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DEMYSTIFYING ARTIFICIAL INTELLIGENCE & ALLIED TECHNOLOGICAL POTENTIALITIES IN PHARMACEUTICAL INDUSTRIES & ORGANIZATIONS

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ABSTRACT

Artificial intelligence (AI) is the term used to describe how machines and computer systems, in particular, replicate human intelligence by learning from the results they produce. Two factors are driving the transformation of pharmaceutical medication development using AI capabilities and technologies. The cost of research is rising, productivity is falling, and medication attrition rates are rising. The AI-driven strategy is being utilized to improve the discovery approach, clinical trial optimization, and failures. However, collaborations between pharmaceutical companies and AI-based pharmaceutical drug discovery are spurring more innovation and improved development success overall. Artificial Intelligence is very emerging technology in drug discovery, optimize the formulation to design drugs, improvement of clinical trials, development and enhancement of the drug delivery system. It helps to reduce overall time and the cost in the pharmaceutical pipeline. Different Artificial Intelligence techniques including machine learning, deep learning and natural language processing predictive and generative models are used for the different perspectives to develop complete intelligent solutions for the pharmaceutical industries and organizations. This paper is focused on AI and allied technologies specially for the emerging applications in Pharmaceutical Management and industries. Paper also tries to identify the issues and challenges of AI in pharmaceutical management and systems effectively.

Keywords: Pharmaceutical Industry, AI Applications, Pharmaceutical Management, Emerging ICT, Pharmainformatics

1.0 INTRODUCTION

Healthcare sector is changing drastically and impacting with emerging Informatics practice and this is reflecting new age healthcare with sustainability and there are various components of Information Technology, and all are influencing healthcare systems [33], [34]. Artificial Intelligence (AI) is the simulation of human intelligence processes by machines, particularly computer systems as they make that utilize outcomes. AI skills and technologies are transmuting pharmaceutical drug development and driven by two things [1], [10], [35]. The cost of research is rising and productivity is going down, while drug attrition rates are staggering. Train on data until October 2023 to increases discovery method, clinical trial failures and use the AI based approach However, these AI based pharmaceutical drug discovery and pharmaceutical organization joint ventures are already catalyzing greater innovation and development success throughout the board. AI is described as a collection of technologies that work together to allow machines to discern, interpret, take action, and acquire knowledge with human level of intelligence. This makes AI in medical industries a vital component, as it helps to analyze personal data of individuals and help to personalize the medicine according to his/her needs. This paradigm shift towards personalized and targeted treatment has the potential to greatly improve patient outcomes and the medical field such as improved treatment AI within the power driven. In the pharmaceutical industries allows personalized medicine

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by analyzing patient data and personalizing the medicines according to his/her needs by the Artificial intelligence. This model builds by individuals to allowing for personalized and targeted treatments that help to benefit of patient outcomes [6], [27], [43]. A new world for the pharmaceutical domain as better and quicker treatment Ai powered tailored medicine was published. AI could revolutionize healthcare outcomes. Artificial Intelligence *(a sphere of technologies)* offers unprecedented opportunities for personalizing medical interventions to be tailored towards the individual properties of each patient spanning everything from the data processing and interpretation, all the way through diagnosis tools and treatment plans. Researchers explained that by speeding up the identification of new drug targets, increasing the effectiveness of drug discovery procedures, and enabling customized medicine, artificial intelligence (AI) has the potential to revolutionize drug research. AI's influence can also be seen in the patient-physician interface, where it improves treatment effectiveness and diagnostic precision, ultimately leading to better patient care. Furthermore, because AI can evaluate large datasets to find important patterns and trends that result in focused treatments for fighting diseases, its potential in disease prevention and outbreak prediction is encouraging. Predictive analytics (PA) focused by artificial intelligence (AI) can antedate therapy outcomes, disease advancement, and patient outcomes [24], [40]. This idea is indispensable because it supports the medical professionals mark well-informed assessments that enrich the patient care and results. Why because it empowers the proactive and focused intermediations, predictive analytics is a crucial component of the pharmaceutical sector. Predictive Analytics (PA) in the Pharmaceutical supply chain decreases medicine excess and shortfall. Through personalized treatment, early illness diagnosis, and increased diagnostic precision. AI-driven data analysis improves the amplified diagnostic precision and early stage illness diagnosis of patient.

2.0 OBJECTIVE OF THE PAPER

The paper entitled '*Demystifying* Artificial Intelligence & Allied Technological Potentialities in Pharmaceutical Industries & Organizations' is focused with the following aim and objectives—

- To learn about the basic and founding applications of Artificial Intelligence and allied technologies in pharmaceutical management.
- To find out the emerging applications and potentiality of Artificial Intelligence and allied technologies managing phrama industries and organizations.
- To gather existing works related to the AI impact and role in managing phrama industry and organizations.
- To learn about the issues, challenges, and concern related to the Artificial Intelligence in phrama industries and organizations.

3.0 METHODS USED

This paper entitled '*Demystifying* Artificial Intelligence & Allied Technological Potentialities in Pharmaceutical Industries & Organizations' is not primary data collection based work and lies on existing works and research and thus secondary sources are used in the field of AI and Allied Technologies, Technologies in Pharmaceutical Industries & Organizations specially AI and emerging technologies. All such analyzed data then gathered scientifically and finally reported here scientifically.

4.0 ARTIFICIAL INTELLIGENCE AND ALLIED TECHNOLOGIES: FUNDAMENTALS

AI (Artificial Intelligence) is the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans. These tasks involved in learning from data, recognizing patterns, making decisions, solving problems, understanding language, and even perceiving visual information. Artificial Intelligence has become the most disruptive technology of this generation, transforming industries like health care, education, finance, manufacturing, agriculture and transportation. Precision and smart farming technologies can improve agricultural resource management by enabling more efficient use of water, fertilizers, and other farm inputs. These approaches also support better monitoring, planning, and decision-making, thereby contributing to improved agricultural productivity and sustainable farming practices [16]. Artificial Intelligence basically becomes its root from algorithms and data. Machine learning algorithms are like sets of instructions for the machine to learn from records and produce results [2], [14]. This is yet another example of how systems can use vast amounts of data coupled with intelligent algorithms to learn and improve over time. This is what we call ML (machine learning), which is a huge part of AI. Machine learning is a form of artificial intelligence that uses experience to learn instead of being programmed for every task. These include recommendation engines, fraud prevention systems, and predictive insights. ***Deep Learning:*** It is similar to human brain circuits, deep learning feeds information through multiple layers of an artificial neural network sequentially to discover the implicit patterns in large data sets. It is especially beneficial in image recognition, speech processing and natural language understanding. Deep learning techniques underlie many applications, such as voice assistants, facial recognition systems and autonomous vehicles. Another allied technology is Natural Language Processing (NLP), which helps machines to understand, interpret and respond to human languages. Applications powered by NLP include things like chatbots, translation systems, sentiment analysis and virtual assistants. Through this technology, text and speech can be analyzed by machines, resulting in a more natural and efficient method of communication between humans and computers [7], [28].

Another field that has gained the image of sister to Aritifical Intelligence is Robotics. On the other hand, AI enabled robots can accomplish jobs with little to no human involvement, like assembly line operations, medical surgeries, warehouse automation as well as even family assistance. These are sensory, camera and artificial intelligence-based robots that can interact with the surroundings in real time to make decisions. Computer Vision is also a significant technology related to Ai, it facilitates machines to process and make sense of visual data from pictures and videos. This technology has applications in surveillance systems and medical imaging and is also used for quality inspection in manufacturing as well as in autonomous vehicles [12], [30]. We can think of Computer vision as enabling machines to recognize objects in pictures or even video and understand what it sees. AI systems are supported by IoT, Big Data Analytics and Cloud Computing technologies.

Fig: 1-Top AI tools and platforms for the pharmacy industry and management

IoT generates tremendous real-time data which can be analyzed with multiple AI techniques. The cloud allows for big data storage and processing at scale, enabling big data analytics to be performed on petabytes of structured, semi-structured, and unstructured information.AI, while beneficial in many ways also comes with challenges such as ethical considerations data privacy problems job displacement and security threats [8], [29]. Therefore, it is crucial that AI technologies are developed and implemented responsibly so that these innovations can benefit society.And, in summary, Artificial Intelligence and its companion technologies are changing the way we think about and approach future through creating machines to execute smart actions at scale. As Artificial Intelligence continually evolves, it will be an important piece in the puzzle of numerous problems facing us on a world scale and enhancing our overall quality of life across many industries. In generally some of the popular tools are emerging and such are depicted in Fig. 1.

5.0 REVIEW THE BENEFITS OF ARTIFICIAL INTELLIGENCE IN PHARMACEUTICAL INDUSTRY

One of the most significant advantages of Artificial Intelligence is its capability to accelerate drug discovery and development and this section review the ample benefits of AI for Pharmaceutical industry as also depicted in Fig. 2. Traditionally, drug discovery is a prolonged and resource-intensive process, often exceeding a decade, with high attrition rates. AI mitigates these limitations by enabling rapid virtual screening of large chemical libraries, accurate prediction of drug-target interactions, and efficient optimization of lead compound. Reported reductions in the early-stage development timeline range from approximately 25% to

50%, although outcomes may vary by therapeutic area and data quality [11], [19]. Furthermore, AI facilitates the exploration of novel chemical spaces, allowing the identification of unique molecular entities that are difficult to detect, making use of conventional experimental or computational approaches. These capabilities significantly enhance the efficiency and success probability of early-stage drug development pipelines.

Another major benefit of artificial Intelligence in the pharmaceutical sector is the reduction in Research and Development (R&D) costs, which are traditionally associated with high investment and uncertainty. AI-driven predictive models improve decision-making in candidate selection and reduce the likelihood of failure in late-stage clinical trials, which represent the most expensive phase of drug development [4], [26]. By optimizing experimental design and forecasting outcomes with greater accuracy, AI contributes to substantial cost savings and improves the efficiency of pharmaceutical pipelines. In addition, AI is transforming the optimization of clinical trials, which are often constrained by delays in patient recruitment and inefficient data management. The analysis of electronic health records (EHRS), genomic data sets, and real-world evidence enables rapid identification of suitable patient cohorts. It also supports real-time monitoring of participants and predictive assessment of adverse drug reactions, thereby improving both safety and efficacy outcomes. The increasing adoption of decentralized and patient- centric clinical trials highlights the role of AI in improving accessibility and inclusivity, and representation of diverse populations in clinical research. These advancements contribute to more reliable and generalisable clinical outcomes [17], [46].

Artificial Intelligence also plays a vital role in advancing precision medicine and personalized therapy, representing a shift from generalized treatment approaches to individualized care strategies. By integrating heterogeneous datasets, including Genomic, Proteomic, clinical, and lifestyle information, AI enables the development of targeted therapeutic interventions tailored to individual patient profile. This approach improves therapeutic effectiveness, reduces adverse effects, and enhances overall patient outcomes, particularly in complex diseases such as cancer, rare genetic disorders, and chronic conditions. In parallel, AI enhances the efficiency of regulatory and documentation processes, which are often time-consuming and prone to human error. AI-powered systems can automate the preparation of regulatory submissions, ensure compliance with stringent guidelines, and improve traceability and audit readiness. Consequently, regulatory workflows are streamlined, facilitating more efficient interactions with agencies such as the US Food and Drug Administration (FDA) and the European Medicines Agency (EMA). This not only accelerates approval timelines but also enhances transparency and accountability in regulatory practices [17], [32].

In post-marketing phases, AI significantly strengthens Pharmacovigilance and drug safety monitoring systems. By leveraging large- scale and real - world data sources, including EHRS, clinical reports, and digital platforms, AI enables real-time detection and analysis of adverse drug reactions. This proactive approach enhances benefit – risk assessment, improves patient safety, and supports regulatory compliance. Additionally, AI is increasingly integrated into pharmaceutical manufacturing and supply chain management, aligning with Industry 4.0 principles. AI- driven predictive maintenance systems have been reported to reduce equipment downtime by up to 30% to 50% in reported cases, although outcomes depend on implementation scale and system maturity [18], [36]. Advanced analytics further improve demand forecasting and Inventory optimization, while automated quality control using computer vision ensures consistency, accuracy, and regulatory compliance in production processes. These improvements enhance the robustness and scalability of pharmaceutical manufacturing systems.

Our second significant benefit of AI is playing a firm role in data-driven decision-making across the pharmaceutical value chain. The industry creates significant amounts of heterogeneous data, such as omics datasets, clinical trial outputs, and commercial market data. AI enables large datasets to be turned into actionable insights that pave the way for informed decision-making across research, development and commercialization. This provides operational efficiency and gives a competitive advantage in a fast-changing world [9], [13]. Additionally, it increases productivity and optimizes workflow by facilitating the automation of repetitive and labour-intensive tasks, including data entry, documentation, and analysis. By freeing and researchers and professionals from lower-value work in core scientific and strategic operations, this can drive innovation and accelerate knowledge generation. Consequently, institutions can realize superior performance results while upholding measures of quality and compliance [20], [23].

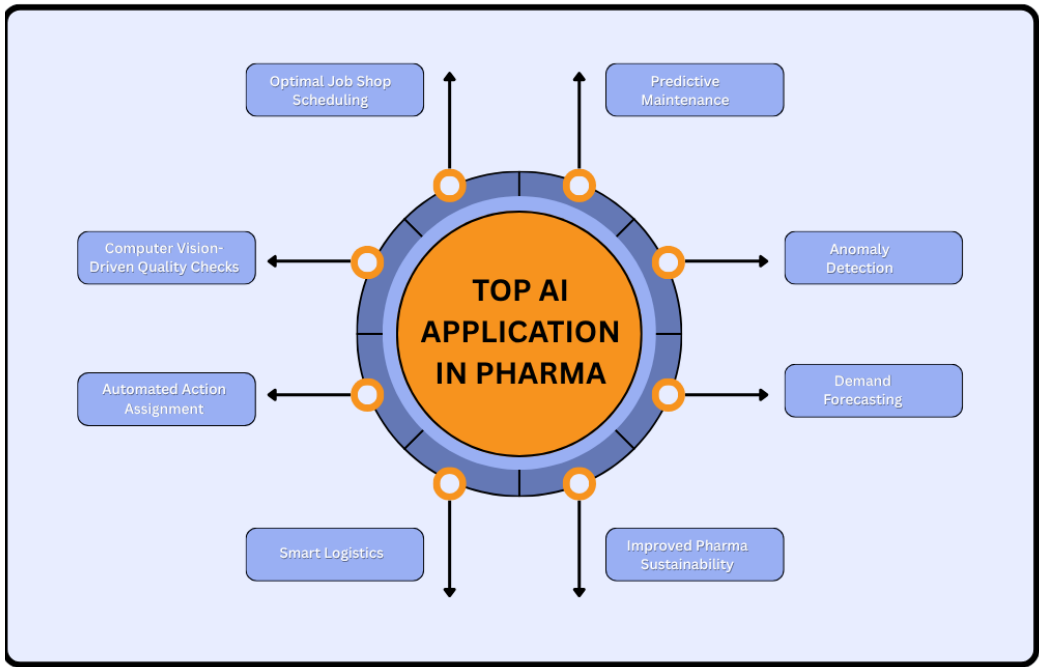

Fig: 2-Top Artificial intelligence applications in pharmaceutical industry and management

Keenly, AI is leading innovation in new therapeutic areas as well, particularly with diseases that have been seen as historically hard or undruggable. Additionally, AI approaches allow for the discovery of novel biological targets as well as innovative therapeutic strategies to more complex diseases such as neurodegenerative diseases, cancer and rare conditions. Automated laboratory systems improve experimental efficiency, reproducibility, and accuracy, which can bring a new era in pharmaceutical. These technologies are anticipated to be a synergy in meeting unmet medical needs and finding solutions for global health challenges [21], [22].

Therefore, as the final note, AI acts as a catalytic enabler of pharmaceutical research and development in uniquely disruptive ways for generating efficiencies, increasing opportunities for accuracy and improving quality to an unprecedented extent. This further diminishes the uncertainty in drug development, improves predictive capability across intricate biological systems, and transforms data from multiple disciplines into actionable knowledge. The trajectory is moving unmistakably from AI as an industry tool to a fundamental infrastructural element of pharmaceutical invention [31], [37]. Further innovations in AI will accelerate this process to deliver safe, effective and personalized therapeutics for global health benefits.

6.0 BASIC AND EMERGING APPLICATIONS AND ROLE OF ARTIFICIAL INTELLIGENCE IN PHARMACEUTICAL INDUSTRY

As far as ***Drug Discovery,*** Artificial intelligence (AI) is acting a substantial role in drug detection by evaluating immense quantities of data, recognizing forms, and guessing potential drug candidates. This conceptual idea is vital as it fast-tracks the drug detection procedure, reducing costs and time. The drug discovery is transforming the pharmaceutical industry by AI and enabling the expansion of new and advanced treatments. Explores the AI-powered tools are being used to analyze vast amounts of data, identify patterns and relationships, and make predictions that can accelerate the development of new drugs and improve their efficacy and safety. Regarding ***Optimization of Clinical Trails*****,** AI will also help optimize clinical trials through data analysis, participant identification, and trial outcome prediction. This concept is culminating as it enhances patient safety, reduces costs, and ensures clinical trials are performed safely and effectively. AI-enabled clinical trial optimization in the pharmaceutical sector is crucial as it enables landmark novel therapy generations [38], [42].

Pharmacogenomics is another field, and AI can examine through genetic data to predict how a patient are respond to medications, leading to tailored treatment strategies. This standard is critical to developing the therapeutic effectiveness and reducing the toxicities. AI in pharmacogenomics is revolutionizing the pharmaceutical industry by enabling targeted and precise treatment modalities. The patient stratification from medical records, the mechanistic prediction of drug response, targets, and their interactions, and the identification of novel regulatory variants found in non-coding domains of the genome and their function as applied to pharmacoepigenomics. As far as ***Analysis of Medical Imaging (AMI) & Patient Engagement*****,** the medical images to diagnose the diseases are monitoring the treatment progress and predict patient outcomes are analyzed by the Artificial Intelligence. The healthcare professionals are enables to make accurate diagnosis and develop efficient treatment plan through this concept. To

improve the better services and outcome to the patients the AI driven medical imaging analysis is crucial trait of the pharmaceutical industry [21], [39]. Artificial Intelligence (AI) should enhance the patient appointment and handling by evaluating the data, find the needed patients, and developing the tailored communication approaches. This type's path is very essential and crucial to improve the patient outcome adherence to treatment plans and overall satisfaction of the patients.By analyzing the patient data to determining requirements and creating customized communication plans of the needed patients. This thought is very essential because it enhances the results, treatment plans adherence and general satisfaction of the patients. In the pharmaceutical sector Artificial Intelligence approach to patients interaction is helps to the medical professionals create focused and intervention. Researcher also explores that a patient rendezvous background has been developed at UCB to fill this gap, and its main motto is ultimately fostering the development and forward better solutions for the people those who are living with medical issues [27], [41]. Herewith the contribution to setting and raising standards in patient engagement shared publicly.

Regarding ***Supply Chain Optimization,*** Artificial intelligence can analyze data and optimize supply chains, ensuring that medications and treatments are delivered efficiently and effectively. This concept is vital as it improves patient access to treatments, reducing costs and enhancing outcomes. AI-driven supply chain optimization is a critical aspect of the pharmaceutical industry, as it enables the development and delivery of life-saving treatments. Artificial intelligence (AI)., initiation to the organizations can connect the power of machine learning algorithms(MLA) and big data analytics to gain greater understanding into their supply chain processes and make more informed decisions. Today, *Robotics and Automation* is highly useful by controlling robots and automating processes like manufacturing and laboratory testing, artificial intelligence may increase productivity and cut expenses. This idea is crucial because it makes it possible for the pharmaceutical sector to create and manufacture therapies faster and more efficiently. Automation and robotics powered by AI are revolutionizing the sector by increasing output and quality [42], [54]. Regarding *Digital Therapeutics***,** Artificial intelligence can also be used to create digital medicines that provide personalized care and support, such as mobile apps and VR programs. This concept is critical, allowing practitioners to deliver new and effective approaches that contribute to the health and wellbeing of their patients. Interactive digital therapies driven by AI are transforming the pharmaceutical industry with innovative, creative treatment options. As far as **Data Analytics,** Artificial intelligence makes it possible to analyze large volumes of data and derive information and insights that can improve operations and inform corporate decisions. This conceptualization is relevant to bio-pharma because it ensures that companies develop targeted and effective plans which lead to improved patient outcomes as well as commercial success. Due to the simplicity of data-driven decision making, AI-driven data analytics is a necessary factor of the sector [11],[47].

Regulatory Compliance is another area where AI has the ability to analyze data and ensure that it is compliant with finance regulations, decreasing the chances of non-compliance and fines. It is an important idea because it allows pharmaceutical companies to work in a timely and cost-effective manner while maintaining high quality standards and product safety. Regulatory compliance in the industry goes hand-in-hand with being patient-centric & creating public trust; hence, AI-powered regulatory techniques are vital. ***Regarding Quality Control*****,** AI and ML systems can predict defects, analyze data ensure quality, reducing potential risk and cost. So this idea is critical because it allows the pharmaceutical companies to uphold the best quality and safest product to avoid injuring patients while maintaining public trust. By handling vast amounts of data, AI-driven quality control is one of the most important features in the industry that allows for high-quality treatments to be involved in the process. Explores the dipping the amount of batches that fail to attain the essential critical superiority points is a key factor for the productivity of the drug producer. Quality control (QC) is a critical aspect of drug manufacturing process [48], [53]. However, Artificial intelligence also analyzes data and identifies possible ***cybersecurity*** threats that can protect sensitive information while inhibiting data breaches. This is important because it helps to keep pharmaceutical companies safe by protecting private and sensitive data from unauthorized access or manipulation, which is essential for the safety of patients and trust in public health. Artificial Intelligence (AI) is labelled as a pool of technologies that work together to permit machines to discriminate, interpret, take action, and obtain knowledge with the human level of intelligence [45], [51].

7.0 CHALLENGES AND ISSUES IN ARTIFICIAL INTELLIGENCE IN PHARMACEUTICAL INDUSTRY

AI has expanded the possibilities for drug development substantially in five areas: research and development of drugs; conduct of clinical trials; manufacturing of medicines; and personalization of medicines. However, ethical and operational issues arise that make implementing AI in the pharmaceutical industry difficult, including the quality of data and the accessibility of data on the Internet as well as other data stores. To train and validate models, all AI systems require reliable, complete, and consistent training and validation datasets. Pharmaceutical data is generally scattered, unreliable, and likely to contain many errors (including missing data), making it difficult for AI to operate effectively [41], [53]. Many drug development issues may stem from proprietary rights of clinical trial information and the

privacy laws associated with patient and genetic records, making it more difficult for AI to access necessary datasets required for producing new drugs. Some of the major issues include working with data that is all over the place, understanding how "black box" algorithms work, ensuring the accuracy and fairness of datasets, and discussing the ethical implications of patient privacy.

Key Challenges and Issues in AI for Pharmaceuticals:

- High quality standardized data is needed for AI models to work effectively; split data from many different data types, varied sources, and legacy systems make it very challenging to obtain high quality data to feed into AI/ML [49], [52].
- **Regulatory and Compliance Issues:** Combining AI with regulations for example cGMP compliance is complicated; regulatory bodies will require audits / control of AI/ML so this is contrary to the non-transparent nature of advanced AI systems.
- **Unclear and non-transparent data are two key barriers to the use of artificial intelligence (AI).** This is often referred to as the "black box" problem of AI because many advanced AI models, including deep learning algorithms, are not easily understood. In an industry where decisions can have a significant impact on patient health and safety, stakeholders—including regulators, clinicians, and researchers—need to clearly understand how conclusions were arrived at. Difficulty interpreting the outputs of AI can damage confidence, slow the regulatory approval process, and limit the widespread use of AI [32], [39].
- **High implementation costs are another barrier.** AI systems require significant investment in both infrastructure and personnel to develop and deploy. Pharmaceutical companies will need to invest in data storage systems, high-performance computing resources, and specialized software to implement AI solutions. In addition, the cost of recruiting and retaining personnel with skills in AI, data science, and bioinformatics can be quite high. As a result, implementing AI will be much more challenging for smaller companies and new ventures.
- **Insufficiently skilled individuals:** Successful use and integration of artificial intelligence require multidisciplinary expertise from experts in the areas of pharmacy, computer science, statistics and regulatory requirements. The world is currently facing a lack of global expertise in this multidisciplinary area, so shortages of individuals with these skills can result in delays in projects related to AI and limit their use. Staff development for existing employees and recruiting qualified new staff continue to be barriers for the industry. In addition to the shortage of expertise in both pharmaceutical sciences and AI, high costs associated with implementation are also barriers to the use of AI [22], [41].
- **Tactical and Operational Integration:** Integrating AI into existing, traditional, and manual processes for developing drugs introduces challenges, including requiring "human-in-the-loop" processes to validate results.
- **Potential Risks and Ethical Concerns:** The requirement for large quantities of highly sensitive health care data creates significant risks to patient safety from data breaches, privacy violations, or data obtained through an inherently biased algorithm. When using unrepresentative (or biased) data to train the model, the resulting algorithms may produce outcome(s) impacted by these biases [17], [42]. Additionally, ethical issues associated with data-driven decision-making in the patient selection process for clinical trial participation or the overall prioritization of projects within a typical drug development zone are difficult to quantify and estimate.
- **Integration of AI to Current Systems and Workflows**: Most pharmaceutical firms operate on legacy technology systems that do not easily integrate with the latest AI technologies. Integrating AI into current processes takes significant re-engineering effort and can be disruptive and resource heavy. Employees and stakeholders may also resist to change due to uncertainties in the potential benefits and fear of possible loss of jobs associated with implementing AI technologies.
- **Validation of AI Models for Accuracy and Reliability**: In the pharmaceutical industry, even small errors in model calculations could result in serious consequences (ex., premature launch of unsafe drugs). Therefore, to ensure the reliability and appropriateness of AI-generated models, they must be tested and validated prior to use in a pharmacy. Due to the complexity of biological manufacturing processes and unpredictability created by variability in data available for model development, validating AI-generated output can be extremely challenging. As a result, ongoing monitoring, and updating of AI-generated models will generate additional operational costs.
- **Issues of intellectual property (IP) and ownership:** With multiple stakeholders creating discoveries through AI, such as technology providers, pharmaceutical firms, and research institutions, questions arise on who actually owns these new inventions. To prevent confusion, therefore, there is a need to develop legal frameworks to provide clarity on how to resolve these ownership disputes and facilitate equal sharing of benefits from such discoveries.

- **limited generalizability of AI models**. Models trained on specific datasets may not perform well when applied to different populations or conditions. This limitation can reduce the applicability of AI solutions across diverse clinical settings and geographical regions. Ensuring robustness and adaptability of AI models is crucial for their broader implementation [23], [54].
- **Trust & Acceptance of AI–** Trust & acceptance are important for healthcare professionals, patients and regulators to believe in AI informed decision making. Trust is established by showing that AI works reliably, transparently, and benefits through data driven results. Communicating and collaborating effectively with all stakeholders is critical in order to promote acceptance.

The application of artificial intelligence (AI) offers many opportunities to change how pharmaceuticals are developed and used in the market. Since AI's full potential cannot be realized until some substantial obstacles are addressed, many issues will have to be resolved before AI can be fully utilized in the pharmaceutical development process [50], [54]. These obstacles include: data integrity, data privacy, data sharing/transparency, data cost, data skill requirements, regulatory compliance, ethical concerns, and system integration. To address these challenges requires collaboration among all members involved in the pharmaceutical supply chain (e.g., manufacturers; payers; clinicians; technology vendors). A framework should also be established by the pharmaceutical industry that will provide a method of implementing the necessary AI technologies; an investment of appropriate personnel needed to assist with the implementation process; and a commitment to using AI technologies in an ethical manner to provide maximum benefit to the development of pharmaceuticals and to ensure the safety of patients [24], [46]. In addition to the basic AI some of the emerging field of AI viz. Agentic AI also has some of the issues and challenges in pharma industry even Agentic AI has ample advantages as depicted in Fig. 3.

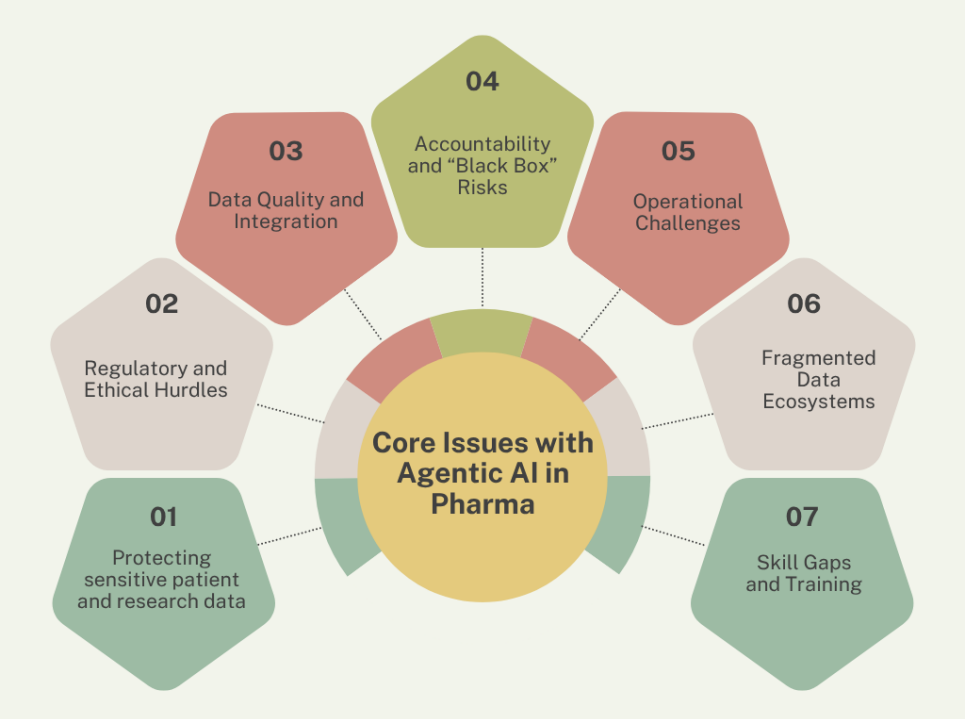

Fig: 3-Core issues of pharmaceutical management in Agentic AI

8.0 FUTURE ROADMAP AND POTENTIALITY OF ARTIFICIAL INTELLIGENCE PHARMACEUTICAL INDUSTRY

Artificial Intelligence makes revolutionary transformation in the drug delivery and in pharmaceuticals organizations. AI has huge potentialities in rapid development of pharmaceutical research. AI implemented in many fields including drug discovery, clinical research, manufacturing of drugs [2], [9]. It is applied in drug discovery and development of new drug within short period by analyzing the large volume of biological datasets including proteomics and genomics. Different AI and machine learning algorithms are applied in drug discovery by analyzing large volume of biological datasets by identifying the causes of the diseases.

The future of Artificial Intelligence in the pharmaceutical industries enhancement is going to be change rapidly. The international market of AI in pharma is supposed to grow from about $1.94 billion in the year 2025 to more than $16.49 billion by the year 2034 [30], [38]. By the

year 2030 early adopters are expected to almost double their operating margin by fully integrating the Artificial Intelligence into their business process. Therefore, there are the immense prospects and potentialities in the future for the development of pharmaceutical industries using AI. Different future prospects and high impact areas in pharmaceutical industries are accelerated drug discovery, decentralized clinical trials, self healing supply chain management, quantum computing integration, personalized and precision medicine [3], [19].

In terms of decentralized clinical trials, plans put "digital twin" virtual copies of the patients at the top of the list. These intelligent solutions can be used to test or investigates how drugs are working and may cut the number of people required for the tests by as much as 35%. Drug discovery process is accelerated in regular basis; AI is moving the timeline of drug discovery from the 5-6 years down to the less than 12 months. Researchers are now using the generative AI models such as Generative Adverbial Networks (GANs) to make or design completely new molecules with very limited properties that required. Artificial Intelligence is continuously changing the industry from blockbuster drugs to treatments that are based on a person's genetics and ways of life. AI helps in making the solutions for the personalized and precision medicine. AI has the vast potentialities and future prospects for the intelligent and automated solutions of the personalized and precision medicine. Utilization of the AI will make it visible in real time where sensitive material are moving and stop shortages or cold chain failures before happen. Upcoming AI integrated with the quantum computing to simulate intricate molecular interactions at velocities impossible for the traditional computer. Therefore, there are many possibilities to enhance the operational, production, research and development domains of the pharmaceutical industries using Artificial Intelligence technology solutions. In future, Hybrid AI power technology integrated with Internet of Thing, Block Chain, Quantum Computing, Digital Twin, and Cyber Physical technologies system develop the pharmaceutical industries work more dynamic, fast and effective [39], [44].

Pharmaceutical industries set their target to minimize the drug discovery timelines in half and the late stage failure with the help of Generative AI that implemented for molecular creation by the year 2026 to 2030 and whereas, the explainable AI (XAI) is used to establish trust and regulatory compliances. The future of Artificial Intelligence in the pharmaceutical industries are transforming from small pilot based isolated projects to the full AI ecosystems projects that are integrated, generative and agentic. Generative, explainable, and agentic AI are the advance AI techniques that have the immense potentialities to extent growth and development of the pharmaceutical industries [4], [7]. Generative AI based models such as GANs, Transformers, and Diffusion models are for text generation but these models are also used in molecular design. Advance AI based solutions develop with generative AI are de novo drug design, multimodal foundational models for diseases detection and its prevention, target identification, and virtual synthesis and optimization. Explainable AI (XAI) is used in addressing the black box nature of deep learning because regulatory bodies such as FDA and EMA are demanding transparency. XAI is applied mostly for the purposes of feature attribution and rational, validating safety, human in the loop, and regulatory compliance [18], [33].

9.0 CONCLUDING REMARKS

Artificial Intelligence (AI) has emerged as a transformative and disruptive technology in the pharmaceutical industry, reshaping drug discovery, development, manufacturing, and health care delivery. The integration of Artificial Intelligence techniques, including machine learning, deep learning, and advanced data analytics, has enabled a transition from empirical time-intensive methodologies towards predictive, data-driven frameworks. Applications of AI powered solutions in pharmaceutical manufacturing industries accelerate the productivity, operations, and management system. AI used in the pharmaceutical industries in various perspectives including product development and manufacturing, regulatory compliances management, commercial strategies improvement, supply chain management, and other operations management. Artificial Intelligence has the important and potentialities in the pharmaceutical industries. Artificial Intelligence has various potentialities in various areas for the development of the pharmaceutical industries and organizations such as human resource management, quality control, supply chain management, research and development, financial management, logistics management, data management, customer relationship management, operations management, and commercial management. AI provide intelligent solutions that automate every task or work associated with these domains of the pharmaceutical industries. Industry 4.0 utilizes the various AI enable autonomous technologies including robotics and system in manufacturing of product without the interaction of the workers physically. Pharmaceutical industries also used AI enable emerging applications that automatically manage every finance related works. To improve the skills of employees and labor or staff in the industries and other operational activities in terms human resource management AI play significant roles in this context. Pharmaceutical companies are continuously focusing on the how to improve the overall production, quality, design and discovery of new drug, and other operational services. In this regard small pharmaceutical industries transform their research and development, master data management, reporting, analysis and human resource business process using Artificial Intelligence solutions. Middle or individual level pharma industries are uses the

AI to develop their business process as per their specialization and requirement. Large level pharmaceutical industries implement AI to reshape production, marketing, sales and analysis business processes. Therefore, Artificial Intelligence has immense potentialities in improvement the business process of the pharmaceutical industries and organization, AI has the ability to transform the pharmaceutical industry by speed up the drug discovery, improve the clinical trial and make it more efficient, and making manufacturing process more efficient. By the year 2034, the AI in pharmaceutical industries and organization market is expected to be extend worth 13.1 billion US dollars. Potential benefits of the AI implementation are finding drug target within month instead of years, minimize production cost, allowing personalized medicine through genomics data analysis, and making the supply chains run smoother and efficiently. Key potentialities of Artificial intelligence in pharmaceutical industries development are accelerated drug discovery and development, optimized clinical trials, personalized medicine and genomics, regulatory compliances and automation, manufacturing and supply chain efficiency.

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