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Nanomedicine: A Review

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Abstract

A highly promising technology of the twenty-first century is nanotechnology. Nanotechnology is being employed in underdeveloped countries to cure and prevent diseases and healthcare difficulties. Nanomedicines are the clinical application of nanotechnology. It is field of medicine that uses the tools and understanding of nanotechnology to cure and prevent medical diseases. Nanomedicine is the application of materials at the quantum level, which might involve biologically compatible nanoparticles and tiny machines, to biological organisms by way of sensing, actuation, medication administration, and disease detection. In nanomedicine, biological apparatuses, molecular nanotechnology, nano-electronic biosensors, and even possible applications for the future are combined with organic machinery. The physically, chemically & mechanical features of nanomedicine & nanoparticles vary according to their spectrum of applications. As nanomedicine plays an exponentially important & revolutionary role in medicine and public health in the twenty-first era, it will be driven by dynamic, proactive, and socially responsible research. This subject has made significant progress by promoting clinical research and basic sciences as well as producing new research questions and queries.

Keywords - Nanomedicine, nanotechnology, nanoparticles.

INTRODUCTION

The science and technology of employing molecules and our understanding of the human body to diagnose, treat, prevent, and relieve pain, as well as to relieve and improve human health, is known as nanomedicine. Underpinned by shared technical difficulties, it encompasses five key sub-disciplines that overlap in numerous ways.

The understanding of nanobiotechnology and nanomedicine that looks at intracellular and intercellular processes in addition to the structure & function of cells.[1] To elucidate the motion of nanostructures and demonstrate the utilisation of nanotechnology across diverse scientific domains, it is imperative to define and explicate the prefix nano. A multiplier of 10-9 or one billionth of a part is represented by the symbol n in the unit of measurement prefix Nano.[2] The word "Nano" which means "dwarf " comes from the Greek word whence the name of the prefix Nano originates. As a result, it is extremely minuscule and invisible to the naked eye.[3] The prospective applications and implications of nanomedicine must be thoroughly investigated and examined via a global health perspective in order to optimise advantages and minimise possible risks for the largest frequency of individuals. Drug delivery to certain bodily cells through the use of nanoparticles has been made possible by nanotechnology. [4]

The goal of nanomedicine can be broadly characterised as the level of molecule engineering of nanostructures& tools together with extensive observation, control, building, resolve, guard& advancement of every biological system in humans with the ultimate goal of achieving medical benefit. Employing molecular instruments & our knowledge of the human anatomy nanomedicine is in its broadest sense, the act of identifying, treating, preventing, and reducing pain, as well as maintaining and enhancing human health.[5] With the use of these instruments, medicine will be able to influence molecular and cellular mechanisms in a sophisticated & regulated manner for the first time. [6] Large-scale material engineering enables the creation of cutting-edge medical treatments, such as more selectively targeting cells with medications based on nanoparticles, which minimises negative effects for patients. [7] For instance, the top-down or bottom-up photonics applications in nano-engineering and miniature electronics use individual atoms and molecules to create nanostructures that more closely resemble chemistry and biology. [8] Simultaneously, there is a constant need to fill up information gaps about the movement and destiny of manufactured nanoparticles in biological systems. [9] It was mentioned that the technology and science of complicated systems with a minimum of two active principles and a nanometre-scale size, the entire system having a unique function related to disease diagnosis, treatment, or prevention, form the foundation of nanomedicine.

Figure 1*: *Nanoscale

History

Nanomedicine is a fast-expanding discipline that uses nanotechnology to improve illness diagnosis, treatment, and prevention. Here is a short history of its development.

Initial Advancements (1950s–1980s)

1959: Interest in nanoscale research is sparked by Richard Feynman's "There's Plenty of Room at the Bottom" talk.

1960s: Liposomes are discovered and go on to become a major platform in nanomedicine.

1970s: Development of nanoparticle-based contrast ants for imaging.

The 1980s saw the separate field of nanotechnology emerge. [10]

The Development of Nanomedicine (1990s–2000s)

1991: First nanocrystal paper published.

Doxil, the first liposomal chemotherapy, is approved by the FDA in 1993.

The US started the National Nanotechnology Initiative (NNI) in 1999.

The 2000s see an acceleration of nanomedicine application research. [11]

Important Developments in the 2010s

2010: The first clinical trial for cancer treatment using nanoparticles.

2011: The FDA authorises Abraxane, a chemotherapeutic drug based on nanoparticles.

2013: RNAi-based nanomedicine development.

2014: The CRISPR-Cas9 gene editing technology emerged.[12]

Recent Developments in the 2020s

2020: Research on nanomedicine is accelerated by the COVID-19 outbreak.

2020: The application of nanotechnology to create messages RNA based vaccinations.

2022: The FDA authorises the first gene treatment based on nanomedicine.

2023: Personalised nanomedicine advances. [13]

2024 and Up

A stronger emphasis on Nanomedicine precision.

AI and nanomedicine together.

Creation of nanorobots for specialised medical care.

Ongoing developments in regenerative medicine and gene editing.

Nanomaterial

The European Commission defines a nanomaterial as a natural, incidental, or produced substance with components in the size range of 1-100 nm for ≥50% of the particles, based on the number size variation. In circumstances of protection, well-being, environment or competitionconcerns50% dispersion of number sizes the requirement might be substituted with a threshold ranging from 1 to 50%. Nanomaterials include organizations with one or more exterior dimensions of less than one nm including graphene flakes, fullerenes& single-walled carbon nanotubes. Compounds with surface area per volume more than 60m2/cm³are also listed.[14]The European Union defines nanomaterials through legislation and policy. Regulatory agencies have issued guidelines to promote drug product development based on this description.

In order to achieve reproducible traits and attributes associated with the particular application of nanotechnology as well as features appropriate for the intended usage(dosage, route of delivery)linked with the anticipated medicle benefit of According to the EMA working group, nanomedicines are nano-engineered systems specifically developed using at least one nanoscale component for clinical use .[15]

According to the previous definition surface area, particle size distribution (PSD), and size are the three main factors that determine if a nanomaterial is present.

Size

Size has particularly important factor because such a thing can be applied via large range of materials. Typically, the range is between 1 and 100 nm. But there isn't a clear cut boundary to establish this bound. The most prominent size at which a substance that can be classified asa nonmaterial is arbitrary since the materials' biological and psychochemical properties stay same significantly at one hundred nanometres. It’s anticipated that additional characteristics ought to be considered to this extent. [16]

There are two different methods applied in pharmaceutical industry both top-down and bottom-down methods for creating nanomaterials. In the top-down process, a bulk substance is split down into one or more smaller pieces by employing mechanical or chemical energy. In the top-down process, a bulk substance is split down into one or more smaller pieces by employing mechanical or chemical energy. In contrast, atomic or molecular species initiate the bottom-up process, which permits precursor substances to grow in size by chemical reactions. These two production methods

give rise to distinct particle shapes known as primary, aggregate, and agglomerate . The appropriate meaning is as follows (sic):

"A particle is a small piece of matter with clearly defined boundaries" "Agglomerate means a collection of weakly bound particles or aggregates where the resulting external surface area is similar to the sum of the surface areas of the individual components".

It makes sense to include aggregates and agglomerates when taking the definition into account. They might nevertheless retain the characteristics of the free particles and even decompose into nanoscale particles. [17]

Particle Size Distribution

A commonly used metric in the identification of nanomaterials, the PSD represents the range of size change. Since particles of different sizes usually make up a nanomaterial that is it is essential to adjust the PSD. [18]

Surface Area

Surface area by volume is a related characteristic that must be calculated when additional regulation is required. As mentioned, if the material's surface area divided by volume exceeds 60m2/cm3, it falls under the definition. But the PSD will take precedence; for instance, a substance is classified even though the volumetric surface area is smaller than the necessary 60 m2/cm3 according to the division of particle sizes, as a nanomaterial. [19]

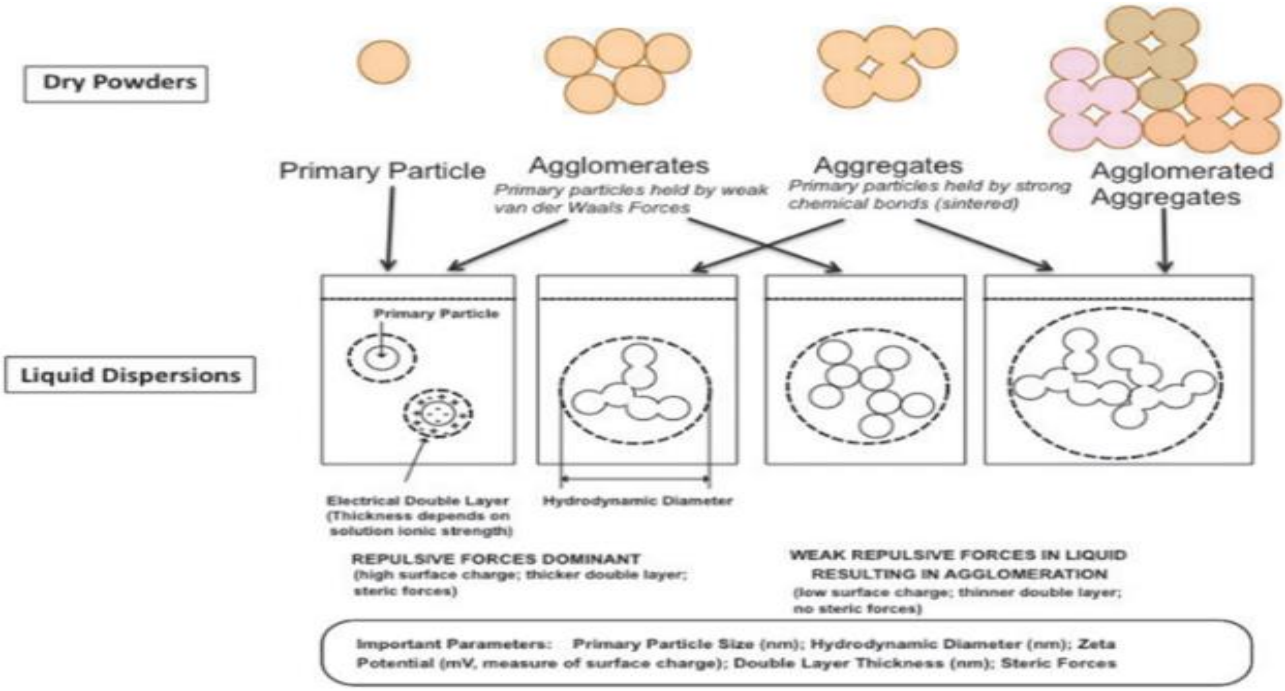

***Figure 2*:** *Schematic representation of the different form of particle primary particle aggregate and agglomerate*

Types of Nanomedicine

Most nanomedicines fall into one of two categories: Either Inorganic nanoparticles such as iron oxide, silica and gold or organic nanoparticles such as polymers, liposomes and micelles. Most applications for such tiny particles appear in medicine & diagnostics. Among the uses for inorganic nanoparticles are the management of anaemia, imaging lymph nodes & hyperthermia. A few among those them have finished clinical trials and preliminary studies with success. In addition to inorganic nanoparticles, organic-based nanoparticles have made it to the phases of clinical practice

& are presently accessible in markets for a number of purposes such as microbiological, cancer infections & vaccinations.

Nanomedicine Based on Liposomes

In this a medication is encapsulated in a phospholipid bilayer structure to boost its medicinal action & biological availability. Among the first varieties of nanomedicines, liposome formulations have well-established methodology. Numerous studies have focused on concentrated liposomes used to encase a variety of materials, including biological compounds like hepatitis A virus vaccines, small molecules like doxorubicin, and nucleic acids such as RNAs. Additionally, if the liposome subunits like cholesterol and sphingomyelin have specific healing effects, it is still possible to use liposomes even when encapsulating drugs. PEGylation is a viable alternative to take into account while utilising liposomes because of its significance in improving the stealth of the delivery mechanism. The majority of authorised cancer-associated diseases are treated with liposome-based nanomedicine.[20]

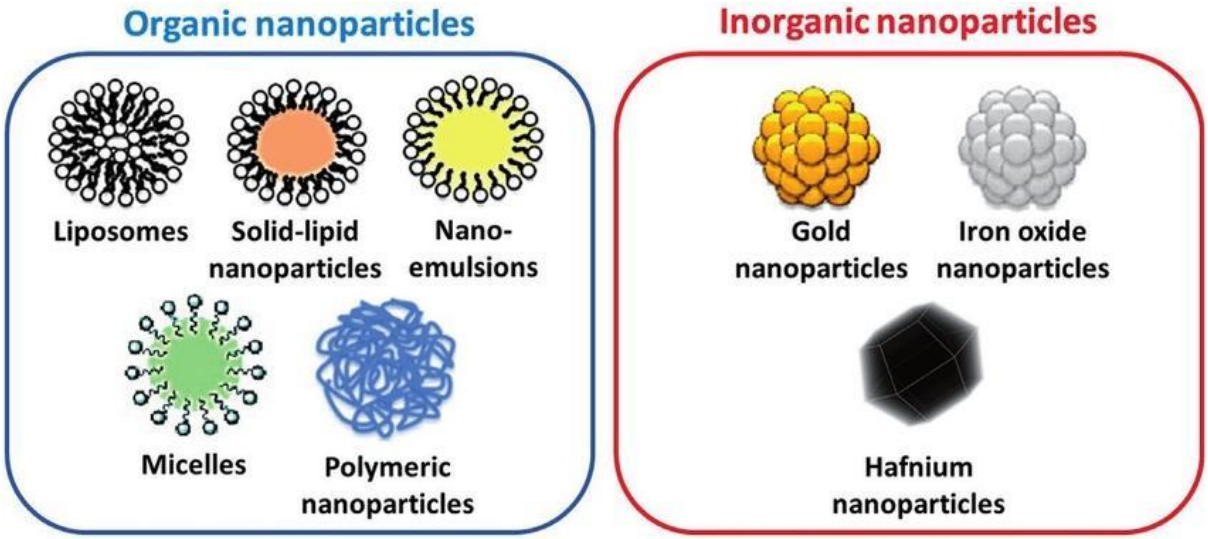

Figure 3*: *Organic and Inorganic nanoparticles

Lipid-based nanomedicines

It is lipid Nanosystem which Comprise solid nanoparticles based on lipids and nano emulsions. In order to improve penetration and control the release profile, they are usually used to enclose hydrophobic materials. To guarantee consistent dispersion, a surfactant is typically utilised. Lipid nanomedicine has the ability to encapsulate certain gene treatments such as siRNA or Imagin opposite chemicals. Lipid nanomedicine frequently improves biocompatibility of the medicine while also improving the pharmaceutical action via-growing drug buildup in certain areas. On the other hand, there are a number of drawbacks such as rapid clearance because of absorption by the reticuloendothelial system (the body), specific limitations on the pathways of administration, and issues having reliable system. [21]

Albumin based nanomedicines

These are a type of nano-system in which albumin specifically albumin inhuman serum (proteins) is used as a carrier. A straightforward self-build process of albumins in a diluted mixture with straightforward crossover allows different materials can be loaded onto albumin tiny structures. The primary benefit of albumin is its biocompatibility. However, among the twenty-nine stated certified nanomedicines and the sixty-five nanomedicines undergoing clinical investigation only two are based on Albumin. These are presently utilised for medication delivery and imaging in the treatment of cancer disorder.[22]

Micelle-based nanomedicine

Micelle is amphiphilic molecules with a water loving and a water-resistant portion that self-build into nanosystems. High permeability and solubility are two of its many benefits, which increase medication bioavailability. They do, however, still have certain disadvantages, such as poor control over discharge of medicine and cell toxicity resulting by introducing the amphiphilic molecules which engage in interactions with the cell membrane. [23] Although some studies have employed block copolymeric micelles to reduce clearance and increase absorption of chemotherapeutic drugs and other types of pharmaceuticals, there are currently no registered micelle-based nanomedicines. Nine nanomedicines based on micelles however are presently going through medicle studies. Most of them are utilised in cancer therapy.

Polymeric based nanomedicine

Biocompatible and biodegradable polymers are used in polymeric-based nanomedicine to create nanoparticles for a range of medicinal uses. By enhancing targeted administration, supplying regulated release, improving medication solubility and bioavailability, and raising imaging contrast and diagnostic accuracy, these nanoparticles. [24] Polymeric nanoparticles come in different forms like micelles, polymer-drug conjugates, lipid-polymer hybrid particles and polymeric nanocapsules. These include gene therapy, vaccine administration, neurological problems, cardiovascular ailments, and cancer therapy (paclitaxel, doxorubicin, etc.). Polymers such as PCL, PLA, PMMA, PLGA, and PEG is often utilised.

Inorganic based nanomedicine

Inorganic-based nanomedicine creates nanoparticles for a range of medicinal uses by using non-carbon-based materials such metals, metal oxides, and ceramics. The distinct physical and chemical characteristics of these nanoparticles allow for enhanced diagnostic sensitivity, targeted treatment, and imaging. Typical inorganic nanomaterials consist of: AuNPs (gold nanoparticles) for imaging and cancer treatment. Antimicrobial uses of silver nanoparticles (AgNPs) nanoparticles of iron oxide (IONPs) for cancer therapy and magnetic resonance imaging (MRI). Drug delivery and imaging using silica nanoparticles (SiNPs). Nanoparticles of carbonate apatite (CAPs) for cancer treatment and vaccine administration.[25] Improved stability, biocompatibility, and scalability are among the benefits of inorganic-based nanomedicines.

Method of Preparation of Nanomedicine

Nanomedicine is a quickly emerging field that applies nanotechnology to the evaluation, treatment, and mitigation of diseases**.** Here is a general approach to becoming ready for nanomedicine.

Solvent Evaporation Method

Procedure

Use a volatile organic solvent to dissolve the medication and polymer.

Emulsify this mixture into a surfactant-containing aqueous phase.

Under lower pressure, the solvent evaporates, causing nanoparticles to form.

Centrifugation is used to gather the nanoparticles, which are then dried

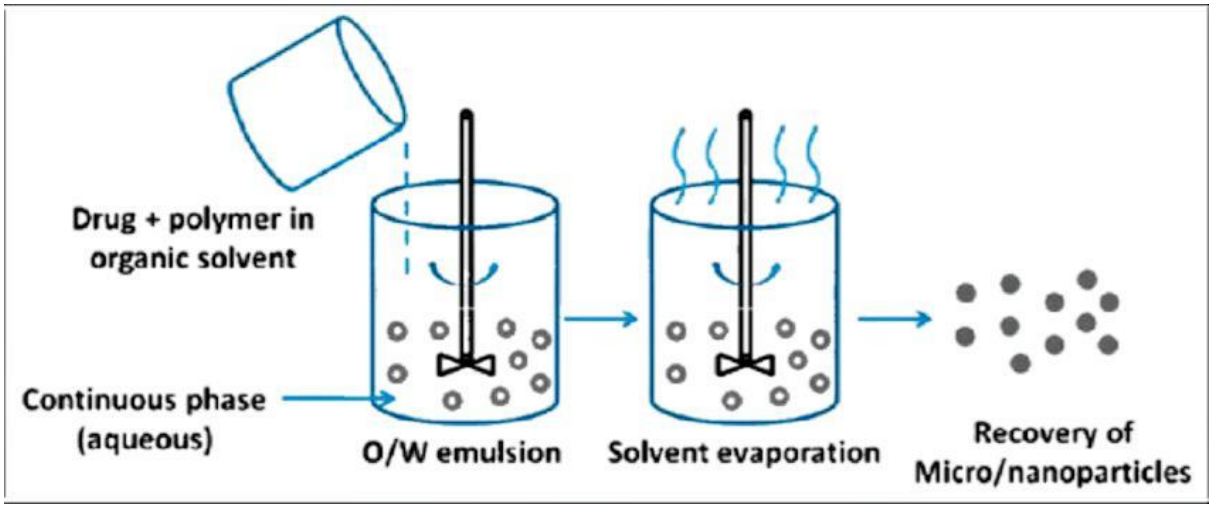

Figure 4*: *Solvent Evaporation Method

Uses

For medications that are lipophilic.

Ionic Gelation Method

Procedure

Aqueous acidic solution is used to dissolve a polymer (such as chitosan).

This polymer solution contains a drug.

Dropwise addition of a cross-linking agent (such as sodium tri-polyphosphate) causes the production of nanoparticles

Centrifugation is used to retrieve the nanoparticles.

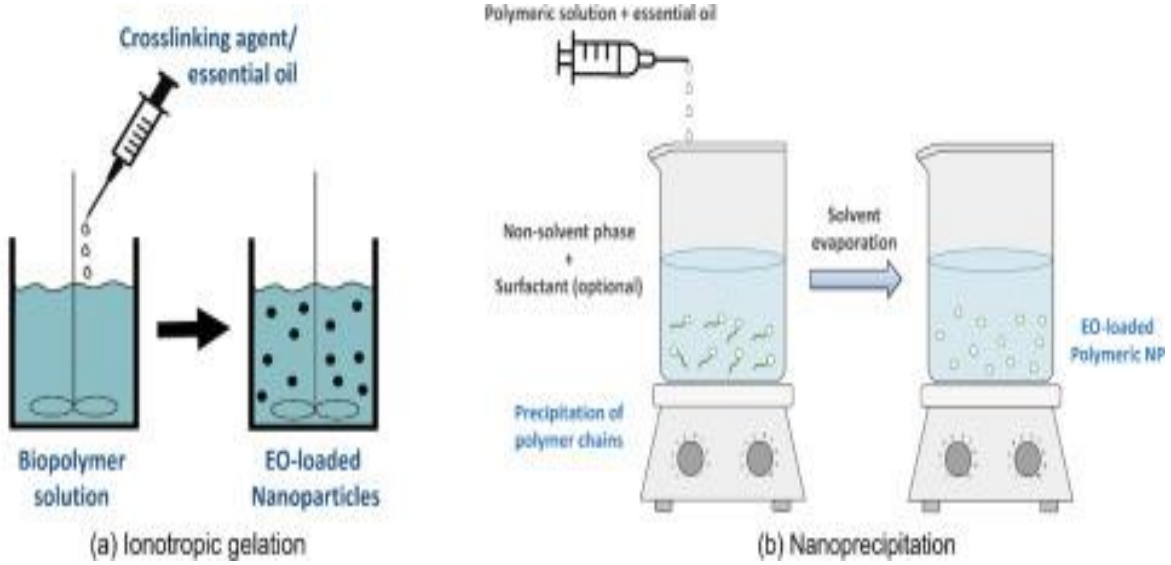

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Figure 5*: *Ionic Gelation Method

Uses

Applied in the production of nanoparticles that degrade naturally

Pressure- Homogenisation Method

Procedure

A high-pressure homogeniser is used to pass the drug and polymer solution through.

The particle size is lowered to the nanometre scale by mechanical forces.

Nanoparticles are gathered and, if required, undergo additional processing.

Uses: For making poorly soluble drug nanosuspensions.

Supercritical Fluid Method

Procedure

The medication and polymer are dissolved using supercritical CO2.

The nozzle is used to spray this solution into an aqueous phase, which causes the CO2 to evaporate quickly and precipitate nanoparticles.

The final nanoparticles are gathered using centrifugation or filtration.

Uses

Since no hazardous organic solvents are used, this process is environmentally safe.

Co-Precipitation Method

Procedure

An organic solvent is used to dissolve the medication and polymer.

The solution is mixed with water, a non-solvent, causing the nanoparticles to precipitate.

Centrifugation is used to separate the nanoparticles, and any leftover solvent is then cleaned.

Uses

Often used to encapsulate medications that are not very soluble in water. [26,27]

Nanomedicine Drug Delivery System

Advanced medication administration is created by combining nanotechnology and medicine to increase the safety and medicinal effectiveness of drugs. With the least amount of negative effects possible, these systems seek to enhance the pharmacokinetics and biodistribution of medications.

Essential Elements of Drug Delivery Systems in Nanomedicine

Nanoparticles

Various types include liposomes, inorganic nanoparticles (such as gold or silica), polymeric nanoparticles, and dendrimers.

Mechanism

Drugs can be encapsulated in nanoparticles to prevent degradation and enable controlled release. It is possible to engineer them to increase stability and solubility.

Mechanisms of Targeting

By taking benefit of the increased permeability and retention (EPR) effect, which is caused by leaky vasculature, passive targeting accumulates nanoparticles in tumour tissues.

Active targeting is the process of changing nanoparticles so that they contain ligands (such as peptides or antibodies) that bind only to target cells and increase uptake by diseased tissues [28].

Systems of Controlled Release

Smart Polymers: These substances release medications in a regulated way in response to changes in pH, temperature, or enzyme levels.

Micelles and hydro-gels that offer profiles of sustained drug release should be included in nano-carrier designs.

Biocompatibility and Stability

Making sure that nanoparticles are biocompatible and stable in biological settings in order to reduce toxicity and immunological reaction.

Production and Extension

Methods for producing nanoparticles at scale in a repeatable manner while preserving their effectiveness and quality.

Observation and Imaging

Utilising imaging methods (MRI, PET, etc.) to monitor medicine discharge nanoparticle dispersion within the living in order to guarantee efficient targeting and positive therapeutic results. [29]

Nanomedicine Pharmacokinetics and Regulation

In the field of nanomedicine, pharmacokinetics (PK) is examination of how nanoparticles act within the human body involving their excretion, distribution, metabolism, and absorption. Important components consist of:

Absorption

The enormous surface area and compact size of nanoparticles make them useful for improving drug absorption. Compared to traditional medications, they are more effective at passing through biological barriers such cell membranes.

Distribution

The presence of targeted ligands, surface charge, size, and shape all affect how nanoparticles are distributed. Tumour tissues can accumulate more as a result of the improved permeability and retention (EPR).

Metabolism

The liver and spleen may break down nanoparticles, and the resulting products of these breakdowns may alter the drug's pharmacological characteristics.

Excretion

For smaller nanoparticles, renal clearance is usually used, whereas for larger ones, the reticuloendothelial system (RES) organs are used.

Regulation of Nanomedicine

Control in Nanomedicine Countries have different regulatory frameworks for nanomedicine, but they all usually aim to guarantee the products' quality, safety, and efficacy. Important points consist of:

Supervisory Authorities

Europe's EMA is in charge of regulating nanomedicine, whereas the FDA is in charge in the United States. Based on their special qualities, they assess the efficacy and safety of nanomedicines.

Recommendations

Organisations have created recommendations especially for the field of nanomedicine, covering topics like long-term impacts, potential toxicity, and particle characterisation.

Clinical and Preclinical Experiments

Before a product containing nanomedicines is approved for sale, it must undergo extensive testing through preclinical research and clinical trials to determine its safety and effectiveness.

Post-Market Surveillance

To identify any negative effects and guarantee continued safety,

Nanomedicine products must be continuously monitored after approval. [30, 31, 32,33].

Current Development in Nanomedicine

Via reducing the volume of distribution, limiting the effect on tissues that are not the intended targets, or decreasing drug clearance rates, drug delivery systems may also be able to minimise tissue harm. Because of their antibacterial qualities or ability to reduce antibiotic resistance, nanoparticles are utilised in combination therapy. It is possible to avoid multidrug resistance (MDR) mechanisms by using nanoparticles. Using gold shells or iron nanoparticles to treat cancer is one of the many possible significant uses. Drug delivery systems can benefit from the rapid advancement of nanotechnology, which also poses potential toxicity concerns and the potential loss of drug efficacy when concentrations of the drug fall below desired ranges. [34]

Uses of Nanomedicine

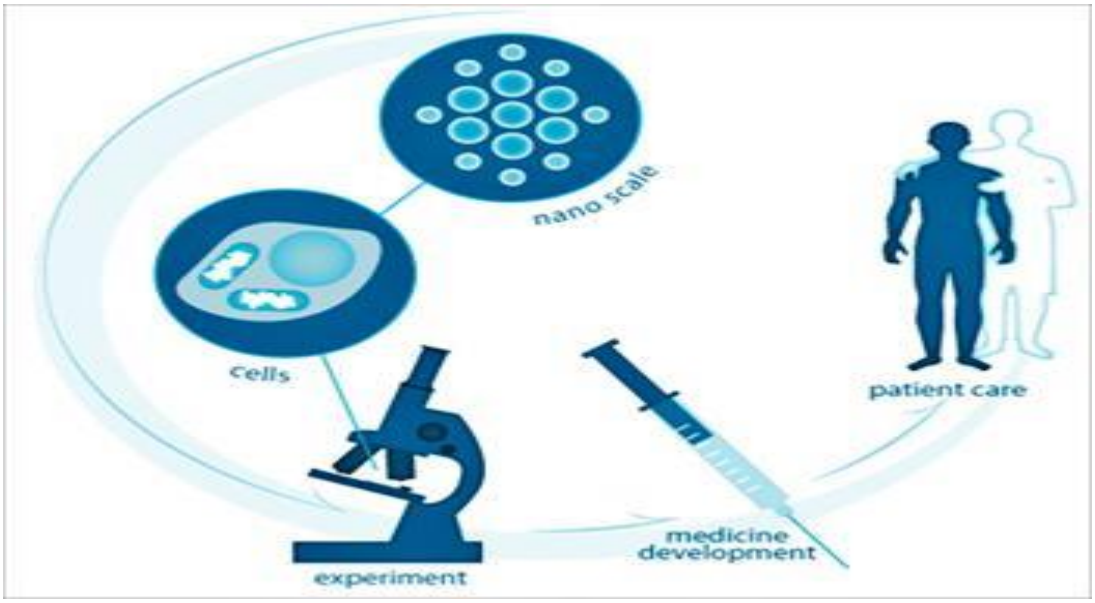

Figure 6: *Three essential pillars support the effective use of nanotechnology in medicine*

Nano scale materials &Nano-instruments may be employed as zippy material transporters, therapeutic aids, and biosensors.

Understanding of genetics, artificially made or modified microorganisms, and molecular medications connected to these fields.

Nanotechnologies that can be used to enhance plant physiological capacities, enable fast diagnosis and therapy, and repair genetic fabrics and laminas.[35]

Nonmaterial & nano-instruments that can be applied as therapeutic Aids, biosensors and carriers of active ingredients.

The understanding of genetics, proteomics and artificially generated or altered microbes in the context of molecular medicine.

The nanotechnologies that can be applied to cell surgery, fast diagnosis and treatment, genetic material repair, and the enhancement of normal physiological Processes.

Application of Nanomedicine

Contrast compounds for visualising cancer cells

When exposed to UV light, cadmium Selenide nanoparticles, often known as quantum dots, illuminate. These seep into cancerous tumours when injected. By using the luminous tumour as a guide, the surgeon can perform more precise tumour removal treatments. [36]

Therapeutics for treating the cancer diseases

Medicines used to treat cancer disorders It is possible to direct the gold nano-shells to attach to the malignant cells. By employing infrared lasers to irradiate the tumor's surrounding tissue, the gold is heated to a temperature that kills cancer cells while also passing through the skin.[37]

Nanomaterials in medicine

When a surgeon attempts to suture the arteries cut during kidney or heart transplants, these could assist address the difficulties and blood leaks that arise.[38]

Electronic nano-biosensors Diagnostic tools

Arthroscopes with lights and cameras are used in surgeries, and nanotechnology is a development in this field that allows surgeons to do procedures with fewer incisions.

Applications in physical therapy

A tiny particle that is injected into the body and triggered by outside light is used in photodynamic treatment. Light is absorbed by this particle, and if it is metallic, the light's energy heats the particle and the tissues around it.[39]

The utilisation of Neuro-electronic interfaces

This innovative objective pertains to the development of nano-devices that will enable the integration and connection of computers with the nervous system.

The use of tissue repair applications

Repairing or replicating damaged tissue could be made possible via nanotechnology. "Tissue engineering" uses appropriate nano-material-based scaffolds and growth agents to artificially increase cell proliferation. On carbon nano-tube scaffolds, for instance, bones may be produced again. Organ transplants and artificial implants may eventually be replaced by tissue engineering. [40]

Molecular nanotechnology

Nano-robots will be injected into the body to detect and repair damage and infections, according to molecular nanotechnology and nano-medicine. Due to various kinds of carbon's inherent strength and other properties (such as those of diamond/fullerene composites), carbon may be the main component utilised to make these nano robots. These robots might be made within workstation nano factories specifically designed for this intent. Applications of nanomedicine involve hearing aids, insulin pumps, nebulisers, glucose and blood pressure monitors, pacemakers, activity monitors, chemotherapy, biochips, over-the-counter testing, and drug delivery systems. Nanobots are used as miniature surgeons in the field of nanomedicine [41]

CONCLUSION

In conclusion, nanomedicines represent a transformative advancement in modern healthcare, offering immense potential to improve the precision and efficacy of drug delivery, diagnostics, and therapeutic strategies. The unique properties of nanoparticles, such as their small size, surface area, and ability to target specific cells or tissues, allow for more effective treatment of diseases, particularly those that are challenging to address with conventional therapies. While progress in the development and clinical application of nanomedicines has been substantial, challenges related to safety, regulatory approval, and scalability remain. Continued research and technological innovation will be crucial to overcoming these barriers and unlocking the full potential of nanomedicines. As we move forward, the integration of nanotechnology into personalized medicine and precision therapies could revolutionize the way we approach treatment and healthcare, offering more effective, targeted, and less invasive solutions for a wide range of medical conditions.

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