A Systematic Overview of the Impact of Artificial Intelligence in Pharmaceutical Science

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A thesis submitted to the Department of Pharmacy in partial fulfillment of the requirements for the degree of
Bachelor of Pharmacy (Hons)

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Brac University
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Declaration

It is hereby declared that

1. The thesis submitted is my own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
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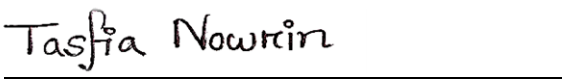

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Approval

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Ethics Statement

The study does not involve any kind of animal trial and human trial.

Abstract

Pharmaceutical sector is undoubtedly a big platform for utilizing Artificial Intelligence (AI). The study was conducted to discuss the varieties and stages of pharmaceutical production and other relevant procedures. Starting from the very beginning step called drug molecule discovery to designing, manufacturing, formulating, artificial intelligence has its different roles. The study can be seen as a synopsis for overall application in the pharmaceutical sector. It also well-defines the tools and their roles in different stages in the industry. The study answers that how artificial intelligence performs the tasks along with greater efficiency. Other related studies are also mentioned here to clarify concepts. Artificial Neural Network (ANN) is mentioned here as most recognized part of AI. Digital science reduces labor cost, time and in contrast increases the yield with greater efficiency. Although there might be some limitations with this intelligence, but they can be rectified. The study exhibits the significance of machine learning in order to enhance the outcome of artificial intelligence. In a nutshell, the study provides a general overview of application of AI in crucial steps of pharmaceutical industry technology.

Keywords: Artificial intelligence (AI), technology, computational, drug, pharmaceutical, artificial neural network (ANN).

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Chapter 1

Introduction

1.1 Artificial Intelligence:

Technology has a huge effect on every sphere of life since it has changed various things in recent decades. Starting from communication, transportation etc., it has its application in medical and pharmaceutical companies. According to the experts, the pharmaceutical industries can be improved via including new technologies. For example, Artificial Intelligence can perform efficiently at the same time with higher accuracy and large-scale productions are easily dealt with reduced time, cost and labor with it. (Ahmed Shaikh et al., 2019). The term Artificial Intelligence refers to the branch relating to computer science, which is completely involved with problem solving. This also includes constructing machines that are capable of dealing with tasks requires human operators who possess intelligence (Sethuraman, 2020). In addition, experts also opine that the pharmaceutical industry can be improved by training the staff about the new technologies. In that case, the pharmaceutical industry owners are also recommended that to implement Artificial Intelligence in such a manner that does not decrease the employment of people. (Ahmed Shaikh *et al.*, 2019).

Artificial intelligence (AI) needs to build computers to do such sorts of things that minds can perform. It involves psychological skills. Examples of psychological skills are conception, association, counting probability, designing plan, and control of machines. A huge number of techniques is applied by artificial intelligence. Addressing various different tasks is also possible with the help of artificial intelligence. Concisely, there are two main aims of artificial intelligence such as technological and scientific.

1.2 Artificial Intelligence in Drug Design:

An essential area of research is drug designing and development for pharmaceutical companies and chemical scientists. Target delivery as well as time consumption along with high cost causes a hurdle during drug design and discovery.The fundamental focus regarding drug design and implementation is to save time and money for manufacturing. With the help of improvements in using technology, computer-aided designing of drug tthat incorporates artifcial intelligence is able to eradicate the challenges and traditional drug design and development. Principles of Artifcial intelligence have been applied in many sectors such as the classifcation of excipients and active ingredients, drug release monitoring, pre-clinical development as well as clinical development, drug screening, biomarker, bioactivity identifcation etc. Also, pharmaceutical manufacturing, physiochemical properties, measuring toxicity, and recognition of mode of action are possoble with the help of artificial intelligence (Gupta, R. *et al*.,2021).

1.3 Impact on Drug Formulation:

Artificial Intelligence (AI) has a great impacton the pharmaceutical field in several ways.In order to produce new and better drugs to combat against fast-growing diseases, the utilization of modern technology can save both money and time. Moreover, supplying higher expertise among different formulation and process parameters is also possible. Artificial neural network (ANN) and pharmacokinetic simulations are preferred for controlled drelease formulations. It has been found that almost 7 formulation variables and tablet variables such as hardness, particle size and moisture are used for 22 tablet formulations of a model. In vitro, the cumulative percentage of released drugs at 10 different evaluation time is used as outputs. In vivo, the dissolution is the rate-limiting step for the absorption of the drug. In vitro release profiles are observed mailny based on the distinction factors. The developmental procedure of pharmaceutical product required the optimization of formulation. And the optimization correlating to the formulation design and regulation is associated with modern technology. (Sethuraman, 2020).

1.4 Conventional vs. Artifical Intelligence Method:

According to the physical sciences, a particle posseses several physical properties such as volume, size or mass. Particles can be in different forms such as solid or liquid droplets dispersed in another immiscible liquid. In pharmaceutical industry,there is a huge demand for enhancing the production methods.A dispersion of one liquid into another liquid (imimiscible, or slightly soluble)is called an emulsion.The production of the particle plays an important role in emulsion preparation.On the other hand, Emulsion droplets are particles but more actual to say that they are the after production droplets which are converted to solid particles. This conversion into solid involves applying of physical or chemical treatments.These procedures were time consuming and labour requiring in previous ages. Since, the fabrication of micro-/nano-particles withuniform size along withgood properties is a crucial requirement pharmaceutical field, the steps required a long time for relevant experimentations (Piacentini E., Dragosavac M., Giorno L.2017). Later, artificial intelligence provided a powerful tool for developing micro emulsion-based drug-delivery systems. With this tool the experimental effort was reduced a lot. Moreover, the tool is utilized for determining the probability of the phase behaviour of micro emulsion-forming systems. The system consists of consisting of oil, water and two surfactants. In addition, Artificial Neural Networkexhibits the application to predict aerosol behaviour, in order to employ this technique in designing the pulmonary drug-delivery systems (Sethuraman, 2020).

1.5 Prediction of Physicochemical Properties during formulation:

Lipophilicity,intrinsic permeability and aqueous solubility,defines the physicochemical properties of drug. while screening for new medications, it is vital to take into account these physcicochemical properties. Drug efficacy ,potency, toxicity, selectivity,as well as ADME properties are prominently reliant on it. (Lipinski, C. A., 2004). Researchers prioritize AI-driven methodologies. This approach associates the molecular descriptors through the physicochemical parameters such asatomic charge, hydrogen bond influenced effects, and surface area. A lipophilic drug has several essential characteristics that must be assessed in a computational modeling approach. This approach associates the molecular descriptors through the physicochemical parameters such asatomic charge, hydrogen bond influenced

effects, and surface area. Other procedures for instance conductor-like screening model (COSMO) or conductor-like screening model for real solvents (COSMO-RS), molecular simulation, linear/nonlinear QSPR etc are driven by quantum chemistry (Zhang, H. S. *et al.*, 2009 ;Yang, S. S. *et al.*, 2009). Aqueous solubility is predicted using in silico approaches. It is commonly acknowledged that these methods can be classified into three distinct categories. The classification scheme was established on the basis of the founding principles. Those are:(1) molecular mechanics simulation, (2) quantum chemical approaches, and (3) descriptorbased approaches. In order to estimate solubility using structure-based procedures, both the molecular topology and fragment data are used. (Todeschini, R. and Consonni, V., 2008).

1.6 Impact on Research of drug chemistry:

There is a current practice going on the use of in silico brain power in the pharmaceutical industry. if there is any area requiring patterns that needs to be identified , in silico can be used. Many newer, less well-known companies are getting creative and shows the desperation to explore the possibilities. They are making improvement with this in silico methods. They are focusing more on their research and development. The future there might be involvement of Artificial Intelligence for playing multiple tasks in drug development process. Also, the increasing personalisation.compound discovery and other academic researches are examples of this technology.(Arifin, 2018)

In silico is a term that refers to the silicon-based computer component. As, In silico methods are rely on computational methodologies that enable the estimatation of effects that would otherwise require the advancement of numerous laboratory methods. In vitro research entails laboratory assays. The assays are performed to evaluate diverse functional roles and functions that are dependent on the cellular over-expression or cell-based “test-tube” assays. Specialized laboratory equipment is required for the in vitro studies, as well as laborious optimizations. For tackling the rapidly increasing amount of bioinformatics information, using computational modeling is an invaluable tool. At this time, the fastest and most effective way to find out if a Single-Nucleotide Polymorphism (SNP) has the potential to cause disease is through computational analysis.

Figure: the function of protein determined with the help of its 3D shape. (Callaway, 2020)

Furthermore, the results must be analyzed under consideration of distinct parameters, including clinical, structural, and bioinformatics parameters. The advent of computational tools has become increasingly commonplace in today's world. As Crystal, structures are increasing in number, and in-silico methods have become vital platforms for methodology research. Computational techniques play a variety of roles in various areas, including describing the basic rules of protein-related chemistry, modeling the three-dimensional structure of proteins, and predicting the amino acid sequences of proteins. (Duarte *et al.*, 2018).

Figure: 3D structure of amino acid

1.7 Role in manufacturing of pharmaceutical products

1.7.1 Tablet Compaction and Granulation:

To achieve greater output at a higher scale, we developed a scale-up granulation process that maintains similarities in geometric, dynamic, and kinematic characteristics. In order to achieve a similar geometric form, the companies' equipment designers build their equipment around specifications, such as bowl height/diameter ratio, impeller design, to create that similarity. Because of the dynamic and kinematic similarities, control of the speed of the impeller is directly linked to the dynamics and kinematics. The impeller speed regulates the forces and collision energy exerted by the granules, as well as the velocity of particles within the granulator. A hybrid artificial intelligence system called neurofuzzy logic is widely used due to the combination of neural network's capability to learn from data and the ability to provide fuzzy logic so that hypothesis can be expressed in an intuitive manner. It has shown significant success as a learning tool for data analysis. The reason for this is that it only gives the user a condensed amount of data, with which they can emphsize key relationships that are vitally important to their research and choices of important variables for forthcoming scientific experimentations.(Landin, 2017)

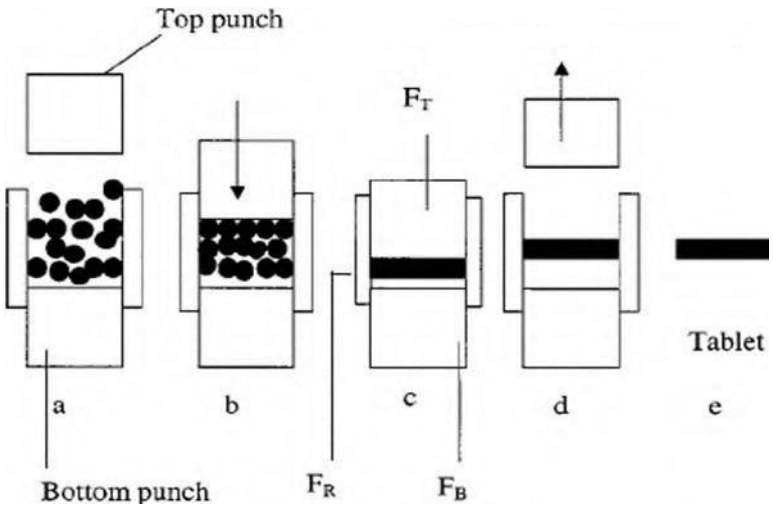

Figure: tablet compaction

1.7.2 Dry granulation:

Dry granulation is another granulation method that uses roll compaction. It is a well known unit operation for production of the solid dosage forms in the pharmaceutical technology. Moreover, dry granulation is widely used if the powder mixture is sensitive enough to heat and moisture and they possess poor flow properties. The control of various steps in this process is possible by using artificial intelligence. (Kazemi, P. *et al.* 2017).

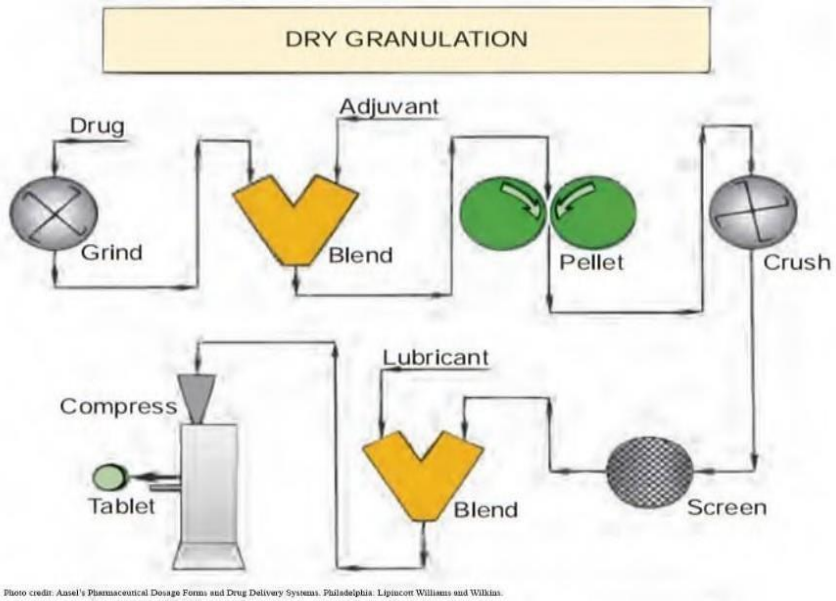

Figure- Dry granulation

1.7.3 Fluid-bed granulation

Last but not the least is named as Fluid-bed granulation. This has the advantage of consolidating multiple wet granulation steps into a single piece of equipment. Particle size, flowability, and moisture are just some of the parameters that affect a fluidized-bed granulation process. As a result, acknowledging the entire process is essential. Regulatory guidelines advise for an enhanced procedure in order to implement new technology to ensure control of each criteria. Novel approach are applied for data mining in a fluid-bed granulation process. Neurofuzzy logic is used to discover and incorporate the concealed knowledge in numerous formulation databases (Shao *et al.,* 2008).The growth of granules is regulated using fuzzy logic algorithms in a fluidized-bed granulator configured with an image probe and an advanced optimization system. . Latest techniques that are getting utilized for enhancing fluidized-bed granulation assist the process by monitoring the use of in-line measurement of process parameters. For instance, moisture content or temperature. (Petrović, J. *et al.,* 2011).

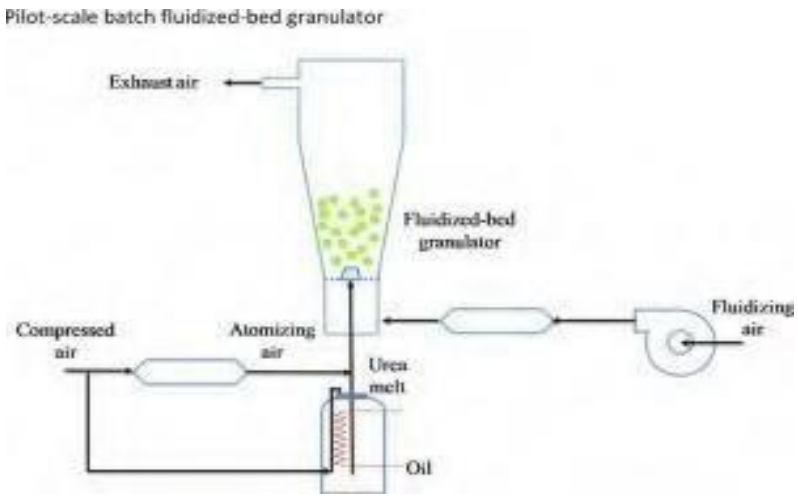

Figure- Pilot-scale batch fluidized-bed granulator.

1.7.4 hard gelatin capsules

We have ascertained that hard gelatin capsules have different secondary characteristics depending on the shell. For instance, knowledge representation, operational speed, and computational capabilities such as algorithm and arithmetic. An already-prepared, pre-filled software application is now available, for these hard-shelled capsules named as

kernels and it is possible to use them frequently. This software embodies a decision-support framework. There are a number of problem solving steps involved in formulation so implementing this system to regulate formulation and understanding of procedures & ingredient properties will ensure that the correct steps are followed in formulating and learning how to utilize those ingredients. To develop a formulation for these pharmaceutical products, a combination of conventional language (11%) shells (66%) and specialized language (23%) is required.(Rowe, R. C. and Roberts, R. J., 1998).

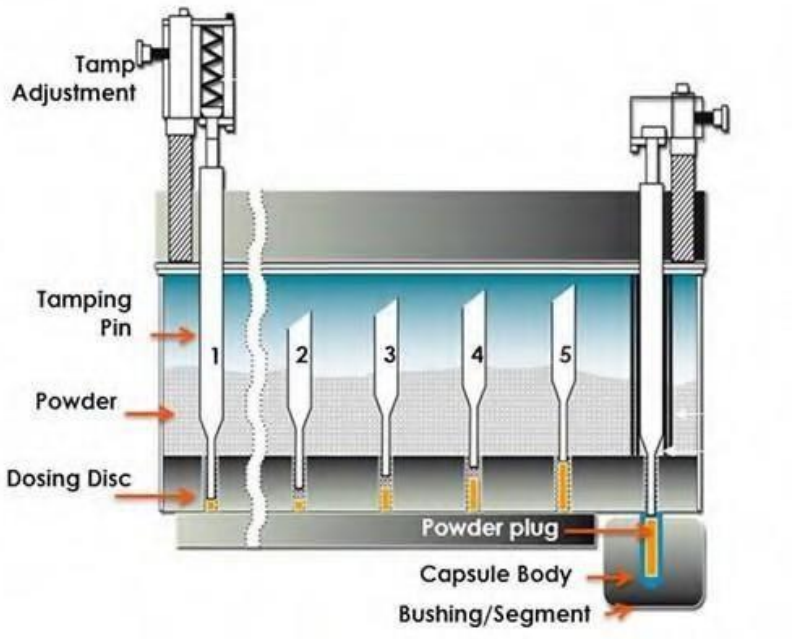

Figure: hard gelatin capsule compaction.(2021,May16)

1.8 Drug Discovery via Artificial Intelligence:

Drug discovery is a intricate, time-consuming, and costly process, with the R&D cycle lasting 10 to 15 years on average. Only one out of every ten potential drug candidates will receive regulatory approval following successful completion of clinical trials (phase I). Despite financial investments by the pharmaceutical industries, R&D continues to search for the next blockbuster drug. (Martin, L. *et al.,* 2017). Using in silico mechanism, one can aticipate the chemical structure that will elicit the intended response at the target site. Additionally, the in silico technique can optimize this structure to meet desired properties such as potency, safety, absorption, solubility, toxicity, and permeability, as well as predict

the compound's physicochemical properties, plan the compound's synthesis, and synthetic tracebility.(Petitjean, M. and Camproux, A.-C. 2016).

The quantitative structure-activity relationship (QSAR) modeling tool has been in use for decades, and it is being put to use once again to evaluate candidates for possible potential new drugs from a million alternatives. Additionally, with the emergence of the deep learning technique known as “big data,” new approaches to machine learning have emerged. The system is capable of handling a significant volume of data generated throughout the drug discovery and development phase.(Zhang, L. *et al.*, 2017).

1.9 Drug development and Artificial Neural Network (ANN)

Artificial Neural networks are constructed using the human nervous system's structure as a model. The perceptron are the fundamental building blocks of these networks. hese simplified versions of human biological neurons act like basic functional neurons. Electrical impulses can be generated in these mimics, enabling them to mimic the electrical impulses traveling in the human brain.(Beneke, F. and Mackenrodt, M. O., 2019). Also,in ANNs, nodes are connected in a specific configuration. Every node receives separate inputs from a group of nodes, and then each node generates a separate output. As with every dynamic network, there are different forms of neural networks. The variation can consist of a single network or multiple networks connected together. ANNs can solve a particular complex problem by reducing the number of variables in the analysis due to the effective application of selection and use. On the other hand, this necessitates adequate training and hands-on experience with standard operating procedures (SOP). ANNs come in a variety of forms. There are three types of neural networks: multilayer perceptrons (MLPs), recurrent neural networks (RNNs), and cellular neural networks (CNNs). (Bielecki, A., 2019)

The MLP network has a number of applications such as recognizing pattern, optimization processes,identification and controls of proceudures , and so on. These can be considered as efficient tools which can do the derivation of various models. That is why these are used as universal pattern classifiers. (Krawczak, M., Sotirov, S. and Sotirova, E., 2012).The RNNs are used as in important area of research and development . These are networks with

a closed-loop and their outputs can be put again as inputs (de Barcelos Tronto, I. F., da Silva, J. D. S. and Sant'Anna, N., 2008). There are various types of RNNs. The types areBoltzmann and Hopfield etc. These can be used for various characteristics as they are closed loops. To give an example, they are able to retrieve data and determine correlations, predict financial issues, and predict the total capacity of wind turbines in order to assess the quality of water. This final point includes a basic premise about dynamic systems that CNNs exemplifies. The local connectivity in these dynamic systems is manifested by topology. They are extremely useful to perform tasks such as image and video processing, biological system modeling, processing complex brain functions, pattern recognition, and complex signal processing, and many others.(Da Silva et al., 2017; Bielecki, 2019)

1.10 Artificial Intelligence in Future Marketing:

Artificial intelligence (AI) has the potential to revolutionize both marketing strategies and customer behavior. It is predicted that in the near future, salespeople will be having the facilty to get assisted by an AI agent that monitors teleconversations. More specifically, utilizing voice analysis-capabilities with increased accuracy. This involves machines, which can mimic "intelligent human behavior". The automation of business processes is possible if the AI algorithms perform tasks in a well-predetermined manner and minimal human input. All data-related and document-processing tasks like shifting data from email and record keeping systems as in updating customer files, executing simple market transactions, or "reading" documents , language processing are the tasks that can be performed by artificial intelligence in pharmaceutical marketing. Second, insights can be gained by AI from a huge number of customer and transaction data. In addition to numeric data, this can also include text and facial expression, as well as voice, image, and data. Using AI-based analytics, companies can predict whether a customer is likely to purchase. Furthermore, AI can anticipate varioud frauds such as credit fraud before it takes place.(Fiorini, 2018).

A good marketing sector focuses on one of the main planning procedures, demand forecasting is an important part of a good marketing strategy.Calculating the appropriate drug dose by using fuzzy expert system for patient can be done by this intelligence. This type of economic issues are considered by it. Pharmaceutical companies are supposed to produce drugs which have high efficiency due toeconomic reasons. However, it is true that the production of more than one dose essential. In that cases, marketing department needs to predict the appropriateamount of product. Later on in another department named as

production planning department, the reckoned values are known as production quantity. (Candan, G., Taskin, M. F. and Yazgan, H. R., 2014).

Chapter 2

Literature Review

A study named as “Artificial intelligence in the pharmaceutical sector: current scene and future prospect” showed the involvement using computer-like machines. It says that these machines can mimic the core and principle ability by help of different data. AI is a suitable technology many functions such as searching ways to solve difficulties withing short period of time, also for the arangement of a large number of input that are provided to it. This can assossiate in analyzing situations via learning and analysis. In addition, it aids to solve certain intelligence based problems. There is an applicable technique called “machine learning” (ML) that supports artificial intelligence. AI has a large number of applications in almost every sectorin the world. The study says- “In recent days, in the pharmaceutical and healthcare sector for many applications for example, drug discovery, design,drug repurposing product development, improvement of manufacturing, drug adherence,dosage, predictive biomarkers, predicting results of treatment, clinical trial candidates identification, personalized medicine, processing biomedical and clinical data, gene expression patternanalyzing , pandemic outbreaks detection, combinatorial synthesis, and a lot. AI and ANNs both are known in the development of the various dosage pharmaceutical and healthcare products.” This consists of different stages of healthcare and pharmaceutical sector. This modern technology has displayed potentiality in lessening cost and other troubles for large amount of production. Moreover, this man made intelligence can be assossiated to robotics. A life changing modisication can be possible with different ease of woks. It can assist in staying hale and hearty and decreased necessity of getting hospitalized. The importance of this modern technique knows no bound. There are a number of industries and companies which have been expressing their optimistic behaviours towards this technology. Majorly, pharmaceutical industries are much optimistic in applying AI because there are certain number of burdensome steps and methods during the manufacturing of various medicinal products. This technology will ultimately be able to manage expenses as well as efficiency. In addition, for the better results of using science in different phamaceutical companies, AI has no alternate. (Kalyane, D. *et al.*,2020)

Another study was held named as Artificial intelligence in drugdiscovery and development. The study discussed about implementing Artificial Intelligence among multiple fields of

pharmaceutical industry has been discussed.Starting from discovery of drug and , iincreasing efficacy of the product as well as clinical trials there is role of AI.To decrease the humanworkload and reaching to desired aims within lessened time is a great achievement with it. The auhtors also discussed the interrelation between the strategies and ideas that are being implemented with current difficulties. The solutions for these problems and thinking for the next phase to apply the methods correctly are mentioned in this study.AI can also contribute in the further establishment of accurate type of dosage with optimization. AI performs these tasks with faster approaches which leads to quick production with improved reproducibility. It can also assist in measuring the safety, efficacy of the product. Assuming market state and further outcome calcalstate and further outcome calculation are also part of it's work..The total achievement of AI relies on the availability of information since it is essential to enrich the system for training (Paul, D. *et al.*, 2021).

"The application and use of Artificial Intelligence to Support Drug Development" was studied. It says that Center for the Study of Drug Development (CSDD) , Drug Information Association (DIA) were along with eight pharmaceuticals examined outcomes for using AI. The study was held to clarify the understanding of AI adoption in the industry. It investigated creactivity that are being planned for using in the future. AI technologies are utilized widely for choosing diseased individuals in order to test the management of data. The study concludes that despite there is less, there are drugs including the utility of AI will be raising as well as it will show it's enhanced activity later on. In future, the researches will determine uses and application in several dryg related researches. (Lamberti, M. J. *et al*., 2019).

In 2019 there was another study held which owned the heading "Artificial intelligence in drug development: present status and future prospects". This study describes that this technology is able to learn from the solutions. The solutions are specific and dififcult situations. Noticable betterments in further successful achievemnets could be utilised in AI technology in order to bring a revolutionary change in drug development. Recently, industries of pharmaceuticals are going through huge difficulties for bearing different plan of actions due to decreased preformance. The paper found out main reasons for complications within recent accpetances of medicines as well as logical methods to rectify potency by using AI process is also discussed. Though no such drugs processing are

inclding AI approaches, further advancements might make it possible within about two or three years to formulate a novel drug in future.The study found that experts strongly believe the permanent change in the pharmaceutical industry for drug doscovery will be caused by AI. Eligible people who are able to operate this man made technology are needed to apply it efficiently in industry. Moreover, assigned personnel should also possess training that is very essential. Thus, perfect space for working can be created where multiple tasks can be performed simultaneously. So, reason is that AI will cross check big sheets of data and chemists will be able to run and opearate different machines and maximum data can be thus arranged as desired in order to get an accurate method. Additionally, AI may assist relevant tasks those are recently unavailable for getting used (Mak, K. K. and Pichika, M. R., 2019).

An study regarding "artificial intelligence in pharmaceutical product formulation: neural computing and emerging technologies" was also done. It says that in the current establishment of AI has brought many other strategies which provides the implementation of pharmaceutical technology. Among all the rising competitions the achievers will be the only one who will be eligible to extract facilities from modern science and apply this strategy. It mentions the main task named as translation. The study mentioned "Neural computing, machine learning, knowledge-based systems and expert systems, derived from artificial intelligence, can assist in the efficient formulation and enhance productivity along with consistency and quality." Writters provided an idea of neural computing and other technologies (Rowe, R. C. *et al.* 1998)

A review named "Digital Pharmaceutical Sciences"elaboartely discussedArtificial intelligence (AI) have gained great interest in knowledge and technology. The large growth of data from enormous sources, advancements in various analytical tools, and continuous developments in machine learning algorithms have caused a rapid interest innew machine learning applicationsin pharmaceutical sciences. The study mentioned the sectors called "drug design and discovery, preformulation, and formulation." The different prcedures are usually applied to indstrial technologies are discussed along with a particular emphasis on artificial neural networks because of their capability in pharmaceutical research. AI and machine learning are common in pharma as well as industrial insights are also reviewed. Beyond traditional approaches, implementing digital technologies to produce more efficient, fast products and economical solutions in pharmaceutical sciences are also

discussed in this.the study provided an information that “an average of $2.6 billion and over 10 years are required to develop new medicines. In last 10 years, there is a growing number of pharmaceutical companies using AI in drug research and development.” Several pharmaceutical industries have collaborated to other renowned companies that can afford the expenses of this technology. It is also able to bear manufacturing load along with digitalization.Investing in data management which includes advancing algorithms along with the availability of big number of informations. The review concludes that AI may improve and huge amount of drug production is possible. (Damiati, S. A., 2020).

“Basic Concepts of Artificial Neural Networks (ANN) Modeling in the application to Pharmaceutical Development” is also discussed in an overviw. The research paper defined Artificial neural networks (ANN) as an advanced process.It is not yet broadly applied. The main purpose of the paper was to give a descriptive detail regarding associating network. The abstract mentioned- “a description of less known networks such as featureextracting and nonadaptive networks. ANN are based on the attempt to model the neural networks of the brain is again claimed like other studies.” Learning algorithms is importantto assossiate ANN which requires mathematical procedures. Authors noted that “networks can be applied in the pharmaceutical field as an alternative to traditional methodology.” The probable sectors for using this smart and advanced technology is dramatically huge. Retail pharmacy to hospital pharmacy, in every small branches, a large number of applications are done by ANN. The article finishes saying that few applications are hopefully able to bring a wide achievement. (Bourquin, J. *et al.* 1997) .

A study was conducted with a heading as “Advancing Drug Discovery via Artificial Intelligence”. This study depicts that Drug discovery is one of those applied sciences which can cause welfare of modern lifestyle. Developing novel compound not a cup of tea at all as well as it is a time-consuming process. “The typical cost is 2.6 billion USD and takes 12 years on average. Reducing expenses and fasten up the new drug discovery has become a burning question in pharmaceutical industry.”- was mentoned by the authors here. Artificial intelligence (AI) wrapped the emerging technologies can turn the novel molecules to an outstanding and blockbuster drug with desired outcomes. Authours discussed the use and predicted the success of this technology for making the manufacturing and other relevant procedures better. Some tools predicts the circle of drug design-development. For future applications, this technology can prove itselt to be successful and helpful if AI in

drug discovery is realized (Chan, H. C. S. *et al.,* 2019).

Damiati, S. A. in 2020 mentioned in his article that “Mary and co-workers in 2019 conducted a survey-based study in order to clarify the adoption as well as results of AI in pharmaceutical and biotechnology companies. Across 217 organizations, a number of important AI activities have been identified including the use of AI for patient selection and recruitment for clinical trials, in addition to identification of medicinal products data gathering. Major factors for not utilizing AI technology have been identified including lack of skilled staff, safety, regulatory, and compliance concerns, and budget constraints”.

Another review paper named “Current and Future Roles of Artificial Intelligence in Medicinal Chemistry Synthesis” illustrated that “Artificial intelligence and machine learning have potential role in predictive chemistry.” A few reports have been found that small number of companies implemet in silico methodology. A program which is based on data is being tested via “Machine Learning for Pharmaceutical Discovery and Synthesis (MLPDS).” According to the Authors ,other models those can assume outcome are also getting used recently. The srudy also discussed MLPDS is currently used in imdustries specially in pharmaceuticals in order to reduce the money and time both. “Many of the current Computer aided synthesis planning (CASP) tools are used for planning routes via reproducible chemistry. The purpose of these tools is to enable chemists to enlighten the synthesis planning” is written by the authors in this conducted study. With the progressing development of machinelearning methods for planning synthesis and a jump for applying CASP in order to lessen the pressure on them as well as it should also be able to adjust with several sectors of pharmacy.For wise handle and tackle various raising difficulties are being solved perfectly with the applying od this new artificial intelligence based technologies are reliable according to the authors (Struble, T. J. *et al*. 2020).

A journal article, “A New Paradigm for Pharmaceutical Applications in Formulations Development” defined Artificial Intelligence as a branch of engineering that is specialized in emerging intelligent machines. It was written in that journal artucle that the utilization of artificial intelligence has elevatedin pharmaceutical technology. Over few years, the sector of artificial intelligence has shifted from theoretical research to real-time applications. The article also says that “Machine learning is an application of artificial intelligence.ML provides systems the capacity to learn in an automated manner as well as operate from experience even without being programmed.” Around $100 billion medicines

are protected in a year. This is possible because of more efficiencies in clinical trials, decision-making practices and innovative tools that are able to assist consumers, ,pharmacists, physicians, to make correct decisions. Neural networks along with fuzzy logic and genetic algorithms are rapidly developing technologies that are utilised for formulation and manufacturing of numerous drugs and medicines. This study shortly depicted it's necessity in the designing of a medicine .A number of AI tools that are available at the present, requires some skillful operators who are expert in operating these type of advanced ideas. (Sethuraman, N., 2020).

Another article possessed a heading as "Artificial intelligence in pharmaceutical research and development." The authorsin this writing were expecting to see more biotech, software companies exploring ways of implementing this in the discovery as well as designing field. Numerous idustries run out of money whereas others are smart enough to become bigger players with AI strategy. The author said "If AI does indeed help to discover drugs, as I expect that it will, in the medium term it will be increasingly integrated into the working practices of organizations both large and small." In addition, it was also expected by author that AI will also change the way of academic science. On large scaless,artificial intelligence is certainly needed measure or predict the effects on employment because jobpatterns will change. And someundoubtedly might disappear involve into new kinds of job or role as researchers or managers. Personalized medicines, Human Genome Project and high throughput screening can be done efficiently with this technology. The improvement of industrialproductivity patients' needs would be better than of last 20 years. Although there are fears which is justifiable regardingdata misuse. There is also a need of rethinking aboutemployees' roles in the organization, the balance between AI with human control and impact on employment. The study depicts that there is no clear vision if the changes that will take place will be evolutionary or revolutionary. But, for now, it seems enough reasonable that in future AI can be utilized as a tool for discovering medicines (Mitchell, J. B., 2018).

There was a study named as "investigation of an artificial intelligence technology" that icluded "Model trees, Novel applications for an immediate release tablet formulation database." This study has found that model trees in as artificial technology is implemented in controlled relaese based methods. Compared with artificial neural networks, this modelling toolis much more strongly set with a large usage among drug related procedures.

Different equations can be established. Authors noted “tablet tensile strength, disintegration time, and drug dissolution profiles of similar quality to neural network models are solved with these multivariate linear equations.” Valuable ideas and informations lying unfound can even be sorted out through them. The investigation ended saying that model trees are useful tools as a transparent technology to formulators (Shao, Q., Rowe, R. C. and York, P. 2007).

”Applications of artificial intelligence in drug delivery and pharmaceutical development” is also reviewed in this study. The study illustrates that AI system can be applied to various tasks as manufacturing, analyzing and researches. With prompt and timely implementation in appears, we can expect great probability of success. An important question was mentioned iftypology of AI would be beneficial into the pharmaceutical field. “Reducing and narrowing the capability of AI to increase productivity as a simple tool to enhance robotic operations and as a passive tool for knowledge/data mining and organization” was mentioned in this study. Author claims that the scopes can be fulfilled to some extent via deep learning technology. It was also expected that the most desired experience is possible by the help of wise implementation of this technology. A robot that is able to integrate building blocks among the unfilled informations with proper examining. (Struble, T. J. *et al*. 2020).

An atricle named as “Artificial Intelligence in Drug Design” describes that “Artificial Intelligence (AI) plays a vital role in drug discovery.” Particularly, ANNs are well-known. Several applications in predicting property and activity such as physicochemical properties and ADME properties express that the tools of this methodolgy are advanced. The study also discussed the role of this technology in searching for novel derug active ingredients for precalculated results. In future, synthesis planning makes it more automated and feasible for drug discovery by computers (Hessler, G. and Baringhaus, K. H., 2018).

“Applications of Deep-Learning in Exploiting Large-Scale and Heterogeneous Compound Data in Industrial Pharmaceutical Research” is also studies by researchers. Recently, the establishment and application of it on industry has shown the researchers hope for testing new drug pharmacore as well as make a list including those drugs at short period. SAR or other different potency testings are developed for profiling experiments. “Next Generation Sequencing or automated microscopy technologies” are also mentioned in this study. In recent days, AI has been developed to tackle difficulties as well as storing a wide range of

informations regarding new drugs. Moreover,computational techniques are evolving. Authors said- “Artificial intelligence has definitely the pivotal function at cheminformatics and bio-image analytics, scaffold hopping, de novo molecule design, reaction/retrosynthesis predictions, and high content screening analysis.” This study summarizes by saying that- “analyzing large-scale compound data in pharmaceutical research and also discussed the impact on the drug discovery process over the last two decades” (David, L. *et al.* 2019).

International Journal of InnovativePharmaceutical Sciences and Research claims that the use of AI at indutrial seems to be raised in a huge amount. Methods of formulations and processes parameters must be learned in that case properly. “Artificial intelligence is a branch of the computer science that deals with the problem-solving by the aid of symbolized programming.” is written in the study. The article shared the idea of authors by weitting that- “from drugs discovery ,tools of AI, manufacturing systems and automated control processes system to predict new treatment ,development of novel peptides from natural foods, treatment and management of rare diseases, drug adherence and dosage, challenges adoption of AI is seen” in pharma are mentioned in this study.The research says that the AI tools has totally changed traditional business a lot. If the healthcare sector is large, it becomes sophisticated and needs to be more advanced technologically. In summary, it depicted that Artificial intelligence is basically the design and application of algorithms in order to analyzethe interpretation and learning of data. (Arvapalli, S. and Sharma, J., 2019)

An overview regarding the “application of data-intelligence algorithms for modeling the compaction performance of new pharmaceutical excipients” was also done. It was enriched with different concepts. Pharmaceutical excipient development process requires some established methods for getting desired activity and result. This study compared previous and recent studies including this smart technology. Here, an experiment was held and it included the prediction of the outcomes from modified starches were gained via using potatoes. Results showed that – “the native starch was modified by three methods.Pregelatinized starch (PS), ethanol dehydrated pregelatinized starch (ES), and acid hydrolyzed starch (AS)- these three types of strach was obtained. Microcrystalline cellulose was used as a reference as it is used in direct compressionof tablet. The role of compaction pressure on the degree of volume reduction of the tablets was also discussed here using

Kawakita and Heckel models.Finally, The data-intelligence results indicated the reliability of the AI-based models over the linear models." However, the Authors expressed the reults by saying that- "the comparative results demonstrated that the Adaptive neuro-fuzzy inference system (ANFIS) outperformed the other two models in modeling the performance of all of the four excipients with considerable performance accuracy." (Khalid, G. M. and Usman, A. G., 2021)

Another study was held regarding the concepts of "Artificial Intelligence for Computer-Assisted Drug Discovery". It is found that there are a number of methods which are currently being researched. According to the study, "some domain-specific AI have been successfully employed for drug discovery and design. This review provides a comprehensive picturization machine learning techniques and their applications in pharmacutical technology. It introduces the basic principles, applications, several machine learning algorithms, current condition of AI-assisted pharmaceutical discovery." "AI utility in structure- and ligand-based virtual screening, de novo drug design, physicochemical and pharmacokinetic property prediction, drug repurposing, and related aspects are also discussed in this study. Summarization of several challenges and limitations for recent methods along with an opinion about potential future for AI-assisted drug discovery and design" is also discussed briefly in the study. (Yang, X. *et al.* 2019).

It has also been found that works on "Artificial Intelligence for Drug Toxicity and Safety" was written and studied by authors. This study suggested that the drugs which causes varoius unwanted results needs to be monitored carefully. A checking process called "Pharmacovigilance" can be reliably used for monitoring and detecting, preventing a number od unwanted and harmful side effects. While developing different studies of drugs, various safety tests are held.Safety efforts begin during it and this continues throughclinical trials, and after that postmarketing surveillance of ADRs is observed. To handle further lethality of drugs and problems which are undesired can be replaced by Artificial Intelligence. Huge amounts of newly available dataprovide ease of utilizing the advanced technology is capable to enhance the safety of drugs. The study explored application of these recently developed methods and technology during preclinical drug safety and post-marketing surveillance. Their impelementations are getting started and prepared for implementation, such as gene therapy and data management. Authors noted that majority of the approaches recently aiming to predict adverse drug reactions. However,the unique

utility in such techniques has still some problems since the possibility can not fully depend upon artificially processed information. (Basile, A. O., Yahi, A. and Tatonetti, N. P., 2019)

“Artificial intelligence in drug design” has been discussed in another review paper. The rapid improvement and development of computing power as well as medicinal chemistry and developmnetal techniques for drugs are being reasonably relied in approximately each step including drug manufacturing . This aids in fastening of research as well as lowers expense. Authors wrote tha significance of machine learning theory in managing pharmacological data. In addition, this advanced technology is strong key that plays pivotal role for drug designing procedured such as “virtual screening,quantitative structure-activity relationship (QSAR) analysis, de novo drug design, and in silico method based evaluation of absorption, distribution, metabolism, excretion and toxicity (ADME/T)” mentioned by the authors. Authors shares their opinion that though it is still a difficult job to provide aphysical explanation to describe the AI-based models. It was depicted in this study that recently deep learning methods are being used for the prediction of different charactersitics of molecules and producing desired results. Authors are optimistic and they said that “This will further promote the impelementation of AI technologies in drug design. QSAR and chemical structureand also vast amount of the pharmaceuticaldata needs assist from AI. Previously learned knowledge can be next applied to discoverand design the molecule of desired properties, optimized molecular properties.” This study put an end lining that “The AI technology has breathed a new life into the computer-aided drug design owing to its powerful data mining capabilities.” (Hessler, G. and Baringhaus, K. H., 2018).

An article was found which describes the “significance of artificial intelligence in drug delivery system design.” The authors wrote that there is growing interest towards the artificial intelligence (AI)technology in order to analyze aling with interprete the any data that are related to the specific task. Rapid identifying in a fastened speed as well asassuming their acccurate behaviour. In addition, Authors wrote that- “Implementation of automated workflows, databases for rapid analysis of enormous data and artificial neural networks (ANNs) for development of the novel hypotheses and treatment strategies, prediction of disease progression, and evaluation of the pharmacological profiles of drug candidates may significantly improve treatment outcomes”. Moreover, the ultimate importance in the development process and other dfficult situations in conjunction with time management that are done by this technology are depicted. In conclusion authors opines that AI can be

one of the significant core formulas for designing a dosage regimen for an individual person with very rare diseases. (Hassanzadeh, P., Atyabi, F. and Dinarvand, R., 2019)

Recently in 2020, “Artificial Intelligence in Drug Treatment” study was conducted. The study illustrates that widely known and recognized implementation of this advanced technology is noticed. Because it has adjust with the requird properties with patients, this technology has to be used very carefully. For assuming different contraindications along with correnct level of accuracy, AI is a reliable tool. The article outlined a few currently established systems that are used in drug design and developing processes. Choosing most suitable and optimum effect requires specific focus on patient data and therapeutic effects of drugs. Moreover, recently developed powerful models which are relavent to this sector are briefly and precisely described here. (Romm, E. L. and Tsigelny, I. F. 2020).

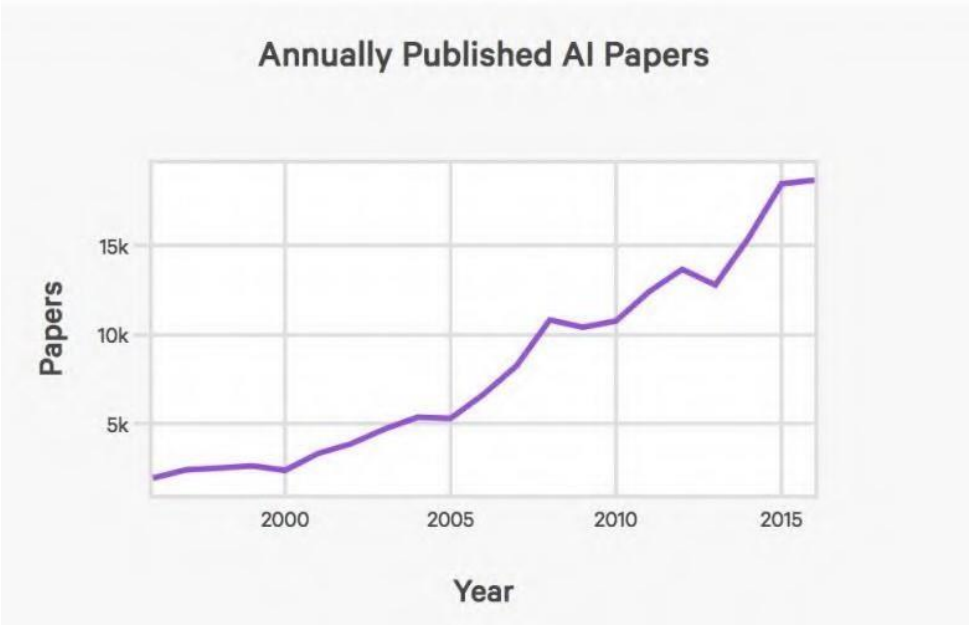

Figure: Raising number of papers regarding AI study (Columbus, L. 2018)

Significance:

Pharmaceutical technologies are crucial because the entire system runs with the help of it. Traditional approaches need a lot of effort to perform all tasks. So, it becomes time-consuming. By earning knowledge regarding Artificial intelligence, we can facilitate drug manufacturing method in each step. Patients can get personalized medicines and different molecular studies can be possoble with this new technology.

Chemsits and researchers can introduce new learning topics to their list. Chemists will be able to perform laboratory based tasks with lesser effort and time. In academic sector, artificial intelligence can be added and students will be interested in science related research fields after learning this topic. Reseraches are really essential in order to make further progress in any new technology.

Structure Activity Relationship and computational chemistry can be made easy with the help of artificial technology. Artificial Neural Network is capable of mimicking electrical impulses of human brain. This will in future take a powerful position in industrial works and marketing as well. Machine learning application is also possible if one wants to implement artificial intelligence based tools.

On the other hand, Mak and Pichika (2019) provided a list of AI and pharmaceutical companies and collaboration areas in drug development. That means, works are developing in this sector. Personalized medicine, drug discovery, physicochemcal property determination, drug formulation can be modified by introducing this science. However, The exclusive use of such models has some limits since the prediction of novel drug effects fully cannot rely on artificially labeled data. (Basile, A. O., Yahi, A. and Tatonetti, N. P., 2019). In that case, human needs to expertise themselves to cope up the operation of these models. Approaches must be validated to overcome the potential challenges and ensure higher accuracy. (Hassanzadeh, P., Atyabi, F. and Dinarvand, R., 2019).

The limitations of artificial intelligence are less. Still we can overcome them if there is no lacking in the whole concept. Pharmaceutical industry is totally dependent of machines and technology. Pharmacists have to technology courses to conduct their education. Studying artificial intelligence can assist them to better understand the pros and cons of each machine and mechanism of action. Varios properties can be modified in aid of AI.

Economical growth can be achieved rapidly by utilizing this new technology. Workers will be able to find a new aspect to involve themselves in a different field. The working experience will not be monotonous anymore. Learning about machinaies and artificial intelligence will lead to reduce cost when large data and long procedures are there.

Objectives of the Study:

The specific objectives of the study are:

- To spread knowledge about Artificial Intelligence.
- To discuss about role of Artificial Intelligence in pharmaceutical industry
- To illustrate the applications of Artificial Intelligence
- To point out the importance of Artificial Intelligence
- To provide ideas regarding Artificial Intelligence related tools

Chapter 3

Discussion

The purpose of the study was to present an overview of artificial intelligence in the field of pharmaceutical technology. Approximately twenty relevant research are presented in this paper, each of which gives hypotheses regarding the implementation and functionality of artificial intelligence and machine learning in industrial pharmaceutical technology, as well as their limitations. According to each study, artificial technology has enormous potential and relevance because it is cost-effective, timely, and less time-consuming than traditional methods.

The majority of studies discussed drug discovery and design, while others discussed the overall application of artificial technology in the pharmaceutical industry and the use of artificial intelligence in fomulation design. Several studies noted that no drugs are being developed at the moment. However, Artificial Intelligence will rapidly evolve into a powerful tool or method in the near future. It will save money as a result of its prudent planning. Training personnel is critical to achieving a successful outcome. In other studies, researchers expressed optimism about the potential for AI to be used to develop new blockbuster and novel drugs.

The use of modern technologies can also have an impact on academic science. Emphasis should also be placed on employment. The balance of human and machine labor will ensure the economy's continued viability. By forecasting outcomes, artificial intelligence can save time. Data misuse should also be carefully monitored in this case. Manufacturing and clinical trials both take a significant amount of time. However, by utilizing AI-based technology, these lengthy stages can be successfully compressed. Marketing sectors intend to increase their investments in advanced technologies or to collaborate with renowned pharmaceutical companies such as Pfizer or Novartis that can afford effective techniques and methodological tools.

If chemists gain knowledge of machine learning and artificial intelligence, it will be easier for them to accelerate difficult, slow chemical processes. Deep learning and machine learning techniques have the potential to transform the pharmaceutical industry.

Almost every article discussed a personalized dosage regimen, molecular-related research and gene therapy, as well as structure-activity relationships. The restrictions were mentioned in less detail. The majority of authors exemplified its utility in their writing. The roles of Artificial Neural Networks and Machine Learning have been extensively discussed in numerous reviews.

Artificial intelligence has already established a foothold in a variety of pharmaceutical industry systems. Numerous actives and excipients are combined to create a formulation in these systems. Cadila Laboratories, headquartered in Ahmedabad, India, developed the Cadila system, which allows tablets to be designed based on their solubility, functional grouping, and dissolution rate. This system's unique feature is that it matches the appropriate properties to the drugs to be prepared. Individual users may select some additional properties. This system is used to make 500 mg paracetamol tablets. Furthermore, the Galenical Development System is used to produce 150 mg griseofalvin in the form of a hard gelatin capsule. Sanofi's Research department has developed a system based on preformulation ingredient detail. Hydrous lactose (224 mg), microcrystalline cellulose (60 mg), Sodium Lauryl Sulfate (4 mg), and talc are used to make hard geltatin capsules containing 100 mg of naproxen (12mg).

Additional research is currently being conducted to determine the efficacy of certain drugs as "model drugs." These include piroxicam, carbamazepine, ketoprofen, diazepam, ibuprofen, and chloropropamide (Rowe, R. C. and Roberts, R. J. 1998).

Individuals must undergo specialized training in order to successfully apply artificial intelligence and operate all systems. In the case of topically applied formulations, not only an expert worker is required, but also a sophisticated system. It has already been demonstrated in several studies that by utilizing AI, significant reductions in both duration and speed are possible. Additionally, this technology saves close to 35% of the time required to develop a new tablet.

Artificial intelligence can also help curtail economic raising costs, but the required materials must be managed more efficiently. Some users of this advanced and intelligent technology have achieved a significant advantage by strategically managing excipients and inventory.

At the moment, Artificial Intelligence is being implemented at a rapid pace in the healthcare sector. More precisely, between 2016 and 2017, several pharmaceutical companies made financial investments in the hope of establishing updated tools. Biomarkers have been shown to improve results in identifying drug targets and planning for new drugs. From conventional procedures to cutting-edge technology, artificial intelligence has significantly crtailed problems. As a result, plethora of relationships are being formed within the Artificial Intelligence firm and pharmaceutical industries. Now, experts and researchers are extremely optimistic and continue to believe that artificial intelligence technology will bring about a permanent shift in the pharmaceutical fields. However, one thing is certain: in order to employ Artificial Intelligence effectively, authorized individuals must acquainted how to conduct the system properly.(Mak, K. K. and Pichika, M. R., 2019)

Chapter 4

Conclusion

Human beings are the most innovative and sophisticated machine which can make impossible task into possible one.It is the human brain, the ultimate organ which is consantly hard at work, putting forth sufficient effort to make something innovative. Also, something that outperforms a human being in terms of efficiency.Any technological system that is capable in doing any provided task and can earna great success while performing that task. One of those great innovations are artificial intelligence. Recently, human being are focusing in the science of solving problems with greater efficiencies. Along with the huge applications in the field of business, pharmaceuticals, health care, and engineering, it is undoubtedly a tremendous force in assisting the entire drug manufacturing process, from drug discovery to drug packaging, via a variety of versatile frameworks. AI-based platforms in order to matchpatients with admissible clinical trials resulting in a significant reduction in errors and enhanced expense management. Moreover, nalyzing molecular data documentation and big data generates renewed interest in the molecular mechanisms underlying a wide variety of diseases. provide new interest into the molecular mechanisms of numerous diseases.To conclude, a great opputuntity is waiting to conquer all the difficulties of pharmaceutical technologies via artificial intelligence.

Chapter 5

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