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Emerging of Artificial Intelligence and Technology in Pharmaceuticals

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Abstract

Artificial intelligence (AI) is an effective technique that utilizes human-like knowledge to quickly solve intricate problems. Significant progress in AI technology and machine learning offers a revolutionary chance to revolutionize the process of discovering, developing, and testing medicinal dosage forms. Researchers can employ AI tools to examine vast biological data, such as proteomics and genomics, in order to find targets linked with diseases and forecast the interactions with possible treatment members. This facilitates the highly effective along with focused strategy for the discovery of drug, hence enhancing probability of fruitful drug approvals. Moreover, artificial intelligence has the potential to decrease development expenses by enhancing the efficiency of development and research procedures. Machine learning tools aid in the process of trial design and have the capability to forecast the toxicity and the pharmacokinetics of potential medication candidates. This feature allows for the prioritization and optimisation of primary chemicals, hence decreasing the requirement for extensive and expensive animal experimentation. The broad range of uses of Artificial Intelligence in drug delivery, pharmacodynamics/pharmacokinetics (PD/PK) drug discovery, process optimization and testing has been examined in this thorough overview. This analysis highlights the advantages and disadvantages of the several AI-based techniques used in pharmaceutical technology. However, the pharmaceutical industry's ongoing exploration and investment in AI present great opportunities for improving patient care and drug development procedures.

Key Words: AI, drug discovery, pharmaceuticals

1. Introduction

Several industries are employing diverse strategy to accelerate their development in order to satisfy the needs and expectations of their clients. The pharmaceutical sector is an important one that is essential to preserving lives. It functions through ongoing innovation and the integration of new technology to meet the demands of the global healthcare system and handle medical crises for instance in the pandemic [1]. Innovation in pharmaceutical sector is usually based on thorough development and research in a number of areas, such as production technology, packaging concerns, and customer-focused marketing techniques, among others [2]. Small molecule drugs and biologics samples are examples of novel pharmaceutical developments. Better stability and high potency are preferred to address unmet needs in disease treatment. There is a great deal of concern over the evaluation of the large levels of toxicity linked to novel medications, which calls for further investigation and study in the near future. Developing therapeutic molecules with the best possible properties and suitability for use in the healthcare sector is one of the main goals. In spite of this, the pharmacy sector faces a number of challenges that need for additional development utilizing technology-driven approaches to meet global medical and healthcare demands [3-5].

The healthcare sector is in constant need of skilled workers, which means that healthcare staff members must be continuously trained in order to increase their participation in routine tasks. The recognition of skill gaps in the work area has been a critical attempt under the pharmaceutical sector. It is crucial to take the necessary corrective action to close the gaps that have been found, even though it can be difficult to provide adequate training. According to a data released by some authorities, almost 41 percent of supply chain interruptions happened in June 2022. The survey goes on to say that the second-most impressive obstacle to overcome is supply chain interruption. In order to improve company resilience, a number of pharmaceutical companies are looking forward to new developments in their supply chains and creative approaches to deal with these difficulties [6]. The coronavirus disease epidemic of 2019 (COVID-19) has significantly disrupted a number of global operations, including current clinical trials [7].

The natural disasters, pandemics, cyberattacks, price adjustments, problems with products and delays in logistics were the possible reasons for the disturbance of the supply chain. The epidemic's effects on transportation have wreaked havoc on global industries and the supply chain. Price fluctuation delays are caused by decision-induced delays for price updates from suppliers because of disagreements over whether to use the new price or the current price for commodities or materials. Countries' tactics for collaborating on cross-border trade give birth to new challenges, including a growth in criminal activity and unstable supply of essential resources for production and operation. Customized footprints must be manufactured to meet patient requirements and ensure compliance.

A large number of COVID-19 vaccinations produced by the pharmaceutical industry were rendered useless during the pandemic because to issues with cold chain maintenance. The main reason for the disruption of the supply chain that came about as a result of the delayed response is that industrial and commercial operations lack innovation and make inaccurate forecasts. Disruptions to the pharmaceutical industry's supply chain can have a substantial impact on prospective revenues, corporate reputation, and consumer happiness (fig. 1) [8,9].

Supply chain activities in the pharmaceutical business are about to undergo a major change due to the introduction of artificial intelligence. In order to provide practical answers for a range of supply chain problems, it also synthesizes a number of AI research initiatives from the previous few decades. The report also makes recommendations for future research directions that can improve supply chain management decision-making tools [10,11].

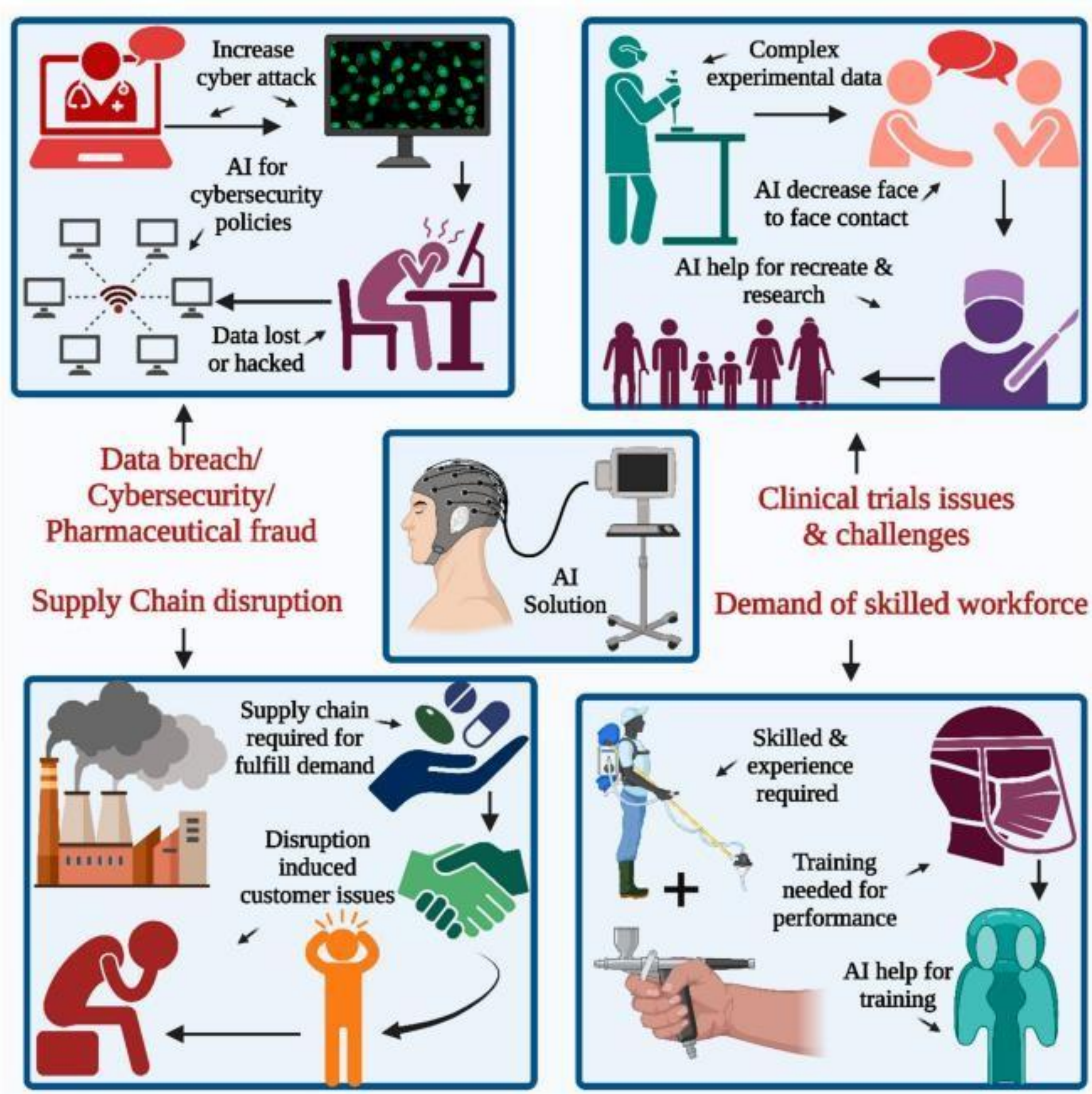

Fig 1: Depicts a possible artificial intelligence (AI) solution to the pharmaceutical industry's challenges: acquiring a proficient workforce is a prerequisite in all sectors to leverage their expertise, proficiency, and aptitude in product innovation. The second pertains to supply chain disruption and clinical trial experimentation challenges. The incidence of cyberattacks is on the rise, with data breaches and security emerging as significant concerns for the industry.

2. Evolution of pharmaceutical industries

The drug industry has historically been the conventional one, focusing on the discovery and development of small-molecule pharmaceuticals that have three key characteristics: (1) sufficient efficacy for the therapeutic objectives; (2) stability; and (3) admissible toxicity for most users. The orderly chemical protection of molecular variations in conjunctional libraries is one of the most effective methods in pharmaceutical R&D. The goal is to identify novel molecules with advantageous properties that can be used in healthcare. But this method is starting to prove inadequate in meeting the ever-increasing demands of the healthcare sector for innovative pharmaceuticals.

The little effectiveness of the technique in the R&D of novel medications can be attributed to several factors. First, many small-molecule drugs for instance, simple chemicals that are readily synthesized chemically, such beta-lactam antibiotics derived from penicillin have previously been thoroughly examined for synthetic alternatives, leaving just a small number of frequently troublesome new prospects for further research and development. Furthermore, a difficult-to- surpass bar for novel compounds is created by the availability of extremely stable and potent molecules for various therapeutic areas. Next, the synthesis of novel compounds becomes slight viable under lack of justifiable product security methods due to the increasingly difficult road by the clinical examination and fierce contesting by the generic companies, with the inconsistency of some specified approaches/rare-disease niches [12-14].

However, it is deceptive to track the pharmaceutical industry's present productivity issue in new compound research and development. Over thirty years, the drug industries has experienced a resurgence thanks to an unparalleled range of methods for the therapeutic advancement of pharmaceutics, which have transformed every obstacle that was previously a scientific or technological one. The small-molecule drug shortage is being made up for by the biomolecular drug business, which is expanding quickly at the moment to fill the void left by underperforming R&D projects. Tiny-molecule medications being made up of very small amount of atoms that work together to form a functional molecule. The atomic composition and bonding of these molecules determine the conformation, activity, stability and reactivity. Contrarily, biomolecules are big structures made up of multiple molecular building blocks, such as ribonucleotides/nucleotides for nucleic acids alongwith amino acids for proteins. In addition to the atomic characteristics of each

unit, spatial conformation and the supramolecular sequence also influence their function and stability.

Blockbuster products have already been produced by efficiently employing the complicated biomolecules as pharmaceutics. These include, for example, adalimumab and insulin, that together account for a sizable portion of the biopharmaceutical market today [15,16]. However, biomolecules are particularly labile, and blood infusion is frequently necessary for their administration. Because there is a limited selection of delivery routes, it is also challenging to modify their pharmacokinetics (Fig. 2) [17]. Looking ahead, many businesses are working on developing nucleic acid-based pharmaceuticals in their R&D pipelines, which will require even more molecular stabilization and pharmacokinetics manipulation [18,19]. Simultaneously, improving challenging small-molecule pharmacokinetics through sophisticated formulations remains a highly pertinent objective for numerous stakeholder in the pharmaceutical sector [20- 22].

Drug distribution is the general term for the field of manipulating molecular characteristics to generate enhanced physicochemical profiles for pharmacological application (Fig. 2). Delivery of drug is an ambidextrous evolution of conventional drug assertion industry in the contemporary R&D industrial landscape. The synthesis of matter (i.e., nanosized) has found to be highly convenient for the interaction with human body and managing the distribution of drug, which is why nanotechnology has become fascinating topic in the delivery of drug since the founding of Nanotechnology National Institute (NNI) in 2000 [23-25]. Nonetheless, the drug delivery systems become more sophisticated due to the emphasis on nanoscale engineering. Subsequently, the high- throughput systematic series of efforts used in Quality-by-Trial techniques lost its ability to explore the vast design space involved in producing these intricate goods. As a result, quality-focused methods are being employed in the development and production of innovative goods to address the growing complexity of the quality of the product [26]. One of the best sectors for the application of artificial intelligence (AI) is fabricating innovation and pharmaceutical R&D, which is currently led by the transition toward quality-based rational engineering based on scientific principles [27,28].

Computational bioinformatics and simulations has grown in importance in pharmaceutical R&D as the lines separating applied physics, biotechnology, engineering, and pharmaceutical sciences

become less distinct. Proteomics and bioinformatics have witnessed a surge in the use of adaptive algorithms like neural networks, thanks to extensive genomics and proteomics initiatives. Modern computer techniques have just lately begun to show themselves as viable options for the industrialization departments and pharmaceutical R&D. Examples of this technology in use today support the development, manufacturing, and diagnosis of pharmaceuticals [29,30]. The early use of neural networks and other cutting-edge computing techniques in specialized fields like atomic simulations and systems biology has largely responsible for their rise to prominence. This is a result of the need for heuristic and fuzzy logic-based parsimonious approaches to complex computation. In pharmaceutical R&D, stratified adaptive algorithms like neural networks are still more common compared to sensing or deductive AI because they easily add computational capacity to already subsisting utilizations like modeling and silico research [31]. Therefore, sophisticated analytical techniques like artificial neural networks have been used in medication research and development for some time and have reached a definite level of maturity. But these were typically used for extremely special scientific jobs, such process control computation or molecular design and screens [29,32-34]. In the pharmaceutical industry, artificial intelligence (AI), which is meant to be a tool for deductive/inductive processes or certain sensing levels has still been used to a lower degree. This is due in part to the fact that AI works best to handle problems with large amounts of data or in surroundings with plenty of information when it is backed by well-organized, trained databases of information. There are currently few transferable AI examples that can be duplicated and developed because to the absence of huge systematized datasets, which is restricting the application of AI in drug industry [35-37]. On the other hand, the most compelling use cases for the product based on quality-by-design (QbD) creation are AI applications in the consumer and cosmetics industries. Here, marketing and product research are combined by joining vast databases of consumer preferences and associated product quality profiles [38].

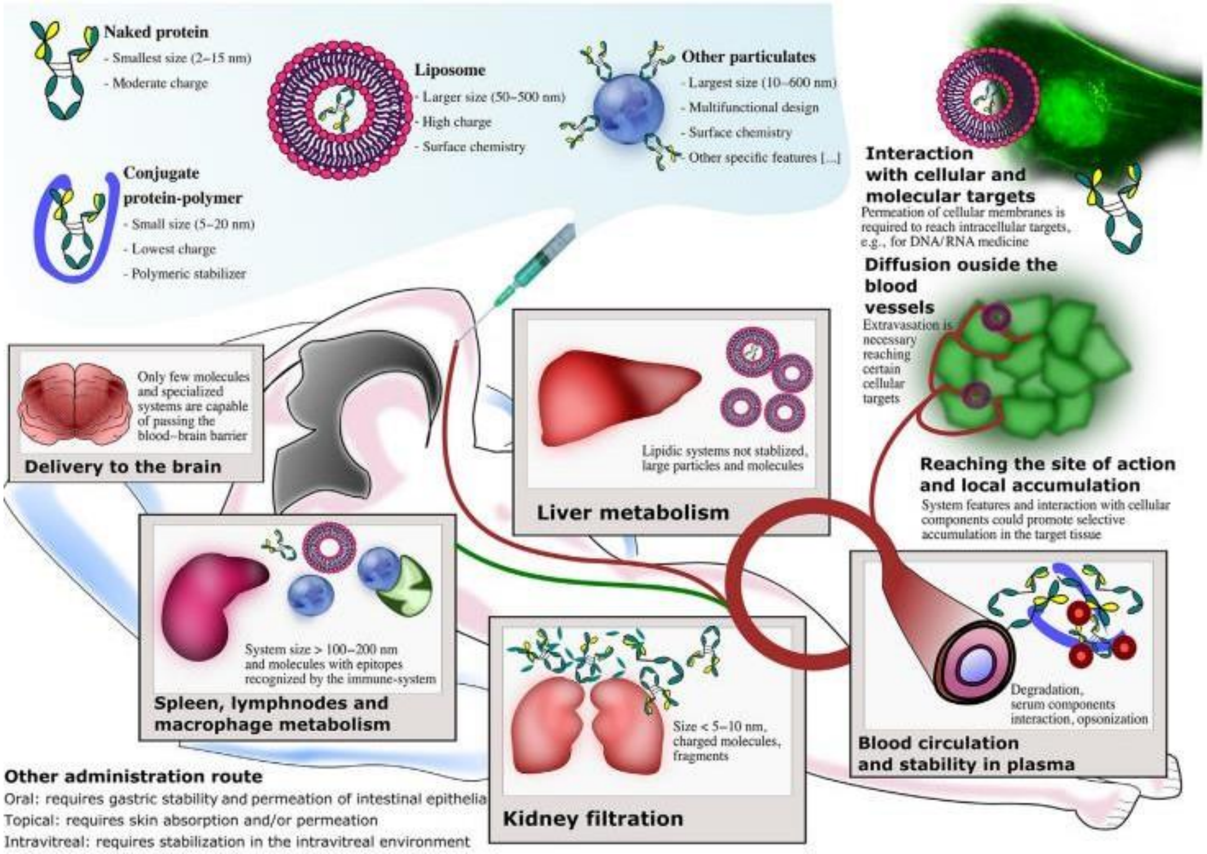

Figure 2. The drug delivery system has been manufactured to assist active pharmaceutical compound to conquer the biological barrier and enhance the absorption, the distribution, the metabolism, the excretion and the toxicity profile of the drug.

3. AI in health care

3.1. Assisted diagnosis: Artificial intelligence (AI) can now analyze MRI scans with significantly less possibility of error, enabling it to detect tumours and other cancerous growths at a much faster pace compared to radiologists. This is made possible by computer vision and convolution neural networks.

3.2. Administration: Artificial intelligence (AI) tools are helping with routine administrative tasks to reduce human error and increase efficiency. Medical note transcriptions using natural language processing (NLP) assist in organizing patient data for easier reading by physicians.

3.3. Robotic surgery: Robotic surgery can do surgeries consistently around the clock without experiencing fatigue and has an extremely narrow margin of error. Due of the great extent of precision could reduce amount of time that the patients require to recover and are therefore less invasive than conventional procedures.

3.4. Telemedicine: Patients can speak with a hospital's AI system outside of emergency situations to have it assess the symptoms, record the crucial signs and decide if the medical attention is needed. Medical professionals' burden has been reduced by only assigning them the most critical cases.

3.5. Vital stats monitoring: A person's health must be continuously assessed in order to determine how well they are doing. The use of wearable technology is growing, but the data it collects is not easily available and needs to be processed in order to yield meaningful insights. The crucial signs could predict changes in health even before the patient is consious of them, therefore many applications potentially save lives [39].

4. Applications of AI for drug discovery

4.1. Structure-Activity Relationship (SAR) Modeling: Artificial Intelligence tools have the capability to link the chemical structure pf the compound to the biological action. This makes it possible for the scientists to synthesize compounds with desired characteristics for instance high selectivity, potential along with advantages in account of pharmacokinetic, in order to optimize therapeutic prospects.

4.2. Drug Repurposing: Large-scale biomedical data can be analyzed using AI techniques to find medications that are currently on the market that may be useful in treating certain illnesses. Artificial intelligence facilitates to lower the cost of drug research by reusing present medications for novel uses.

4.3. Identifying the Target: Artificial Intelligence tools has the ability to recognize possible therapeutic targets by analyzing diverse data sources which includes clinical data, proteomic and genomic. AI helps in the drug growth that can modify biological processes by analyzing the molecular pathways linked to disease and targets.

4.4. Optimization of Drug Candidates: Pharmacokinetics, safety, and efficacy have been a few variables which AI algorithms may take into account while analyzing and optimizing drug candidates. Thus aids in the fine-tuning of medicinal compounds by researchers to maximize the effectiveness and reducing the negative effects if any.

4.5. Virtual Screening: Artificial Intelligence (AI) makes it possible to efficiently screen through large chemical libraries to find therapeutic members which have high likeliness of binding to the specified target. Artificial Intelligence aids researchers in saving time and resources by prioritizing and choosing compounds for testing the experiments by modeling the chemical interactions and scrutinizing the binding affinities.

4.6. Predicting the toxicity: AI tools has the ability to predict the toxicity of drug by examining the compound's properties and chemical structure. Machine learning algorithms that have been trained on toxicological databases are able to recognize potentially dangerous structural features or predict negative consequences. By doing so, researchers can reduce the possibility of unfavorable reactions in clinical trials and prioritize safer compounds.

4.7. De Novo Drug Design: Generative models and reinforcement learning are two tools that AI computers can use to suggest new chemical structures that resemble drugs. AI widens the chemical space along with supporting the design of the novel therapeutic prospects by drawing the understanding from the experimental data and chemical libraries.

All things considered, methods derived from AI in pharmaceutical development and research is likely to refine and hasten the procedure of optimizing, finding and scheming the nobel therapeutic members, which will eventually lead to highly effective and efficient drugs [40].

5. Application of AI in Pharmacodynamics and Pharmacokinetics

The process of developing drugs is intricate and encompasses various phases which includes the discovery of drug, preclinical investigations, clinical trials and the regulatory endorsement. Pharmacodynamics and pharmacokinetics play pivotal roles in the development of drug as this dictate the appropriate administration method, safety and dosage of the drug within the body [41]. Conventional experimental techniques for pharmacodynamics and pharmacokinetics research could be costly and time consuming and they might not always yield reliable predictions of the safety and efficiency of drugs [42,43]. Studies on pharmacokinetics and pharmacodynamics have often been carried out through experimental techniques including animal research and human trials. These techniques face significant obstacles, including sample size, inter individual variability, and ethical considerations. Furthermore, it's possible that these studies don't always yield precise estimates of the pharmacokinetics and pharmacodynamics of drugs in humans. Computational models and artificial intelligence techniques have been produced to overcome these constraints and forecast drug pharmacodynamics and pharmacokinetics more accurately, quickly and affordably [44,45].

6. Use of AI in drug delivery

The discipline of pharmaceutics has developed computational pharmaceutics, which uses multiscale modeling techniques to improve medication delivery processes. This is the result of the incorporation of data and AI in pharmaceutics. Machine learning and the AI tool pathways has been utilized in analytical pharmaceutics to assess enormous datasets and predict the behavior of medication. Without the need for lengthy trial-and-error studies, researchers can assess multiple scenarios and optimize drug delivery systems by simulating the articulation of drug and the process of delivery. This reduces the time it takes to develop new drugs, diminishes the costs and enhances the output. Modulating the delivery of drug at many scales, from molecular interactions to macroscopic behavior, is the focus of analytical pharmaceutics. To analyze the drug activity at each scale, artificial intelligence tools can examine the relations among formulation elements, pharmacological qualities and physiological variables. This helps in comprehending the drug delivery processes on a broader scale and facilitates the development of efficient systems for the drug delivery. It assists in the analysis of the drug's stability, physicochemical characteristics and in vitro release of drug. Together with the in vivo-in vitro correlation research, the same technique is also used for improved evaluation of in vivo pharmacokinetic frameworks and the distribution of drug. Researchers can identify the difficulties and the dangers associated with drug delivery systems by the use of the suitable set of AI tools (Fig. 3). This helps in enhancing the efficacy of drug and bringing down the risks by making adjustments. The likelihood of unanticipated results is decreased when AI and computer modeling are used instead of costly and time-consuming trial- and-error experiments [46,47].

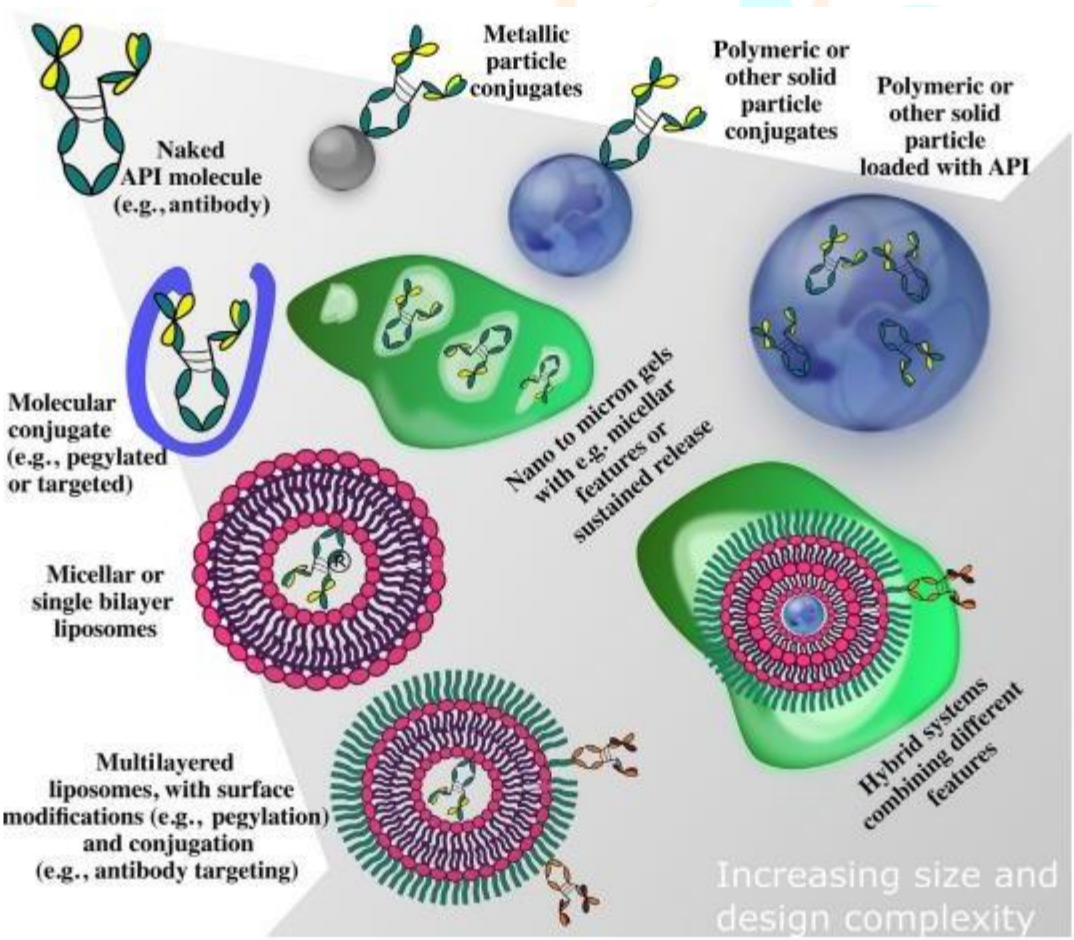

Figure 3. Drug delivery: Each system has been characterized by the high-quality profiles that could be utilized to enhance the effectiveness of the API or optimize its pharmacokinetics.

7. Challenges in Pharmaceuticals and the Role of Artificial Intelligence

Small molecules offer numerous benefits, thus the pharmaceutical industries are always researching them to improve goods and customer pleasure. One can make synthetic derivatives cheaply and with ease using the straightforward chemical synthesis procedure. The pharmacy industry therefore has a wide range of stable and effective small-molecule-loaded products. Clinical studies and sophisticated data are necessary for the introduction of many novel small compounds, with the exception of treatments for uncommon disorders, as they compete with generic molecules. Companies are under additional financial pressure to innovate as a result of these procedures. Nonetheless, in order to make up for the crises brought on by tiny molecules and inadequate research and innovation dissemination, the biomolecular pharma sector is nonetheless

expanding quickly. The shape and reactivity of small molecules determine their effects [48-54]. Ribonucleotides or nucleotides for nucleic acid are typically found in biomolecules coupled with amino acids from protein. The spatial conformation and supramolecular sequence also have an impact on their stability and function [55]. Certain biomolecules, like insulin and adalimumab, are highly profitable products. Given that infusion is these biomolecules' preferred and most practical mode of administration, the pharmacokinetic characteristics of these compounds are complicated. Important facets of research based on nucleic acid include molecular stability and pharmacokinetic modulation. Important objectives are the augmentation of the molecular forms and pharmacokinetic exposure. Recent technology developments could be useful in addressing these problems and resolving associated ones [56-61]. AI offers enormous potential for improving medicine delivery and discovery, but it also has significant drawbacks that eventually necessitate human intervention or the need for experts to understand the intricate outcomes. The datasets provide the majority of the AI predictions; but, because of the gray area in the results, human interpretation is necessary to arrive at the right conclusion. When processing data for predictions and evaluating hypotheses, AI may encounter problems with algorithmic bias. Furthermore, the finding of inactive molecules is a frequent outcome of docking simulations [62]. Therefore, in order to effectively make decisions and do cross-verifications in order to rule out system bias issues, a careful review of these factors still requires human input. However, given AI's enormous potential for use, a great deal of effort may be able to lessen its drawbacks and improve its effectiveness and dependability [63].

In terms of artificial intelligence, the approach that is being used makes use of machine learning/any of the portion of it, including natural language processing and deep learning. Both unsupervised and supervised learning are possible, and the kind of algorithm used is also very important. Unlike unsupervised learning, which works with unknown outcomes, supervised learning (machine learning process) makes the utilization of the familiar inputs and outputs. With the supervised approach, several inputs or attributes are used to predict the output for instance targets or labels. Conversely, the goal of unsupervised classification is to form feature- homogeneous groupings [64].

7.1. Limitations of AI:

AI-based models have many drawbacks along with their advantages which includes the requirement of huge datasets, lack of accountability and possible prejudice. To guarantee the safety and effectiveness of medications, models based on artificial intelligence should be utilized in conjunction with conventional experimental techniques. Below are some of the restrictions that are highlighted:

7.1.1. Lack of ability to Incorporate New Data: It might be difficult to update an AI model or add new data once it has been trained. With respect to the development of drug, where fresh data and information are continually coming, this might be a severe restriction.

7.1.2. Interpretation of Results: Even for professionals in the area, artificial intelligence models can produce outputs that are challenging to understand due to their complexity. Clinicians and researchers may find it difficult to comprehend and interpret the results if the models are unable to clearly explain how they came to their conclusions. It could occasionally be challenging to interpret the data into useful information for medication development or clinical practice. Further limiting their use is the possibility that using AI models may demand a technical proficiency that not all researchers and practitioners possess. In order to guarantee that the predictions made by AI models can be comprehended and applied efficiently, it is necessary to enhance the interpretability and explain ability of these models [65,66].

7.1.3. Absence of Transparency: Artificial intelligence tools, many a times known as "black boxes" as it is difficult to understand by what means the model makes the analysis. The AI models has been built by the use of intricate algorithms. The absence of transparency makes it tough to persuade the regulators to affirm the development of drug based on AI tools and is hard to prove that the model is fabricating convincing and precise analysis. A loss of confidence in the model's predictions can also result from a lack of transparency, especially if the model produces predictions that are at odds with what researchers or doctors would expect [67,68].

7.1.4. Limited Ability to Account for Variability: Large datasets have been typically utilized to instruct the AI algorithms, which can skew the results towards average responses seen in the data. Because of this, the algorithms might be unable to analyze the drug responses for people whose responses differ greatly from the norm. This is especially problematic when it comes to medications that cause a large variety of responses in various patients (like cancer patients), where the variability might be substantial [69].

7.1.5. Insufficiency of Clinical Expertise: Even though artificial intelligence can find correlations, it's important to understand that treatment plans for specific patients can differ even when correlations are found. Artificial intelligence algorithms are generally based on a statistical model, which may restrict their understanding of the complex variables and the significant impacts that particular parameters can have [70]. AI models that are mainly concerned with statistical associations face a hurdle due to the complicated nature of the situation, where treatment decisions are influenced by multiple unique aspects.

8. Conclusions

AI has been useful in a number of drug discovery domains. AI could support scientists with pharmaceutical development and delivery planning, design, quality control, maintenance, and management. It is not a panacea and won't cause drastic improvements over night, but it can boost productivity, offer practical insights, and bring to light fresh viewpoints in the discovery of the pharmaceuticals. Pharmaceutical firms are going through the radical change right now, where risk is being carefully handled in the creation of new practices and science. The degree to which AI integrates numerous novel and unfamiliar domains will determine how successful it is in creating drug research and development process. In this discipline, artificial intelligence can be used for medication discovery, managing data, digital consultation, treating diabetes, and other purposes. There is strong proof that medical artificial intelligence can greatly improve the efficiency with which patients and physicians provide healthcare in the 21st century.

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