Magnetic Nanoparticles For Antitumor Drug Development

[1]Vaishnavi Khalate, [2]Sakshi Kamthe, [3]Mohini Mane, [4]Dr Tushar Shelke
[1,2]*Final year B pharmacy, Genba Sopanrao Moze College of Pharmacy, Wagholi, Pune, Maharashtra*
[3]*Assistant professor, Genba Sopanrao Moze College of Pharmacy, Wagholi, Pune, Maharashtra*
[4]*Principal, Genba Sopanrao Moze College of Pharmacy, Wagholi, Pune, Maharashtra*

Abstract: One of the most significant problems facing medical research today is cancer. Even in cases of advanced and metastatic cancer, the objectives are to enhance not only the therapeutic outcome but also the treatment approaches, which frequently have significant side effects. Furthermore, it is necessary to take into account recent events including population growth, demographic shifts, and rising healthcare expenses. Most likely, nanotechnology can play a big role, especially when it comes to the application of magnetic nanoparticles made of iron, cobalt, and nickel. The drug delivery systems have the most promise since magnetic nanoparticles can be functionalized by binding to a variety of chemicals, such as radionuclides, chemotherapy drugs, nucleic acids, and antibodies.

Around the world, millions of people have died from cancer. The traditional cancer treatment methods now in use are linked to adverse side effects. This discovery led researchers to look at other therapy modalities that have a higher benefit-to-risk ratio. Nanoparticles, which range in size from 1 to 100 nm, have shown great promise as cancer treatment agents. Particularly, magnetic nanoparticles have drawn interest due to their distinct magnetic characteristics and numerous biological uses.

Index Terms: Magnetic Nanoparticles (MNPs), Nanoparticle (NP), Magnetic Resonance Imaging (MRI), Iron Oxide Nanoparticles (IONs), Superparamagnetic Iron Oxide Nanoparticles (SPIONs), Polyethylene Glycol (PEG)

1.INTRODUCTION

The cancer death rate has only been marginally, not significantly, reduced in the last 50 years despite tremendous efforts. However, significant progress has been made in treating other illnesses, such as pneumonia and cardiovascular and cerebrovascular disorders.[1]Globally, cancer has a significant impact, contributing to 20.3% of all fatalities, with 23.4% of cancer cases occurring in Europe. Despite improvements in cancer detection and treatment, worries about low response rates, therapy-related side effects, postoperative relapses, and benefits limited to particular patient groups persist. Emerging cutting-edge technologies, including magnetic nanoparticles (MNPs), have gained attention due to their distinct physicochemical and multifunctional characteristics as a result of advances in nanotechnology and interdisciplinary research. Nowadays, MNPs made of metals and polymers or pure metals are being utilized more and more in fields pertaining to magnetic resonance imaging (MRI), medication release control, and biosensing.[2] Conventional therapeutic modalities, including radiation, surgery, chemotherapy, and photodynamic therapy, whether administered singularly or in combination, exhibit significant limits that result in numerous side effects and toxicity concerns.[3]

The use of antibodies in oncology is also growing, despite the fact that anti-body therapy is frequently costly and can occasionally have negative systemic effects. For instance, Her2-targeting antibodies are used to treat a subset of individuals with breast cancer.[4]In general, there hasn't been a significant advancement in cancer treatment yet. According to the US National Cancer Institute's projections, nanomedicine will lead the way in cancer prevention, diagnosis, and therapy in the future.[5]The potential for MNPs' size, shape, morphology, chemical makeup, and magnetic behavior to change in response to an external magnetic field could have an impact on their application in medicine.[6]To improve specificity, they can be coated with high-affinity ligands. A magnetic field can then direct them to malignant regions without harming healthy cells. They are also used in MRI to improve proton relaxation and visualization as well as

to boost the contrast of particular tissues in pictures. For prompt cancer identification, accurate and efficient cell and biomarker quantification is essential, and cancer assessment instruments that are very sensitive in identifying a variety of particular compounds can help with a prompt diagnosis. Due to the distinct advantages that MNPs offer over conventional detection techniques, their usage in biosensors has attracted attention.[7]Because of their superior T2/T2 relaxation capabilities and enhanced magnetization upon application of an external magnetic field, MNPs function as effective (MRI) agents.[8]

It is extensively utilized in several fields, including regenerative medicine and imaging. However, those chemicals must be thoroughly investigated to ascertain their effects on the body before being employed for medicinal purposes. We refer to this area of study as nanotoxicology. It looks into the consequences of both naturally occurring (found in the environment) and artificially produced nanoparticles from traffic and industry. Magnetic nanoparticles appear to have the most promise for success in medicine, despite the fact that a wide range of materials are being employed. Clinical usage of them as MRI contrast media is already well-established; examples are Resovist ® and Sinerem ®.[9]Furthermore, non-invasive guidance of these particles is possible (drug delivery).[10]

2.TYPES OF MNPS

MNPs are a novel class of nanomagnetic materials with important uses in physical theory and medicine. Iron, nickel, cobalt and other metals, along with their corresponding oxides, are combined to create MNPs, which are composite materials with magnetic properties.[11]

2.1.Silica-coated MNPs:

MNPs covered in silica Silica-coated Drug distribution, diagnosis, and targeted therapy greatly benefit from the silica coating's chemical inertness and biocompatibility as well as the inner magnetic cores magnetic responsiveness.[12]

A common technique for functionalizing a silica surface is to apply organosilane chemicals to it. By adding various functional groups, such -COOH, -NH_2, or -OH, to the nanoparticles (NPs') surface, this technique enables further alterations with biomolecules like proteins. These altered surfaces increase NPs capacity to interact with biological systems,expanding the range of potential applications. Iron oxide nanoparticles (IONPs), which are commonly found as the magnetic core of nSio2 microspheres, have notable advantages in terms of medication administration. Their capacity to deliver drugs in enhanced by their small size and large surface area, and their magnetic properties allow for a precise distribution. These NPs can pass through biological barriers including the blood-lung barrier, allowing for a variety of administration techniques such injection, percutaneous penetration, and inhalation. Depending on the particular therapeutic needs, this feature enables both targeted therapy and systemic distribution.[13]

2.2.Vesicle type or lipid coated MNPs:

Lipid-coated MNPs, sometimes referred to as vesicle-type MNPs or magnetic liposomes, are hybrid nanostructures where magnetic particles are encased in a phosphor-lipid bilayer. These Structures combine the advantageous properties of MNPs and liposomes, making them perfect for a variety of biological applications.[14]

The term "magnetic liposomes" was initially used to describe a small-scale structure where iron oxide particles are encased in phospholipid layers. These NPs are usually made up of an iron oxide core that is surrounded by a phospholipid bilayer and has a diameter of about 14nm.[15]

Furthermore, they are promising candidates for drug delivery for the treatment of hyperthermia due to the lipid bilayer's ability to encapsulate medications and the magnetic core's ability to generate heat when exposed to an alternating magnetic field. A less invasive method of therapy hyperthermia treatment employs the heat generated by NPs to kill cancer cells.[16]

Lipid-coated and vesicle-type magnetic nanoparticles (NPs) are generally effective and adaptable instruments for improving imaging, targeted therapies, and diagnostics in the medical domain. Combining magnetic properties with biocompatible coatings

creates new possibilities for the detection and management of a number of diseases, particularly cancer.[17]

2.3.Polymer-coated MNPs:

Polymer-coated MNPs are a significant advancement in nanotechnology, particularly in the areas of biomedicine and medication delivery. By combining the flexibility of polymer coatings with the magnetic properties of inorganic NPs, researchers have produced materials that can be precisely controlled by external influences like magnetic fields, temperature changes, or pH level alterations. The distinct combination of MNPs permits them to operate as carriers for precise medication administration, and the polymer coating offers protection against early degradation of the therapeutic chemicals, durability, and interaction with biological systems. Furthermore, the magnetic core helps direct the NPs to certain bodily locations, increasing treatment accuracy and reducing the likelihood of adverse consequences.[18]

In the field of nanomedicine, this intelligent system that responds to stimuli has created new prospects by offering better and more individualized treatment alternatives. Nanoparticles of superparamagnetic iron oxide Nanoparticles of superparamagnetic iron oxide (SPIONs) are MNPs that are less than 50 nm in diameter. When exposed to high-frequency magnetic fields, MNPs show a magnetocaloric effects, have substantial specific surface areas, and can carry tiny molecules, proteins, and RNA. Iron oxide phases, such as Fe2O4 (magnetite and Fe2O3 maghemite), make up the majority of SPIONs. This discovery suggests that SPIONs are ideal for a variety of biomedical applications because they can become magnetized when subjected to an external magnetic force, but they lose their magnetism when the force is withdrawn.[19]

Their remarkable biocompatibility and ability to generate strong magnetism at low magnetic fields have made them extremely useful in drug delivery, medical imaging, and the treatment of hyperthermia. They are useful for improving pictures in MRI scans since they may also bind to biological substances like hemoglobin. Specifically, SPIONs enhance the T2-weighted imaging signal, producing sharper, more detailed pictures that aid in the diagnosis of diseases like cancer.[20]

3.SYNTHESIS METHODS

Fig.1: Methods of MNP synthesis

3.1.Coprecipitation:

One popular and easy method for producing MNPs, specifically magnetite ($Fe3O_4$) and cobalt ferrite NPs, is coprecipitation. The mixing of solutions of ferrous (Fe_2+) and ferric (Fe_3+) salts in a 2:1 molar ratio with a base such as ammonia is the method used in this process.[21]Adjustments like high-pressure homogenization or slower reaction conditions can improve control over the size, magnetic properties, and crystallinity of the NPs generated. The procedure can be carried out at room temperature or higher. Coprecipitation has an advantage in producing MNPs with specific properties for many applications, including medication administration, MRI, and environmental cleaning, due to its capacity to customize the synthesis parameters.[22]Ge and colleagues provided an illustration of this method by creating paramagnetic IONPs via coprecipitation in a water-based solution containing a 2:1 molar ratio of ferrous and ferric chloride. To initiate the precipitation process, the mixture was aggressively stirred in the presence of concentrated ammonia and a nitrogen environment. Consequently, a black solid developed and was thereafter distributed in a acidic solution with a pH of 3.0 and cleaned with deionized water. Brown IONPs were created in the final step, which involved oxidizing the precipitate at 90 °C with air present. Coprecipitation is a versatile technique for fabricating nanomaterials, as demonstrated by this process, which effectively produces excellent MNPs with distinct magnetic characteristics.[23]

3.2.Hypothermal Synthesis:

By managing the crystallization process, hydrothermal synthesis at high temperatures and pressures is an effective method for producing MNPs. This process helps create nano-crystals by using water as a solvent, usually in a closed environment. The hydrothermal method is particularly useful for creating MNPs because it allows precise control over the NPs' shape and crystallinity. By altering variables like temperature, pressure and residence time, researchers may alter the size and form of MNPs, which impacts their magnetic characteristics and multipurpose effectiveness.[24]In order to promote the formation of NPs with uniform sizes and structures, the process usually entails subjecting a precursor solution to high temperatures and steam pressure. After the reaction is finished, the product is carefully cleaned to get rid of any last traces of impurities and rapidly cooled, or quenched. One important element influencing the size and quality of the NPs is the residence time, or the time frame in which the reaction takes place under certain circumstances.[25]

3.3.Polyol Based Methods:

During polyol synthesis, metal salts go through a reduction process in a polyol medium. In order to create a synthesis method that doesn't require high pressure, polyols serve as solvents, reducing agents, and stabilizers. This makes the approach appealing for creating MNPs in the shape of flowers. This characteristic is explained by polyols' capacity to control the rate at which structures form and enlarge.[26] The polyol mixture could consist of polyethylene glycol (PEG) or diethylene glycol, and the reaction is carried out at a lower pressure. The characteristics of the resultant NP are affected by variables including reaction conditions and solvents. Curcio and colleagues used polyol synthesis to produce water-soluble iron oxide nanoflowers. This entailed combining ferrous and ferric chloride solutions in a 2:1 molar ratio with diethylene glycol and N-methyldiethanolamine in a 1:1 volume ratio, stirring for an hour. NaOH, an alkaline substance, was combined with a special blend of polyols of the same kind, combined with the iron oxide solution, and stirred for three additional hours. To continue the heat treatment, the mixture was heated to 220 °C for 50 minutes, agitated for 2.5 hours, and then allowed to cool to room temperature. Following magnetic separation, a 1:1 ethanol–ethyl acetate mixture was used to rinse the sediment containing the NPs. It was then treated with 10% nitric acid at 80 °C for 45 minutes, washed with an acetone–diethyl ether solution, and then dispersed in water.[27]

3.4.Thermal Parsing :

One sophisticated technique used to produce MNPs with precise control over their size and shape is thermal parsing. This method involves oxidizing organometallic precursors in organic solvents with a high boiling point, usually in the presence of stabilizing surfactants. Surfactants are necessary to maintain uniformity in the synthesis process and stop particles from clumping together. Compared to other synthesis procedures, thermal parsing is a more complicated and regulated process since it typically entails high temperatures and exact control over the reaction conditions. Because of this precision, MNPs with precisely defined characteristics that are essential to their efficacy in certain applications can be produced.[28]

Temperature, reaction time, and the ratios of the starting reagents are the key variables influencing the outcome of thermal breakdown. Researchers can get the right particle size and shape by carefully modifying these parameters. Previous studies have demonstrated the enormous potential of IONPs produced through thermal decomposition as MRI contrast agents. The development of sophisticated nanomaterials for medical diagnostics and other high-precision applications benefits greatly from thermal parsing since it can produce NPs with consistent sizes and magnetic properties, which boosts their effectiveness in improving MRI signal contrast.[29]

3.5. Sedimentation Technique:

By removing metallic components from salt solutions, the sedimentation technique provides a practical method for producing MNPs. By adjusting variables including temperature, ionic strength, and pH, this technique involves combining metal salts in a liquid and encouraging the formation of NPs. The kind of salt employed and the particulars of the reaction have a significant impact on the size, shape, and dispersion of

the final MNPs. This method is regarded for producing a lot of NPs, which makes it a cost-effective choice for many applications.[30]

Despite their advantages, controlling the size distribution and homogeneity of NPs can be challenging due to the intricacies of crystal growth dynamics. Small particles are created during nucleation, and these nuclei then develop into larger crystals as part of the process. In order to maintain consistent particle quality and achieve uniform sedimentation in a reaction, circumstances must be precisely observed and modified. The sedimentation technique has been effectively used in a variety of biomedical applications, including hyperthermic treatments, which employ MNPs to provide concentrated heat for cancer treatment and to enhance fluid magnetic characteristics in the manufacturing of magnetic fluids.[31]

3.6. Sol-gel Technique:

A versatile method for producing MNPs is the sol-gel procedure, which involves reacting metal precursors with hydrolysis and polycondensation. In this process, metal alkoxides or chlorides are dissolved in a solvent to create a colloidal suspension known as a "sol." As the solvent dries and the particles assemble, this sol proceeds through a gelation process, turning into a solid or semisolid "gel" phase. The resulting gel is subsequently heated to remove any last traces of organic material and encourage the NPs' crystallization.[32]

The sol-gel method's capacity to produce uniform NPs with little size fluctuation is one of its main advantages. It is beneficial to produce high-purity amorphous phases and modify the magnetic characteristics by precisely manipulating the NP structure and size by low-temperature processing. Notwithstanding these advantages, the sol–gel approach has limitations in circumstances requiring high endurance, such MRI contrast agents The performance of the end products created using some procedures in imaging applications may be impacted by their lesser stability compared to those produced using other approaches.[33]

3.7.Microemulsion Technique:

The microemulsion technique is a sophisticated way to synthesize MNPs that controls particle formation by using the unique properties of microemulsions. Three distinct phases—water (polar phase), oil (nonpolar phase), and a surfactant—combine to form a stable, isotropic liquid mixture known as a microemulsion. At the boundaries between these phases, the surfactant molecules produce a stabilizing layer that causes the creation of various microstructures, including oil droplets in water and water droplets in oil. These tiny structures function as miniature reactors, providing a limited area for precisely regulating the production and growth of NPs.[34] The surfactant-stabilized nanodroplets in the microemulsion technique act as templates for the chemical processes that produce NP. Combining metal precursors in the microemulsion and then managing the nucleation and growth within the droplets are typical steps in the process. Washing or other purification techniques are usually used to remove the surfactants after the NPs have been produced. Because the nanoreactors offer a steady environment for particle formation this method is useful for producing MNPs with exact sizes and uniform distributions. Nevertheless, the process of eliminating surfactants is challenging, and precise control over the microemulsion parameters might be problematic.[35]

3.8.Electrochemical Method:

The electrochemical synthesis method of producing MNPs uses regulated redox reactions of metal salts in an electrochemical environment. This process is well-known for its accuracy and scalability, making it easier to produce ultrapure NPs with exact control over their size. NPs are produced when metal ions are reduced on an electrode surface during the electrochemical process. By controlling reaction parameters including voltage, current density, and electrolyte composition, this approach offers several advantages, including the capacity to precisely modify particle size and shape.[36]

Although the electrochemical synthesis approach offers benefits, there are drawbacks as well. The potential presence of residual solvents or surfactants from the synthesis process is a serious worry since it could affect the NPs' surface properties. These residual compounds have the potential to interfere with surface changes, impact biocompatibility, and result in

undesirable side effects like cytotoxicity. To solve these issues and ensure that the MNPs have the qualities required for specific applications, like drug administration or imaging, efficient purification and synthesis condition optimization are essential.[37]

4.PROTEIN BASED NANOPARTICLES IN CANCER THERAPY

Mechanism of action:

4.1.Targeted drug delivery:

Through targeted medication delivery, peptide-based nanoparticles (PBNPs) present a fresh approach to cancer therapy. In contrast to normal cells, cancer cells frequently express certain receptors or antigens that are either overexpressed or exclusively located on their surface. This feature makes it possible to create PBNPs with peptides or ligands that attach to these tumor-specific markers in a certain way, guaranteeing that the nanoparticles will only build up in malignant cells.[38]

Since the concentration of the therapeutic agent is higher in tumor tissue than in healthy tissues, PBNPs' selective targeting of cancer cells improves the overall effectiveness of the medicine being administered. Furthermore, PBNPs can be engineered to transport a range of therapeutic substances, such as proteins, RNA-based therapies, or small molecules. This adaptability enables a customized treatment plan depending on the patient's unique requirements and the tumor's features.[39]

4.2.Controlled release:

The capacity of PBNPs to enable the controlled release of therapeutic medicines is a noteworthy benefit in the therapy of cancer. Conventional chemotherapy frequently entails giving high dosages of medications at brief intervals, which can result in dangerous drug concentration peaks that can be damaging to healthy tissues.On the other hand, PBNPs can be designed to release their payloads in a regulated way, sustaining therapeutic drug levels for a long time.[40]

There are several ways to regulate the therapeutic agent's release from PBNPs, including alterations in pH, temperature, or enzyme activity. These triggers, which are frequently linked to the tumor microenvironment, enable the delivery of medications only to the malignant region. For instance, medications enclosed in PBNPs can be released in response to the acidic pH typically present in tumors. PBNPs offer a more effective and efficient method of delivering medications to tumor cells by creating nanoparticles that react to these particular environmental conditions, enhancing the overall result of treatment.[41]

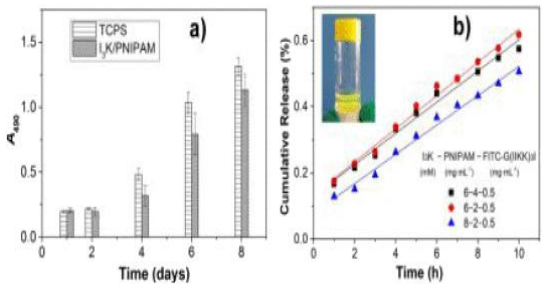

Fig.2: Controlled Release

4.3.Tumor microenvironment modulation:

Tumor resistance to therapy is largely influenced by the tumor microenvironment (TME). It is challenging for traditional medicines to reach and efficiently treat cancer cells due to characteristics such an acidic pH, low oxygen levels, and a weak blood supply. PBNPs may alter the TME in ways that improve the effectiveness of cancer therapies. The blood-tumor barrier's permeability, which normally restricts the delivery of medications to tumor cells, can be enhanced by functionalized PBNPs. PBNPs improve medication delivery and efficacy by enhancing the permeability of blood arteries within the tumor, which facilitates greater penetration of chemotherapeutic drugs.[42]

For instance, Zhang and Xu (2023) stress how tumor cell-stromal cell interactions inside the TME have a major impact on treatment resistance and cancer progression.[43]

In addition to promoting tumor growth, stromal cells in the TME, such as fibrosis-related cells, infiltrating immune cells, and angiogenic vascular cells, also make medication delivery ineffective by establishing barriers and fostering a hostile microenvironment. Therapeutic peptides have shown impressive potential in targeting these stromal cells and modifying the

TME. They can self-assemble or interact with polymeric substances to produce nanoparticles.

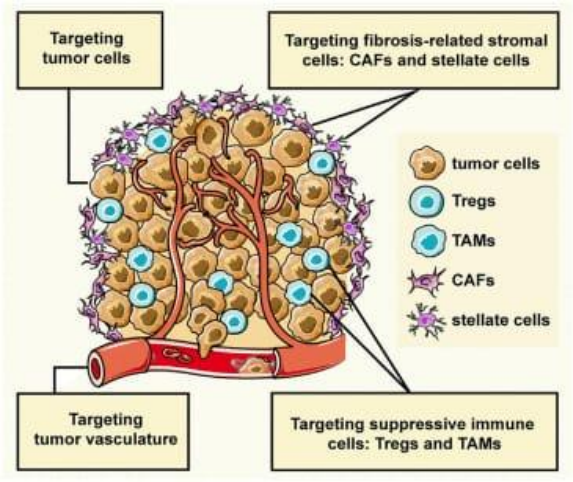

Fig.3: Tumor microenvironment modulation.

Fig 3. Cancer growth is greatly influenced by interactions within the tumor microenvironment (TME), which is made up of tumor cells and three main types of stromal cells: tumor fibrosis-related cells, infiltrating immune cells, and angiogenesis-related vascular cells. The peptide-assembled nanoparticles intended to target tumor cells and stromal cells for improved cancer therapy are depicted in this picture.[44]

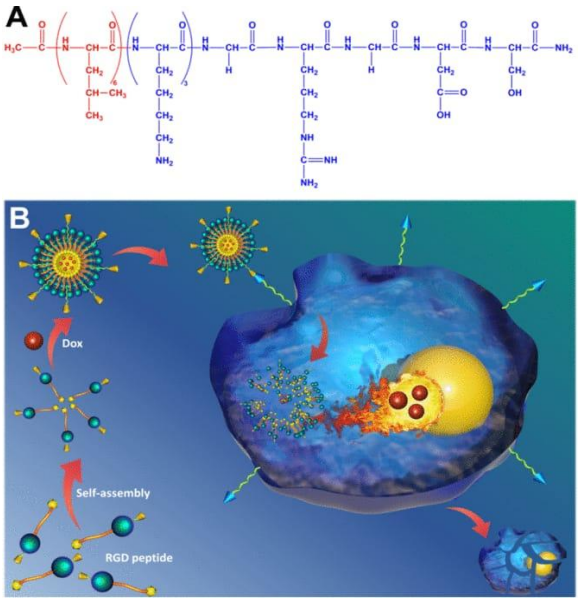

Fig.4: Tumor microenvironment modulation

Fig 4. (A) Molecular structures of the RGD peptide LKR. The red represents hydrophobic areas, and the blue represents hydrophilic areas. (B) Self-assembly behavior and acid-responsive morphological transformation of LKR. After the targeted nanoparticles reached the tumor site, the slightly acidic tumor environment triggered the rupture of the spherical nanoparticles, resulting in the release of the encapsulated antitumor drug and achieving a combined antitumor effect.[45]

4.4.Photothermal and photodynamic therapy:

When combined with cutting-edge techniques like photothermal therapy (PTT) and photodynamic therapy (PDT), peptide-based nanoparticles (PBNPs) present a substantial opportunity for combination therapies in the treatment of cancer. These methods minimize damage to nearby healthy tissues while utilizing the special qualities of light-activated processes to accomplish precise, localized tumor elimination.[46]

By converting light energy into heat, photothermal treatment elevates the temperature of tumor tissues in order to cause cell death. Due to their capacity to absorb particular light wavelengths and transform them into localized hyperthermia, PBNPs—including those made of materials like ferritin—perform exceptionally well in this application. A feature of precision cancer therapy, this tailored heating effect is essential for destroying cancer cells only while preserving healthy tissues.[47]

5.ENCAPSULATION AND PROTECTION STRATEGIES

It is crucial to create masking techniques that stabilize MNPs against deterioration and enhance biocompatibility due to SPN instability and the strong cytoxicity of certain magnetic materials.[48]Adding an inorganic layer, like silica, or an organic layer, like polymer poly-(methyl methacrylate), to cover the metallic core is a common protection technique.[49]Surface coatings protect the magnetic core from reactive species in the surrounding environment and prevent MNPs from clumping together. They also give the MNP more functionality; for instance, particles might be coated with antibodies or targeting ligands that target particular cells.[50]

When there is a higher chance of opsonization, polymer-based shells like PEG and dextran are frequently employed. This is mostly because the nanoparticles are larger than 100 nm and hence more susceptible to being sequestered by the reticuloendothelial system.[51]Though PEG-based shells lessen the chance of MNP opsonization, synthetic polymers like poly(acrylic acid) are preferred because of their capacity to carry and attach to biological macromolecules like DNA because of their neutral pH, which prevents the conjugation of functional groups.[52]It's interesting to note that employing a less reactive metallic shell can occasionally increase the stability and biocompatibility of nanoparticles by fusing two otherwise distinct magnetic phases and enhancing the structure's overall magnetic characteristics through the exchange-bias effect.[53]

The quantum mechanical pairing of two magnetic atoms across the interface between a ferromagnetic and anti-ferromagnetic material is what causes the exchange-bias effect.[54]Numerous systems, such as Fe3O4-CoO, have shown exchange coupling, which can provide as an additional source of anisotropy to stabilize unstable nanocomposites.[55]

6.LIMITATIONS AND POSSIBILITIES

Even with nanotechnology, treating metastasized cancer will continue to be extremely difficult. Almost half of the cancers had spread by the time of diagnosis. Because of this, the majority of these individuals can only receive palliative treatment. However, treatment of the primary focus has therapeutic effects on the metastases as well.[56]

Naturally, not all satellite tumors are amenable to targeting.by MDT, as the Section for Experimental Oncology and Nanomedicine (SEON) pursues, but one can concentrate on metastases that pose a serious threat to life or significantly impair quality of life. Nonetheless, there are currently methods for treating metastasized cancer with the goal of curing it. A novel magnetic lymphatic-targeting drug delivery method based on functionalized carbon nanotubes was presented by Yang et al. By subcutaneously administering gemcitabine-laden magnetic multiwalled carbon nanotubes and loaded magnetic-activated carbon particles in a magnetic field, they were able to successfully suppress the metastasis of lymph nodes.[57]

7.Application of Magnetic Nanoparticles in Cancer Therapy:

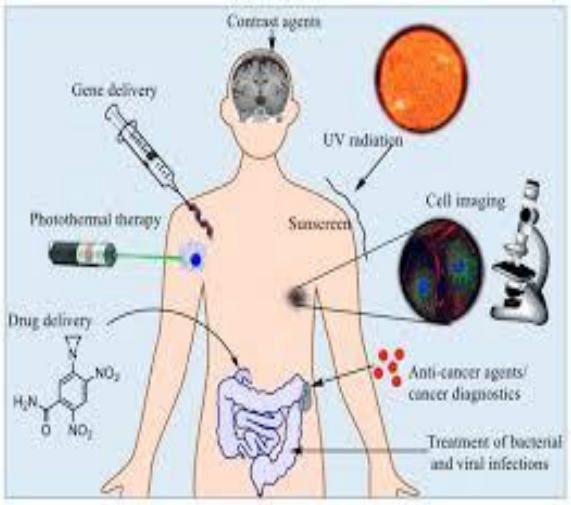

Fig.5

7.1.Targeted Drug Delivery:

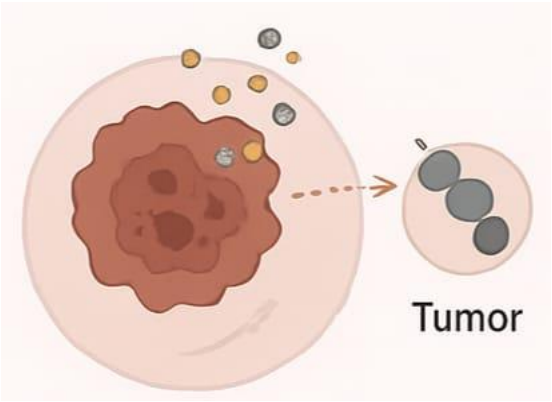

Fig.6

By taking use of the increased permeability and retention (EPR) effect, nanoparticles (NPs) can deliver anti-cancer medications straight to tumor tissues.

This enhances medication accumulation at the tumor location and decreases systemic toxicity.

Ex.doxorubicin-loaded liposomes (Doxil®) are used to treat ovarian cancer.

7.2.Overcoming Drug Resistance:

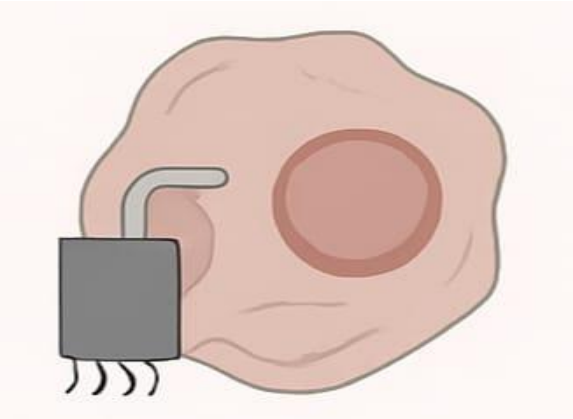

Fig.7

Multidrug resistance (MDR) is a common development in tumor cells.

Nanoparticles (polymeric NPs, micelles, lipid-based NPs) can bypass drug efflux pumps, improving therapeutic effect.

7.3.Gene and siRNA Delivery:

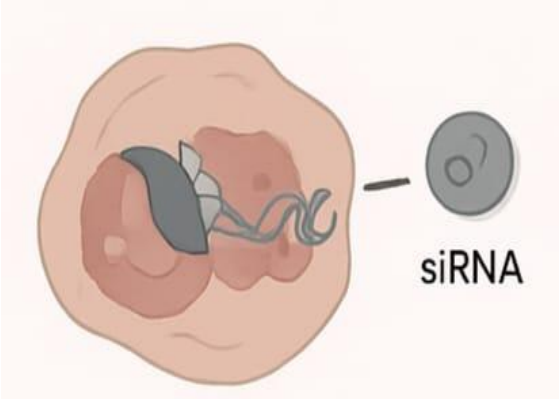

Fig.8

To mute oncogenes or restore tumor suppressor genes, nanoparticles can transport siRNA, miRNA, or CRISPR/Cas9 systems.

For instance, siRNA delivered by lipid nanoparticles targets KRAS mutations in pancreatic cancer.

7.4.Combination Treatment:

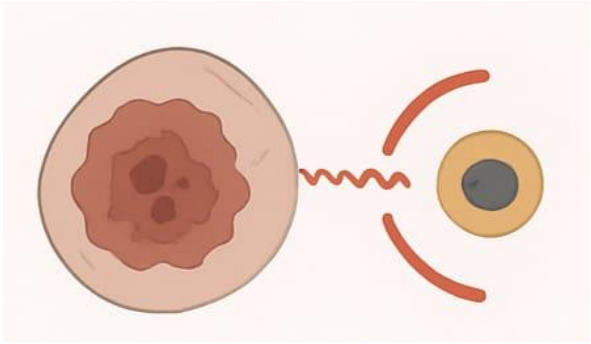

Fig.9

Co-delivery of several drugs is made possible by nanoparticles (e.g., chemotherapy + immunotherapy or chemotherapy + photothermal therapy).

Using gold nanoparticles exposed to near-infrared (NIR) light, tumors can be photothermally abated.

7.5.Stimuli-Responsive Drug Release:

To Stimuli Drugs can be released by smart nanoparticles in a controlled manner at the tumor site in response to pH, temperature, enzymes, or magnetic fields.

7.6.Immunotherapy Enhancement:

To enhance immune responses, checkpoint inhibitors or tumor antigens can be delivered using nanoparticles.

Ex.PLGA nanoparticles containing antigens linked to tumors in cancer vaccinations.[58-62]

8.FUTURE PROSPECTS

MNPs have demonstrated effectiveness in preclinical research, but their clinical use has been sluggish. No MNP-based treatment for cancer has received approval as of yet. Many studies are currently being conducted to increase the safety and effectiveness of MNPs in humans, and some are undergoing clinical trials for the treatment of cancer.The evidence of their Therapeutic efficacy is undeniable ,even though they are sound science fiction.In the future creating NPs is artificial intelligence and Machine learning techniques can help create treatments tailored to individual patients.To increase patient compliance, real-time temperature and other condition monitoring

at the tumor location must be improved. NPs can develop further as theranostic agents by fusing treatment modalities like medication delivery or heat with imaging techniques like MRI. These characteristics will support ongoing therapy progress monitoring. It is possible to investigate stimuli-responsive NPs to enhance the targeting and on-demand release of drugs. In the future, with more extensive research on surface modification strategies, highly biocompatible and safe MNPs can be developed. More research into this field is needed for the clinical translation of these efficient magnetic carriers.

9.CONCLUSION

MNPs are novel medicinal interventions that could fundamentally alter the way cancer is identified and managed. MNPs are produced using a variety of synthetic techniques. The most widely used methods include coprecipitation, thermal breakdown, hydrothermal processes, and polyol synthesis. Because of functionalization, MNPs' compatibility with biological systems has been increased.

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