems engineers have emerged as a result of companies reorganizing and investing in data science and artificial intelligence (AI), which are now seen as essential activities. Ethical questions, such as how much access firms should have to personal data and how the notion of privacy is changing, are a blight on the AI industry as a whole [21].

Role of Artificial Intelligence in Industrial Applications

Managers often have difficulties in recognizing and executing the essential organizational, cultural, and technical enablers, that contribute to the under-awareness and lack of widespread adoption of AI in industrial applications. Within this framework, research has uncovered several AI-related potentials in various industries [22]. Medical research—especially in fields like neurology, cardiology, and radiology—and public health are among these, as are efforts to safeguard healthcare personnel and reduce the transmission of infectious diseases as COVID-19 [23]. Chemical and pharmaceutical companies, marketing, and the social sciences (including politics) are some of the other fields that use AI. Artificial intelligence also assists with scheduling, product creation, pricing strategies, supply chain models, and business-to-business (B2B) commerce [24]. Modern Internet of Things (IoT) devices significantly enhance AI applications by collecting data, transmitting results from AI algorithms, and integrating AI into physical items. The IIoT, which incorporates IoT technology into manufacturing processes, is where the greatest influence is felt [25]. Productivity, quality, and efficiency are all improved as a result of this integration, which also reduces costs. When integrated with AI, IIoT excels at facilitating real-time analysis and modifications to industrial plants [26].

Role of Artificial Intelligence in Social Applications

In studies focused on social applications, AI demonstrates its value in enhancing marketing research by helping to understand consumer social behaviour. Techniques such as fuzzy logic, Artificial Neural Networks (ANN), and other AI-based methods are used to manage the uncertainties that arise during the development of marketing strategies [21]. These contributions primarily aim to increase the effectiveness of marketing activities through a deeper understanding of end consumers, achieved by analysing their social interactions. AI also aids in interpreting consumer choices by generating descriptive models that can be integrated into optimization frameworks [22]. The enhanced connectivity with consumers made possible by emerging technologies strengthens the relationship between businesses and their customers, making it more meaningful and resilient. Furthermore, data serves a crucial function in enabling personalized offerings through AI-driven predictions of consumer purchasing likelihood and in supporting marketing strategies that involve sensory experiences and automation [23].

Role of Artificial Intelligence in Admission

The use of AI begins with the admissions process, as it offers valuable benefits across various aspects of life, especially in education. Many educational institutions promote admissions on their websites, and students expect efficient services, including accurate admissions information and support [24]. Today, numerous universities and colleges utilize web-based service systems to deliver necessary services to applicants or their guardians. Therefore, a key focus for technology innovators is ensuring that these systems are as user-friendly as possible [25]. Although websites are helpful in streamlining admissions, they can sometimes lead to an overload of queries and extended response times, ultimately affecting visitor satisfaction. AI has the capability to provide information and answer questions just like a human. One of the most recognized tools for this purpose is the chatbot a computer-based system that communicates with users [25]. A chatbot is

defined as "software that simulates conversation with human users using text, voice, visuals, or a combination of these methods." Many educational and commercial institutions employ chatbots to engage with visitors in a human-like manner [25]. These chatbots, or technology-driven virtual assistants, operate using either AI or pre-programmed scripts to deliver accurate admission-related information around the clock. By doing so, they not only assist users in getting timely answers, but also significantly reduce the workload on admissions staff. This study focuses specifically on the role of chatbots in the admissions process and their effectiveness in easing departmental responsibilities, rather than discussing their technical framework or algorithms [26]. In other words, chatbots function by searching a script or dataset using keyword or string similarity techniques to generate relevant responses. They also provide a web interface for both administrators and users, as well as additional helpful content for users who are unsatisfied with initial responses. Thus, the present research highlights that AI tools such as chatbots are increasingly supporting educational institutions in their recruitment processes. These tools enhance the efficiency of the admissions system while also alleviating the burden on staff handling inquiries [27].

Role of Artificial Intelligence in Marketing

Artificial Intelligence (AI) encompasses rapidly evolving technologies that can perceive, learn from, and act on data. Presently, commonly used AI types include digital assistants, chatbots, and machine learning systems [28]. AI operates in three primary modes: aided intelligence, which is widely accessible and enhances existing human and organizational activities—such as GPS systems in vehicles that adjust routes in real-time based on traffic; augmented intelligence, which is emerging and allows individuals and organizations to accomplish previously impossible tasks—like ride-sharing apps that have introduced new business models; and autonomous intelligence, which is still in development and enables machines to function independently—a key example being self-driving cars, anticipated to become mainstream in the near future [29]. With the AI market expected to reach $70 billion by 2020, its transformative potential spans consumer, enterprise, and government sectors worldwide [28]. While challenges remain, many believe AI will play a significant role in advancing medical breakthroughs, increasing access to expensive services, improving customer support, and reducing the burden on the workforce. Technology enthusiasts are optimistic that AI will enhance human capabilities by improving how we process, analyse, and interpret the vast data in the surrounding area [30]. This advancement could free up time for humans to engage in strategic thinking, creativity, and high-level decision-making. Moving toward an AI-driven future, understanding public perception, the technology's transformative power, and the ethical principles required to manage this shift is essential [30]. Already, real-world AI applications have shown that early-adopting companies experience notable improvements in customer satisfaction and retention, which translates to increased revenues. This clearly indicates that adopting AI can significantly enhance marketing performance and overall profitability. However, in India, AI adoption remains relatively slower than in many other countries, except in certain sectors such as BFSI (Banking, Financial Services, and Insurance) [31]. This industry has seen rapid AI integration in recent years and is likely to continue growing. For instance, Indian banks such as ICICI have used AI to reduce turnaround times for resolving disputed transactions by up to 80%. Many of these AI innovations in BFSI can also be effectively applied to industries such as retail, telecom, and media/entertainment to boost marketing efficiency and support broader business transformation [28]. AI role in different fields for drug developments are shown in Figure 1.

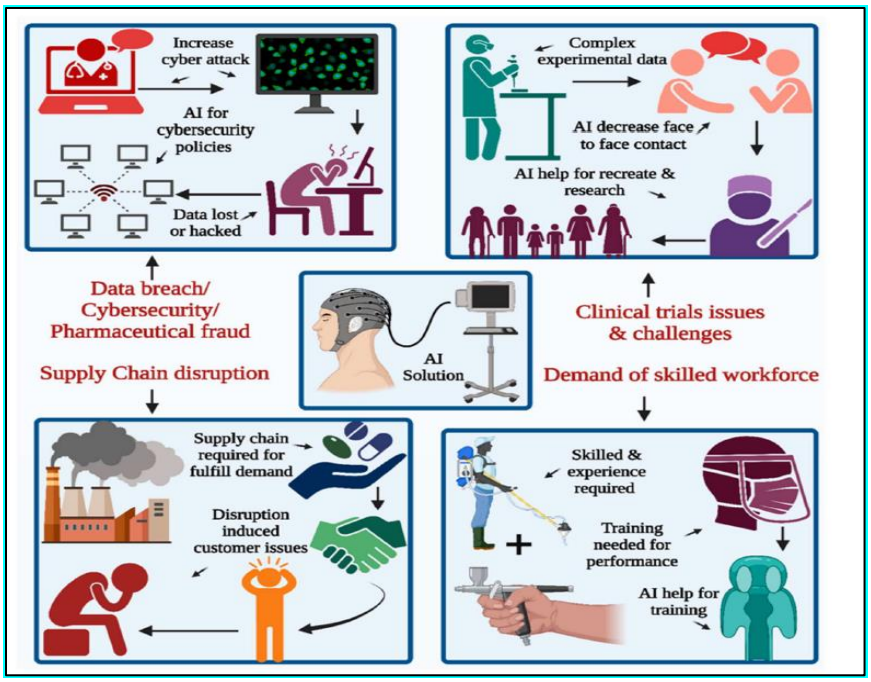


Figure 1: AI role in different fields for drug developments [106]

Role of AI in Retail and Online Shopping

The retail and e-commerce industries are perhaps the most visible arenas where the general public can observe the use of AI. In this highly competitive landscape, retail businesses are continually seeking ways to identify patterns in consumer behaviour to better align their strategies and gain an edge over competitors [32]. It is fair to say that AI has truly found its niche in this domain. For instance, the product recommendations you receive on your Amazon account are generated by sophisticated AI algorithms that work in real time to predict the items you are most likely to purchase. Moreover, AI is increasingly being utilized to enhance the overall customer experience [28]. One notable example is the widespread use of AI-powered chatbots on e-commerce platforms, which are designed to provide instant responses to a broad range of common customer inquiries. These applications play a key role in improving customer satisfaction by delivering timely and relevant support, thereby streamlining interactions between users and the platform [33].

Role of AI in food Science

Artificial Intelligence (AI) has proven valuable in the field of nutritional science and the food industry. Imagine having a robot prepare your tea—this concept has become a reality. Culinary technology company Hi Arya, in collaboration with Leeway Hertz, has developed a robotic tea maker using AI and IoT [34]. This smart tea maker can be operated through a web interface, smartphone application, or the physical device itself, enabling users to customize their tea blends. Customers can place their orders via the machine, app, or website, and the device begins preparing the tea immediately. Through a live-feed feature, users can even watch the tea being made in real time [35]. AI has also made significant inroads into commercial food processing. For instance, Tomra Systems has implemented AI technologies in processing peeled potatoes, French fries, and various cuts of meat. These advancements help streamline operations, improve efficiency, and ensure consistent quality in food production [36-41].

Applications of Artificial Intelligence

AI in Astronomy

When it comes to tackling difficult challenges about the cosmos, artificial intelligence is

invaluable. Among other things, it can provide insight into the universe's beginnings and how it works now [42].

AI in Healthcare

Artificial intelligence (AI) has been increasingly useful in healthcare over the last five to ten years and is poised to have a profound effect in the near future. Artificial intelligence is helping doctors make better, quicker diagnoses than humans [43]. Furthermore, it aids medical professionals by revealing when a patient's health is worsening, allowing for prompt medical action before the need for hospitalization [44].

AI in Gaming

AI has applications in the gaming industry. Artificial intelligence systems can play chess and other strategic games, where the computer must weigh a huge number of moves [45].

AI in Finance

Artificial intelligence and the financial sector are very complementary. The financial industry is integrating AI, chatbots, algorithmic trading, machine learning, and automation into its operations [46].

AI in Data Security

With the proliferation of cyberattacks, data security has become an absolute must for all businesses operating in the modern day. Data security and safety may be improved with the aid of AI. Examples of tools that can identify software defects and cyberattacks better include the AI2 Platform and the AEG bot [47].

AI in Social Media

Artificial intelligence (AI) for social media: Twitter, Snapchat, and Facebook are just a few of the many platforms that collect and handle billions of user profiles. When dealing with massive volumes of data, AI is a lifesaver. Current trends, popular hashtags, and user demands may be discovered by analysing massive databases [48].

AI in Travel and Transport

The need for AI in the transportation sector is growing rapidly. It is capable of proposing hotels, airlines, and the most efficient routes to clients, as well as performing other travel-related duties [49]. Chatbots powered by artificial intelligence are also being used by travel businesses to provide faster and more efficient responses to consumers in a human-like way [50].

AI in Automotive Industry

The use of artificial intelligence (AI) by some automobile companies to provide virtual assistants for better user experience is on the rise. As an example, the Tesla Bot is an AI virtual assistant that Tesla has just released. A number of businesses are also putting effort into creating autonomous vehicles with the goal of making transportation safer and more secure [51].

AI in Robotics

When it comes to robotics, artificial intelligence (AI) is crucial. While most robots are designed to carry out certain, predetermined duties, artificial intelligence has opened the door to the development of smart robots [52] that can learn from their own experiences and apply that knowledge to new situations. As an illustration of the use of AI in robotics, consider humanoid robots. Erica and Sophia are just two examples of the recently created intelligent humanoid robots that can mimic human speech and behaviour [53].

AI in Agriculture

For optimal outcomes, agriculture demands a great deal of time, energy, money, and resources. There has been an uptick in the use of artificial intelligence (AI) in the agricultural industry recently [54]. Agriculture is making use of artificial intelligence through the employment of agricultural robots, predictive

analysis, and soil and crop monitoring. There are several ways in which farmers might profit from using AI in agriculture [55].

AI in E-Commerce

AI is boosting online retailers' competitiveness and demand for their services. By suggesting items based on criteria such as size, colour, or brand, it aids consumers in discovering complementary products [56].

AI in Education

As a result of AI's capability to automate grading, instructors will have more time to concentrate on actually teaching. By conversing with students, AI chatbots may assist teachers. Artificial intelligence has the potential to one day function as a student's own virtual instructor, available at any time and from any location [57].

Some Other Applications

1. Fraud detection: The financial services industry uses artificial intelligence in two ways. Initial scoring of applications for credit uses AI to understand creditworthiness. More advanced AI engines are employed to monitor and detect fraudulent payment card transactions in real time [41].
2. Virtual customer assistance (VCA): Call centres use VCA to predict and respond to customer inquiries outside of human interaction. Voice recognition, coupled with simulated human dialogue, is the first point of interaction in a customer service inquiry. Higher-level inquiries are redirected to a human [42].
3. Medicine: A medical clinic can use AI systems to organize bed schedules, make staff rotations, and provide medical information. AI also has applications in fields of cardiology (CRG), neurology (MRI), embryology (sonography), complex operations on internal organs, etc. [43].
4. Heavy Industries: Huge machines involve risks in their manual maintenance and operation. Thus, in becomes necessary part to have an efficient and safe operational agent in their operation.
5. Telecommunications: Many telecommunications companies utilize heuristic search in the management of their workforces for example BT Group has deployed heuristic search in a scheduling application that provides the work schedules of 20,000 engineers [44].
6. Music: Scientists are attempting to make the computers emulate the activities of the skilled musicians. Composition, performance, music theory, sound processing are some of the major areas on which research in music and AI in focused; for example, chucks, Orchextra, smart music, etc. [45].
7. Antivirus: Artificial intelligence (AI) techniques have played increasingly important role in antivirus detection. At present, some principal artificial intelligence techniques applied in antivirus detection [46]. It improves the performance of antivirus detection systems, and promotes the production of new artificial intelligence algorithm and the application in antivirus detection to integrate antivirus detection with artificial intelligence [47].
8. Deep Learning in Medicine: The use of AI in medical imaging has been proposed to enhance accuracy, consistency, and efficiency in reporting. In 2017, Arterys became the first FDA-approved clinical cloud-based deep learning (DL) application in healthcare [48]. Its initial product, Cardio AI, could analyze cardiac MRI scans within seconds, delivering details such as cardiac ejection fraction. Since then, the application has expanded to cover liver and lung imaging, chest and musculoskeletal X-rays, as well as non-contrast head CT scans [49].
9. AI in Gastroenterology: Over the last decade, the use of AI in gastroenterology has grown significantly. Computer-assisted diagnosis can be integrated with colonoscopy to enhance the detection and distinction between benign and malignant colon polyps [50]. Additionally, by utilizing the endoscopic ultrasound platform, AI has been employed to assist in differentiating chronic pancreatitis from pancreatic cancer, which is a frequent clinical challenge [51].
10. AI-Assisted Endoscopy: Artificial intelligence-assisted endoscopy is an exciting new area of study. In its early stages, CAD was primarily employed for the detection, differentiation, and

characterization of colon polyps, both cancerous and non-neoplastic. Recent research involving 1,058 patients found that CAD significantly improved adenoma detection rates (ADR) compared to standard colonoscopy (29% vs. 20%, p<0.001), and it also showed higher detection rates of diminutive adenomas (185 vs 102, p<0.001) and hyperplastic polyps (114 vs. 52, p<0.001) [58]. When it came to identifying large adenomas, however, there was no discernible difference. Using CAD models of images and videos recorded from narrow-band imaging (NBI), chromoendoscopy, and endocytosis, many research groups have investigated optical biopsy of colorectal polyps [59]. Diagnostic accuracies between 84.5 and 98.5 percent have been shown by these models. Furthermore, a convolutional neural network (CNN) was trained to evaluate the invasiveness of colorectal mass lesions that were suspected of being malignant, achieving a diagnostic accuracy of 81.2% [60].

Table 1: Applications of artificial intelligent with different benefits

Name of the Application	Feature	Case Example	Benefits Obtained	Ref.
Saffron	Customer support forecasting	USAA tested it to enhance customer service by accurately predicting how a specific consumer might contact them in the future.	The accuracy of their predictions increased from 50% to 88%.	[37]
Albert	Marketing automation	Harley Davidson used Albert to centralize and automate their online marketing efforts, from planning through execution.	Dealership leads increased 29-fold within three months.	[38]
Conversica	Software for automated sales assistants that ranks leads	CenturyLink, a telecom company, used this program to reach out to, engage with, qualify, and follow up with leads through two-way email communication.	CenturyLink saw a return of $20 for every dollar invested.	[39]
Wordsmith	Generating content	Yahoo uses Wordsmith, an NLG tool, to help convert their fantasy football data into detailed match previews, recaps, and reports.	Yahoo increased audience engagement by over 100% through its collaboration with Wordsmith.	[40]
Centiment	Semantics in social context	Euler Hermes used Centiment to gain deeper insights into customer perceptions of their product and brand."	The projected conversion rate for Euler Hermes' incoming leads increased by 38.1%, reaching 51.98.	[41]

Artificial Intelligence in Cardiology: Current Applications

Atrial Fibrillation

Detecting atrial fibrillation at an early stage was one of the first medical uses of artificial intelligence. Kardia, developed by AliveCor and approved by the FDA in 2014, is a smartphone app that can identify atrial fibrillation and allow for electrocardiogram monitoring. A new study, REHEARSE-AF, found that mobile individuals might be better detected with remote ECG monitoring using Kardia than with usual treatment for atrial fibrillation [61]. Additionally, the Apple Watch Series 4 was cleared by the FDA. It allows for easy ECG capture and atrial fibrillation diagnosis, and the data can be communicated with the selected healthcare professional via smartphone. While

wearable and portable ECG devices have their advocates, others have voiced concerns about their limitations, such as the possibility of motion artifacts leading to false positive readings and the difficulty in reaching older patients, who are at increased risk for atrial fibrillation [62].

Danger to Heart and Lungs

Artificial intelligence (AI) applied to electronic patient data has outperformed conventional scoring systems in predicting the likelihood of cardiovascular illnesses, including acute coronary syndrome and heart failure. New meta-analyses, however, have shown that study sample size does affect reliability [52].

Medicine for the Airways

According to reports, one area where artificial intelligence (AI) might be useful in pulmonary medicine is in the interpretation of pulmonary function testing. In the context of interpreting findings from pulmonary function tests, recent research detailed how AI-based software offers more accurate interpretations and functions as a decision support tool [61]. Among the many criticisms leveled at the research was the fact that its pulmonologists had a much lower rate of correct diagnoses than the national norm [63].

Endocrinology

Diabetic patients may receive valuable information about the direction and pace of change in their blood glucose levels with continuous glucose monitoring, which provides them with real-time interstitial glucose measurements. The Guardian system, a glucose monitoring device that connects with smartphones, was approved by the Food and Drug Administration by Medtronic [64]. Together with Watson, IBM's AI system, the business created Sugar.IQ in 2018 to help customers prevent hypoglycemic episodes through continuous monitoring and repeated measurements. Patients may improve their glucose management and lessen the social stigma of hypoglycemic episodes through continuous blood glucose monitoring. While patients did trust the alerts, they also felt like failures when they couldn't control their glucose levels, according to research on patient experiences with glucose monitoring [65].

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Dialysis

Nephrology clinical practice has utilized AI in a number of different ways. For instance, it has been shown to be helpful in determining the likelihood of developing IgA nephropathy and anticipating the decrease in glomerular

filtration rate in individuals with polycystic kidney disease. Nevertheless, as pointed out in a recent study, the small sample sizes needed to draw valid conclusions are limiting current research [68].

Digestive Health

Numerous artificial intelligence (AI) therapeutic applications are advantageous to the gastroenterology area. By analysing endoscopy and ultrasound images using convolutional neural networks and other deep learning models, gastroenterologists have been able to spot abnormal structures such as colonic polyps [69]. The use of artificial neural networks has expanded beyond its original applications to include the diagnosis of atrophic gastritis and gastroesophageal reflux disease, as well as the prediction of gastrointestinal bleeding outcomes, the survival rate of esophageal cancer, IBD, colorectal cancer metastasis, and esophageal squamous cell carcinoma.

Neurology

Epilepsy

As a kind of ongoing ambulatory monitoring, intelligent seizure detection systems show great promise for improving seizure treatment. With the help of electrodermal sensors, Empatica's wearable device Embrace was approved by the FDA in 2018. This device can identify generalized epilepsy seizures and send a signal to a mobile app that notifies trusted doctors and loved ones, giving them more details about the patient's whereabouts. Among other things, a study that patients with epilepsy showed a high level of interest in and no hurdles to utilizing wearables for seizure detection, in contrast to those for heart monitoring [53].

Gait, Posture, and Tremor Assessment

To objectively evaluate posture, tremor, gait, and MS, PD, and HD, wearable sensors have been shown to be a useful tools [54].

Cancer Diagnosis via Computational Methods in Histopathology

The FDA has recognized Paige.ai as a breakthrough company due to its AI-powered algorithm. This system can efficiently identify cancer in computational histopathology, freeing up pathologists to focus on the most important slides while saving time [70].

Medical Imaging and Validation of AI-Based Technologies

Deep learning algorithms and radiologists were pitted against one another in an eagerly anticipated meta-analysis of imaging-based diagnosis. The scientists pointed out that 99% of the papers they examined did not have a trustworthy design, even though deep learning seemed to be just as good as radiologists for diagnostics [71]. Additionally, only 1% of the articles that were evaluated actually tested the algorithms on medical images from various demographics to confirm their findings. These results emphasize the need for conducting thorough clinical studies to validate AI-based solutions [72].

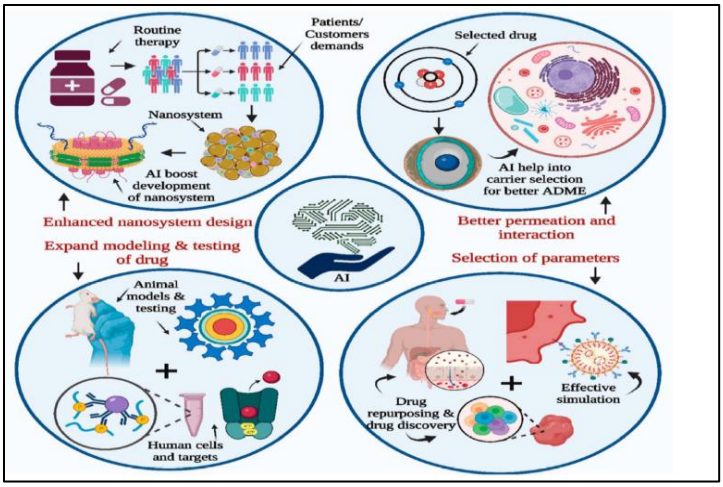


Figure 2: AI process involvement in drug developments [73]

Validation of AI-Based Technologies: Toward a Replication Crisis?

In the coming years, clinical validation of the newly created fundamental ideas and tools will be a significant obstacle for AI applications in medicine. Despite the fact that many studies have shown AI's promise and presented prospects based on encouraging results, confirmation of these findings is likely to be impeded by several well-known and often-cited limitations of AI research (Figure 2) [73,74]. Then, over three of these restrictions are discussed and some suggestions are provided on how to overcome them. To begin, the majority of research comparing AI and human doctors' abilities has flawed designs and never uses primary replication, which means they don't test their algorithms on data that isn't originally utilized for training. In the age of open science, where open data and open procedures are being advocated as best practices in research, this difficulty might be lessened [75,76]. Nevertheless, medical AI businesses whose main focus is software development may find the shift to open science quite challenging Second, low sample sizes and retrospective methods are common in research on AI's therapeutic applications. Overfitting occurs when models are trained to perform well on one dataset but not on another due to selection and spectrum bias introduced by these designs [77,78]. After implementing algorithms that may be overfitting, it is crucial to continually re-evaluate and calibrate them to ensure the software can adjust to different patient demographics. Furthermore, there is growing agreement on the need for creating algorithms that are suitable for larger populations while still considering specific subgroups into account [79,80]. Third, there has been a lack of research comparing AI and doctors using the same datasets. Even in those studies, there have been critiques about the diagnostic accuracy of specialized physicians being lower than predicted. Despite how often it appears in scientific articles, comparing AI to doctors may not be the best way to gauge their level of competence in the field. A number of recent studies have shown that when humans and AI work collaborate, they achieve greater results than when they work alone [81,82].

Ethical Implications of Ongoing Monitoring

With a projected market value of close to one trillion dollars in 2019, the medical technology industry is one of the most exciting sectors of the modern economy. Although younger people are not the main target market, a rising portion of this income comes from the sale of medical equipment (such as cardiac monitoring devices) to this demographic. This is because atrial fibrillation is less frequent in this age group [83,84]. The Internet of Things (IoT) is changing the way people think about health and wellness in response to this trend [85,86]. This is because it brings together the concept of the quantified self, which refers to personal health indicators kept on smartphones or wearables,

with a variety of lifestyle parameters offered by wearable devices, such as activity monitoring, weight control, and more. In order to distribute their goods on a massive scale, a number of wearable firms have recently inked big deals with governments or insurance companies. Changes in lifestyle among large populations are the primary goal of these efforts [87,88]. Ethical concerns about constant medical monitoring via IoT devices are becoming more prominent as Western nations move toward health systems that prioritize individual accountability for health and wellness. Constant surveillance and the risk of privacy breaches, for instance, might make those with chronic illnesses or low socioeconomic status even more stigmatized, and those who cannot conform to the new healthy living standards could be punished, for instance, by having less access to health insurance or treatment. Regardless, health policy conversations have given these essential concerns very little consideration [89,90]. Data ownership and protection have been hotly debated subjects for over twenty years, but their significance within this technopolitical context is growing. While some have argued that patients should have joint ownership of their data to facilitate tailored therapy, the current trend in the research is in favour of patients having exclusive ownership of their data. Research shows that this method increases patient involvement, and it has the potential to boost information sharing if a data usage agreement is in place between patients and doctors [83,91,92].

The Need to Educate Augmented Doctors

To meet the increasing demand for programs that train doctors and engineers to address the challenges that AI will bring to healthcare, some schools have started to revamp their medical curricula. Computational science, algorithmics, coding, and mechatronic engineering are all a part of these curricula, which also emphasize on a solid grounding in mathematical and physical sciences [84,93,94]. These "augmented doctors" would be able to teach patients and other medical professionals, manage the digital transition, solve contemporary health problems, and shape healthcare organizations' digital strategies [85,95,96]. They would also possess clinical experience. These experts might be a boon to healthcare organizations and the general public by serving as a check on medical AI procedures and a catalyst for new ideas and discoveries. To keep up with the ever-changing field of digital medicine, it is necessary to provide continuing education programs for practicing doctors, in addition to basic medical education [86,97,98]. This kind of specialist is often known as the Chief Medical Information Officer (CMIO) at state-of-the-art hospitals around the world [87,99,100].

Future of AI

We can put our trust in artificial intelligence because of its many useful characteristics and uses. Considering how fast AI is progressing, one may question whether the world of the future is becoming more and more artificial. The paradigm of non-biological computing and intelligence is growing at an exponential pace, whereas biological intelligence remains the same since it is an ancient and mature paradigm [88,101]. It is estimated that the human brain can store around 10 billion binary digits. The majority of this space, meanwhile, is likely used for wasteful purposes like storing visual impressions. Thus, due to the finite and unpredictable nature of natural intellect, computers may become more indispensable in the future. The advent of artificial intelligence (AI) has been a watershed moment in the history of computing, and it will undoubtedly play an important role in the software of the future. The number 104 There is a danger and an opportunity in this new development. Cyber operations, whether defensive or offensive, will benefit from AI. Additionally, new forms of cyberattacks targeting AI are anticipated to surface in the near future. A re-evaluation of data security measures is necessary since AI relies on massive volumes of training data, which in turn increases the importance of data. To guarantee that this revolutionary technology brings about extensive security and wealth, it will be essential to have a global government that is both deliberate and efficient [89,102].

Conclusion

Up to this point, we have had a brief discussion on artificial intelligence, covering topics such as its fundamental principles, wide-ranging applications, and significant accomplishments. The primary objective of the scientists and institutions working in the field of artificial intelligence is to solve problems and complete tasks that are beyond human capabilities. Undoubtedly, the world will undergo a significant transformation due to the achievements that have been made in this particular field of computer science. To advance this field, it is now the responsibility of the most talented engineers available.

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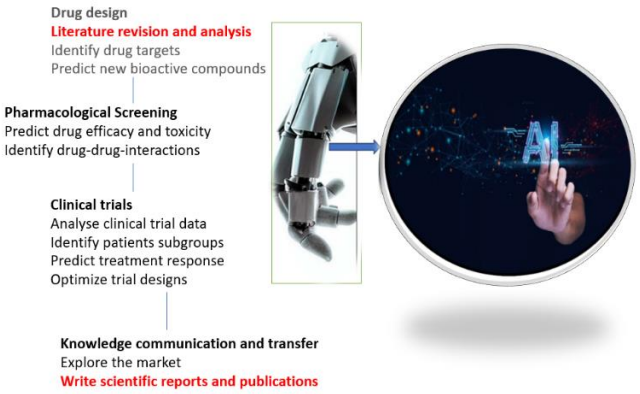
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