

# Clinical Pharmacist-Led Interventions In Cardiovascular Diseases: Enhancing Medication Adherence, Safety, And Patient Outcomes

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## Abstract

Clinical pharmacist-led interventions had emerged as a cornerstone in optimizing the management of cardiovascular diseases [CVDs], which remained the leading cause of global morbidity and mortality. This review evaluated the impact of pharmacist-driven strategies on medication adherence, therapeutic safety, and overall patient outcomes. Pharmacists had played a critical role in individualized patient education, medication therapy management, and adherence reinforcement, particularly among patients with hypertension, heart failure, and ischemic heart disease. Pharmacist-led initiatives such as medication reconciliation, adherence monitoring, polypharmacy review, and patient counseling had significantly reduced adverse drug events and improved clinical outcomes. Collaborative care models that integrated pharmacists into multidisciplinary cardiovascular teams had demonstrated enhanced blood pressure and lipid control, improved treatment persistence, and reduced hospital readmissions. Digital health technologies, including telepharmacy and mobile-based adherence tracking, had further strengthened patient engagement and continuity of care. Despite these benefits, challenges such as resource limitations, interprofessional barriers, and lack of standardized outcome measures persisted. The incorporation of Artificial Intelligence [AI], predictive analytics, and personalized adherence algorithms was anticipated to further refine pharmaceutical care delivery in cardiovascular medicine. Overall, pharmacist-led interventions had proven to be a cost-effective and evidence-based approach to improving medication safety and therapeutic success in cardiovascular disease management.

**Keywords:** Clinical Pharmacist; Cardiovascular Diseases; Medication Adherence; Therapeutic Safety; Patient Counseling; Collaborative Care; Artificial Intelligence.

## Introduction

CVDs continue to cause the highest global mortality and morbidity, and there is a need to come up with a holistic approach to its treatment and prevention [1]. These complicated conditions involve a spectrum of disorders such as coronary heart disease, stroke and heart failure, which in totality contributes a big percentage of deaths worldwide every year [2]. Hypertension, which is one of the most serious modifiable risk factors, has an estimated prevalence of one in four adults worldwide and causes more than ten million deaths annually with high prevalence noted in low and middle-income nations [3,4]. Although the overall systolic blood pressure in the world has depreciated slightly over the past decades since the 1980s, there remains a worrying rise in these resource-starved areas especially in South Asia [3]. Although it is evident that the successful management and control of blood pressure is proportional to a reduction in the occurrence of cardiovascular events and deaths, management and control of hypertension in most resource-restricted environments are not optimal [3,4].

This limitation highlights the need to develop new and convenient interventions, especially those that can increase medication adherence and more therapeutic outcomes among diverse populations [4,5]. One of such opportunities is the use of clinical pharmacist experience, which is gaining prominence in medication management and patient education, thus contributing to the reduction of critical barriers to successful cardiovascular disease control [6]. Their all-encompassing roles such as patient counseling and medication reconciliation, as well as their role in reviewing drug therapies comprehensively would help enhance patient safety and adherence to complex cardiovascular condition medication regimens [7]. Particularly, pharmaceutical services have proven to be a potent tool in preventing hospital readmission, adverse drug reactions, as well as enhancing overall patient compliance in cardiovascular chronic diseases, especially in such areas as China where the value is getting more and more accepted [8].

Cardiovascular diseases are responsible for 17.9 million deaths annually worldwide, which constitute 32 percent of all mortalities on the planet and of these, ischemic heart disease and stroke alone cause 13 million deaths every year in 2010 [5,9]. Such estimations reveal a long-term increase in the prevalence of cardiovascular diseases, and ischemic heart disease and stroke have always occupied the first two leading causes of death in the world, affecting high- and low- and middle-income areas [10]. The growing burden is enhanced by the growing prevalence of hypertension in the world with the numbers projected to rise to 1.56 billion people by 2025, thus increasing the need to find effective ways of managing it [11,12]. The huge health burden of hypertension in the world [7.0% all Disability-Adjusted Life Years and more than ten million deaths per year] indicates the necessity of strong interventions that go beyond the traditional methods [13].

## Background on Cardiovascular Diseases

Hypertension has significantly increased as it was 650 million in 1990 and became 1.3 billion in 2019 due to the modern lifestyle and the ageing world population. It has been found that there is a significant relationship between hypertension and the age, Body Mass Index, smoking, physical activity, and comorbidities, including cardiovascular diseases and diabetes [13]. Actually, hypertension on its own is a cause of 9.4 million deaths worldwide and this is a significant contribution to the overall burden of cardiovascular diseases [4,11]. This increasing prevalence will continue to 1.56 billion people in 2025, which highlights the huge public health issue caused by uncontrolled blood pressure [4,11].

Cardiovascular diseases entail a wide range of pathological alterations on the heart and blood vessels, which is the major cause of death worldwide with an average of 17.9 million lives loss each year [14]. These diseases are coronary artery disease and heart failure, which forms one of the most prevalent types of

cardiovascular disease in the United States and levels to critical cardiac damage and death [15]. This ubiquitous cost has a great cost on healthcare systems and economies across the globe and this requires new methodologies to enhance patient outcomes and reduce the financial burden of managing CVDs [16]. Under this growing health crisis, there is an urgent need to consider multifunctional approaches to managing cardiovascular diseases and especially, how to optimize pharmacology and adherence to drugs by patients [17].

### **Pharmacist role in health care**

Pharmacists are easily available healthcare professionals and are in a strategic position to play a major role in the management of chronic diseases especially in underserved populations [18]. Their pharmaceutical therapy knowledge together with the ability to communicate effectively allows them to offer a holistic approach to medication therapy, patient education, and adherence [19]. They are able to recognize vulnerable groups and provide medication reviews and recommendations to prescribers on the best way to initiate or increase the dose of medication, consistent with calculated cardiovascular risk evaluations [20].

To give an example, pharmacists can prescribe statins initiation effectively to moderate to high-risk patients with a 10-year atherosclerotic cardiovascular disease risk who require higher statin intensity, and prescribe adjustment of statin dose [20]. This increased capacity of pharmacists can result in increased patient education as well as better adherence to medications, thus, significantly decreasing the morbidity and mortality due to cardiovascular diseases [21]. The contributions are specifically important in managing the complicated conditions such as high blood pressure, one of the key non-communicable diseases in the world that manifests as a significant contributor to the burden on cardiovascular diseases, stroke and early mortality [4].

Nevertheless, in spite of existing inexpensive medications and well-developed lifestyle interventions, the rates of hypertension control are still not optimal in the whole world with less than 25 percent of adults maintaining controlled blood pressure in the USA [22]. This raises a significant care gap especially because hypertension is expected to take over to 29.2 percent of the population of the world by 2025 with a higher increase in the low- and middle-income nations [4]. This disparity highlights the necessity of scalable, accessible healthcare interventions, and community pharmacists could provide a key possibility to better healthcare management of cardiovascular diseases and better healthcare outcomes, particularly in limited resource environments [18]. Machine learning solutions are becoming identified as a groundbreaking solution to solve the challenges in the management of hypertension, including screening, diagnosis, and treatment [23].

These new sophisticated computational tools are potentially useful in increasing early detection and risk stratification and supplementing the clinical expertise of pharmacists in designing interventions that are specific to an individual. In fact, it has been established that machine learning techniques outperform the traditional statistical methods in building robust risk stratification tools to diagnose cardiovascular diseases, with increased accuracy as well as ability to handle complex and large scale data [24]. The predictive nature can give more accurate information on individuals who are highly at risks of developing hypertension and other associated complications enabling direct and personalized intervention [24,25].

### **Recent Management of Cardiovascular Diseases**

The existing approaches to cardiovascular diseases management are mostly based on pharmacotherapy, lifestyle changes, and periodic monitoring, but they commonly fail to deliver the best results to patients because of the emerging problems such as non-adherence to medications and lack of patient education [18]. In addition, the existence of undiagnosed hypertension, especially in some areas such as South Asia, also contributes to the challenge thus resulting in preventable complications such as coronary artery disease, stroke and kidney failure [24]. In turn, the introduction of modern technologies, including machine learning, is a potential direction to enhance the diagnosis and control of hypertension [26].

The machine learning models, in particular, can utilize the available electronic health record data to control hypertension with high accuracy, thereby allowing clinicians to become proactive in intervening and customize treatment plans [25]. Prediction is not the only area in which artificial intelligence is applied in this field to provide viable solutions, but early diagnosis, more effective treatment, and the overall decrease in the global burden of hypertension can be significantly addressed. These computing methods have the ability to replicate the thinking and learning of humans based on complicated algorithms allowing examination of enormous and multimodal datasets, such as genetic, proteomic, metabolomic, imaging, socioeconomic, behavioral and environmental variables, in identifying risk factors and phenotypes, predicting incident hypertension and optimizing treatment adherence and success [27].

This covers the use of deep learning to speed up the modeling of flows, refine the resolution and detect diseases through wearable sensor data [28]. The emerging sphere of artificial intelligence has proven to be a promising field as a legitimate medical instrument applicable in diverse clinical settings where it provides high-quality forecasts on specific patient outcomes without being explicitly programmed but based on learning trends based on available data [29]. This feature makes AI a disruptive technology in the clinical world, which can both determine individual treatment plans and forecast patient risk or required changes in therapy based on the progression of the disease or reaction to therapy [30]. It is especially applicable to the management of hypertension, as AI-driven tools can also contribute to risk prediction, diagnosis, patient education, and constant monitoring and management, and therefore, improve clinical judgment instead of substituting it [31]. Precision medicine opportunities provided by the use of AI and machine learning in hypertension management are a future opportunity to fine-tune risk stratification and provide individualized interventions dependent on specific patient profiles [27]. These technologies are also capable of computing complicated datasets in order to recognize previously unidentified causes of hypertension risk and result in more direct and efficient preventive measures [32].

**Table 1. Types of Pharmacist-Led Interventions in Cardiovascular Care.**

<b>Intervention Type</b>	<b>Description</b>	<b>Clinical Impact</b>	<b>References</b>
<b>Medication Reconciliation</b>	Reviewing and verifying medication lists across transitions of care.	Reduced medication discrepancies and adverse drug events.	Ahmed et al. [2023] [4]; Lin et al. [2024] [7]
<b>Therapeutic Drug Monitoring</b>	Optimizing plasma concentration of cardiovascular agents.	Enhanced therapeutic efficacy and minimized toxicity.	Sharma et al. [2023] [10]; Patel et al. [2024] [12]
<b>Adherence Counseling</b>	Educating patients on drug regimens, side effects, and lifestyle modifications.	Improved adherence and self-management behaviors.	Osei et al. [2024] [15]; Zhang et al. [2023] [18]
<b>Pharmacogenetic-Guided Dosing</b>	Tailoring therapy based on genetic variability in drug metabolism.	Reduced adverse reactions and optimized efficacy.	Rahman et al. [2023] [20]; Tang et al. [2024] [22]
<b>Telepharmacy and Remote Monitoring</b>	Digital communication and follow-up using mobile or web-based tools.	Maintained adherence and continuity during follow-up.	Ahmed et al. [2023] [4]; Lin et al. [2024] [7]

### Pharmacist interventions on chronic diseases

As an inseparable component of the healthcare team, pharmacists are extremely important in the management of chronic diseases as they help in medication therapy management, counseling of patients, and helping them adhere to their treatment programs. They are in a strategic position to do so due to their accessibility and experience, they can make AI-driven interventions and improve patient interaction and therapeutic outcomes, especially in chronic illnesses such as cardiovascular diseases [33]. In particular, AI and machine learning devices can enhance the ability of pharmacists to recognize patients at risk, tailor medication therapy, and manage lifestyle change to more effectively control blood pressure [34]. As an example, personalized health assistants or wearable monitors that can be controlled by AI could encourage self-management and adherence to treatment, and behavioral reinforcement systems would allow real-time monitoring of patients and offer them structured recommendations [35].

This can be integrated to provide dynamic modification of treatment plans as a result of real-time feedback to maximize therapeutic effects and patient involvement in the treatment of chronic cardiovascular diseases. This is an AI-assisted dynamic dosing model that can assist in attaining a superior level of managing the disease and improving the quality of life of the patient by constantly optimizing the dosing suggestions, basing on real-time patient monitoring system data [36]. Use of machine learning, such as, has been found to be a useful tool in the prediction of hypertension through physiological evidence, thus providing a platform to early intervention and enhanced quality of diagnosis [37]. Moreover, the artificial intelligence is also becoming more actively applied in the research of hypertension in order to improve the blood pressure measurement, increase the diagnostic precision, and promote the prognosis and managing the disease [33].

This integration allows identifying more accurately those at risk, including those who do not have classic risk factors, and developing a individualized treatment plan due to the combination of genomic and clinical data [38]. Such sophisticated analytical possibilities make it possible to gain a better insight into the complex etiology of hypertension, which opens the way to specific therapeutic interventions [29,39]. The use of AI in pharmacy practice gives the pharmacist advanced technology to make evidence-based decisions, including drug-drug interactions and drugs safety and efficacy. Through machine learning, AI algorithms can assist pharmacists in making well-informed suggestions on each patient needs based on large volumes of data involving medical records, lab outcomes, and medication profiles [40].

### **Influence on Adherence to Medication**

Medication selection and predicting adverse drug events can also be optimized by means of the integration of AI, which ultimately improves patient safety and treatment outcomes [41]. In particular, AI-based applications can provide real-time forecasts about adherence trends in patients using clinical data and enable the use of individualized treatment regimens and reduce the risk of adverse drug interactions [42]. In addition, AI technologies assist the creation of customized treatment regimes, where various patient data such as genetic profiles, lifestyle, and imaging outcomes are combined to provide customized therapeutic treatment [43]. This method improves the safety and efficacy of drugs, as well as simplifies the process of drug development, maximizing the formulation and finding new therapeutic targets [44].

The increased use of AI in the pharmaceutical sector including drug discovery and formulation is a demonstration of its widespread influence on healthcare beyond clinical intervention [36]. It is a strategic use of AI to drive novel knowledge creation, greater accuracy in the prediction of the pharmacokinetic parameters of therapeutic drugs, and the ability to continually monitor and not just hypothetically but practically implement pharmacology. Such advantages include enhanced drug delivery, and detecting the possible diseases at an early stage, which highlights the role of AI in developing pharmaceutical science [44]. The implementation of AI also leads to the recognition of complex tendencies in large volumes of data that allows more reliable forecasting of the characteristics of drugs and therapeutic effects [45]. This type of development enables the achievement of substantial progress in the accuracy and effectiveness of medication, especially in difficult diseases in which many variables affect the response to treatment [46]. The holistic incorporation of AI into the pharmaceutical practice, therefore, improves the accuracy of drug

development, as well as the effectiveness of a personalized approach to medication administration [40,44]. In addition, AI can also be used to administer personalized counseling and lifestyle management to patients and encourage treatment compliance and improved health outcomes by offering pharmacists with the assistance to improve patient education and clinical decision-making [41,47].

This enables optimization of drug delivery dosage forms and also can simulate and predict drug behavior in the body automatically [44,48]. The ability of AI to analyze large volumes of data in a short duration enables the determination of the best drug compounds, thereby shortening the development cycle and the associated expenses [46,49]. Using AI algorithms, researchers can understand the hidden correlations and patterns of complex datasets to make predictive models that are credible in predicting the drug degradation pathways and stability profiles [50]. This analytical power is a valuable contribution to safer and more effective pharmaceutical products, as it greatly helps to select excipients, streamline the manufacturing processes [51]. Furthermore, AI-driven systems speed up the process of selectiveness of the candidates and clinical trials, hastening the decision-making process, clinical trial design, and patient stratification due to processing large volumes of data [50]. It is also possible to make on-demand dose changes and have a perfect control over the drug release rates with the help of AI, which is essential to create drug-releasing systems with intelligence [44]. This will assist in the creation of more advanced drug delivery systems that will be capable of responding dynamically to the physiological changes, thus enhancing the outcome of therapy and reducing the side effects [48].

**Table 2. Effects of Pharmacist Interventions on Clinical Outcomes.**

<b>Clinical Domain</b>	<b>Pharmacist Role</b>	<b>Observed Outcomes</b>	<b>References</b>
<b>Hypertension Management</b>	Dose titration, adherence checks, and patient counseling.	Reduced systolic and diastolic BP; improved adherence.	Sharma et al. [2023] [10]; Patel et al. [2024] [12]
<b>Heart Failure</b>	Monitoring diuretics, ACE inhibitors, and patient symptoms.	Fewer hospital readmissions and better symptom control.	Osei et al. [2024] [15]; Tang et al. [2024] [22]
<b>Dyslipidemia</b>	Counseling on statin adherence and side-effect management.	Improved LDL-C goal attainment rates.	Ahmed et al. [2023] [4]; Zhang et al. [2023] [18]
<b>Post-Myocardial Infarction Care</b>	Review of antiplatelet and anticoagulant regimens.	Enhanced medication safety and reduced bleeding risks.	Lin et al. [2024] [7]; Rahman et al. [2023] [20]
<b>Polypharmacy Optimization</b>	Identifying drug-drug interactions and deprescribing.	Decreased medication burden and improved safety.	Patel et al. [2024] [12]; Tang et al. [2024] [22]

### **Impact on Medication Safety**

AI capacity to process a lot of patient medical history and drug history is vital in predicting adverse drug events, dosage optimization, and workflow efficiency, which in turn increases patient safety and therapeutic efficacy [47]. It is possible to prevent possible risks in advance and decrease the number of medication errors and improve the situation overall with the patient care. AI-enabled applications have even more potential to assist pharmacists with routine tasks to devote more efforts to more complicated clinical decisions and face-to-face communication with patients [52]. Drug-drug interactions and adverse drug

reactions can also be analyzed in a more comprehensive way with the help of AI that will help filter through extensive pharmacological information and other patient-specific aspects [40].

This is also applicable in forecasting the individual patient response to different drugs based on the effect of genetic predispositions and comorbidity which goes a long way in enhancing medication safety. Moreover, AI can be used to optimize drug regimens by taking into consideration a patient's overall clinical history, taking into account real-time physiological data and adherence behavior and ensures the best possible therapeutic effect with minimal risk [36] [49]. The real-time tracking opportunities of AI enable the detection and anticipation of a great number of diseases at an initial stage, which provides pharmacists with a potent instrument to manage patients proactively. This does not only increase the level of the pharmaceutical care, but also changes the role of the pharmacist to a more analytical and patient-focused position especially in the management of complex diseases such as cardiovascular diseases [44].

The further implementation of AI models within the clinical decision support systems can also help pharmacists to make medicine-related decisions, optimize dosages and identify potential drug-drug interactions with greater precision and efficiency [40]. Such ability of analysis is vital in cardiovascular disease management because polypharmacy and complicated comorbidity require accurate medication administration to eliminate the adverse outcomes [53]. In addition, AI systems can be useful to monitor patient compliance with cardiovascular drugs in real-time to detect deviations and provide prompt interventions to enhance therapeutic compliance and decrease hospitalization rates [54]. This means that machine learning in pharmacy practice could be used to generate the potential of remarkably improving medication management, maximizing therapeutic outcomes, and improving patient safety [55].

This disruptive technology is no longer in the theoretical debates but in practical use, where the medication mistakes, patient compliance, and substantial cost reduction have been achieved in different health care environments. It is especially noticeable in the pharmacy environment of hospitals and communities, where AI and machine learning use have proven to enhance care provision by automatizing processes and offering insights driven by data [56]. Actually, according to community pharmacies, drugs adherence has increased by 40 percent and prescription refill missed by 55 percent after AI technologies have been incorporated [55]. Such developments highlight the fact that the concept of AI can transform pharmaceutical care to be more efficient, accurate, and patient-centered [36].

### **Impact on Patient Outcomes**

Predictive analytics, especially machine learning algorithm, are the most crucial factors to anticipate patient health outcomes in the pharmacy practice to implement proactive measures and tailored treatment plans [57]. This will allow pharmacists to stop providing reactive care and use data-driven knowledge to adapt therapeutic coverage plans and predict possible complications [40]. With the account of complex patient variables, such as demographics, comorbidities, and inherited predispositions, AI tools may reveal people who are more vulnerable to adverse events or non-response to treatment and enable a streamlined and timely clinical response. Such a predictive potential makes it possible to dynamically adjust the courses of medication and achieve maximum therapeutic effectiveness and reduce possible risks. Moreover, AI methods are also highly effective to recognize complex relationships between a large number of variables, and it is irreplaceable in stratifying patients to undergo therapy, particularly complex cases, such as cardiovascular disease, in which the interaction between gender, genetics, lifestyle, and environmental factors [44].

AI-based predictive modeling has the potential to revolutionize patient stratification in clinical trials, taking molecular and clinical data and discovering subpopulations more likely to respond to treatment with a high probability, resulting in more focused clinical trials [50]. In addition, the ability to generate innovative knowledge along with the enhancement of accuracy and computer simulations enable AI to constantly track the performance and, in particular, perform early diagnoses of diseases, which is especially helpful in the management of long-term diseases [44]. That allows pharmacists to stop working in a reactive manner and

utilize the power of data-driven insights to individualize treatment plans and predict possible complications. The potential of AI to process large datasets of patient demographics, genetic data, and treatment history can be used to learn more about the disease progression and tailored responses to treatment. These advanced analyses can help to enhance the quality of clinical decisions so that clinical interventions are more effective and they must be specific to the biological and clinical conditions of every patient [40].

The ongoing transformation of AI, which is supported by the development of machine learning and data science, has made it possible to come up with new solutions to intricate problems in the pharmaceutical industry [47]. In particular, AI algorithms can be used to forecast the efficacy, toxicity, and any other potential adverse effects of the new drugs, optimizing the drug development process and decreasing the costs and timeframes [58,59]. It is especially transformative in drug discovery, where AI uses a vast amount of biological data to find disease-relevant targets and predict their relationships with the possible drug candidates, streamlining the process and making it more focused. The most recent breakthrough in AI and machine learning is a revolutionary opportunity in the process of drug discovery, formulating and testing pharmaceutical dosage forms [48].

### **Effect on Adherence to Medication**

Using AI is not limited to the field of discovery but can be used to optimize treatment regimens and the patient outcomes process by transforming the modeling of drug release and reducing side effects caused by personalized medicine approaches [60]. This involves the application of AI and its analysis of a large volume of patient information to result in more efficient and patient-centric clinical trial designs and finding optimal dosing regimens [50]. In addition to the optimization of individual patients, artificial intelligence is radically transforming the pharmaceutical environment in general, including the development of drugs, as well as the production of tailored therapy and medications [49]. These technologies can be used to analyze large amounts of data to streamline drug formulations and predict patient reactions, thereby introducing precision medicine [61].

This comprehensive application of AI to the pharmaceutical continuum would result in the optimization of drug development and formulation and delivery to meet the needs of the specific patient, which would positively affect the therapeutic outcomes and the absence of adverse events [44,51]. The paradigm shift is in the form of incorporation of AI and ML, which manifests itself at all stages of the drug development process, starting with the discovery of a drug and ending with the development of an advanced formulation. Advanced artificial intelligence algorithms have already enabled predictive models that can be used to simulate drug degradation pathways and stability profiles, which scientists can use to make informed decisions throughout the formulation process [50]. In addition, machine learning algorithms process large volumes of data to determine the best formulations by establishing important relations between formulation variables, excipients, and drug properties [50].

These AI-centered methods allow identifying new therapeutic candidates that have better efficacy and reduced side effects, which further improves the rational drug design and development processes [45,61]. Moreover, AI and ML technologies can be used in personalized medicine to analyze patient-specific information to optimize dosage regimes, predict treatment response, and improve the effectiveness of treatment [45]. It is done through the use of AI and ML to customize treatment and dosage based on the profile of a specific patient, leading to effective and personalized patient care [36]. The use of AI on this aspect makes the drug development process very simplified, providing comparatively more efficient, timely, cost-effective, and very optimized procedures in contrast to the traditional trial and error methods [44,45]. This speed will play an imperative role in introducing new therapies into the market earlier, particularly in the complex diseases like cardiovascular diseases where rapid intervention can greatly affect the morbidity and mortality of patients [44]. Such sophisticated calculation programs are also useful in

enhancing the drug solubility and absorption thus increasing the bioavailability which is an important parameter of drug formulation [36].

### **Impact on Medication Safety**

The combination of AI and machine learning algorithms offers a revolution in the determination of drug stability and optimization of formulations, thus, accelerating drug development. The data-driven model reduces the time and costs of experimentations and also enhances the chances of coming up with robust and effective drug products by a significant margin [50]. Additionally, AI models, including generative adversarial networks, can be used to generate new chemical structures and optimize their properties, resulting in a variety of diverse and structurally or functionally enhanced drug candidates [36]. This has increased the rate of development which is facilitated by AI and ML making it possible to identify and optimize drug formulations faster and reduces the time interval between the laboratory and clinical use [50]. Also, predicting drug-target interactions, analyzing biological activity, and optimization of lead compounds are tasks that machine learning helps to accomplish, and this is all that will advance the creation of new pharmaceutical agents faster [46].

The combination of AI, consequently, reduces the current development of drug development, indicating different phases of drug development, including discovery and preclinical and clinical validation [62]. Pharmacovigilance is a potential use of AI, such as in adverse drug event monitoring and the detection of signal, which can be done in a sophisticated way and is very useful in improving the safety of drugs [63]. In addition, AI models may forecast the possible new applications of approved drugs, simplifying the process of repurposing all existing medications and speeding up the process of providing medicines to new indications [50]. This analytical power is further expanded to optimization of drug preparations to identify possible stability problems or degradation routes prior to huge lab experiments [45].

AI-based predictive models can also be used to optimize the size, shape, and surface characteristics of nanoparticles to deliver drugs locally to specific targets, decrease the off-target effects, and increase the effectiveness of treatment [36]. The integration of machine learning and artificial intelligence in the formulation process of drugs has transformed the conventional processes through which the development of advanced drug delivery systems was carried out through conventional trial and error approaches [44]. This transformation towards AI-based approaches makes the process of development much faster, and more efficient, timely, cost-effective, and highly optimized and especially useful in the context of complex drug delivery systems such as nanomedicines. This method severely decreases time, financial and human resources usage, which is usually involved in developing a conventional drug delivery system [44].

Most notably, the swift US drug approval and creation of COVID-19 vaccines in just 1-2 years to date reflects the transformative influence of AI on speeding up drug creation [64]. This fast movement highlights the fact that artificial intelligence and machine learning are transforming the pharmaceutical industry by hastening, refining, and streamlining the pharmaceutical discovery and development process [36,65,66]. In fact, it is possible to predict new therapeutic targets and more accurately and faster identify drug candidates through the analysis of large datasets by artificial intelligence to identify complex patterns [51]. Moreover, AI algorithms play a critical role in optimization of the poly[lactide-co-glycolide] nanoparticle properties and, therefore, simplify the experimental design and exploration of unreachable design spaces in the drug formulation [67].

This technological synergy plays a central role in the development of nanomedicine where nanocarriers can be manipulated accurately to deliver them to targeted sites and also increase therapeutic efficacies, especially in the treatment of complex conditions like cancer [49]. AI tools such as neural networks and fuzzy logic are essential to maximize the drug release kinetics and accurate localization of therapeutic agents in the body [46]. This combination of AI and nanotechnology is useful in the creation of new drug delivery systems, which can increase drug efficiency, minimize side effects, and decrease nanoparticles and improve nanoparticle control by enabling the precise design and behavior of nanoparticles [68,69]. As an

example, AI algorithms can be used to improve numerous features of nanoparticle design, including size, charge, drug encapsulation efficiency, and biomaterials interactions, to enhance the effectiveness of therapy, like cancer therapy [45,70].

**Table 3. Barriers and Challenges in Implementing Pharmacist-Led Care.**

Challenge	Description	Implication	References
<b>Resource Constraints</b>	Limited clinical staff and funding in outpatient settings.	Restricted scalability of pharmacist programs.	Ahmed et al. [2023] [4]; Sharma et al. [2023] [10]
<b>Lack of Standardized Outcome Metrics</b>	Variability in reporting adherence and clinical outcomes.	Difficult to compare and generalize study results.	Osei et al. [2024] [15]; Patel et al. [2024] [12]
<b>Interprofessional Barriers</b>	Poor collaboration between physicians and pharmacists.	Reduced integration into clinical decision-making.	Lin et al. [2024] [7]; Rahman et al. [2023] [20]
<b>Patient Non-Adherence</b>	Socioeconomic and behavioral barriers to following treatment plans.	Limits the long-term impact of interventions.	Tang et al. [2024] [22]; Zhang et al. [2023] [18]
<b>Data Integration Limitations</b>	Inconsistent digital documentation systems.	Challenges in monitoring adherence trends.	Sharma et al. [2023] [10]; Ahmed et al. [2023] [4]

### Impact on Clinical Outcomes

Additionally, such accuracy has the potential to create nanorobots that can be directed to precise locations in the physiological body to administer therapeutics to diseased cells, creating less systemic toxicity and the highest possible therapeutic effect [46]. The further applications of AI are in the domain of personalized medicine, i.e., patient-specific data are processed to optimize the formula of drugs and their dosage, which enhances the level of adherence to treatment and treatment outcome and reduces the number of adverse effects [45]. This enables real-time treatment adjustments to improve treatment regimens, maximize therapeutic time and reduce the risk of developing drug-related complications. The combination of artificial intelligence and nanotechnologies presents a potential solution to quick processing of large numbers of patients, forecasting the development of a disease, assessing the pharmacological characteristics, and identifying cancer biomarkers [71].

Furthermore, AI is also very efficient in enhancing these processes, which is why it is priceless in the creation of individualized drug preparations, which increase the treatment results [36,71]. With the help of AI, nanomedicine can gain numerous benefits in the form of optimization of material properties, the interaction of drugs with the immune system or cell membranes, and the expedient evaluation of drug synergy [71]. Analysis of large amounts of data through the use of AI will help develop very personalized treatment plans, taking into account genetic differences and environmental elements, and eventually leave the approach of considering medicine as a single size fits all [36]. This type of AI-led personalized recommendations is essential to address chronic disease management, which requires constant monitoring and accurate medication dose, to greatly increase the safety and effectiveness of patient treatment [46].

The combination of AI and nanomedicine is especially crucial in cases when intra-tumor and inter-patient heterogeneity make the design and analysis of diagnostic and therapeutic platforms complex to make more precise predictions and classifications [72]. The combination of nanomedicine and AI not only enhances the accuracy of the diagnosis and the treatment focusing but also enables the elaboration of new drug delivery systems, especially in the field of oncology when it is important to target the drug to the tumor and reduce off-target actions [46,69]. This convergence opens the possibility to make advanced diagnostic nanomaterials that will produce patient-specific disease profiles, which are used by therapeutic nanotechnologies to enhance the outcomes of treatment. Such integration can be used to gain a deeper insight into complex biological systems, and nanosystems can be designed to incorporate a specific set of properties that are required in a particular field of medicine [72]. As an example, intelligent nanoparticles can be designed using AI to navigate biological systems with high precision to bring therapeutic cargo to the desired cells with minimal side effects to healthy tissues [70].

This mutualistic interaction between nanomedicine and AI thus provides a groundbreaking frontier in cancer care, which is predicted to bring a new dawn in the diagnosis, treatment, and management of patients through the approaches of targeted drug delivery and the advanced analysis of data [69]. Such a synergy is especially clear with respect to the creation of AI-based nanomedicines which have demonstrated promising results in pre-clinical trials, and are now undergoing a transition to clinical versions, providing a new paradigm of precision medicine [64,69]. This combination allows building of intelligent drug delivery systems, which will be able to react autonomously to physiological changes, improving the targeting of therapy and patient safety [44,71].

### **Intervention Satisfaction among patients**

Taking into consideration the complexity of the system to measure patient satisfaction with cardiovascular interventions, AI-based systems may process large volumes of data to determine the degree of satisfaction of individual patients and what factors lead to positive experiences, which will make it possible to develop more individualized and effective care plans. Besides, AI is able to tailor treatment plans based on the genetic composition, lifestyle, and comorbidities of a patient in order to ensure the drugs work better without causing side effects [36,44]. With such sophisticated analytics, it is possible to detect complex links among different attributes of patients such as gender, genetics and environmental factors that are essential in-patient stratification of patients in cardiovascular interventions [44].

Such an advanced analysis will help create individual interventions plans, which are essential to enhance medication compliance, safety, and clinical outcomes, overall, when managing cardiovascular disease. Artificial intelligence and machine learning have revealed themselves as having a great potential in transforming the process of cardiovascular disease treatment through improving diagnostic precision, forecasting disease progression, and streamlining clinical processes [73]. They are critical technologies that have allowed conducting accurate risk screening, diagnosing early diseases, and shaping treatment plans that are extremely customized, unlike the old methods of generalization [44,74]. Particularly, clinical decision support systems based on AI have the capacity to process large volumes of patient data to find the hidden associations and provide healthcare workers with evidence-based and timely suggestions that will improve diagnostic and treatment accuracy [75].

In addition, AI promotes the creation of individualized treatment boards by incorporating various patient information such as genetic code, lifestyle, and imaging findings, hence promoting customized treatment procedures [43]. The domain of AI usage in cardiology can be applied to the interpretation of different types of imaging, such as echocardiograms and MRIs, and the analysis of electrocardiograms, typically exceeding the ability of humans to diagnose [76,77]. It is not only a way of reducing the level of human error but also results in the streamlining of healthcare procedures in the context of complex cardiovascular conditions [73]. The integration of multimodal sources of data and data collections [ECG, echocardiography, cardiac magnetic resonance imaging, genomics, etc.] makes it possible to identify the patterns of the hidden disease and predict the long-term cardiovascular outcomes with the help of AI [78]. Such analytical capabilities

enable AI algorithms to go past aggregating data, to detect complex relationships in large amounts of healthcare data, which are often not easily discernible with more basic statistical techniques [24,79].

This incorporates the capability of analyzing complex clinical data available in electronic health records hence enhancing the accuracy of the risk assessment of different diseases [39]. Introducing artificial intelligence to clinical decision support systems can greatly improve the outcomes of patients due to their ability to process large volumes of data, identify hidden relationships, and offer evidence-based suggestions to medical practitioners in a timely manner [75]. Such an ability allows clinical decisions to be based not only on the most recent research but also on the specifics of physiological and pathological peculiarities of patients [43]. This type of predictive model that is obtained with the help of AI facilitates personalized care as it creates patient-specific treatment plans and, therefore, represents a great transition towards precision medicine [75].

The advent of artificial intelligence in the cardiology field, e.g., is already having a major influence on the disease diagnosis, treatment, and risk prediction through the ability to analyze complex and vast data to deliver precise prognostication [80]. This encompasses its ability to perform better than the traditional statistical procedures in creating risk stratification instruments used to diagnose cardiovascular diseases to conduct massive data involving intricate interactions in a more cost-effective manner. Although traditional statistic-based approaches usually have problems with bias reduction, the handling of missing variables and the control of confounding variables, machine learning algorithms are more effective in such aspects, resulting in better results [24].

### **Conflict of Interest**

The authors declare they don't have any conflict of interest.

### **Author contributions**

The first drafts of the work is written by the first author and the cross-ponding author's supervisor it. Each author wrote a portion of the manuscript, collected data, edited it, created tables, and got permission to submit it to a journal for publication.

### **Acknowledgement**

The authors acknowledge the availability of open access materials from numerous databases, including DOAJ, Cochrane Library, BMJ Clinical Evidence, Google Scholar, Embase, PubMed, and Medline.

### **Ethical Approval**

Not Applicable

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