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## Review Article

# Emerging Technologies: Application Of Artificial Intelligence and Machine Learning in Pharmaceutical Quality Assurance

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## ABSTRACT

This review's objective is to provide an early look at upcoming technology advancements in the pharmaceutical and healthcare sectors. In order to do this, we assess cutting-edge medical advancements from both fields in addition to existing technologies. Artificial intelligence, for instance, is able to understand the connections between different formulations and process variables. Artificial intelligence (AI) has developed into a powerful tool that employs human knowledge to swiftly resolve challenging issues. [4] Significant advancements in machine learning and artificial intelligence present a revolutionary opportunity for drug development, formulation, and testing of pharmaceutical dosage forms. By employing AI algorithms that analyze enormous volumes of biological data, including proteomics and genomes, researchers may identify disease-associated targets and predict how they will interact with potential therapy choices. Machine learning approaches not only help with experiment design but also anticipate the pharmacokinetics and toxicity of possible medications. [5]. This study provides an overview of the many AI-based approaches utilized in pharmaceutical technology and analyzes the benefits and drawbacks of each. However, the pharmaceutical industry's continued investment in and research into AI also has encouraging prospects to enhance drug development processes. AI has become a crucial component in all fields of science and technology, from basic engineering to medicine. Health care and pharmaceutical chemistry have been significantly impacted by AI.

## INTRODUCTION

New methods of working, partly motivated by the need to produce new process modalities and the

need to supply new facilities more quickly and economically, have caused the pharmaceutical industry to experience a period of accelerated technology adoption. The industry is changing

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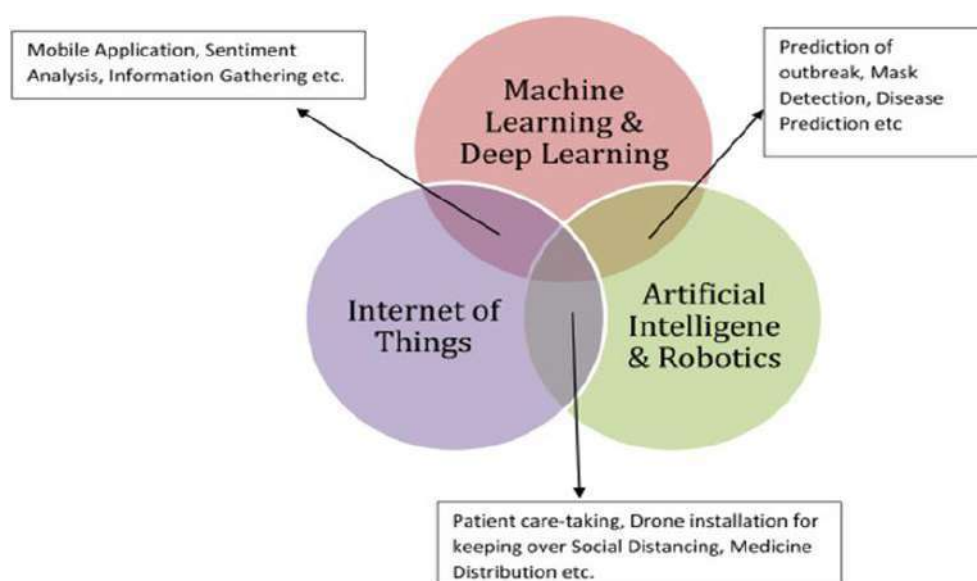


dramatically due to the quick adoption of new technologies like wearables, big data, cloud computing, industrial internet of things, robots, artificial intelligence, additive manufacturing, and cybersecurity. They accomplish this while adhering to the appropriate regulatory standards by improving accuracy, speed, safety, and other aspects. New approaches to supply chain management, production, and sourcing have resulted from this. Artificial intelligence (AI) methods, which range from machine learning (ML) to deep learning (DL), are essential to many facets of wellbeing. Innovative clinical processes, patient data and medical history management, and the treatment of several medical problems are all made possible by these technologies. In addition to developing innovative machinery and technologies, the biopharmaceutical and pharmaceutical industries have also led the way in novel concepts and interpretations in the domains of mechanical and chemical engineering.[6]

### What Are Emerging Technologies?

Technology can be seen as a set of systems designed to perform specific tasks. It helps solve some of the problems businesses face today. The

term "emerging technology" is often used to describe new technologies that are still being developed or are expected to be available in the next five to ten years. These upcoming technologies, though not fully realized, will likely change the current way things work. Emerging technologies are influencing our societies and continue to impact how we live, work, and interact with others. There is no clear agreement on what counts as "emerging." It's a flexible term because one person might see a technology as emerging, while another might not. A technology is still considered emerging if it hasn't yet become essential. An emerging technology is one that could create new economic opportunities and affect many industries. Emerging technologies are used in various fields like media, healthcare, business, science, education, and defense.[8] The pharmaceutical and consumer healthcare industries are using artificial intelligence (AI) and machine learning more and more. AI, a field of computer science, can analyze complex medical data. It can find important patterns in large amounts of data, which can be helpful in making medicines, predicting health trends, identifying patients for clinical trials, providing treatments, and detecting and diagnosing diseases.[9]



**Fig.1 Emerging Technologies in Pharmaceuticals**

## Emerging Technologies in Pharmaceuticals

The following areas are covered in this examination of artificial intelligence's role: diagnosis of a disease; individualized care using digital therapy: Radiation therapy, retinal damage, and cancer

- Additional chronic illnesses

Finding new drugs:

- Bioactivity and toxicity prediction; Clinical trials
- Designing clinical trials, identifying, recruiting, and enrolling patients
- Trial, patient adherence, and endpoint detection monitoring.
- Predicting a pandemic or epidemic [10]

## Types of Emerging Technology

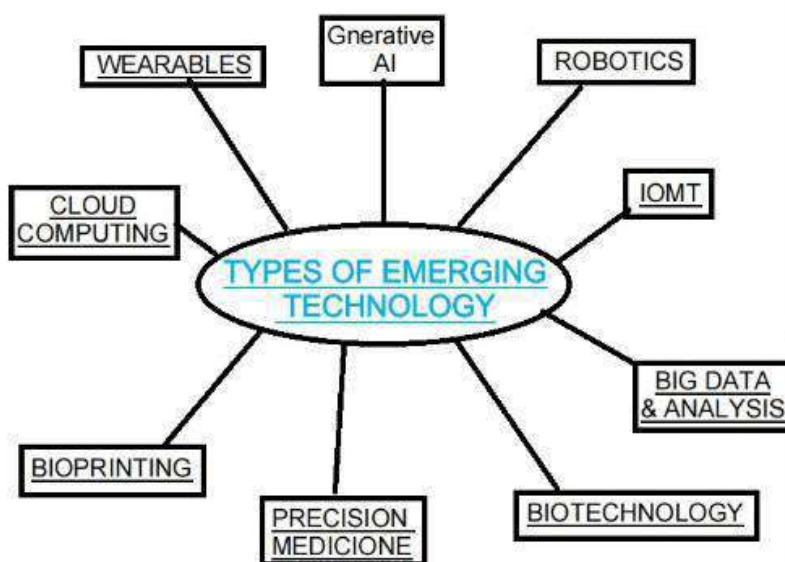


Fig.2 Types of Emerging Technologies [7]

### 1. Generative AI –

Generative AI refers to a class of artificial intelligence models designed to generate new content, such as text, images, music, or even videos, based on training data. Generative AI use deep learning techniques to produce unique outputs that are frequently indistinguishable from human-generated content, in contrast to classical AI, which depends on preset rules and algorithms. This technology has wide applications, including content creation, drug discovery, design, and problem-solving in complex systems. [7]

### 2. Robotics -

The design, building, and operation of robots is the focus of the multidisciplinary engineering and scientific area of robotics. Robots are programmed devices that can perform activities either fully or partially on their own, frequently in dangerous situations for people. This technology improves productivity, accuracy, and safety in many applications across a range of industries, including consumer goods, healthcare, manufacturing, and space exploration.[7]

### 3. Internet of Medical Things (IoMT) -

Real-time patient data collection, transmission, and analysis are made possible by the Internet of Medical Things (IoMT), a network of

interconnected medical equipment, sensors, and software programs. Personalized care, diagnosis, and ongoing monitoring are made possible by this networked system. Healthcare professionals can increase the effectiveness of healthcare delivery, improve patient outcomes, and make better decisions by utilizing IoMT. [7]

#### **4. Big Data and Analytics -**

The act of gathering, processing, and evaluating massive, intricate data sets in order to identify important patterns and insights is referred to as big data and analytics. These data sets frequently contain unstructured, semi-structured, and structured data, all of which need for sophisticated processing, analysis, and storage methods. Organizations can optimize their operations and goals by using the insights gained by big data analytics, which are essential for decision-making in a variety of industries, including marketing, finance, healthcare, and scientific research. [7]

#### **5) Biotechnology -**

Biotechnology is the application of biological systems and organisms to develop products or processes for specific uses in various fields such as medicine, agriculture, and environmental science. It involves the manipulation of living organisms or their components, such as genes, proteins, or cells, to create innovative solutions. Modern biotechnology includes areas like genetic engineering, biopharmaceutical production, and regenerative medicine, revolutionizing industries by providing more sustainable, efficient, and personalized approaches.[7]

#### **6) Precision Medicine -**

A new trend in healthcare called precision medicine, sometimes referred to as personalized medicine, customizes medical interventions and

treatments for each patient according on their genetic composition, way of life, and surroundings. Precision medicine seeks to enhance overall patient outcomes, reduce side effects, and offer more effective medications through the use of genetic testing and sophisticated data analytics. This strategy marks a departure from the conventional "one-size-fits-all" therapy paradigm. [7]

#### **7) Bio Printing -**

In order to produce three-dimensional biological structures, bio printing is a specialized type of 3D printing in which living cells and biomaterials are deposited layer by layer. By making it possible to create customized medical implants and tissues and organs for transplantation, this cutting-edge technology has the potential to completely transform regenerative medicine. Additionally, researchers can use bioprinting to examine the safety and effectiveness of pharmaceutical substances by printing human tissue models during the drug testing and development process.[7]

#### **8) Cloud Computing -**

Cloud computing refers to the delivery of computing services, including storage, processing, and software, over the internet (the "cloud"). This technology enables individuals and organizations to access and manage data and applications remotely without the need for local infrastructure. Cloud computing offers scalability, flexibility, and cost efficiency, allowing businesses to scale their operations, collaborate across geographies, and innovate rapidly while reducing IT costs.[7]

#### **9) Wearables -**

Wearables are electronic devices that can be worn on the body, typically in the form of accessories such as watches, fitness trackers, or clothing, and



are designed to collect data about an individual's health, activity, and environment. These devices often incorporate sensors to monitor parameters like heart rate, steps, sleep patterns, and even blood oxygen levels. Wearables are becoming increasingly important in healthcare, enabling continuous health monitoring and providing valuable data to both users and healthcare professionals for preventive care and personalized treatments.[7]

### Benefits -

Emerging technologies in the pharmaceutical sector are driving significant improvements. These advancements help streamline drug development, enhance precision medicine, and optimize manufacturing processes. Digital tools, robots, and sensors make it easier to gather and analyze real-time data, enabling more efficient research and personalized treatments. As these technologies become more affordable and accessible, they open up new opportunities for both better patient outcomes and stronger returns for investors.[8] The result is a thriving pharma sector that benefits everyone. New technologies like AR/VR, AI, and 3D printing are helping pharmaceutical companies speed up research and development, create products tailored to individuals, and test in new and creative ways.

### Including other benefits by following way

- 1. Improved patient safety :** Automated medication dispensing system scanning, and robotic systems are reduce and minimize risks related to medication errors.
- 2. Enhanced patient involvement :** by using Telepharmacy services, mobile apps, and digital platforms facilitate for the patient-pharmacist communication, improving adherence and health outcomes.

**3. Increased efficiency :** In which the Automated dispensing system artificial intelligence (AI), barcode scanning optimized prescription workflow, reduce manual tasks, and real-time monitoring.

**4. Cost Reduction:** To maintaining financial sustainability for provide the quality care and help to reduce overstocking , just -in- time inventory direct impact on cost reduction consequently.

**5 .Personalized medicine :** Pharmacogenomics, precision medicine, and Individualized preventive care ,improving efficacy and reducing adverse drug reactions.[2]

**6.Flexible Production:** The pharma industry is altering its manufacturing to meet new needs, like producing smaller batches for precision medicine. As per customer demands.

**7.Advanced clinical decision support :** AI-powered systems provide real-time clinical guidance, enabling pharmacists to make informed decisions.by using advanced system in for their better decision.

**8.Counterfeiting Issue:** Emerging technologies in the pharmaceutical sector can help combat counterfeiting. Any patient can use digital technology to verify the authenticity of medications, for example, by scanning the barcode on the packaging.

**9.Transparency:** This has always been an extremely important factor in the pharmaceutical industry. Transparency refers to the sharing of information. The data results that come from research and development can be extremely valuable, providing insights for various parties. This was seen during the pandemi .

### Some emerging technologies in pharmacy include:

1. Artificial intelligence (AI) and machine learning (ML)
2. Internet of Things (IoT)
3. Robotics and automation



4. Telepharmacy and digital health
5. Pharmacogenomics and precision medicine
6. Blockchain and secure data sharing
7. 3D printing and personalized manufacturing
8. Virtual and augmented reality

These technologies have the potential to transform the pharmacy profession, improving patient care, enhancing efficiency, and the role of pharmacists.[9]

### Challenges -

Integrating new technologies into the pharmaceutical industry has great potential to bring positive changes. However, there are several challenges that need to be overcome. [8] These challenges include:

#### Some of the key challenges:

- 1. Regulatory frameworks:** Evolving technologies require updated regulatory frameworks, which can be slow to adapt, creating uncertainty and potential hurdles.
- 2. Data security and privacy:** Increased use of digital technologies and data analytics raises concerns about data security, privacy, and

compliance with regulations like health insurance portability and accountability.

**3. Interoperability and standardization:** Integration of new technologies with existing systems and infrastructure can be challenging due to lack of standardization and interoperability.

**4. Cybersecurity:** Increased connectivity and reliance on digital technologies create vulnerabilities to cyber threats, which can compromise patient data and disrupt operations.

**5. Sustainability and environmental impact :** The increased use of digital technologies and e-waste generated by emerging technologies raise concerns about sustainability and environmental impact.[1]

**6. Equity and access:** Emerging technologies may exacerbate existing health disparities if access to these technologies is limited to certain populations, highlighting the need for equitable access and digital literacy.

**7. Clinical validation and evidence:** Emerging technologies require rigorous clinical validation and evidence to demonstrate their safety, efficacy, and effectiveness.[8]



Figure 1: Challenges overcome by use of artificial intelligence

### Some specific challenges related to emerging technologies in pharmacy include:

1. Robotics and automation
2. Artificial intelligence (AI) and machine learning (ML)
3. Tele pharmacy and digital health
4. 3D printing and personalized manufacturing

### Application of AI:

- AI for Drug Discovery [1]
- AI Tool Application in Dosage Form Designs [1]
- AI for Drug Delivery [1]
- AI for Pharmacokinetics and Pharmacodynamics [1]
- Artificial intelligence in research and development [2]
- AI in pharmaceutical manufacturing [2]
- AI for quality assurance and quality control [2]
- AI for quality assurance and quality control [2]
- AI in Personalized Medicine[2]
- AI in health care [3]
- AI of next-generation 3D printed medicines [3]

**1) AI for Drug Discovery:-** AI for Drug development: In many respects, artificial intelligence has transformed drug research and development. The following are a few of AI's major contributions in this field:

a) Target Identification: To find possible therapeutic targets, AI systems can examine a variety of data types, including genomic, proteomic, and clinical data.

b) Virtual Screening: AI makes it possible to efficiently screen large chemical libraries in order to find drug candidates that are highly likely to bind to a particular target. AI saves time and money by helping researchers prioritize and choose compounds for experimental testing by modeling chemical interactions and forecasting binding affinities.

c) Structure-Activity Relationship (SAR) Modeling: Artificial intelligence (AI) models are able to create connections between a compound's chemical structure and biological activity. This enables scientists to create compounds with desired properties, such high potency, selectivity, and advantageous pharmacokinetic profiles, in order to optimize therapeutic prospects.

d) De Novo Drug Design: AI algorithms can suggest new chemical structures that resemble drugs by using generative models and reinforcement learning. through gaining knowledge from experimental data and chemical libraries. AI broadens the chemical space and facilitates the creation of novel therapeutic options. [1]

### 2) AI Tool Application in Dosage Form Designs:-

To comprehend the effects of medication distribution, the human body system is separated into multiple compartments. Biological membranes serve as the basis for further simplification of the compartments. Biological compartments require physicochemical barriers, which can be used in accordance with the medication delivery method inside the body. The rate of penetration based on the route of administration is one of the most important parameters for effective drug delivery system monitoring. [1]

### 3) AI for Drug Delivery:-

To evaluate massive datasets and forecast medication behavior, computational pharmaceutics uses AI algorithms and machine learning approaches. Researchers can assess different scenarios and improve medication delivery systems without requiring lengthy trial-and-error studies by simulating drug formulation and delivery procedures. This accelerates the drug



development timeline, reduces costs, and increases productivity. Computational pharmaceuticals involves modeling drug delivery systems at different scales, ranging from molecular interactions to macroscopic behavior. AI algorithms can analyze complex relationships between drug properties, formulation components, and physiological factors to predict drug behavior at each scale. This facilitates the development of effective drug delivery devices and enables a more thorough understanding of drug delivery mechanisms. It aids in forecasting 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 to improve the evaluation of in vivo pharmacokinetic characteristics and drug distribution.

#### ● AI for the Development of Oral Solid Dosage Forms

- Formulations for Drug Release Prediction.
- AI for Tablet Defect Detection;
- AI for Physicochemical Stability Prediction;
- AI's Role in Dissolution Rate Predictions;
- AI Tools for the Development of Biologics Products. [1]

#### 4) AI for Pharmacokinetics and Pharmacodynamics: -

Drug discovery, preclinical research, clinical trials, and regulatory approval are all steps in the intricate process of developing new drugs. Because they establish the ideal dosage, mode of administration, and safety of a medicine in the body, pharmacokinetics and pharmacodynamics are essential components of drug development [85]. Pharmacokinetic and pharmacodynamic investigations using traditional experimental methods can be costly and time-consuming, and they might not always yield reliable forecasts of a drug's safety and efficacy. Studies on

pharmacokinetics and pharmacodynamics have historically been carried out using experimental techniques like animal research and human clinical trials. Critical issues with these approaches include sample size, interindividual variability, and ethical considerations. Prediction of Drug Release and Absorption Parameters; AI-Based Computational Method for PBPK; and Based Methods to Predict Pharmacokinetic Parameters

#### 5) Artificial intelligence in research and development:-

Pharma firms worldwide are using state-of-the-art machine learning algorithms and AI-powered platforms to expedite the drug development process. These intelligence technologies can be used to solve issues pertaining to complicated biological networks because of their capacity to identify intricate patterns in large datasets. This skill is excellent for examining the trends of various illnesses and determining which medication formulations might work best to address specific aspects of a particular ailment. Pharmaceutical companies can therefore invest in the development of drugs that have the best chance of healing a disease or other medical condition. [2]

#### 6) AI in pharmaceutical manufacturing: -

The pharmaceutical industry is the most recent to use AI, and the results are encouraging so far. AI has the power to revolutionize medicine development, discovery, and patient delivery. With AI-powered drug discovery platforms discovering possible therapeutic candidates more quickly and correctly than conventional approaches, the application of AI in drug development is already demonstrating promise. The intricacy of production processes and the growing demand for efficiency and improved product quality have prompted modern manufacturing systems to try to automate human



expertise. The pharmaceutical industry may benefit from the application of AI in manufacturing. Modern manufacturing systems are trying to transfer human expertise to robots as production processes become more complex and consumers want higher-quality and more efficient products.

### **7) AI for quality assurance and quality control:-**

To get the desired outcome from the basic components, a number of qualities need to be harmonized. In order to conduct quality control tests on the products and maintain consistency between batches, manual intervention is necessary. This indicates that AI deployment is required at this time, even though it might not always be the wisest course of action. The FDA changed current good manufacturing practices (cGMP) by implementing a quality by design approach in order to gain a better understanding of the crucial steps and particular needs that impact the pharmaceutical product's final quality. [2]

### **8) AI Applications in Personalized Medicine:-**

Customizing medical care for each patient according to their genetic composition, medical background, and other variables is known as personalized medicine. By evaluating enormous volumes of patient data to find individualized treatment alternatives, artificial intelligence (AI) has the potential to completely transform personalized medicine. AI can be used to forecast possible adverse effects or interactions with other medications, as well as to identify individuals who are more likely to respond to a given treatment. Better patient results and fewer adverse effects may result from this individualized strategy. [2]

### **9) AI in health care:-**

- Administration: To reduce human error and increase efficiency, AI systems are helping with routine administrative tasks. Transcriptions of medical notes using natural language processing (NLP) assist in organizing patient data for easier reading by physicians.
- Telemedicine: In non-emergency situations, patients can get in touch with an AI system at a hospital to enter their vital signs, study their symptoms, and decide if they need medical help.
- Assisted diagnosis: AI is now capable of reading MRI scans to look for tumors and other malignant growths at an exponentially faster rate than radiologists can, with a significantly narrower margin of error, thanks to computer vision and convolution neural networks.[3]

### **10) AI of next-generation 3D printed medicines:**

AI and the pharmaceutical 3D printing (3DP) pipeline can collaborate. The traditional "one size fits all" approach to medicine needs to give way to the administration of customized drugs. Pharmaceutical 3DP can provide personalized drugs in the clinic, but it currently requires the presence and expertise of certified 3DP professionals.[3]

### **CONCLUSION:-**

New technology has historically been adopted slowly by the pharmaceutical sector. Maintaining industry competitiveness requires embracing evolving technologies. Pharma operations leaders now have the chance to provide even more value to their companies by accomplishing this change in emphasis, but they need to move fast to stay ahead of the obstacles facing the sector. Being on the cutting edge of technical advancements is essential for the pharmaceutical sector. It will be crucial to identify the future leaders of the pharmaceutical sector by integrating cutting-edge technologies while maintaining



regulatory compliance and putting patient care first. You may get more details on new technology in the pharmaceutical sector in the books.[8]

## REFERENCES

1. Review Artificial Intelligence in Pharmaceutical Technology and Drug Delivery Design Lalitkumar K. Vora 1,\* , Amol D. Gholap 2 Keshava Jetha 3,4 , Raghu Raj Singh Thakur 1,Hetvi K. Solanki 5 and Vivek P. Chavda.
2. Revolutionizing the Pharmaceutical Industry with Artificial Intelligence Krishnagiri Krishnababu1\*, Gururaj S Kulkarni2, Yogaraj R3, Padmaa M Paarakh4 1\*,2,3Department of Pharmaceutics, the Oxford College of Pharmacy, Bangalore. Indiana Department of Pharmacognosy, the Oxford College of Pharmacy, Bangalore. India.
3. Emerging of artificial intelligence and technology in pharmaceuticals: review Ayesha Sultana1, Rahat Maseera2, Abdul Rahamanulla3 and Alima Misiriyal.
4. Vora, L.K.; Gholap, A.D.Jetha, K.; Thakur, R.R.S.; Solanki,H.K.; Chavda, V.P. Artificial Intelligence in Pharmaceutical Technology and Drug DeliverDesign. *Pharmaceutics* 2023, 15, 1916.  
<https://doi.org/10.3390/pharmaceutics15071916>
5. Shinde PS, Pawar AY, Talele SG. The Role of Artificial Intelligence in the Pharmaceutical Sector: A Comprehensive Analysis of its Application from the Discovery Phase to Industrial Implementation. *International Journal of Drug Delivery Technology*. 2023;13(4):1578-1584
6. International Journal of Trend in Scientific Research and Development (IJTSRD) Volume 8 Issue 6, Nov-Dec 2024 Available Online: [www.ijtsrd.com](http://www.ijtsrd.com) e-ISSN: 2456 – 6470
7. Sadiku, M. N. O., Adekunle, P. A., & Sadiku, J. O. (2024). Emerging technologies in the pharmaceutical industry. *International Journal of Trend in Scientific Research and Development (IJTSRD)*, 8(6), 768-774. Available at: [www.ijtsrd.com](http://www.ijtsrd.com)
8. Emerging Technologies in Pharmaceutical Industry Matthew N. O. Sadiku1, Paul A. Adekunle2, Janet O. Sadiku31 Roy G.
9. Emerging technology trends in Pharmaceutical industry Grishma H Patel \* Bhumi P Suratiya,Dhara V Patel and Dhananjay B Meshram
10. Artificial Intelligence in Pharmaceutical and Healthcare Research Subrat Kumar Bhattamisra 1,\* , Priyanka Banerjee 2, Pratibha Gupta 2, Jayashree Mayuren 3, Susmita Patra 2 and Mayuren Candasamy 41.

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