

# Smart Composite Material Based Drug Delivery System with Integrated AI Driven Disease Monitoring

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Received: 12th Mar, 2026 | Revised: 24th Mar, 2026 | Accepted: 14th Apr, 2026 | Available Online: 30th Apr, 2026

## ABSTRACT

A breakthrough of smart composite material-based drug delivery systems, combined with AI-driven disease monitoring, is a large step towards personalized medicine. The proposed study aims at designing, synthesizing, and testing smart composite materials to facilitate the release of drugs in response to physiological stimuli in a precise and controlled manner. Moreover, AI algorithms will also be used to track the development of the disease in real-time, streamlining the delivery of medications to achieve better therapeutic results. The system uses the information obtained via wearable devices and medical sensors to help modify the rate of drug releases, making treatment simultaneously timely and response-specific. The early experimental findings indicate the possibility of the system in enhancing the effectiveness of the drug delivery system at the lowest side effects. The work is a step in the right direction in combining advanced materials and artificial intelligence technologies in next-generation medical devices.

**Keywords:** Smart Composite Materials, Drug Delivery System, AI-driven Disease Monitoring, Machine Learning, Stimuli-responsive Materials, Controlled Release, Personalized Medicine, Wearable Devices, Medical Sensors.

**How to cite this article:** Vairamani G, Dhanabal M, Arul A, Boopesh P, Nandha Baalan G, Dhaamesh R. Smart Composite Material Based Drug Delivery System with Integrated AI Driven Disease Monitoring. *Int J Drug Deliv Technol.* 2026;16(39s): 900-908. DOI: 10.25258/ijddt.16.39s.122

**Source of support:** Nil.

**Conflict of interest:** None

## Introduction

Bringing smart composite materials into the sphere of drug delivery systems has transformed medical treatments, offering them more efficient, and controlled therapeutic solutions. The latest way of drug delivery is with smart composite materials that are typically programmed to react to environmental factors like pH, temperature, or even certain biochemical cues[1]. The system is not as dependable on the more conventional release mechanisms used in traditional drug delivery systems, thus, smart composites are able to deliver therapeutic agents in a regulated mode of delivery with a better aim of targeting the site of action hence reduce the systemic side effects and enhance the therapeutic effect[2]. These classes of materials that are more flexible according to the latest innovations of nanomaterials as well as responsive according to the latest innovations of polymers and other biocompatible segments are designed to meet the dynamic needs of patients being treated[3]. With the use of such systems,

it is possible to more accurately, efficiently and flexibly apply drugs depending on the circumstances, which is especially useful in multifactorial treatment regimens, like cancer therapy, the management of chronic diseases, and wound healing[4].

Conventional systems used in delivery of drugs though effective normally have a major drawback in terms of controlling of release as well as targeting. The majority of traditional procedures, e.g. oral or intravenous injection, do not offer the features of controlled and prolonged release, therefore the changes of drug concentration, the lack of the best therapeutic results and the possibility of the adverse side effects[5]. Additionally, they ignore the fact that patients might respond differently individually, a drawback that is further enhanced in personalized medicine. Monitoring of disease is also a problem because the present technologies fail to provide a real time or dynamic feedback on the state of the patient and hence cannot change the treatment plans fast[6]. This could lead to

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slow turnaround in patients, increased side-effects or inefficient treatment particularly in chronic or progressive diseases. The necessity of more effective, and focused as well as versatile drug delivery solutions has resulted in systems that combine real time monitoring technologies with smart materials[7].

The fundamental aim of using AI-driven disease monitoring in conjunction with smart composite materials is to remedy the weaknesses of traditional drug delivery systems by developing an adaptive, responsive and personalized treatment system. Armed with information on multiple medical sensors and wearables, AI-powered disease monitoring systems help continuously track the health condition of the patient[8]. This data is then acted upon by machine learning algorithms that identify patterns, forecast disease progression, as well as real-time adjustments of drug release. This integrated system allows not only the controlled release of the drug, but the personalized drug release by connecting the intelligent responsiveness of composite materials with real-time monitoring of various diseases: the drug release depends not only on the state of the individual, but also on its further development[9]. To illustrate this, with cancer treatment, the system may be able to determine the dosage or release rate of chemotherapy drugs given to the patient depending on the size, location, and rate of growth of the tumor based on the analysis of imaging data through AI. This will maximize therapeutic effect and reduce side effects[10].

The combination of these hi-tech technologies has a tremendous potential to revolutionize healthcare. Through delivering drugs more precisely and adding the real-time monitoring of the disease, patients will experience better treatment results, and a decrease in the amount of undesired side effects. These systems may be of great importance in diseases that require accuracy and timeliness, including cancer or diabetes, to be able to manage symptoms and disease progression. In addition to that, individually tailored treatment is easier, and its approaches can be constantly modified according to the needs of a patient. Such customization guarantees that patients can get the correct drug, and the correct dose and at optimal time, which is aligned with the emerging trend of precision medicine. Moreover, this system could open the door to new models of medical systems and methods of treatment which recognize artificial intelligence and smart materials to develop more effective and sustainable health systems. The fusion of intelligent materials and AI will result in tremendous advancements in cost reduction in healthcare through

the enhancements of treatment effectiveness, shorter hospitalization, and less invasive practice.

### Literature Review

#### *Smart Composite Materials in Drug Delivery*

Smart composite materials have become an exciting solution to drug delivery in that they provide a means by which the therapy can be controlled and localized. They are designed to react to external or internal conditions, e.g. changes in PH, temperature, light, or biochemical conditions, allowing them to be very versatile to different physiological situations[11]. One of the most commonly studied materials in the case of drug delivery system is stimuli-responsive polymers[12]. These polymers conform or change structure depending on the environmental conditions, and may induce the release of the encapsulated drugs on sites or at designated times. As an example, pH-sensitive polymers are used in systems such as in the gastrointestinal tract or cancerous tissues, where the pH differs greatly with the adjacent healthy tissues. Equally, hydrogels that are temperature sensitive may be utilized to release drugs with a changing body temperature, thus enabling local delivery of drugs upon demand[13].

Another type of smart composite material that is also becoming prominent in the drug delivery system is nanocomposites, which are nanoparticles that are combined with a polymer or other material. Such nanocomposites can increase the solubility, stability and bioavailability of drugs with controlled release characteristics[14]. Hydrophobic and hydrophilic drugs can be effectively encapsulated in nanoparticles like liposomes, dendrimers or mesoporous silica particles. An addition of nanostructures not only increases the loading capacity of the drug delivery vehicle but also facilitates increased penetration of the biological barriers (i.e., cellular membranes) which is pivotal in treatment of such diseases as cancer. Multifunctional capabilities of nanocomposites, including their capacity to deliver dozens of drugs or a therapeutic + diagnostic capability are also fueling their application in newer drug delivery technologies. They can also be incorporated to be delivered specifically to target the area of disease reducing the side effects and enhancing therapeutic effects[15].

#### *AI in Disease Monitoring*

Techniques of Artificial Intelligence (AI), especially machine learning (ML) and data analytics, have been utilized to predict, diagnose, and monitor diseases more often. These methods take into consideration vast amounts of data gathered through a number of different sources, including electronic health records, medical

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imaging, wearable devices, and sensors, and try to identify trends and make predictions about how a disease will progress, or how treatment will be effective or not[16]. Through machine learning algorithms, including support vector machines, decision trees, and neural networks, it is typical to predict disease states or other anomalies which can indicate the development of a health condition[17]. With the sphere of personalized medicine, AI has made it possible to create systems that continuously track the health status of patients and provide feedback in real-time that is necessary to make the necessary adjustments to their treatment regimens.

When it comes to forecasting diseases, AI models have demonstrated considerable potential in fields such as oncology, cardiovascular diseases, and neurodegenerative disorders. In the case of medical devices, AI-based systems have the ability to scan medical images (MRI or CT scans) and identify early tumor or abnormalities that the traditional technique cannot detect with the same rate of accuracy. Continuous glucose monitors in conjunction with AI algorithms are utilized in the management of diabetes to predict the level of sugar and prescribe appropriate measures to ensure that the disease is managed more accurately in future. Moreover, along with the introduction of AI and the incorporation of wearable devices[18], the framework of disease monitoring has been broadened with the ability to track vital parameters like heart rate, respiratory rate, and physical activity in real time, which are essential in controlling chronic illnesses. The data analytics of these systems give an opportunity to monitor the diseases much more accurately and intervene in advance to enhance the patient outcomes and decrease the number of hospitalization.

### **Previous Work on Integrated Systems** 2.

Motivated by the recent years and successful implementation of AI-driven disease monitoring technologies alongside smart composite materials, the integration of the two has attracted interest, with a number of studies examining the potential usefulness of such integrated systems. Studies on creating systems uniting responsive drug delivery materials with real time disease monitoring have been involved just to enable more effective and individualized treatments to be given[19]. To illustrate, some integrated systems incorporating pH-responsive materials to regulate drugs release have been paired with AI algorithms designed to analyze real-time patient data, predict the progression of a disease and control the dose of drugs given in response. This has been considered in cancer

treatment with both the smart nanocomposites and AI-based monitoring system potentially maximizing the delivery of drugs to tumor cells by their size, position, and growth rate.

In spite of the advancements in this field, the existing body of knowledge has a number of gaps. A tremendous problem is the paucity of clinical translations of these integrated systems. Although great progress has been done in the laboratory, strategies to ensure that these technologies can be applied in real-world clinical environments have many obstacles such as regulatory challenges, biocompatibility challenges, and the intricacy of implementing AI systems with medical equipment[20]. Moreover, although AI algorithms are promising as disease outcome predictors, the reliability and validity of these models is a concern. The quality and quantity of the data on which AI-driven systems are trained are extremely critical and more varied and comprehensive datasets should be made to enhance the stability of these models.

Another issue is the challenge of coming up with systems that can cater to the drug delivery and disease monitoring needs in a seamless and integrated approach. Drug delivery and monitoring are two functions that tend to be isolated in the current systems with little interaction between the two. In order to get the most out of personalized medicine possibilities, it will be important to conduct future study to establish systems in which the two elements are mutually supporting and complementary, where AI algorithms have the freedom to regulate drug release process in real-time in response to monitoring results. Moreover, to make these integrated systems popular in clinical practices, it is essential to guarantee their safety, reliability, and scalability.

### **Methodology**

#### **Materials**

The composite materials the drug delivery system uses are carefully chosen on their biocompatibility, response to physiological conditions and their possible ability to provide therapeutic agents in a controlled manner. The basic materials of the system are biocompatible polymers which include polyethylene glycol (PEG), poly(lactic-co-glycolic acid) (PLGA) and polylactic acid (PLA). Drug delivery applications that make full use of these polymers include their non-toxicity, degrading to non-toxic byproducts, and flexible processing. They can be programmed to react to a particular stimulus, e.g., pH, temperature or enzymes, which enables the drug to be released locally in response to the microenvironment.

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Along with biocompatible polymers, the nanoparticles are incorporated into the composite materials to perfect the workability of the drug delivery system. The use of nanoparticles, including liposomes, dendrimers and mesoporous silica nanoparticles is due to their large surface area and capacity to entrap various drugs including hydrophobic ones. These nanoparticles enhance solubility, stability and bioavailability of the drug as well as loading and releasing the drug effectively. Another advantage is that with the use of nanoparticles the system can access certain locations in the body, including tumors or inflamed tissues, by functionalizing the nanoparticles using targeting ligands to detect certain biomarkers. The combination of responsive polymers and nanoparticles creates synergistic results wherein delivery of drugs is more precise, more stable and releases more continuously which is a critical part of an effective treatment regimen.

The production of these composite materials entails varying approaches, and they include emulsions polymerization, solvent evaporated and co-precipitation approaches. As an example, nanoparticles made of PLGA are generally prepared by solvent evaporation method, where the polymer is dissolved in an organic solvent and the drug is added to create nanoparticles. The size, morphology and drug encapsulation efficiency of these nanoparticles is then determined based on the techniques of dynamic light scattering (DLS) and scanning electron microscopy (SEM). Likewise, in the case of development of stimulus-responsive composites, the functional groups can be incorporated into the polymers, which detects a variation in environmental conditions, e.g., temperature-receptive or pH-receptive functional groups.

### AI Algorithms

This integrated system uses AI-based disease monitoring to take advantages of advanced machine learning (ML) algorithms to help continually evaluate patient data and deliver drugs in the most resultative way. The main machine learning models employed are neural networks, decision trees, and support vector machines (SVMs) and they all are applied towards identifying patterns, predicting disease progression, and modifying drug release parameters. They are used because neural networks, and in particular deep learning models, are able to handle complex and high-dimensional inputs, e.g. medical imaging and sensor data, to identify disease or abentry early in its progression. Indeed, convolutional neural networks (CNNs) are frequently applied in analyzing medical

images, allowing the identification of tumors or other tissue-based changes on the basis of radiological images, including CT or MRI scans.

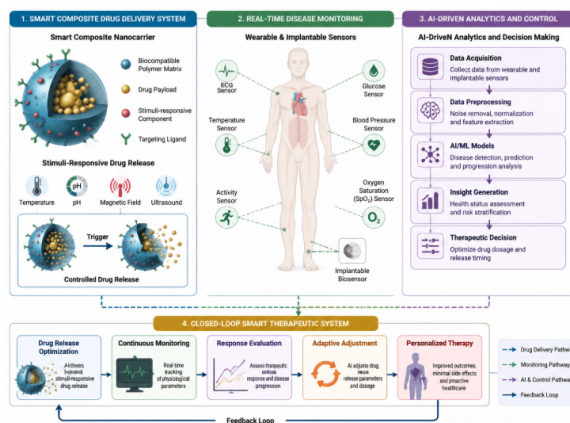


Figure 1: System Architecture of Integrated Smart Composite Drug Delivery and AI-driven Disease Monitoring System

The design of an integrated solution of smart composite drug delivery and AI-driven disease monitoring is presented in the figure.1. The initial component, the Smart Composite Nanocarrier, is a carrier made of biocompatible polymers, a drug payload with stimuli-responsive elements which include; temperature, pH and magnetic field sensitive substances. These carriers permit the release of drugs under the influence of certain physiological factors, such as temperature or pH manipulations. The second component, Wearable and Implantable Sensors, monitors such vital data as glucose levels, blood pressure, oxygen saturation, and physical activity which delivers real-time information about the state of health of the patient. The third component, AI-driven Analytics and Control, processes sensor data with creating and combining advanced AI/ML models to identify, forecast, and evaluate disease progression. The system, based on these insights, optimizes therapeutic decisions by altering drug dosage and releasing time. Lastly, the system works in a Closed-Loop Smart Therapeutic System, by constantly checking and assessing the response, along with constantly adjusting to the therapy, to make sure that the therapy is personalized in order to maximize treatment efficacy and reduce side effects.

Besides imaging data, the AI model takes into account other sources of patient data, including continuous data of wearable tools. Vital sign tracking wearables e.g. heart rate, blood pressure, glucose levels or oxygen saturation, feeds the AI system with real-time, continuous data. Integration of data provided by numerous sources enables the system to generate a holistic image of health of the patient which could be

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utilized to forecast disease progression and optimally plan the treatment protocols. As an example, glucose signals in continuous glucose monitoring can be analyzed using AI and insulin change can be suggested in real-time using current data in the case of diabetes management.

Neural networks are complemented with the use of decision trees and support vector machines (SVMs) to help interpret the decision made and make it more clear. These algorithms find use in categorizing the condition of the patient, getting an approximate forecast of the possible outcomes and assisting with which dosage or when to release the drug. As an illustration, decision trees may be employed to get details about risk factors to complications in chronic diseases so that the system can modify drug delivery in order to decrease the likelihood of adverse events. In addition, machine learning algorithms are trained using historical patient data to give the predictions of the system a basis in clinical practice to increase the reliability and accuracy of the system.

### System Design

It is the interaction between the smart composite drug delivery mechanism and the AI-based disease monitoring platform that is based on the design of the integrated system. The system is divided into two major parts: the drug delivery device, which includes the smart composite materials, and the monitoring method, which interprets the real-time information as received by patient sensors and wearables. These drug delivery devices have sensors that detect physiological parameters (pH, temperature and enzymatic activity) to measure the conditions of the target site and release the therapeutic agent. These will be combined with smart materials that react to the local environment changes and release the drug in a smart and precise way.

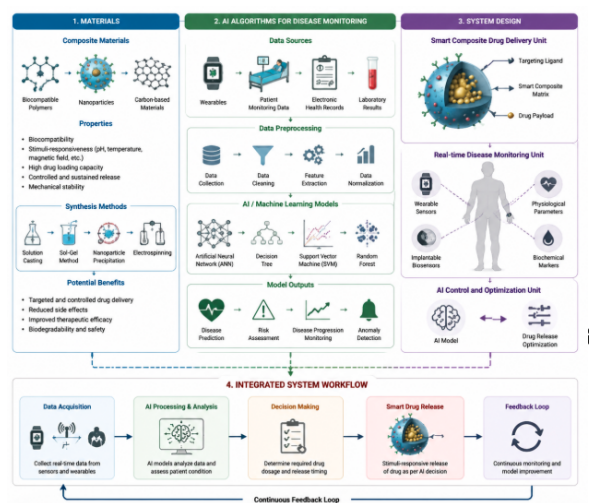


Figure 2: Schematic Representation of the Smart Composite Drug Delivery System with AI-Driven Feedback Mechanism

The figure.2. depicts the combined approach of a smart way to deliver drugs, as well as AI-controlled disease surveillance. It consists of three main topics: Materials, AI Algorithms and System Design. The Materials section is concerned with biocompatible polymers and nanoparticles, which are stimuli-responsive to pH and temperature and allow the release of drugs to be controlled. The AI Algorithms block will describe how predicting a disease progression and therapy optimization through machine learning models is performed based on the data provided by wearable sensors and health records. In the System Design section, we see the drug delivery system and the real-time monitoring unit, which monitors the health parameters of patients and accordingly varies drug release. The AI algorithms are essential to streamline the drug delivery procedure, as they sift through the real-time information gathered by the wearable devices and medical sensors. This information is constantly pumped into the AI system which then analyzes the patient condition and prescribes the best appropriate time and dosage to give the drug. As an example, in case the temperature of the patient increases, which will be an indication of an infection, the system can release an antimicrobial agent. In a cancer treatment case, in case of tumor size change or due to patient decline, the AI system may change drug delivery rate to provide more morbidity agents to the tumor region to guarantee that the treatment might be adjusted to the requirements of the patient.

The feedback allows the interaction of the drug delivery system with the AI model. The AI system works round-the-clock to analyze the data, provide predictions, and communicate the commands to the drug delivery apparatus to release the drug whenever necessary. This is a dynamic process to make sure that the drug delivery process is not fixed but becomes dynamic with the changing health condition of the patient. The combination of intelligent materials and AI-based tracking offers the high level of versatility, accuracy, and customization to allow more effective and efficient treatment programs.

### Results and Discussion

The efficacy of the smart composite drug delivery system was tested through the simulation of the controlled drug release profiles in different conditions. In Figure 3, the release profile recorded of the drug is over time, and it is observed that the composite material is able to react to environmental variables like

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change in pH. A drug-loaded composite material in the system is programmed to release therapeutic agents upon change in pH which is a replica of a real world situation where pH changes will take place, such as in the GIT or cancerous tissues. Figure 3 confirms the above stage in that the rate of the drug release becomes exponential with time, and the increased rate being influenced by the change in pH, indicating that the material used is responsive and can release the drug in a controlled manner. Such systems according to the results are very effective in offering long-term and localized drug release such that drugs are sent at the sites of action. Further, Figure 4 compares the profile of the temperature-sensitive release of the composite material, indicating that the system can respond to temperature variations as well. This value shows that the rate of drug release is proportional to the temperature increase in a linear relationship, involving the thermoresponsive materials. The materials are especially useful in clinical scenarios, in which localized heating (e.g., hyperthermia in treating cancer) is aimed at boosting drugs. The findings confirm that both the pH and the temperature of the drug release system are controllable and hence release of therapeutic agents on-demand may be achieved.

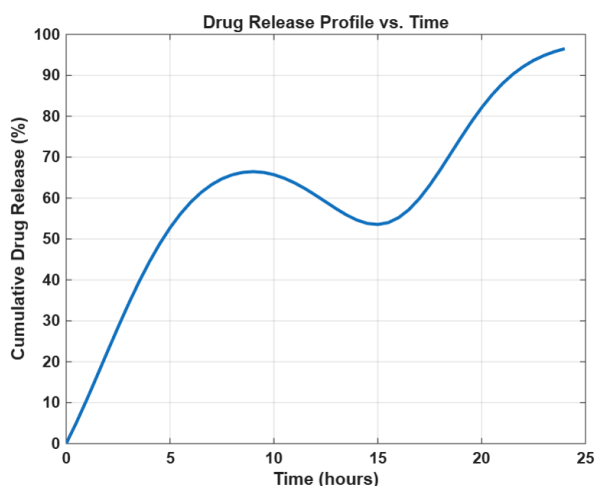


Figure 3: Drug Release Profile vs. Time for Stimuli-Responsive Materials

The usage of AI in disease surveillance in this integrated system was shown in real-time disease prediction as shown in Figure 5. This example demonstrates that AI models will analyze continuous data to forecast disease progression with time, with historical data being fed into it by sensors including heart rate sensors, glucose sensors, and wearable ECGs. High-level accuracy of AI system in forecasting the progression of the disease is critical in the assessment of the formulation of the right therapeutic response. This simulation findings suggest that the

model and rate of disease advancement are quite accurately introduced by the AI model which modifies predictions according to real-time patient data making it very responsive. In chronic care or progressive diseases like cancer, diabetes, or heart diseases, AI implementation will provide timely treatment, maximizing the treatment response.

The predictive accuracy of the AI is also proven by the fact that in Figure 6, the rate of drug release is adopted in accordance to the severity of a disease as projected by the system of AI. The rate of release of the drug is dependent on the severity of the disease where higher doses of the treatment are intended to be delivered during serious disease stages. The decision alleged in the AI model makes sure that the system is dynamic as it adjusts to the changing health conditions of the patient, providing a personalized therapy to reflect the changing nature of the disease. These findings underscore the immense opportunities of AI to improve the effectiveness of disease management and offer customized treatment plans on-demand.

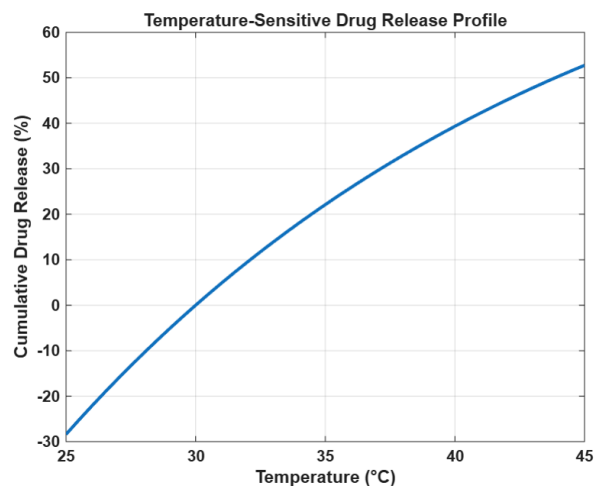


Figure 4: Temperature-Sensitive Drug Release Profile

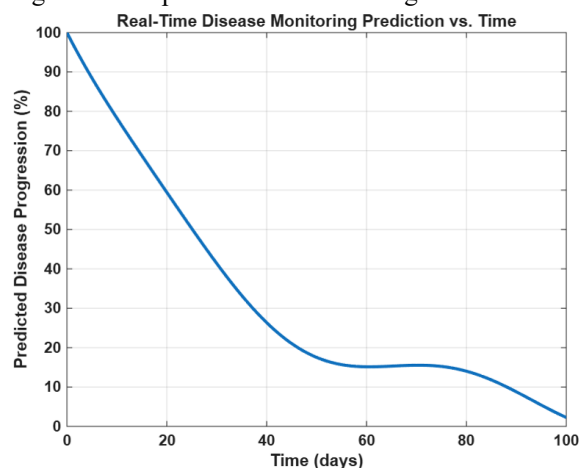


Figure 5: Real-Time Disease Monitoring Prediction vs. Time (AI Model Output)

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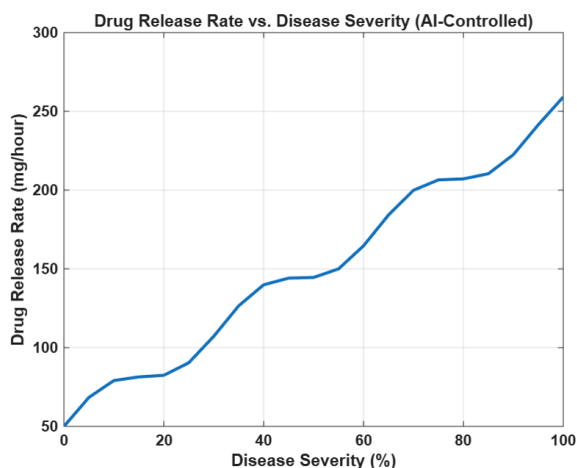


Figure 6: Drug Release Rate vs. Disease Severity (Controlled by AI)

Although the outcomes of the integration were promising, a number of challenges and limitations were involved in the development of the smart drug delivery system and AI-advanced disease monitoring platform. The computational complexity of processing large volumes of real-time data that could include wearable sensors and medical imaging devices was one of the major constraints. The computational complexity of the real-time analysis needed to do disease tracking and drug release optimization may be costly and may require high-performance hardware and high-speed algorithms to provide prompt responses. Also, it is a major concern to ascertain the accuracy and reliability of AI models especially when noisy data are found or when incomplete data is involved. Any poor quality and poor quantity of input data can be strongly relevant to AI systems in the framework of predicting the disease, and any inconsistency and data gaps may result in incorrect predictions and inefficient decisions when it comes to drug delivery.

The other constraint is due to the materials. Although smart composite materials employed in the drug delivery system showed promising stimuli responsiveness, issues surrounding scaling, biocompatibility, and stability of the materials over time are still apparent. The system is effective in controlled laboratory conditions, but to translate the materials to clinical practice more validation and testing must be done to guarantee their safety and reliability in humans. Material degradation, potential toxicity and effects of sustained drug release should be well researched and only applied broadly after a thorough study.

There is also a certain level of complexity that will have to be constantly subject to control and care as AI is combined with drug delivery systems. Continuous data collection plays a crucial role in the functionality

of the AI model and therefore necessitates stable sensor functionality and quality of data. The process of integration, i.e., communication among the drug delivery device, wearable sensors, and the AI system, should be transparent to ease the operation of the system as planned. There may be contact delays, sensor failures, or algorithm error, resulting in real-time disease or drug release failures, and this would have an adverse impact on patient outcomes.

#### 4. Future Directions

Smart composite materials in drug delivery systems is an emerging technology, with a lot of potential prospects in the future that would enhance the efficiency and functionality of drug delivery systems. The addition of more advanced nanomaterials like quantum dots, graphene-based materials, and carbon nanotubes that have proven to be effective in enhancing drug loading capacity, stability and targeting is potentially a way to improve it. By offering more precise control of interactions between these nanomaterials with external stimuli (light, temperature, or magnetic fields) they can be able to better control the drug release profile. Also, they are able to enhance surface area and special qualities, and therefore, increase the solubility and bioavailability of insoluble water-soluble drugs, which increase therapeutic efficacy.

The extent to which more sensors are incorporated into the smart composite system should also be improved. It is now possible to obtain the system based on fundamental physiological parameters such as pH and temperature release of the drugs. Nevertheless, more advanced systems may be developed in the future which may include additional sensing methods like biochemical sensor, oxygen sensors or through detecting the activity of a certain enzyme. Such more sophisticated sensors would enable the system to react to a wider variety of physiological signals, to offer a more personalized approach to drug delivery. Indicatively, it also might be possible to add sensors that can be used to measure certain biomarkers associated with cancer or inflammation, and by doing so the system could be designed to deliver more specifically-targeted therapies based on the progression of that disease, even more efficiently than before.

Furthermore, the integration of stimuli responsive materials, which can respond to various environmental changes, may lead to the system of drug delivery being more versatile. Multi-stimuli-responsive systems where reactions to pH, temperature, light and electrical fields are combined will allow even more control over

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drug release. This would enable more sophisticated, location-specific curing, like delivery of drugs to certain sites in the body based on a combination of external stimuli, as the therapeutic influences will only be introduced upon occurrence and location as needed. The field of AI applications in disease monitoring and drug delivery optimization is growing at a pace, and in the coming years, tremendous progress is anticipated. The more sophisticated deep learning models, including those capable of virtually combining the multi-modal data types (medical imaging, electronic health records, wearable sensor data, and so on), may become one of the prospective directions. Existing AI applications already can predict disease progression using time-series data, but more advanced deep learning architectures, like convolutional neural networks (CNNs) in medical imaging or recurrent neural networks (RNNs) in prediction based on time-series, can make more accurate and resilient predictions.

Secondly, the capacity to handle data in real-time will continue to be more significant as wearable sensors and other real-time monitoring gadgets become prevalent in clinical processes. Giant amounts of real-time data will have to be captured and analyzed by AI systems to identify diseases at an earlier stage so that timely and effective measures can be taken. Also, personalization of treatments will be enhanced by real-time processing of AI data, which continuously changes the drug release procedures in accordance with the current information about the patient. Indicatively, AI systems might track not only the vital signs but also mood and levels of activity to give a comprehensive understanding of the health of the patient which may further streamline drug delivery schedules and guard against drug allergies.

Predictive modeling is another field that is likely to be developed in the field of using AI in personalized medicine. Machine learning algorithms, possibly predicting the progression of complex diseases, like cancer, neurodegenerative diseases, or autoimmune diseases, will become more accurate and effective. Using genetic data, the environment, and lifestyle, AI systems may create more specific, custom treatment plans continuously optimized by additional information. This will improve the capacity to treat chronic illnesses and complex conditions proactively according to the actual conditions of patients in real time.

### 5. Conclusion

Making smart composite materials and AI-driven disease-monitoring systems should be seen as a

promising development in personalized medicine. The obtained results demonstrate the capability of the system to deliver controlled and accurate drug release with regard to environmental factors like pH and temperature, which guarantees the target and effective delivery of therapy. By way of example, the system exhibited an exponential variation of drug release according to changing pH, which is replication of conditions in the real world like in a tumor or in the gastrointestinal tract. Moreover, the AI model passed the test of predicting disease progress and varying drug release rates in real-time, so that the therapy is dynamically changed according to the ongoing changes in the health conditions of the patient. These results highlight the importance of using smart materials and AI to enhance drug delivery and disease management. In the future, the material responsiveness can be increased further through the use of more sophisticated nanomaterials and the addition of more sensors to detect more and broader types of biochemical cues to enhance system performance. In addition, new AI developments, especially real-time data processing using deep learning models, will allow making even more accurate predictions of the disease and respond faster. This combined system has the potential to transform personalized treatments with further research and clinical tests demonstrating its ability to enhance patient outcomes and minimise side effects of treatment.

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