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The Future of Pharmacy: AI and Machine Learning in Medication Management

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Abstract

The life science industry has long leveraged AI and machine learning, but the expectation is that the next several years will witness a growing agility and evolution across the board. One further step then is to consider a more tangible application of how AI can assist in more effective and responsible medical practice—the management of medications. The capacity of pharmacists, really at their apex, is to provide the best advice in all aspects of medication that a patient may need. The primary reason for this is that managing medications is very complicated. In a way, the additional techniques provide ways of tackling a small amount of the complexities of medication management while at the preclinical level, rather than waiting for the problems to emerge further down the line.

In this short article, we will provide two AI machine learning techniques that are very close to commercial deployment, having gone through multiple prototypes and extensively demonstrated internally, and may be positioned to different strategies in managing medications. The first technique will enable medications to be taken orally that otherwise can only be injectable, and could potentially shift medical practice toward orally administered and less expensive medical solutions. The second will involve user generation of new small molecules and increase the drug repertoire of pharmacists, while also potentially reducing the cost for drug companies to discover the medications.

Keywords: Life science industry, Artificial intelligence (AI), Machine learning, Medication management, Pharmacists, Medical practice, Medication complexities, Preclinical level, Commercial deployment, AI techniques, Oral medication, Injectable medications, Medical solutions, Drug discovery, Small molecule generation, Drug repertoire, Cost reduction, Pharmacological innovations, User-generated molecules, Medication strategies

1. Introduction

A 90% likelihood exists that by the year 2026, artificial intelligence (AI) and machine learning will take over at least one role that is now performed by pharmacists. In 2005, discoveries in understanding the human genome were incorporated into improved, specific medications for humans—precision medicine. Pharmacogenomics arises when pharmacogenetics is combined with medications. Newer precision medications are targeted to individuals of specific genetic types. These new medications require a higher level of knowledge on the part of those health professionals who handle medications daily. With rapidly changing guidelines on pharmacogenomic testing and knowledge related to drug-to-drug interactions, is it reasonable to rely on a single provider human database to answer this question instantaneously and do so correctly every time?

Absent other major changes, what would necessitate the use of medication experts with doctorate degrees to be in the direct line of fire? When shifts in demand develop, it is more likely that corporations may be more interested in investing in technology to cut costs rather than recruiting professionals with advanced degrees. However, a major danger lurks—public health could erode if inadequately trained medication specialists undergo burnout due to not having appropriate technology support. Policymakers, providers, and leaders in the pharmaceutical, insurance, and health industries must be ready to provide resources to effectively harness the quickly developing AI and machine learning technologies. Those not having the protection of the powerful do, however, have some opportunities to have a say in how AI and machine learning technology become incorporated. With any medical outcome, the potential reward is not without commensurate risks.

1.1. Background and Significance

Currently, licensed clinical pharmacists review prescriptions and ensure they are safe, appropriate, and indicated. The pharmacist also decides on how to label the medication for the patient, while ensuring that the instructions on how to correctly take the medication are given. In addition, the pharmacist tells the patient how, when, and why the medication should be taken. Medication management platforms address the need to evaluate the medical condition and ensure that the appropriate medication is being prescribed. Nevertheless, regarding other important features related to the examination of the drug itself, such as dosing, route, frequency, or safety in the mother and fetus, these do not currently exist outside the pharmacist's scope of work, especially not at scale, for the millions of these individuals. Therefore, given the rapid discoveries in molecular medicine and the DTC business model, we anticipate that the consumer market for these platforms will continue to grow. Researchers will need to develop methods, such as machine learning and artificial intelligence, to qualitatively assess over-the-counter medication components that comply with pharmaceutical quality in specific tailored populations. We will now discuss how pharmacy and pharmaceutical science are related, and what we hope to see when considering the state and future of pharmacy. This is one of the first discussions in the pharmacy community to fully explore the potential benefits, risks, and regulatory challenges that AI and machine learning present in DTC pharmacy consumer use. We demonstrate that failure to co-collaborate and develop this vision of the future could not only reduce pharmacy provider efficacy but may also result in gaps in person-centered care. Nevertheless, and most importantly, shared efforts can ensure success in machine learning and AI that could be used to complete successes in pharmacy and provide best-in-class proactive person-centric care. Support for these efforts is provided by several key stakeholders in pharmacy practice.

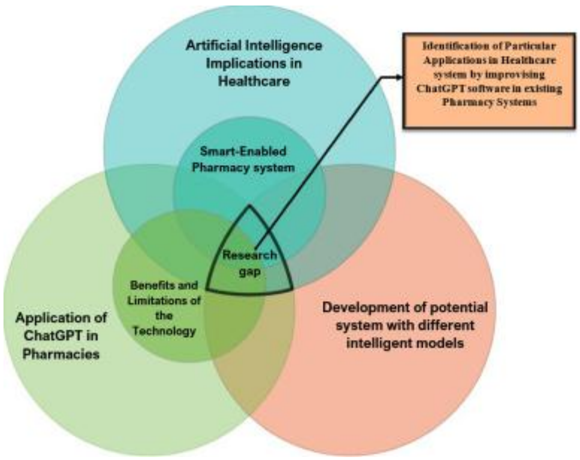

Fig 1 : The future of pharmacy: How AI is revolutionizing the industry

1.2. Research Aim and Objectives

This proposed research aims to provide cutting-edge, affordable, and accessible medication management through developing an AI-aided decision support system in pharmacy contexts. With a vibrant scope in proposing pharmacy practice, including medication management in various healthcare sectors, promising support for the professional roles of pharmacists, impacts on professional attitudes, satisfaction, or health promotion activities, and feasible technical requirements to self-sustain for regular use and public distribution. Medication management is a nascent field, and significant accomplishments have been achieved using data mining, machine learning, or AI-based decision support system approaches. The salient advantage of this technology adoption is in promoting the role of pharmacists who can take an active interest in assessing and achieving more with the limited staff they may have, as well as implementing a variety of medication management programs while freeing their time to interact, educate, counsel, and monitor the process of administration or reminding users to take their medications on time. The objectives included in fulfilling the aim are: to provide a scientifically and medically interpreted AI-aided decision support system framework for pharmacists to use in medication management services, produce beneficial pharmacy operations, and enhance overall customer satisfaction in a health management context. To specifically address medication management problems with intelligent solutions at the pharmacy level. To thoroughly investigate the users, systems, technologies, datasets, and evaluation methods required in the development and implementation of supporting medication management prototypes. To explore potential business models and practical benefits that AI-aided decision support systems can render in conjunction with current and near-future applications.

Equation 1 : Patient Medication Optimization (Personalized Dosing)

In personalized medication management, AI can help optimize the dosage of drugs based on individual patient characteristics (such as age, weight, genetic profile, and medical history).

$$D_{opt}(P) = f(P, A, W, G, H)$$

Where:

$Dopt(P)$ = Optimized dose for patient P

A = Age

W = Weight

G = Genetic profile (e.g., pharmacogenomics data)

H = Health history (including comorbidities, previous drug responses)

The function f would represent an AI model trained to predict the optimal dose based on these variables.

2. AI and Machine Learning in Healthcare

AI and machine learning allow companies to analyze the data that they and their third parties hold to accurately predict what might happen and how they should react or decide upon it. These aren't surprising fields of research and adoption in healthcare, given that health is fundamentally about patterns and responses to treatments, patterns, and treatments influenced by a myriad of genetic and environmental factors. AI and machine learning can be applied to these, as well as to more day-to-day operational aspects of healthcare, such as existing predictive algorithms that are used to drive preventative care management, asthma, and COPD patient management algorithms, as well as readmissions software.

More interestingly, AI and machine learning seem to be very effective tools to reduce the burden of increasing administrative workload for healthcare providers, whose activities are extremely disrupted by electronic health records, consumer demand, increased breadth of services offered, and continually changing payment models and reporting requirements. At the start of 2020, with resources appearing to be expensive and in short supply, perhaps we can be cautiously optimistic that AI and machine learning—as well as IoT and other technologies—can start to layer some insights into that data and algorithms. And when adding that it will create more well-being, it will be a cheap and good investment.

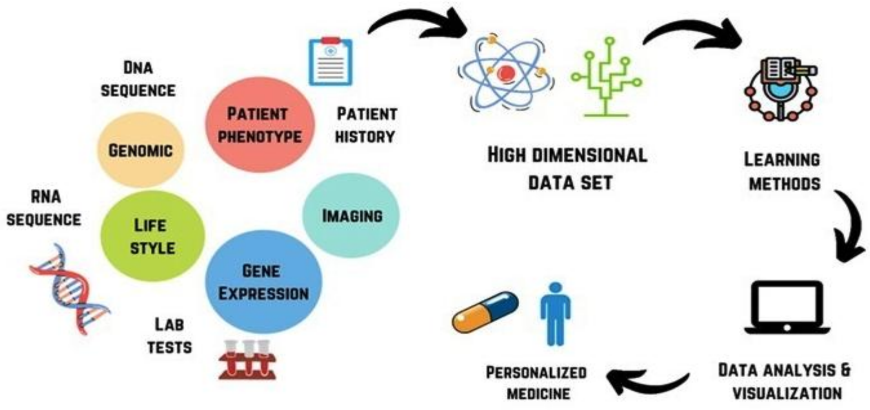

Fig 2 : Artificial Intelligence for Research in Medicine and Healthcare

2.1. Overview of AI and Machine Learning

AI is fundamentally about making computers learn from data. It involves a variety of learning methods, all of which are partly addressed in the environmental scan. Working definitions of these terms include: - Deep learning:

A brain-like approach to machine learning models. It works by uncovering layers of parameters in a way that allows for feature extraction. - Machine learning: Using models to learn from data, improve their performance, and adjust to new data. There are three types of learning: supervised (learns a function that maps an input to an output based on input-output example pairs); unsupervised (learns the data characteristics to group data accordingly); and reinforcement learning (an agent invents a model of its environment and makes decisions based on the model, to maximize long-term reward). - Predictive modeling: A mathematical framework or model used to predict a future course of events. Though the focus is often on projections involving future events, predictive modeling can also be applied to any type of unknown event, regardless of when it occurred. - AI in healthcare: AI involves the development of a large number of diverse processing models that facilitate the discovery of patterns in data. These patterns can be translated into automated, predictive decision-making, which in turn can support inferences on diagnoses, such as detecting diseases.

2.2. Applications in Healthcare

There are several promising applications of AI and machine learning in the domain of healthcare, from managing patient data to supporting clinical decisions. Healthcare is especially suited to the strengths of neural networks, which work well with complex, multimodal data. In drug development and discovery, for example, neural networks have been shown to make faster initial predictions of molecules that have the potential to enter the drug discovery pipeline. Convolutional neural networks have been used to model the mechanisms of action and create neural fingerprints, which make compact quantitative descriptions of possible effects. Furthermore, neural networks can learn health knowledge on trustworthy and data-intensive databases utilizing tasks that make no assumptions. In pharmacovigilance, recurrent neural networks are promising in combination with attention modules for careful inspection of historical adverse drug event reports. The same model managed to support predictions of treatment switches and side effects using electronic health record data. Health record data, sometimes in combination with imaging studies, genomics, or proteomics, have been the target of many natural language processing and interpretation methods utilizing neural networks. These innovative tasks range from early detection of lung cancer to molecular analysis of breast cancer subtypes, including molecular borrows and phenotypic inference. These solutions present a variety of techniques, from sequence models, transformer models, and deep reinforcement learning, to generative adversarial networks and quantile regression and prediction models. Other reviewed techniques are convolutional and recurrent neural networks, custom architectures such as prediction-enriched message-passing models, unequal metric learning models, and federated learning. Considering this range of potential applications, AI and machine learning open the door to new methods of medication management.

3. Current Challenges in Medication Management

Medication management is generally about ensuring that a patient is taking the right medications, in the right way, at the right time. The overarching goal of medication management is to help optimize the patient’s quality of life. However, medication management itself can be challenging for several reasons. One area that continues to present difficulties is adherence to the prescribed medication regimen. Medication adherence continues to be an essential aspect of not only the medication management process but also one of the most common areas of treatment failure. Accurate and comprehensive medication lists are necessary for medication adherence and other needs, both within the clinical environment and in the patient’s or individual’s own life. Medication lists help not only to ensure medication safety but should also be accurate and in real-time, based on the medications the individual is taking.

Lack of medication list accuracy can be particularly impactful during care transitions, which are at high risk for transitions of care issues due in part to the patient’s risk of unintentional medication discrepancies, among other contributing factors. The undeniable medication list discrepancy rates identified and documented for care transitions of patients also continue to add to the persisting issue around medication lists. Documented rates of discrepancies, in some cases, range up to 40% regarding unintentional medication discrepancies at hospital admissions or discharge.

Equation 2 : Medication Adherence Prediction (Behavioral Modeling)

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AI models can predict whether a patient will adhere to their prescribed medication schedule based on historical data, lifestyle, and socio-economic factors.

$$A_{adh}(P) = g(H, S, C, D)$$

Where:

$Aadh(P)$ = Adherence probability for patient P

H = Health literacy (how well the patient understands their condition and treatment)

S = Socioeconomic factors (e.g., income, education level)

C = Comorbidity burden (having multiple health conditions)

D = Drug-related factors (e.g., complexity of the regimen, side effects)

g represents a machine learning model (like logistic regression or a neural network) predicting adherence.

3.1. Adverse Drug Events

Each year, more than 2 million adverse drug events (ADEs) occur due to various factors including medical errors, incorrect prescribing, dispensing the wrong medication or dosage to the wrong patient, patient noncompliance, or inappropriate selection of drugs for multiple treatments. ADEs account for billions of dollars in hospital costs and are often avoidable. Nearly 25% of adverse drug events are avoidable medication errors that may occur during physician ordering, transcription of the physician's order, nurse administration, as well as medication delivery. Medication management systems that utilize decision support tools can detect prescription errors such as the wrong medication, wrong dosage, allergies, duplications between drugs, and drug-drug interactions to prevent serious medical conditions and adverse drug events. Personalization of ADE alerts also mitigates the most common problem of alert fatigue, where the volume of alerts overwhelms overall attention and minimizes meaningful alerts. Consequently, the value of alerts diminishes because some of them may not be taken seriously by the provider. Furthermore, by tailoring alerts to each profession and specialist, AI can avoid alert fatigue and improve the overall effectiveness of decision support.

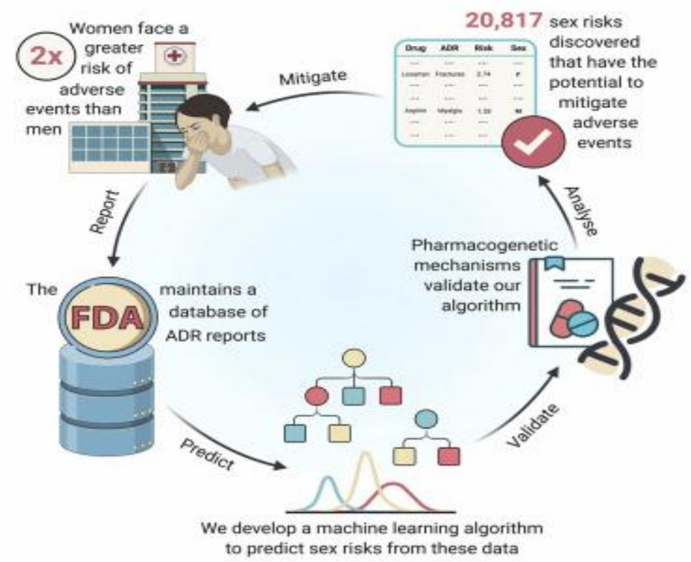

Fig 3 : Identify Adverse Drug Effects

3.2. Medication Adherence

Most large pharmacy chains also offer a medication adherence service for their customers. This service is often bundled with a prescription delivery service. The customers, many of whom have chronic conditions, find that getting to a pharmacy to pick up their prescriptions is increasingly problematic as their health stresses grow. The pharmacy delivery solution for these customers has a driver taking the prescription to the customer's residence, usually once a month. If a prescription is to be filled with more than one month's supply, a call or a later delivery is required. These types of services are currently for the customer's convenience but help manage the prescription inventory. If a customer had a prescription filled for a 90-day supply and the quantity on hand is sufficient for 70 days, the shipping date can occur in 20 more days. These actions are beneficial from the customer's point of view, but they do not always help the problem of setting the customer without the medication. If the customer is using other medication management services to monitor and address their health issues, month-end inventory concerns are taken off the customer's plate and assigned to professional drivers.

4. Role of AI and Machine Learning in Medication Management

Artificial intelligence (AI) and machine learning (ML) models can support AI-based medication management to avoid medication errors and provide patients with the most effective medications. To achieve this goal, AI models are built to optimize the processes at different stages in medication management, including admissions, chronic medication management as an inpatient or outpatient, medication reconciliation at transitions of care, and discharge, as well as patient education and follow-up. Machine learning (ML) models must be trained with real-world clinical data and integrated into clinician workflows to help clinicians with their tasks. In building a model, the data and features need to be carefully designed so that the predicted outcome can be reliable. Evaluation metrics and external validation processes are essential steps to ensure model quality and to allow AI-based decision-support systems to make accurate predictions.

Machine learning (ML) models can be trained, evaluated, and successfully deployed to help clinicians make informed decisions about medication regimens. The ML model's predictions can guide clinicians to streamline care pathways. AI-based decision support can reduce the risk of poor drug therapy and improve patient outcomes. To develop high-quality AI-based decision support models, important reporting statements should be followed. AI models require an adequate amount of real-world clinical data to be trained, validated, and evaluated. To allow the deployment of models into real-world clinical practice, models need to demonstrate good-to-excellent discrimination, calibration, and generalization performance. Expert guidance, along with patient preference, cost, and health system factors, should be integrated into the model. In the long run, the performance of the model can be enhanced. Model modifications can enable the updating and upbringing of real-world evidence.

4.1. Drug Discovery and Development

Drug discovery and development is a notoriously long and costly process. The cost to bring a single drug to the market has been cited at over $1 billion and typically takes over a decade to accomplish. Given the importance of both minimizing the time and cost and ensuring the highest chances of drug success, many efforts are focused on using computing models to aid the process. Despite these efforts, of all diseases, cancer drug research has seen the highest success relative to all related projects, but still accounts for just a fraction of all drugs brought to market, typically focusing on cancer drug signatures, predictions for improving cancer treatment, and cancer therapeutic classes.

Researchers and drug companies have attempted to use machine learning algorithms to identify and develop new cancer treatments, and despite some breakthroughs, many challenges still exist in this space. The tools and biological datasets needed for research are complex and require advanced hardware and bioinformatics knowledge, all of which are typically never held by a single person or company. As such, collaborations between governments, universities, the public sector, and big pharma are forming to analyze drug-related data spaces to speed up the drug development process. Given drug companies' scientific advances, it is highly likely that machine learning advances will continue to support drug research and thus accelerate drug development work.

4.2. Personalized Medicine

Treatments have long been designed around data based on statistics for the 'average' person. For example, most people receive conventional, one-size-fits-all prescriptions and therapies that are not tailored to their genetic and clinical profile. In response to this, personalized medicine has emerged to tailor more targeted therapeutic options for those patients who respond to classical pharmacology poorly. Personalized medicine is a term used to describe individualized management of patient care. This approach is promising for the treatment of chronic diseases, which are increasingly common and thus extremely costly. The potential benefits include early and accurate diagnosis to enable earlier and more effective treatment, and more accurate prediction of individuals' responses to particular drugs at particular doses, enabling treatments to be tailored to individuals. Given the growing incidence of chronic diseases, focusing personalized medicine on early diagnosis and prevention is potentially cost-saving for healthcare systems even before considering the potential cost benefits of reducing the adverse effects of prescription drugs.

However, the development and adoption of personalized medicine are faced with several barriers. Ethical and privacy issues associated with genome scanning and genetic profiling must be addressed. Bringing new targeted and multisite diagnostic tests to market will require validation and regulation. The risks, benefits, and costs of personalized pharmacogenomic treatment have received considerable attention, but the potential benefits that could be achieved by using established drugs and established patient data for new purposes seem to be relatively neglected.

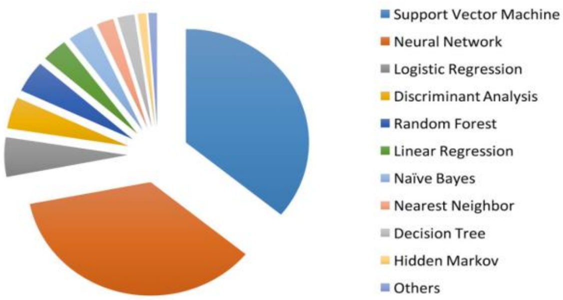

Fig 4 : Top AI Algorithms in Healthcare

5. Ethical and Regulatory Considerations

As these issues are addressed, there will be more opportunities for pharmacists to take on additional roles in healthcare without falling back on the automation of their traditional tasks. This represents an important chance for the profession to not just advocate for incorporating respect for human dignity and patient well-being into the interfaces, but also to guard against the built-in marginalization and neglect of some user types and groups that are liable to be produced through uncritical dedication to the possibilities of improved functionalities. At the heart of this will be patient care, with pharmacists using enhanced technology solutions to expand their capacities to transform care delivery and advance medication optimization. These potential advances should provoke both excitement and concern among practitioners, educators, legislators, healthcare delivery organizations, and patients. There is a possible blurring of the lines of accountability as pharmacists, as the human link in the medication management process, could delegate many responsibilities to algorithms and then disavow faults when a problem arises. Yet, if used responsibly and ethically, AI and ML solutions could promote medication optimization and patient safety in ways that have not even been considered. As opportunities emerge to transform care delivery, overcome long standing challenges in medication optimization, and rise to new challenges, it will be important for these issues to be balanced within the pharmacist's personalized medication management approach.

5.1. Privacy and Data Security

Privacy and security of data in AI/ML applications in health care are of utmost importance. The collection of data requires ensuring consent from users. Informed consent needs to be sought from users for the use of the data for building models. Anonymizing the data is a critical step in making the data suitable for use in AI/ML algorithm development. Different processes exist for data anonymization, each with its unique challenges. While removing select fields from data can help with anonymizing the data, they often change the nature of the data and its value to algorithms. Irreversible anonymization processes involve detuning. Changes may involve the artificial introduction of noise. The impact of the noise on the ability to build useful models needs to be addressed. Given the nature of data available for development, the model built needs to be usable across different sites. Transfer learning and incremental learning approaches can help ensure that data from different sites can be used effectively. Protected health information rules need to be studied thoroughly in developing use cases. Entities need to ensure that their business model and functioning comply with the regulations applicable to health care.

The value of data needs to be weighed in terms of regulation both at a global level and in the country of operation. Developers of AI algorithms often start with an in-depth understanding of regulation relevant to health data. New regulations from governing bodies create significant barriers in the development processes. Measures may need to be in place to handle the requirements of these regulations. The data that is provided to develop models needs to adhere to good research practice guidelines. Having technology in place to monitor and control access to stored data is important. The data that is used for model development and hosting is likely to be sensitive. Controls need to be in place to manage access control. A governance system that defines roles and responsibilities is essential to oversight. The architecture for hosted applications should be built out in compliance with the data residency needs. Tools to ensure that the data can be removed are crucial for ensuring compliance in healthcare systems. Data privacy is of significance in health care, which is a diverse domain. Technologies need to be compatible across different health systems. The methodologies of operation need to maintain user trust. Ethical reporting guidelines are paramount in health care, especially in the context of algorithms that are capable of autonomous decision-making.

5.2. Bias and Fairness

Many have expressed concerns about the potential impact of AI algorithms, given that all have built-in biases. Studies have shown racial disparities in machine learning models that predict which patients will need extra medical services to manage their care, proposing a way to make the algorithms fairer. An important first step to ensure that these algorithms don’t perpetuate disparities in access to medical care is their ability to recognize that the data have shortcomings. Machine learning models are increasingly used to prioritize patient care by targeting resources and services within healthcare provider organizations, determining which patients are at the highest risk for adverse outcomes, and identifying those who would benefit most from additional healthcare resources and services. This can help in designing programs for, for example, readmissions, emergency utilization, and mortality.

One future solution could be to create personalized algorithms for particular datasets for which a disparity-alleviating algorithm would be most beneficial. A personalized algorithm may give disadvantaged group members a higher probability of a positive outcome. The relative disadvantage in the scores violates ideal fairness, which treats similar individuals similarly, giving all sources of bias towards underestimating risk for disadvantaged groups the greatest negative weight. The future is undoubtedly bright for AI and machine learning in the pharmacy space. An effective design and implementation of AI and machine learning in pharmacy will revolutionize medication management. It is, however, important for pharmacists to understand and guide the technology developers to ensure that it is used to give the best outcomes to the patient population.

Equation 3 : Drug-Drug Interaction Prediction

AI can be used to predict potential drug-drug interactions (DDIs) based on the chemical properties of the drugs involved, patient data, and historical interaction data. $DDI_{risk}(P, D_1, D_2) = h(P, D_1, D_2, F)$
Where:

$DDIrisk(P,D1,D2)$ = Risk of a DDI for patient P with drugs $D1$ and $D2$

F = Pharmacokinetic and pharmacodynamic features of the drugs

h = AI model (such as a decision tree or neural network) predicting the interaction risk

This equation allows AI to predict whether the combination of two drugs could result in an adverse reaction, considering both the drugs' properties and the patient's individual characteristics.

6. Future Trends and Implications

In this chapter, we have documented the emerging trends in AI and ML in medication management. Researchers and experts in the field are optimistic about the potential of such technologies and are encouraged to see the quick and promising advancements. The benefits of AI and ML in medication management are numerous. Once the solution is developed and validated, it can be scaled quickly and delivered efficiently in a relatively short amount of time. It is necessary to understand the promise and central role of pharmacy in the medication management movement and increase awareness of advances enabled by technology among pharmacists.

We would like to add that, among other effects of AI and ML, their applications in science and technology changed the cost of many often manually done tasks, such as processing, interpreting, classifying, and predicting patterns in different data available to humans. Since compound discovery and synthesis were once very time-consuming and labor-intensive tasks entirely done via mechanical processes, it is possible to think that AI and ML have the potential to change those fields, leading to cheaper, faster, and better chemicals to explore and advance. Those reasons are why we agree with the insight that AI and ML will be a very powerful enabler and a threat to various capabilities of humanity.

6.1. Impact on Pharmacy Practice

Not limited to such, AI offers opportunities that could improve the efficiency of pharmaceutical care. Firstly, it can help provide better medication therapy by synthesizing evidence from large data sources to provide real-time, evidence-based guidance that is tailored to the individual patient. Using phenotypic and genotypic data, AI can provide medication selection and dosing recommendations specific to individual patient factors. Pharmacist intervention would provide an extra level of security, which is important to account for in the clinical practice of pharmacist medication therapy management; however, being able to guide a pharmacist's recommendations to have more concrete information on medications, such as dosage form, preservatives, diluents, excipients, and petite doses to tally estrogen doses in combined estrogen-progestin pills.

The provision of medication therapy will thus be more effective and efficient, helping to increase value over time through real-world evidence collection. Being able to collaborate with AI to make better, evidence-based recommendations will increase the value delivered in medication therapy management. Pharmacies utilizing AI will then become more appealing to payers and other stakeholders who are interested in increasing the impact of pharmaceutical care. Furthermore, utilizing AI correctly will provide a sustained competitive advantage, requiring both passive and active data analysis to stay current and accurate. Coordinates of a specific region of a biosimilar tablet, interpreted by AI algorithms.

6.2. Research and Development Opportunities

There is no dearth of research opportunities in this vertical, especially if you consider the three-step ladder offered. A spectrum of intelligent decision support tools seeks to exploit research conducted in computer science, information systems, and cognitive sciences to support human decision-making in many application areas within healthcare, including health IT architecture, diagnostic systems, management decision support, and personalized health prediction. Without question, specific sophisticated tools can apply artificial intelligence to complex clinical decision-making. Less thorough are implementations of basic knowledge management, in the sense of managing ongoing support of intelligent systems, which is essential to translate AI research advances to the real-world functioning of clinical decision support systems. Finally, the lowest level on the ladder, the creation of non-synthetic expert systems, is a glaring neglected area of AI research and healthcare delivery planning, and we argue that investment at this level is an essential front in the broad war against rising healthcare costs.

One stream of research we have initiated addresses the fundamental issue of the reliability of AI-based clinical decision support. Here, we have adopted a multi-faceted approach: basic AI research in the areas of knowledge control and system organization that have been neglected in clinical DSS research is combined with experimental evaluation of our prototypes, embedded in developments of particular healthcare management systems, to measure the short-term impacts of the deliberative use of the resulting DSS products. While the research is continuing, initial tests of portions of our clinical DSS technology have been promising indeed. Instead of treating knowledge as a slab of information, permanently and rigidly embedded within its assigned architectural components, our prototypes store the nature and identification of each source, category, and unit of knowledge within units whose architectural flexibility permits their incorporation within the process of decision-making. Our basic units of knowledge are interconnected dynamically and are available at all stages of processing for a principled, context-sensitive revision in the light of relevant local and global updating events. This knowledge control technology recognizes that phenomena are complex, typically involving intangible abstractions, ambiguous descriptions, incomplete instances, and intermingled agents with unclear objectives to be accomplished under complex and often rapidly changing circumstances. The context-sensitive paradigm we have developed provides a promising avenue for addressing this complexity, whereby we compensate for incompleteness, uncertainty, and inconsistency of our lessons and aspirations by maintaining flexible connections among pieces of esoteric and technological information that are meaningful to act upon when specific consideration is demanded.

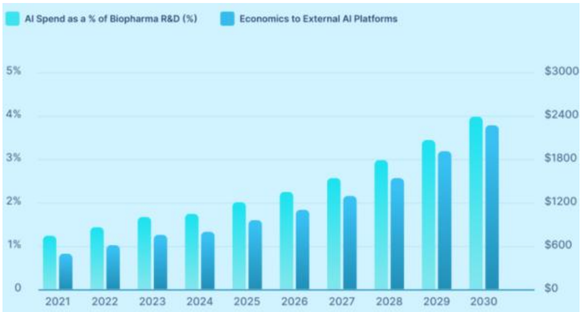

Fig 5 : AI Investment within Biopharma Research and Development

7. Conclusion and Recommendations

Conduct regular updates of medication regimens. Such updates should be conducted at specific frequencies or event-driven, for example, when a patient is admitted to or discharged from a hospital or has recently lost poor health status due to daily activities. Whenever a patient fails to adhere to the current medication regimen, this suggests an approach to be explored for deriving optimal and patient-suitable medication regimens, even when data is limited. Furthermore, we discuss how individualization also has to consider multiple medications and that data- and model-driven approaches may overcome risk-benefit assessment bottlenecks. The handling of medications should be performed near real-time, and machine learning needs to handle continuous repetitive learning, also in a concept drift understanding. The use of AI and machine learning in healthcare must be safe before exposing the output decisions to patients and the population.

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