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A REVIEW ON: ARTIFICIAL INTELLIGENCE- AN ASSET TO THE DRUG DELIVERY SYSTEM

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ABSTRACT

AI transforms drug delivery by improving treatments and making medicine better for patients, changing how we see the future of healthcare. Artificial intelligence (AI) algorithms that examine actual patient data can support personalized medicine strategies, improving patient adherence and treatment outcomes. The broad range of uses of AI in drug discovery, drug delivery dosage form designs, process optimization, testing, and pharmacokinetics/pharmacodynamics (PK/PD) research are examined in this thorough overview. This analysis highlights the advantages and disadvantages of the several AI-based strategies used in pharmaceutical technology. However, the pharmaceutical industry's ongoing investment in and investigation of AI presents promising opportunities for improving drug development procedures and patients.

Keywords: Artificial intelligence, Robotic Surgery, Drug Delivery System, Nano Robot

INTRODUCTION- [1, 2, 3]

The pharmaceutical industry is one of the many industries that are pushing novel approaches and accelerating their development to meet client expectations. Its operations depend on constant innovation

and assimilation of new technologies to address global healthcare challenges and respond to medical emergencies, like the latest epidemics. Pharmaceutical innovation depends on substantial R&D across various

domains. In recent years, there has been an increase in the focus on targeted delivery methods for treatments, to provide optimal efficacy and minimal side effects. Packaging solutions protect potency during storage and transportation, promoting patient compliance and medication stability. Customer-focused marketing techniques are also essential because they influence how treatments are viewed and used. Two primary categories emerge in this innovative landscape: biologics and small drug molecules. These developments prioritize improved stability and potency to address gaps in medicine. Small pharmacological molecules target particular pathways, potentially providing effective treatment for diseases that were previously difficult to treat. Conversely, biologics use biological systems to produce treatments that were previously impossible. These developments promise to change patient care in addition to offering better treatments. Customized delivery methods can improve drug absorption, reduce side effects, and guarantee accurate dosage, completely changing the way treatments are given. This development demonstrates the industry's dedication to improving healthcare and advancing the field toward safer, more efficient, and patient-centered solutions.

CURRENT PHARMACEUTICAL CHALLENGES AND THE

ROLE OF AI [4, 5, 6]

Due to their many benefits, small molecules are being researched in the pharmaceutical industry for better products and customer satisfaction. The chemical synthesis process is straightforward, and the preparation of synthetic derivatives is affordable, so many stable and potent small-molecule-loaded formulations are available in the pharmacy sector. Aside from treating rare diseases, many novel small molecules compete with generic molecules, and complex data and clinical trials are needed before they can be introduced. These procedures put more financial pressure on businesses to pursue more innovation.

AI offers enormous potential for improving medicine delivery and discovery, but it also has significant drawbacks that eventually necessitate human intervention or experts' demand to understand intricate outcomes. The datasets provide the majority of the AI predictions; but, due to 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.

APPLICATION OF AI [4, 7, 8, 9]

Several compartments within the human body are used to evaluate the effects of drug delivery. The biological membranes serve as a basis for additional compartment simplification. Physical-chemical barriers are essential for biological compartments and can be applied by the body's internal drug delivery system. The rate of permeation derived from the route of administration is one of the most important criteria for effective drug delivery system monitoring. The medication taken orally needs to penetrate the intestinal or gastric lining to enter the stomach environment. The drug's continued bloodstream distribution depends on this step. The medicament is delivered to the site of interest which may be material or any of the distinct cellular constituents during the dissemination step.

AI offers cutting-edge technology for this kind of multilayer data analysis. A deeper comprehension of the study units will result from the analysis's thoroughness. To optimize results, the methodically applied model and parameter evaluation are based on a variety of variables, including replication, assessment, and enhancement, at every stage of the research process. The system biology type of the databases indicates that a thorough perception of the drug-biological interaction is necessary for improvement. AI training within a biological setting involves teaching AI

systems to learn and adapt using data from living organisms or their surroundings. Artificial neural networks, among other cutting-edge AI technologies, can be used to conduct pharmacokinetic studies.

AI FOR DRUG DELIVERY [10, 11]

Computational pharmaceutics is the use of computers and mathematical models to design and optimize drug formulations and delivery systems that uses multiscale modeling techniques to improve the procedure of delivery of drugs. This is the result of the incorporation of AI and big data in pharmaceutics. To evaluate massive datasets and forecast drug behavior, computational pharmaceutics is used. Artificial intelligence algorithms and methods in machine learning without the need for lengthy trial-and-error experiments, researchers can assess different situations and improve the delivery of drugs by simulating the composition of drugs and delivery processes. This shortens the time it takes to develop new drugs, lowers expenses, and boosts output. Modulating drug delivery systems at various scales, from tiny interactions to big behavior, is the focus of computational pharmaceutics. To forecast drug behavior at every scale, AI algorithms can predict how drugs will behave at different levels by studying the complex connections between the elements used in their formulation. This makes it possible to comprehend drug delivery

mechanisms on a broader scale and facilitates the creation of effective drug delivery systems. It aids in the prediction of the drug's stability. In addition, AI makes a multitude of databases available, such as chemical, genetic, and observable databases, to enable a more thorough knowledge about how drugs interact with each other and an effective exploration of the role of intricate component that molecules play in them. Certain techniques are also employed to look into how the drug delivery system influences the drug's pharmacokinetics to fully understand the toxicity and disposition of the medication. Methods for drug delivery systems require designing quality and criticism. In addition to in vivo-in vitro correlation studies, this technology is employed to better evaluate in vivo pharmacokinetic aspects and drug distribution attributes and analyze how they will affect the trials before any actual trials are conducted. *in vitro* drug release profile, and physicochemical characteristics. At the initial stages of the development process, researchers can detect possible risks and difficulties related to the system of delivery of drugs by employing the appropriate set of artificial intelligence tools. This makes it possible to proactively make changes and adjustments to reduce risks and enhance the efficiency of medications. The likelihood of unanticipated results is decreased when Artificial intelligence and computerized

simulation are used instead of costly and time-consuming trial-and-error experiments.

TOP 10 LIST OF COMMONLY USED AI MODELS IN THE PHARMACEUTICAL INDUSTRY- AI/MACHINE LEARNING MODEL-

Generative adversarial networks (GANs)-

GANs (Generative Adversarial Networks) play a significant role in generating diverse chemical structures and refining their properties in pharmaceutical development. They consist of a discriminator network evaluating molecule quality and a generator network creating new variations to enhance drug candidate selection.

Recurrent neural networks (RNNs) [12] -

Recurrent Neural Networks (RNNs) are commonly utilized in drug development for tasks involving sequences, such as designing peptide sequences, analyzing genomic data, and predicting protein structures. They excel in generating new sequences by learning patterns and understanding the order of elements within data sequences.

Convolution neural networks (CNNs) [13]

Convolutional Neural Networks (CNNs) are effective in tasks related to images, such as recognizing potential drug targets and examining molecular structures. Their capability to extract key features from molecular images aids in target

identification and the process of drug design.

Long short-term memory networks (LSTMs) [14]

Long Short-Term Memory Networks (LSTMs), a variant of Recurrent Neural Networks (RNNs), specialize in capturing and predicting time-dependent relationships. These networks have proven valuable in assessing drug effectiveness and predicting drug concentration-time profiles within pharmacokinetics and pharmacodynamics research.

Transformer models [15]-

BERT(Bidirectional Encoder Representations from Transformers), a type of Transformer model, is used in the pharmaceutical field for understanding text. It helps researchers gather important information from patents, clinical trials, and scientific papers to create new drugs.

Reinforcement learning (RL) [16]

Reinforcement Learning (RL) methods have revolutionized healthcare by crafting tailored treatment plans and refining drug dosing strategies. These techniques enable sequential decision-making by learning from interactions with the patient's environment, without relying on predefined rules. By leveraging RL algorithms, healthcare providers can optimize doses and enhance patient outcomes by adapting to individual responses and circumstances.

Bayesian models [17]

Bayesian models, such as Gaussian processes and Bayesian networks, play a crucial role in drug development by handling uncertainty and aiding decision-making. They assist researchers in assessing risks, refining experimental designs, and providing predictions based on probabilities. These models are valuable tools that support informed choices throughout the drug development process.

Deep q-networks (DQNs) [18]

Deep Q Networks (DQNs), merging deep learning and reinforcement learning, have significantly enhanced drug discovery. They predict compound activity levels, identifying promising candidates for further experimentation. This amalgamation of techniques assists in streamlining the drug discovery process by suggesting potentially high-potential compounds for focused research and development efforts.

Autoencoders [19]

Autoencoders, an unsupervised learning tool, play a crucial role in drug development by extracting features and reducing the complexity of data. Their application in virtual and compound screening aids in identifying potential drug candidates. Moreover, autoencoders excel in capturing vital molecular aspects, contributing significantly to understanding and analyzing intricate details within molecules.

Graph neural networks (GNNs) [20]

Graph Neural Networks (GNNs) are specifically crafted to handle and analyze data structured in graphs, making them exceptionally fitting for tasks within drug discovery that revolve around molecular structures. Their unique architecture enables them to effectively interpret and extract valuable information from the complex relationships present in molecular graphs, proving highly advantageous in various stages of the drug discovery process.

DRUG DELIVERY SYSTEM IN PHARMACEUTICAL FORMULATION DEVELOPMENT-

1. Optimizing drug release from matrix tablet
2. Solid dispersion
3. Implants
4. Emulsion
5. Beads
6. Pellets
7. Microparticles
8. Transdermal Formulation
9. Nanoparticles
10. Nanomedicine
11. 3D Printing
12. Medical Devices
13. AI for Oral Dosage Form Development
14. Nanorobot-
15. Microrobot-

1. Optimizing drug release from matrix tablet- [21, 22, 23]

The release of drugs from matrix tablets made using the method of direct compression can be optimized by using AI methodologies. To model the dissolution patterns of various matrix tablets, researchers have created both static and dynamic Artificial Neural Networks (ANNs). ANNs were optimized using the GA optimizer tool or Monte Carlo simulations. The lipid and hydrophilic matrix tablet formulations with controlled release profiles had precise dissolution profiles that were predicted by Elman dynamic neural networks along with decision trees utilized. Elman neural networks were shown to be more effective at modeling drug release profiles in various types of matrix tablets than the most popular static network, MLP. Utilizing an Artificial Neural Network (ANN) model, enhancements were made to optimize the formulation and release behavior of time-dependent tablets. The technique of backpropagation neural networks played a key role in modeling and refining the tablet properties to achieve optimized results. In the optimized formulation, drug release data were close to the ANN-predicted release pattern, suggesting the usefulness of

ANN-based methods for designing and optimizing complex dosage forms.

2. Solid dispersion [24]

The most straightforward, effective, and widely accepted method of oral administration of drugs. Nevertheless, increasing drug solubility is a major obstacle to the oral administration of drugs and a significant current challenge for the field of pharmaceutical manufacturing. Thankfully, since the first SD formulation was discovered by Sekiguchi and Obi in 1961, researchers have discovered that SD can successfully enhance the drug release of poorly water-soluble medications, increasing the bioavailability of those medications. The procedure for developing new drugs has been considerably sped up by computational approaches, particularly machine learning methodology, as a result of the rapid expansion of data and the growing development of artificial intelligence. Machine learning utilized over the past few years not only to identification of therapeutic targets in medication, virtual screening, pharmacokinetics and toxicity of drug (i.e., ADMET) property evaluation, and drug repurposing but also progressively to address particular drug delivery issues. Machine learning techniques have been utilized to analyze and forecast the release of drug

behaviors and the physical stability of SD formulations.

3. Implants- [25]

It has been suggested that coating the cochlear implants would allow for the topical delivery of medications to treat infections or inflammation to handle the postsurgical issues related to cochlear implantation. The formulation variables and release profile of dexamethasone from the cochlear implant coatings have been predicted using an artificial neural network (ANN). An evaluation was conducted on the capability of the ANN model to identify the ideal levels of formulation parameters to obtain a suitable drug release profile. In addition to expediting the formulation design process, the artificial neural network (ANN) model accurately captured the drug-dispersing behavior from the implant device, and the model's efficacy was displayed by the results' remarkable similarity to the experimentally obtained.

4. Emulsion- [26]

A significant degree of experience and technical understanding is essential for adequately preparing the emulsion. To manufacture stable emulsions, artificial neural networks (ANNs) capable of modeling and optimizing the intricate interactions between formulation factors and the effects they have on product

quality have been utilized. This is because RSM has drawbacks, such as insufficient estimation of the best emulsions.

ANNs were utilized in a work by Kumar *et al.* to optimize the concentration of a fatty alcohol and create a stable oil-in-water emulsion. Lauryl alcohol concentrations and time were incorporated within the input data, and the variables zeta potential, particle size, viscosity, and conductance were taken into consideration as the outputs. The outcome of the validation studies showed that the values predicted by ANN agreed well with the experimental data.

5. Beads- [27]

The influence of process and formulation variables, such as coating weight gain, curing time, and plasticizer concentration, on the in vitro release profile of verapamil HCl from multi-particulate beads formulated with a novel aqueous-based pseudo latex dispersion was modeled by Vaithiyalingam *et al.* using artificial neural networks (ANNs)]. Verapamil HCl was employed for load nonpareil (inert beads), which were then coated with a conventionally made aqueous-based pseudo-latex cellulose acetate butyrate dispersion. A variety of bead formulations were created using a centered central composite experimental design as the

foundation. Using CAD/Chem software (version 5.1), the ANN model was built using the formulation and process factors mentioned above as inputs and the cumulative percentage of drug released at five different time points as outputs. The formulation and process factors intended for optimized formulations were chosen using a trained artificial neural network (ANN). The best possible formulations were then created and put to the test in vitro. Ultimately, it was determined that the optimized formulations' drug release data closely matched the ANN model's predicted release pattern.

6. Pellets- [27]

To predict the dissolution profiles of matrix-controlled release theophylline pellets made of glyceryl monostearate (GMS) and microcrystalline cellulose (MCC), Peh *et al.* created several artificial neural network (ANN) models. The NEURAL program constructed a multilayered perceptron (MLP) neural network with four inputs and one output to predict the theophylline pellets' dissolution profile. The ANN model was trained using the conjugate gradient and simulated annealing algorithms. The percentage of drug released at every sampling point was used as the output, and the quantities of MCC and GMS in the pellet formulations, the sampling time, and the disparity between the release rates of the preceding two time points served as inputs. An approach called LOO cross-validation

was used to train the ANN models. Every time point was predicted, resulting in a comprehensive release profile. The similarity factor, f_2 , was used to assess how similar the dissolution profile that the ANN predicted and the actual dissolution profile was. High f_2 values (above 60) in the results showed that the dissolution profiles predicted by the ANN were similar to the dissolution profiles derived from the physical experiments.

7. Microparticles- [28]

One of the two medicinal agents used to treat Chagas' disease is benzimidazole (BZL). However, because of its poor water solubility (0.4 mg/mL), BZL's application in the majority of pharmaceutical formulation and research studies is still restricted. To get around the oral absorption step where the dissolving rate is limited, chitosan microparticles are made using the coacervation method.

Due to the polymer's non-toxicity and the method's mild conditions, they were chosen. The impact of process parameters like as encapsulation efficiency, size, yield, and dissolution speed was optimized using artificial neural networks (ANNs).

Artificial neural network (ANN) analysis was utilized in the preparation and optimization of chitosan (CH) microparticulate systems made by the coacervation method (Ya-I *et al.*, 2007). Several factors' effects on the formulation of

the microparticles were assessed, to identify those that significantly impact the following four responses: size, encapsulation efficiency, yield, and rate of dissolution among the microparticles.

Investigating BZL microparticles' potential for the creation of quick-release systems was the goal of this work. The solubility of most oral medications affects how well they are absorbed in the gastrointestinal system. By using biocompatible polymers like CH for microencapsulation, this parameter can be changed (Daniel-Mwanbete *et al.*, 2004).

8. Transdermal formulation- [29, 30]

Transdermal ketoprofen hydrogel optimization has been achieved utilizing the creation of an ANN model. The response variables' ideal values were used for the optimization of the gel composition. The results of the optimal formulation were in reasonable agreement with the ANN model's predictions.

ANNs and RSM have been used for transdermal melatonin delivery to optimize vehicle composition. To avoid melatonin's remarkable hepato-gastrointestinal first-pass metabolism and to maintain its steady-state plasma concentrations for the necessary duration of time, the transdermal route was chosen.

Since stratum corneum's compact lipophilic matrix prevents melatonin from passing through, several solvents and their mixtures were utilized to enhance melatonin flux and

decrease lag time. It was decided to generate a multilayer feed-forward backpropagation network to determine the optimal solvent mixtures for each response and evaluate the inter-relativity among the responses. The results of the experiment matched the predictions.

9. Nanoparticles- [31]

When compared to traditional formulations, NPs can have several benefits. Small molecule and/or biopharmaceutical encapsulation. In addition to offering months of continuously controlled API release, NPs may protect the API from environmental factors, keep API concentrations within a safe therapeutic range, and deliver combinations of APIs in a synergistic ratio to improve the therapeutic effect. However, the number of NP formulations is small, at about 50 and 20 formulations, respectively, in comparison to the thousands of sustained-release oral delivery systems that have obtained regulatory approval over the previous 30 years. Because of their complexity—many parameters need to be considered to engineer the ideal formulation—it is challenging to introduce such advanced drug delivery systems to the market. The design of nanomedicines has also incorporated machine learning. Advanced delivery platforms that are nanoscale in nature, like NPs based on polymers or lipids, possess the capability to surmount significant obstacles

linked to conventional medications. One such barrier is the inability to administer combinations of active pharmaceutical ingredients (APIs) in a manner that maximizes their synergistic effects, as demonstrated by Vyxeos®. The utilization of nanomedicines is not limited to the administration of small-molecule chemotherapy drugs.

10. Nanomedicine- [32, 33]

Maintaining therapeutic doses at the target site has greatly enhanced the treatment results of extremely complex and deadly diseases. Nanomedicine integrates nanotechnology and medical practices for disease diagnosis, monitoring, and treatment. A common strategy for treating conditions like AIDS, cancer, diabetes, inflammatory disorders, and asthma is to prescribe multiple medications. When compared to monotherapy, medication combination improves safety and effectiveness through drug synergism. Recently, research has been focused on multifunctional nanoparticles that can deliver drugs and diagnostics at the same time. It is believed that these multifunctional nanomedicines will solve the issue concerning traditional cancer treatment.

Important considerations in drug design include the estimation and measurement of nano and the interplay of molecular interactions at the microscale, cellular mechanisms at the microscale, and resulting

physiological effects at the macroscopic level impact the drug's absorption, targeting, and delivery, targeting, and delivery on various scales. distribution networks. The US Food and Drug Administration (FDA) has recently taken advantage of computational tools to help recognize and fix issues during the formulation stage of the design of various medical devices.

11. 3d printing- [34, 35]

Three-dimensional printing (3DP) is a new rapid prototyping method that builds solid objects by simultaneously depositing multiple layers. The evolution and use of 3D printing have resulted in significant advancements in a broad spectrum of industries, including the pharmaceutical, tissue engineering, aerospace, architecture, and biomedical research fields. Because of its versatility and diversity, 3D printing technology appears to be leading a new era of the next industrial revolution. With advancements in science and technology, 3D printing technology has reached a point of maturity where anyone can use it with open-source software at a significantly reduced material cost. Interest in the potential to revolutionize healthcare lies within 3D printing technology, which has increased with the recent release of the first FDA-approved 3D-printed medication. Pharmaceutical formulation development is paying more and more attention to 3DP as an effective way to get around some of the

problems with traditional pharmaceutical procedural activities. For example, different final product qualities in terms of drug loading, drug release, drug stability, and pharmaceutical dosage form stability can arise from the traditional manufacturing unit operation of milling, mixing, granulating, and compressing. AI models can continuously learn and understand both structured and unstructured data. By taking these factors into account, the user won't need to keep training the models. Using this innovative method, four crucial parameters were predicted: extrusion temperature, filament mechanical properties, printing temperature, and printability to create drug-loaded 3D printed formulas. Several formulations were used to test and train the AI model. It was discovered that the M3DISEEN AI model had a high degree of accuracy in predicting printability, filament characteristics, FDM, and HME temperatures. A 3D bio-printed pseudo-bone drug delivery scaffold has been optimized to have the morphology, matrix strength, and matrix endurance of healthy human bone using MATLAB software and artificial neural networks (ANN).

12. Medical devices- [4]

A medical device is any kind of device, tool, equipment, machine, implant, or reagent used for particular medical purposes. It can be used in vitro to treat patients' medical problems Independently or when paired

with software or any other applicable system. AI has significantly improved medical device technology, changing healthcare in several ways. Since the pandemic, remote health monitoring and personalized medicine have become crucial and Independent or when paired with software or any other applicable system. Below are several instances highlighting the utilization of AI within medical devices.

Diagnostic assistance- helps medical professionals identify and diagnose diseases, artificial intelligence (AI) algorithms can examine data from medical imaging tests like MRIs, CT scans, and X-rays. For instance, AI-powered algorithms can assist in locating cancerous lesions on medical images or finding abnormalities on ECGs.

Remote monitoring- Artificial intelligence (AI)-medical devices empowered by technology can track vital indicators and other pertinent data continuously while remotely monitoring patients' health conditions. Patients with chronic conditions can benefit most from this as they can receive individualized care in the convenience of their own homes. AI systems can evaluate the gathered data and give healthcare providers warning or advice.

Wearable devices-Wearable technology includes AI in biosensors, health monitors, and smartwatches. Numerous health parameters, including blood sugar levels,

physical activity, sleep patterns, and heart rate, can be identified by these devices. AI algorithms can help with data interpretation and offer users practical advice for enhancing their health and well-being. **Surgical assistance- Artificial intelligence (AI)** is being used in surgical instruments to help surgeons during operations. For example, robotic surgical systems utilize AI algorithms to aid surgeons in conducting precise, minimally invasive procedures. Additionally, to enhance surgical results and offer live assistance, AI can analyze both preoperative and intraoperative data

Social media monitoring -

Social media use has been found to have many potential benefits in the healthcare sector. Social media is being used by patients to connect with people who have similar conditions and to research their symptoms.

Social media platforms are now the primary means of communication for health organizations to communicate with patients and other stakeholders. Health institutions can obtain useful data at various levels from these interactions, which also enhances remote patient monitoring. First of all, patients may use social media platforms to share health-related information with others, including symptoms, diagnoses, and available treatments. Health organizations can use this user-generated content to learn more about trends in public health, like the

spread of infectious diseases or the efficacy of particular treatments.

These instances illustrate the integration of AI into medical devices to enrich diagnostics, monitoring, treatment, and patient care.

For Instance, The multinational healthcare technology company Medtronic has created cutting-edge AI applications to support diabetes patient in effectively managing their condition. The Medtronic Guardian Connect system is one prominent example, which combines Artificial intelligence (AI) with continuous glucose monitoring (CGM) technology and provides immediate insights and assistance to individuals managing diabetes. In 2016, IBM Watson and Medtronic worked together to create the Medtronic Sugar IQ app, a mobile personal assistant for people with diabetes. With the use of artificial intelligence (AI), this app offers useful features for managing diabetes well. "Insights" is one of the main features of the Sugar IQ app. The patient receives customized messages and notifications from the app, which also analyzes the user's glucose patterns over a period to spot trends. People can better understand how particular behaviors, routines, and outside conditions affect their blood sugar levels thanks to these insights. Through acquiring this knowledge, individuals can make knowledgeable choices and proactively address their diabetes to enhance its

management. "Glycemic assistance" is the Sugar IQ app's second key feature. The application makes use of AI algorithms to offer users advice and suggestions in real-time based on their current blood glucose levels.

If glucose levels are consistently high or low, the app can suggest actions to assist the user in maintaining a more stable glucose range. This feature serves as a virtual assistant, offering users reminders and personalized support to help them make decisions about managing their diabetes. Lastly, there is a "food logging" feature in the Sugar IQ app.

Through the app, users can track their carbohydrate intake and log their meals. The software can then assess how various foods affect glucose levels and offer insights into how particular meals or food selections impact glucose levels. With this knowledge, people can make better-informed dietary choices, which improves glycemic control.

13. Ai in the development of oral dosage form - [36, 37]

AI uses modern software and hardware to develop abilities similar to those of humans. In recent years, this kind of innovation has been beneficial in many industries, including the pharmaceutical sector, especially in the product development stage. Using these technological advancements can reduce the amount of time, money, and resources needed for production and

efficient supply chain delivery to final consumers. Additionally, it offers a more complete structure for understanding how process parameters affect the formulation and manufacturing.

Run Han *et al.* conducted research into the utilization of machine learning methods for predicting the stability of six-month solid dispersions... Machine learning as a technique for studying the dissolution of solid dispersions was examined by Hanlu Gao *et al.* They created a classification model using a random forest algorithm, which aids in further differentiating between the parachute and spring forms of dissolution profiles. Moreover, it supported the preservation of supersaturation with 86% sensitivity and 85% accuracy. The random forest algorithm generated a regression model utilized for predicting the time-sensitive drug release.

Tablets represent one of the most prevalent pharmaceutical dosage forms, particularly in the pharmaceutical industry, where solid forms are prominent. Depending on the kind of tablet, there are numerous components involved in its preparation. AI aids in researching the desired attributes essential for the formulation and assists in seeking the most efficient form of those attributes. With the help of automated technologies and algorithms, AI is also anticipated to handle obligations. The regulatory bodies are faced with a challenge in changing policies related

to current good manufacturing practices (cGMP) due to the implementation of AI. Artificial Intelligence (AI) includes various technologies, including neural networks, fuzzy logic, and genetic algorithms. These technologies are employed for the development of solid dosage forms and to enhance comprehension regarding inputs and outputs in processing and operations. Genetic algorithms predict outcomes based on input parameters, while artificial neural networks (ANNs) specifically improve the prediction capabilities for solid dosage forms.

14. Nanorobot- [38]

Nanorobots, or smart structures capable of intelligent behavior such as actuation, sensing, signaling, information processing, manipulation, and swarm behavior at the nanoscale, are examples of nanorobots, that are used in nanomedicine. According to Wagner *et al.* (2006), nanorobots are unique medical devices based on their structural makeup. The treatment for several diseases and disorders, such as AIDS, diabetes, and cancer, may be greatly improved by the use of nanorobots. Several academic fields, such as biology, chemistry, physics, engineering, and computer science, are working together to create this new drug-delivery technology. According to Cavalcanti *et al.* (2008a) and Zhou and Wang (2011), the first healthcare applications of nanorobots are anticipated to be developed shortly and may have a variety

of biomedical uses. There are several benefits to using nanorobots for drug delivery in cancer treatment compared to the existing methods of chemotherapy and radiation. Chemotherapy drugs target fast-growing cells in the body, including cancer cells and healthy cells as well. They are introduced into the body through the mouth or are injected. This may result in adverse side effects like hair loss as well as degenerative health effects like damage to the heart and digestive system (Cavalcanti *et al.* 2008a). The harmful side effects effectively reduce the amount of drug that reaches the tumor by limiting the dose of the drug that is administered. In a specific drug delivery system, the nanorobots recognize the tumor cells and deliver the drugs directly to them as shown in fig no.1. By doing this, the patient's quality of life would increase and the unwanted effects would be reduced. Both during and following the course of treatment (Karan and Majumder 2011; Cavalcanti *et al.* 2008b). In addition, because there is a lower chance of adverse effects, the dosage of the medication that reaches a tumor cell can be managed and even increased.

Microrobot- [39]

The of the drug from release from a microrobot is shown schematically. Together with a drug reservoir for time-controlled, targeted drug delivery, the robot is made up of microsensing, microactuating,

and microcontrol units as shown in Fig no.2. Microrobot moves toward the target under the control of microcontrollers and then releases the drug. Because microrobots are reusable, they can return to the specific target area with a different drug reservoir.

Many developments in effective drug distribution have resulted from the drug delivery system's advancements over the past few decades. Microrobots are thought to be the best drug delivery systems because they can effectively deliver drugs by converting other sources of energy into motion and propulsion. Moreover, it can be beneficial because it is focused on specific locations that are beneath physiological conditions and environments. Their ability to encapsulate, transport, and supply therapeutic contents directly to disease sites has been validated, improving therapeutic efficacy and reducing the toxic drugs' systemic side effects.

Microrobots have a lot of promise for precise targeting and manageable side effects in controlled drug delivery. Robot path planning for coverage area is one of the main challenges for controlled drug delivery. The advancement of electronics and nanotechnology have resulted in novel developments that will revolutionize the current methods of diagnosis and treatment. This innovation, known as Medical Capsule Robots, is based on the science fiction notion of robots entering the body to detect

and treat illnesses. The capsule endoscope, designed to take pictures of the gastrointestinal system, was the first commercially available capsule robot. The current methods of identification and therapy could be completely changed by capsule robots. The uses of medical capsule devices for medication delivery, surgery, and diagnostics are covered in detail in this paper. A thorough examination of wireless capsule endoscopes in diagnostics has been provided, along with a discussion of the problems with commercially available models and the literature's solutions.

ADVANCEMENTS DRUG DELIVERY SYSTEM- [40]

Merging Advanced Technologies with Drug Delivery-

The use of AI and machine learning methodologies in biomedical research offers fresh opportunities to improve medicine delivery. Artificial Intelligence (AI) possesses the capability to create strong correlations between release patterns and formulation parameters and enhance the drug delivery system performance. To anticipate medication diffusivity from various mucoadhesive formulations, for instance, a cascade computer model was created. AI still progressing in practical applications, even though it has the potential to revolutionize drug delivery. To take full advantage of AI's indications in medicine

delivery, further work must be done to enhance interpretability, provide assistance in choosing machine learning models, and enhance the quality of the data acquired.

Combining soft electronics, sensors, chips, an external or internal power source, micro- or nano-robots, and medicine delivery is an interesting new avenue. For instance, the ingestible wirelessly transmitted IntelliCap (AAPS) gadget has temperature and pH sensors in addition to a microcontroller that controls the pump and a motor that facilitates medication release. A different example is a robotic pill based on a liquid autoinjector that has been demonstrated to enhance the bioavailability of biologics, such as peptides or proteins, by up to 80% when taken orally. Long-lasting medication delivery systems that integrate safe, energy-efficient microchips with chip-to-cloud technology may provide continuous data access, enabling both the patient and the physician to track the release profile and make any adjustments.

To verify the correct functioning of a drug delivery microchip, for instance, a computer-based programmer interacted wirelessly. The microchip was intended to administer microgram amounts of an antiosteoporosis medication once daily for a maximum of three weeks. Additionally, we anticipate a rise in the usage of apps and mobile devices to collect data that might be used to spot important trends, such as

treatment regimen adherence, and ultimately boost overall efficacy.

While combining these cutting-edge technologies with drug delivery is exciting, a deeper comprehension of biological processes, robot interactions with organs and cells and their movement mechanisms, and algorithms for controlling against environmental perturbations are necessary for these technologies to advance toward clinical use.

Capsule robots for drug delivery-

The capsule robots that are currently on the market are passive devices that typically need surgery after a condition is diagnosed. Capsule microbots have the potential to accurately diagnose and treat diseases in the future. Pathologies such as small bowel tumors, Crohn's disease, and obscure gastrointestinal bleeding require clinical attention. The idea of remotely controlled capsules, or RCCs, was first conceived in the 1980s, long before WCEs were developed. Researchers have been motivated to create capsule robots that target and treat particular gastrointestinal disorders by the success of these robots in diagnosing GI disorders.

Robotic surgery- [41]

Surgical innovations that are successful concentrate on improving patient safety and quality of life. A virtual patient model can aid in planning and simulating the surgical approach. The 3D model can even be

combined with real-time patient images to provide an instrument for intraoperative navigation that shows target structures and anatomical differences. Combining real-time visuals and artificially produced images on a computer is described as the use of augmented reality. A robot is a mechatronic device, which combines mechanics, electronics, and informatics. It can be manually operated through a mechanical or computer-based interface, or it can be programmed to carry out specific tasks or task sequences automatically. In the 1970s, robotics was used in surgery as part of a military project supported by the Défense Advanced Research Project Administration (DARPA) and approved by the National Aeronautics and Space Administration (NASA). The goal was to replace the surgeon's physical presence in the operating room and to provide care for soldiers in combat zones or astronauts in spacecraft. In the event of a natural disaster, remote-controlled robots could operate in secure surgical groups. Robots of the first generation entered the operating theatre to carry out precision tasks guided by images. In 1985, a CT-guided brain biopsy utilized a modified PUMA 200 industrial robot (Programmable Universal Manipulation Arm; Unimation, Stanford, California, USA). The da Vinci® Surgical Robotic System represents a remarkable amalgamation of technology.

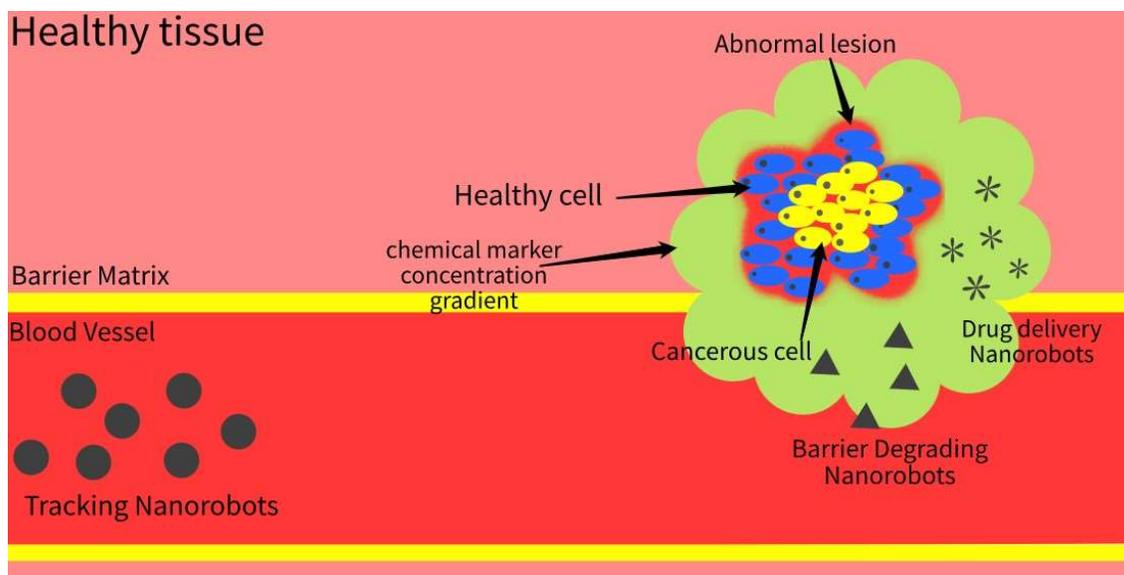


Figure 1: Biosensors and transducers embedded in nanorobots have the potential for targeted drug delivery and the detection of tumor cells

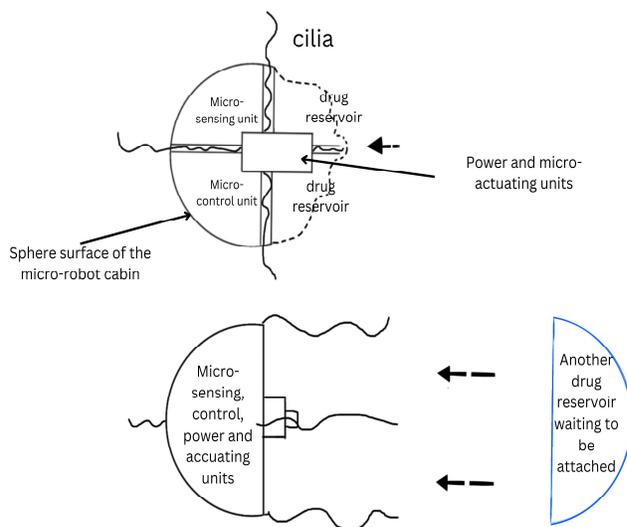


Figure 2: Drug Release from Microrobot

Table 1: AI Based Technology Used for drug delivery

Sr. No.	API	Technology	Formulation	References
1	Salicylic Acid	Stereolithography	Facial Mask	42
2	Pseudoephedrine		Cubic tabular devices	42
3	Aripiprazole	Abilify Mycite	Tablet	43
4	Insulin	Implantable Robotic device	PILL Refill	44
5	Aptatinib	Implanted triboelectric nanogenerator (iTENG)	PILL Refill	45
6	Morphine	Medtronic Synchromed		46
7	Corticosteroid	ELLIPTA Inhaler	Aerosol	47
8	Corticosteroid	DISKUS DPI	Aerosol	47

CONCLUSION- Artificial intelligence in drug delivery systems is a big deal.

AI has changed how medicines are delivered. It helps make drugs better, finds the right way to give them, and makes developing new drugs faster. By using AI's smart algorithms, we can analyze a lot of info to predict how drugs work together, make treatments just for you, and make giving medicine easier. This helps make treatments better and more exact for patients.

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Abbreviations:

PK/PD	Pharmacokinetics/Pharmacodynamics
GAN	Generative Adversarial Networks
RNN	Recurrent Neural Networks
CNN	Convolution Neural Networks
LSTM	Long Short-Term Memory Networks
BERT	Bidirectional Encoder Representations from Transformers
RL	Reinforcement Learning
GNNs	Graph Neural Networks
ANN	Artificial Neural Network
SD	Solid Dispersion
GMS	Glyceryl Monostearate
MCC	Microcrystalline Cellulose
CH	Chitosan
API	Active Pharmaceutical Ingredients
FDA	Food and Drug Administration
CGM	Continuous Glucose Monitoring
RCC	Remote Controlled Capsule
WCE	Wireless Capsule Endoscope