WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Utilization of Artificial Intelligence in Pharma Field for Drug Delivery

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ABSTRACT

The science and technology of designing, creating, and using robots is known as artificial intelligence. Researchers in robotics also investigate software, mechanics, and electronics. By maximizing therapeutic delivery to the intended location, reducing off-target accumulation, and promoting patient compliance, drug delivery methods have made it possible to manufacture a wide range of pharmaceutical treatments that enhance patient health. Drug delivery systems evolved to meet the new problems as treatment modalities—which now include nucleic acids, peptides, proteins, and antibodies—expanded beyond tiny molecules. In this Review Article, we identify three drug delivery paradigms that serve as the foundation for modern drug delivery, talk about how they have aided in the initial clinical successes of each class of therapeutic, and discuss seminal approaches that led to the development of successful therapeutic products involving small molecules and macromolecules. We also describe how the paradigms will help administer treatments using living cells.

Keywords: Artificial Intelligence (AI) ,Drug delivery, Macromolecules, Therapeutic products.

INTRODUCTION

Paul Ehrlich had envisioned a magic bullet that could target specific sick parts of the body early in the 20th century. Scientists have been working nonstop to realize this idea ever since [1] around the globe. While more recent innovations such as tailored medicine delivery systems had great promise, the science fantasy notion of a medication-delivering mini-submarine that could travel within the body and target specific locations remained outside the range of possibility. Scientists are now more optimistic that they may realize this ideal thanks to developments in miniature electronics and sensors in the early 21st century [2]. In his well-known 1959 speech, "There's plenty of room at the bottom," Richard Feynman discussed ingesting tiny devices that may act as surgeons to heal illnesses inside the body. Nanotechnology was also launched with the speech [3]. Many methods for producing nanoscale materials have been developed during the past 60 years, and additional analytical methods have been created to describe these materials. The field of electronics has seen a remarkable shift as a result of advancements in nanotechnology [4, 5, 6]. According to Gordon Moore's well-known Moore's law from 1965, an integrated circuit's transistor count doubles every two years. These transistors used to be 10 μm in size, but now they are less than 30 nm [7].

The development of nanoscale electronic circuits facilitated the creation of capsule robots, which can enter the body to cure and detect illnesses.

Endoscopy was among the first fields in which these robots were used. A flexible endoscope is used in traditional endoscopy, when a physician inserts it into a patient's bodily cavity to image a suspicious area. Since their creation more than two centuries ago, physicians have been employing these endoscopes. They have been successful in helping medical professionals see the human body's urinary tract, gastrointestinal tract, and respiratory tract. However, using these endoscopes comes with a number of issues, including the possibility of infection, puncture, and rip. Furthermore, their primary disadvantage lies in their lack of user-friendliness, as endoscopy can only be performed under a physician's supervision [8].

Given Imaging introduced PillCam, the first commercial capsule endoscope, to the market in 2001. An appealing substitute for the conventional scope-based endoscopic method of viewing the GI tract was made possible by the easy, non-invasive eating of the tablet and the lack of anesthetic required [9]. As seen in Fig. 1, a variety of capsule endoscopes then inundated the market. Although capsule endoscopes were originally designed to examine problems in the small intestine, they are now used to evaluate problems in the stomach, oesophagus, small intestine, and large intestine. Still unsolved in the marketed goods are a number of issues including passive locomotion, telemetry, improved vision, and image sensing.

Robots have not yet succeeded in delivering drugs on a targeted basis, despite the success of capsule endoscopes. Many drug carriers, such as vesicular drug delivery systems [11], [12], particulate drug delivery systems [13], polymeric nanoparticles [14], carbon nanotubes [15], and quantum dots [16], have been used in targeted drug delivery. Each of these systems has a significant flaw. After these systems are ingested by the body, there is either little or no control over them. Furthermore, there are concerns with the existing form of these devices, including insufficient drug loading, stability, and safety issues. The success of WCEs has sparked a surge in research into creating intelligent capsule robots. The majority of these capsule robots may be generally divided into two categories: those that use non-mechanical systems and those that use microelectromechanical systems. Microelectromechanical systems (MEMS) employ wireless signals to regulate the release of the medicine and may or may not use anchoring mechanisms to remain in the targeted location. In non-mechanical systems, however, anchoring mechanisms are produced via magnetic interactions between an external magnet outside the body and a permanent magnet inside the capsule. In an attempt to improve controllability over capsule location and accomplish remote actuation of the drug release mechanism ,a number of capsule robots have been designed[17].

ROBOTIC PHARMACIES

Several hospitals and major health care clinics use robots to deliver medication because of the possible risks and enormous quantities. The number of robotic pharmacies in hospitals and clinics is rising quickly. That market is being served by a number of businesses, and interest in it will only rise. Local pharmacies will have difficulties when it comes to robotics on a retail level. Robotic pharmacy will proliferate more quickly due to regulations than because of accessible technology[18].

Such a system is currently in place at the UCSF medical center in California, and it is doing wonders for improving overall efficiency. The removal of incorrect medicine dosages and other faults mostly caused by human error may be the biggest advantage. Hospital pharmacies used to operate on a centralized paradigm, but this is starting to change. The intricacy of larger hospitals, with hundreds of beds spread across many divisions, makes it challenging to monitor the movement of medications from pharmacy to patient. Automated methods provide for far more efficiency in this type of tracking. Smaller hospitals do not yet have the resources available to cover the significant upfront expenses associated with implementing such automated systems, which is one issue. Nonetheless, there is a broad movement in that direction, so expenses will eventually decrease[19] .

ADVANTAGES OF INDUSTRIAL ROBOTS

1. Design Benefit

Robots that are swift, nimble, and flexible are ideal for pick-and-place and assembly tasks in a pharmaceutical setting. Industrial robots can construct blood sugar kits and other bespoke orders thanks to vision technology.

2. Safety Advantage

Robots safeguard patient and staff health as well as the integrity of pharmaceutical items. It is safe to combine hazardous substances with industrial robots. These specific robot types are intended for use in environments with clean rooms. These versions never contaminate product thanks to sealed arm structure and hydrogen peroxide vapor (HPV) cleaning. Robots that never stop picking and placing low-payload tasks that would be too labor-intensive for humans are now in charge of them.

3. Reliability

The Food and Drug Administration (FDA) mandates that every drug be monitored and traceable during the entire manufacturing process. Pharmaceutical firms find it simpler to meet these standards with the help of industrial robots. In a similar vein, robots reduce material waste and accidents.

4. Quality

Robots have the power to significantly raise the caliber of products. Applications are run consistently, precisely, and very reproducibly. It may be difficult to attain this degree of consistency in any other manner.

5. Can work continuously in any environment

Another advantage in the laboratory is that robots are impervious to many environments that would not be safe for humans. A robot can operate twenty-four hours a day, seven days a week without a dip in accuracy.

6. Increase Efficiency

Automation can boost productivity, which will drive down the cost of the medication itself. People are not as efficient as machines when it comes to producing pharmaceuticals, especially when they are donning protective gear. More space is also needed for those wearing safety gear to work in.

7. Cost

Payback periods for the acquisition of robotic equipment in the pharmaceutical sector, considering the quantity of production shifts, the relatively high hourly labor rates paid to staff, and the cheap cost of capital. An average robot installation might run up to $200,000 when accessories, conveyors, safety barriers, and personnel are included. The robot would be paid for in just over a year and a half via salary savings alone if it were to replace four manual laborers who each made around $30,000 annually [20].

DISADVANTAGES OF INDUSTRIAL ROBOTS

1. Dangers and fears

Fears and worries over robots have been voiced frequently in a broad range of literature and films, despite the fact that it is thought that contemporary robots have not evolved to the point where they offer any harm or risk to civilization. The main idea is that robots may be more intelligent and capable than people, and that if they did, they may grow morality and the desire to either exterminate or subjugate humanity.

2. Return on investment (ROI)

Using industrial robots does not ensure success. Without preparation, businesses may find it challenging to accomplish their objectives.

3. Expertise

Employees will require training in programming and interacting with the new robotic equipment. This normally takes time and financial output.

4. The future of robots in pharmaceutical manufacturing

The pharmaceutical business has a wide range of visual applications, making it one of the industries in robotics with the greatest development potential. In fact, it's only now that the full range of applications for material handling robots is becoming apparent. It is certain, although, that the core principles of speed, payload, and flexibility will remain crucial, and that TM Robotics and Toshiba Machine will keep working to provide industry-leading machines that both meet and exceed these demands.

WHAT ARE THE BENEFITS?

At the moment, robots are limited to using either the packed-down "unit doses" approach or the original packs method, which is also referred to as "one stop dispensing." A hospital should decide which approach to automate and which to use for the bulk of dispensing in order to reap the most benefits. The majority of US and European hospitals have previously delivered medications mostly in their original packaging or via unit dosage distribution before the introduction. The UK, on the other hand, combined these approaches, thus before robots was used, most of the supply chain needed to be reformed in order to adopt a "one-stop" or original pack strategy. Since this reform was completed, more than 150 hospital robot installations have been installed successfully[21].

Method of dispensing

In the UK, whole pack dispensing and imprest control are the main advantages of robotic dispensing. Although individual patient dispensing was formerly the more typical method, whole pack distribution has not always been as widespread, and pharmacy in the UK has developed when practicable. The UK Audit Commission's "A Spoonful of Sugar" report supported the practice change in order to lower overall costs and inefficiencies in the discharge and post-discharge procedures, as well as to make it easier to introduce robotic dispensing. Although the complexity of Australia's state and commonwealth split is recognized, this does not mean that the task is impossible to complete. With the shift towards polypharmacy, robotic dispensing has also shown improved time efficiency on prescriptions with several packs.

Type of products

Even in the brief period that they have been available on the market, robot technology has improved quickly. If jurisdictional legislation permits, fridge lines and schedule eight restricted medicine storage can now be permitted. But suppliers still have difficulties with freezer lines, bulky products like fluid bags and unboxed liquids, and this needs to be especially taken into account in pediatric and palliative care settings[22].

Transaction data

Since robot capacity ranges from 8,000 to 11,000 packs, tandem systems consisting of two to three robots are used in several bigger UK hospitals. Data on capacity and throughput, both current and anticipated, is required to determine the needs of specific institutions. This needs to be utilized with the kinds of items that the scope of services covers[23].

Safety & quality	**Financial**	**Process efficiencies**
Decrease in mistakes when dispensing	Lowering of stock holdings	Quicker dispensing procedure to shorten wait times for patients
Dispensary staff released to provide direct patient care in support of the new Clinical Pharmacy Model	Enhanced stock turnover and decreased waste from expiring inventory.	• After-hours operations; • Remote work with on-call availability; • Enhanced space usage

Fig1: Robotic Pharmacy Dispensing System Benefits

Artificial Intelligence for Drug Discovery

Drug development and research have been transformed by AI in several ways. Among AI's major contributions in this field are the following:

1. **Target Identification**

AI algorithms are able to find possible treatment targets by analyzing a variety of data sources, including clinical, proteomic, and genomic data. Artificial Intelligence aids in the development of drugs that can alter biological processes by identifying targets and molecular pathways linked to illness.

2. **Structure-Activity Relationship (SAR) Modeling**

AI models have the ability to connect a compound's chemical structure to its biological action. This enables scientists to create compounds with desired properties, such high potency, selectivity, and advantageous pharmacokinetic profiles, in order to optimize therapeutic prospects[24][25].

3. **Optimization of Drug Candidates**

Pharmacokinetics, safety, and effectiveness are just a few of the variables that AI algorithms may take into account when analyzing and optimizing drug candidates. This aids in the fine-tuning of medicinal compounds by researchers to maximize their efficacy and reduce any possible negative effects.

4. **Drug Repurposing**

Large-scale biological data may be analyzed using AI algorithms to find medications that are currently on the market that may be useful in treating certain illnesses. Artificial intelligence (AI) expedites and lowers the cost of drug research by repurposing current medications for novel use[26][27].

5. **Toxicity Prediction**

AI algorithms can forecast medication toxicity by examining a 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 may reduce the possibility of unfavorable reactions in clinical trials and prioritize safer compounds[28]

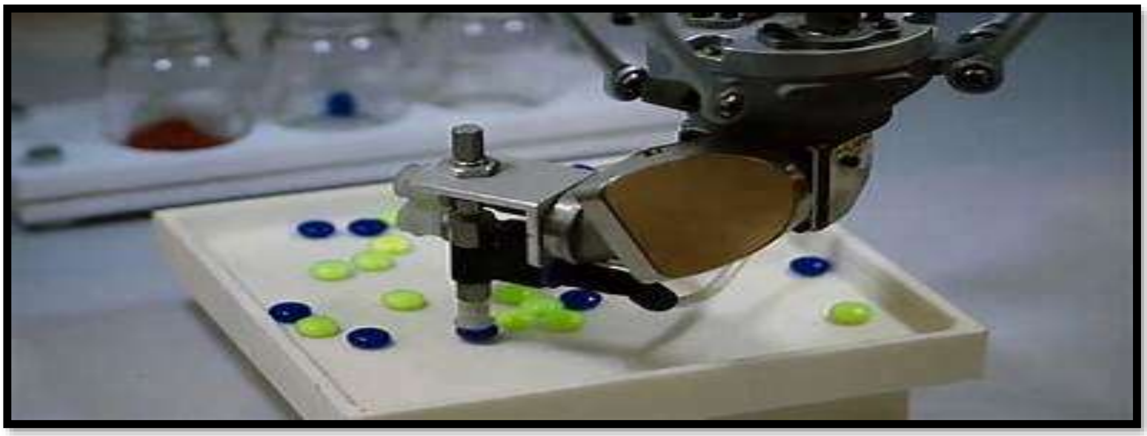
Artificial Intelligence for Drug Delivery

The discipline of pharmaceutics has benefited from the combination of AI and big data, as seen by the emergence of computational pharmaceutics, which uses multiscale modeling techniques to improve drug delivery procedures[29].

To forecast drug activity at every scale, AI systems may examine intricate correlations between formulation elements, physiological variables, and pharmacological qualities. This makes it possible to comprehend drug delivery mechanisms in more detail and facilitates the creation of effective drug delivery systems. It aids in the prediction of the medication's stability, in vitro drug release profile, and physicochemical characteristics. Along with in vivo-in vitro correlation research, the same technique is also used for improved assessment of in vivo pharmacokinetic parameters and drug distribution[30].

AI for Oral Solid Dosage Form Development

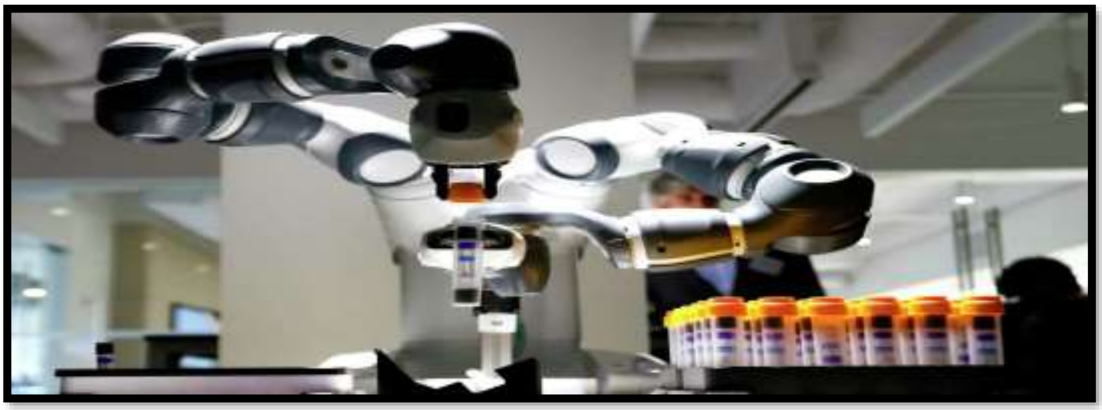
Tablets are one of the most often used dosage forms in the pharmaceutical industry, where solid dosage forms are the norm. Depending on the kind of tablet, there are several components to the preparation. AI can support both the investigation of the desirable properties involved in the formulation and the search for its optimal form[31][32]. With the use of automated technologies and algorithms, AI is also anticipated to handle duties. The regulatory bodies face a problem in updating their regulations about current good manufacturing practice (cGMP) due to the deployment of AI. A variety of artificial intelligence (AI) technologies, including neural networks, fuzzy logic, and artificial neural networks (ANNs), in addition to genetic algorithms, are used to design stable dosage forms and improve comprehension of the inputs and outputs for operations and processing. While genetic algorithms are used to forecast the outcomes of the usage of input parameters, artificial neural networks (ANNs) are utilized to improve prediction skills for solid dosage forms [33].



- **Prediction of Dug Release through Formulations**

Stable quality control is undoubtedly possible with medication release prediction. In vivo and in vitro techniques, which are regarded as foundational technologies routinely assessed or tested during product development, are used to carry out drug release studies. When processing settings and essential material qualities are combined, the medication is released from oral solid dosage forms. Compaction parameters, such as the pressure used to set the tablet's hardness, the geometric features of the tablets, and the properties of the drug loading are some of the frequent variables influencing drug release. Numerous analytical approaches have been used, such as spectrophotometric techniques, or drug release studies are often necessary for further in-depth research.

This work is laborious and time-consuming since the drug release findings have to be adjusted in accordance with the formulator's specifications, which necessitates repeated testing and batch preparation in order to produce an optimal batch [34]. Because AI is included into drug formulation and helps forecast drug release, fewer runs are needed to optimize the batch, which further reduces labor and expenses throughout pilot batch scale and production processes. Artificial Intelligence has the potential to forecast drug release and dissolution patterns, investigate disintegration times, and facilitate the efficient selection of the optimal batch for subsequent large-scale processing. With the use of artificial neural networks (ANNs), some researchers have integrated AI algorithms for the prediction of dissolution profiles into the hydrophilic matrix type of sustained-release tablets. Regression analysis and the support machine vector (SVM) are also used in the data analysis and dissolution profile prediction processes. Process analytical technology (PAT) was used to gather the data for the drug release modeling investigation in addition to vital material properties. It was discovered that the most important factor in model prediction was the particle size distribution.[35][36]



- **Application of AI for 3D-Printed Dosage Forms**

By allowing individualized medication and improving drug delivery methods, the use of AI in the field of 3D-printed dosage forms has transformed the pharmaceutical manufacturing industry. AI algorithms can provide customized pharmacological regimens by optimizing the design and composition of 3D-printed dosage forms based on patient-specific parameters like age, weight, and medical history. AI can evaluate massive datasets and simulate the behavior of 3D-printed dosage forms by utilizing machine learning and computational modeling. This enables quick prototyping and optimization of dose strengths, geometries, and drug release patterns. AI also helps with quality monitoring, printing parameter optimization, and anticipating and resolving any production issues. AI-driven feedback systems may also be used to constantly enhance 3D printing processes by improving accuracy, repeatability, and scalability by learning from real-time data. All things considered, the use of AI in 3D-printed dosage forms has enormous promise to advance customized medicine and enhance patient outcomes [37][38].

- **Application of AI for the Detection of Tablet Defects**

Quality control procedures in the pharmaceutical manufacturing industry have been completely transformed by the use of AI in the identification of tablet flaws. Images of tablets are analyzed using AI algorithms and computer vision techniques, which makes it possible to automatically and effectively detect flaws like chips, fractures, discolouration, or changes in size and form. Large datasets of annotated photos are used to train AI models, which help the system learn to precisely categorize and identify various fault kinds with high recall and precision. The interior structure of tablets has been studied using conventional techniques like X-ray computed tomography, however these techniques still take time and interfere with the need for quick tablet manufacture. To find tablet flaws, X-ray tomography and deep learning are used together. Ma et al. investigated using X-ray tomography-assisted image analysis to apply neural networks to tablet flaw detection. These scientists have produced many batches of tablets employing mannitol and excipients like microcrystalline cellulose. The so-called image augmentation approach was used to examine the created batches. In the same study, three distinct models were employed, one of which was UNetA, which may be used to identify tablet features from bottle characteristics. With the usage of enhanced analysis, Module 2 was utilized to identify certain tablets. With the aid of UNetB, the internal fissures in the tablet's interior structure were examined. These UNet networks have been utilized to more accurately verify tablet faults, making defect identification easier and requiring a large decrease in time, money, and effort [39][40].

CONCLUSION

Drug delivery systems are being revolutionized by AI, opening the door to individualized, tailored, and adaptable medicines. Pharmaceutical researchers and medical professionals may increase medication efficacy, reduce adverse effects, and improve patient outcomes by utilizing AI's strengths in data analysis, pattern identification, and optimization. Pharmacokinetics and pharmacodynamics are fields that have been transformed by AI-based techniques. They are superior to conventional experimental techniques in a number of ways. AI-based models can mimic medication distribution and clearance in the body, predict pharmacokinetic parameters, and optimize drug dose and delivery methods. Animal research and human clinical trials may be avoided by using AI-based computational techniques for PBPK models, which can streamline the creation of such models and optimize their parameters.

With the use of artificial intelligence (AI) and big data, computational pharmaceutics transforms the medication distribution process by offering a more effective, economical, and data-driven method. It makes it possible to optimize medication formulations, customize treatments, comply with regulations, and minimize risk, all of which eventually result in better drug manufacturing procedures and better patient results. All things considered, the incorporation of AI technology has enormous potential to expedite medication development, enhance patient outcomes, and completely transform the pharmaceutical sector, propelling it from an era 4.0 to an era 5.0.

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