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A Comparative Review of Nanomaterials for Neuroprotection in Neurodegenerative Diseases

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ABSTRACT

Neurodegenerative illnesses like Alzheimer's, Parkinson's, and ALS cause progressive injury to the brain, causing loss of memory, movement, and cognitive functions over time. The problem with these diseases is that most drugs cannot pass through the brain's protective barrier—the blood-brain barrier (BBB). In this review, the new use of nanomaterials—extremely tiny particles measured in nanometers—is described to transport drugs across the BBB without harming brain cells. We analyzed eight of the most well-researched types of nanomaterials: fat-based, plastic-like, dendrimers, carbon-based, gold, cerium oxide, iron oxide nanoparticles, and quantum dots. Each was assessed on its ability to deliver drugs to the brain, safety, stability, and performance in laboratory tests. Fat-based and plastic-like nanoparticles outperformed all others based on biocompatibility and drug delivery ability. Gold nanoparticles were highly multifunctional and versatile for therapy and imaging. Cerium oxide proved to be a great antioxidant and could protect neurons from injury. However, some nanomaterials like carbon nanotubes and quantum dots were of concern due to toxicity. The review concludes that just as there is no single nanomaterial that is perfect, their benefits can be leveraged in hybrid systems to enable more powerful, targeted, and safer treatment. In fact, nanotechnology has tremendous potential for future advances in the fight against brain disease by enabling precise and protective drug delivery to the brain.

Keywords: *Nanomaterials, Neurodegenerative Diseases, Blood-Brain Barrier (BBB), Drug Delivery, Neuroprotection, Theranostics*

INTRODUCTION

Neurodegenerative diseases like Alzheimer's, Parkinson's, Huntington's disease, and Amyotrophic Lateral Sclerosis (ALS) are widespread across the globe, affecting millions of people. These diseases silently attack the brain and nervous system over a time period, leading to memory, movement, and cognitive issues. Unfortunately, there is no permanent cure for these diseases, and most of the treatments available only reduce symptoms for a short time. One of the main reasons for this is the protective shield of the brain, i.e., the blood-brain barrier (BBB). Although this barrier is very important in keeping harmful chemicals out, it also blocks most medicines from entering the brain, making it very difficult to treat brain-related diseases.

In recent years, researchers have been looking to nanotechnology to address this issue. Nanotechnology is the science of working with things that are incredibly small—so small they are measured in nanometers (1 nanometer = one-billionth of a meter). These nanomaterials can be engineered to carry drugs and cross the blood-brain barrier. Some nanomaterials are composed of fats (e.g., liposomes), some of plastics (e.g., PLGA), and others of metals such as gold or iron. Due to their small size and unique properties, these nanomaterials are able to shield brain cells from damage, carry drugs to targeted areas in the brain, and even facilitate healing in the brain. The usage of nanomaterials in the medical world is not only exciting; it is also immensely important. Experiments on animals have shown that certain nanomaterials possess the capability to improve memory, reduce poisonous molecules in the brain, and protect nerve cells from damage. For instance, cerium oxide nanoparticles have been found to remove harmful reactive oxygen species (ROS), which are linked with brain injury in diseases like Parkinson's disease. Similarly, fat-based particles have been found to carry drugs easily across the blood-brain barrier and into the targeted areas of the brain.

However, not all nanomaterials are equally safe or effective. Some nanomaterials, i.e., carbon nanotubes or quantum dots, will be functional in the lab but are unsafe to bring into the human body. Some will be effective in the cure of one disease but not another. This is why it is necessary to compare different nanomaterials. With this comparison of what is safest, most effective, and easiest to deliver, scientists can determine the best candidates for use in future treatment.

In this review article, we will compare and discuss eight prominent classes of nanomaterials that have been studied for their potential to protect the brain from diseases such as Alzheimer's and Parkinson's. These include:

i. Fat-based nanoparticles (like liposomes and solid lipid nanoparticles)
ii. Plastic-like nanoparticles (like PLGA and chitosan)
iii. Dendrimers
iv. Carbon-based nanomaterials (like graphene and carbon nanotubes)
v. Gold nanoparticles
vi. Cerium oxide nanoparticles (nanoceria)
vii. Iron oxide nanoparticles
viii. Quantum dots

We will take into account the function of every nanomaterial, how well they will penetrate the brain, their safety profiles, and their efficacy in animal models. At the end of this paper, we will have a good idea of which nanomaterials will cure brain disease in the future.

FAT-BASED NANOPARTICLES

Liposomes and solid lipid nanoparticles (SLNs) are two of the most promising brain drug delivery systems. Composed of fat-like substances that are biocompatible and biodegradable, these particles are released or absorbed safely from the body. Liposomes, composed of spherical vesicles and water-loving interior with the outer shell of fats as its covering, are ideal drug carriers for water-soluble and fat-soluble drugs.

One of the noteworthy advantages of fat-based nanoparticles is that they penetrate the blood-brain barrier (BBB) very effectively. Many studies have proven that liposomes, when designed with molecules like transferrin or PEG (polyethylene glycol), are very effective in delivering drugs to the brain. In a case study by Kakkar et al. in 2018, for instance, it was found that in Alzheimer's mice who were administered drug-encapsulated liposomes, there was a whopping 70% increase in drug delivery to the brain and a 60% decrease in brain cells destroyed.

SLNs offer even more stability than liposomes. They can remain in their form longer in the blood, giving drugs more time to get where they need to go. Zhang et al. wrote an article in 2020 that demonstrated that curcumin-loaded SLNs significantly improved memory and decreased inflammation in mice with mild Alzheimer's.

Fat-based nanoparticles are generally safe. Built from materials such as food and cosmetics, they rarely lead to side effects. Their softness and flexibility also put limitations on the capacity to trigger the immune system. But there is one major issue remaining; liposomes occasionally leak their drug payload before they arrive in the brain. To overcome this issue, scientists are developing new coatings and lock devices engineered to safeguard drugs until they arrive in brain tissue. Fat-based nanoparticles are among the best characterized and most consistent nanomaterials that have been designed to cure brain disease. Their unprecedented ability to deliver a range of drugs safely through the blood-brain barrier, along with their proven effectiveness in animal models, make them top contenders for future treatments.

PLASTIC-LIKE NANOPARTICLES

Plastic-type nanoparticles, including poly(lactic-co-glycolic acid) (PLGA) and chitosan nanoparticles, represent another type of nanomaterials that have proven very promising for brain protection. PLGA is a synthetic polymer that has been FDA-approved for drug delivery due to the fact that it is biodegradable and nontoxic. Chitosan is a natural polymer obtained from shellfish, on the other hand, but renowned for its safety and ability to be easily modified.

The most significant advantage of plastic-like nanoparticles is their prolonged release of medication over a long duration. This feature makes the impact of a single dose last for an extended period, which is especially useful in treating chronic brain disease. In an article published in 2019 by Lee et al., PLGA nanoparticles loaded with dopamine showed a sustained release of the drug for 48 hours, resulting in improved locomotion in rats with Parkinson's disease.

Chitosan nanoparticles also have special advantages. Being positively charged, they can adhere to the negatively charged surface of brain cells and the blood-brain barrier, enhancing absorption. In a 2017 Kumar et al. report, memantine (Alzheimer's medication)-loaded chitosan-coated nanoparticles enhanced drug levels in the brain by 45% and enhanced memory in experimental animals.

Plastic-like nanoparticles are actually extremely safe and extremely tolerable in the body. However, they do not always have the same capability to cross the blood-brain barrier on their own as their fat-based counterparts. To address this problem, scientists usually alter them with special molecules, such as PEG or ligands, that can bind specifically to brain receptors.

Another challenge that plastic-like nanoparticles pose is that they can induce mild inflammation, particularly when the particles are too big or carry remaining chemicals from the manufacturing process. To counteract this threat, scientists are working round the clock to improve their formulations so that they can avoid this risk.

DENDRIMERS

Dendrimers are tree-like, branched nanomaterials that have gained attention as they are seen to have the potential to cure neurodegenerative disease.

Dendrimers are artificial polymers built in layers (called generations) that allow for exact control of their size, shape, and surface functionality. This special architecture makes dendrimers very valuable as drug delivery agents, especially for crossing the blood-brain barrier (BBB).

One of the most striking benefits of dendrimers is their multifunctional surface, which can be cleverly modified with drug molecules and targeting agents. For instance, in 2017, Kannan et al. explored a hydroxyl-terminated polyamidoamine (PAMAM) dendrimer that was conjugated to an anti-inflammatory drug. When it was administered to mice suffering from cerebral palsy—a disease marked by inflammation of the brain—the dendrimer-drug complex selectively targeted the inflamed tissues of the brain and reduced neuroinflammation significantly without impairing healthy tissue. While not technically a traditional neurodegenerative disease, targeted delivery observed in this study holds promise for the treatment of diseases such as Alzheimer's and Parkinson's, where inflammation plays a key role.

Dendrimers have the potential to increase the solubility and stability of drugs. The majority of neuroprotective drugs have low water solubility, and therefore, they are limited in their use. Dendrimers release drugs via encapsulation or conjugation across the blood-brain barrier. In Singh et al.'s research in 2021, a fourth-generation PAMAM dendrimer was used to deliver curcumin to the brain in an Alzheimer's disease mouse model. The new approach caused enhanced memory performance and 40% reduction in oxidative stress as compared to free curcumin.

Another important advantage of dendrimers is that they are of low toxicity, particularly when their surfaces are modified with neutral or biocompatible moieties. However, unmodified PAMAM dendrimers—particularly positively charged (amine) surfaces—can be toxic to cells. In order to make them more biocompatible, scientists are increasingly using surface modifications like PEGylation or hydroxylation.

While promising, dendrimers are not without limitations. They are difficult and costly to produce because of the precise layering required. They are also not yet fully understood in terms of their long-term behavior in the body and thus require more research to determine their long-term safety.

CARBON-BASED NANOMATERIALS

Carbon nanomaterials, including fullerenes, carbon nanotubes (CNTs), and graphene, have been identified to be powerful tools in diagnosing and treating neurodegenerative disease. These nanomaterials exhibit remarkable electrical, mechanical, and thermal properties along with high surface area and outstanding biocompatibility. They have the ability to penetrate the blood-brain barrier (BBB) by interacting with neural tissue, a special property that renders them extremely valuable for treating diseases such as Alzheimer's (AD), Parkinson's (PD), and Huntington's disease.

Fullerenes or buckyballs are spherical molecules of carbon with high antioxidant properties. They possess the capacity to scavenge reactive oxygen species (ROS), which are involved in the pathogenesis of the majority of neurodegenerative diseases. In 2016, Gharbi et al. showed that hydroxylated fullerenes (C60-OH) were capable of reducing oxidative stress effectively in rat models of neuroinflammation, and this was correlated with enhanced motor function and neuronal survival. These observations indicate that fullerenes are most likely to be useful in preventing or delaying neuronal damage in the initial disease stages of diseases like Parkinson's.

Carbon nanotubes (CNTs), which are rolled-up sheets of graphene in the form of cylinders, are highly conductive and are also being researched for drug delivery and neural interface applications. Functionalization of the CNTs allows researchers to design them to carry drugs, genes, or biomolecules to the targeted brain location. In a 2018 publication by M. Bianco and co-authors, CNTs were used to deliver dopamine to targeted areas within a Parkinson's model and exhibited enhanced motor control and fewer side effects than conventional systemic delivery. CNTs are also being researched as neural scaffolds to repair damaged neurons, since they can mimic axonal structures and cause neurite outgrowth. Graphene and graphene oxide (GO) provide a high-surface-area 2D planar structure and therefore the ability to carry several drugs. GO also has the ability to bind amyloid-beta (Aβ) aggregates—a characteristic of Alzheimer's disease—and potentially inhibit their formation. GO sheets grafted with polyethylene glycol (PEG) suppressed Aβ fibrillation in vitro and exhibited neuroprotective properties in an AD mouse model in a 2020 article published in Nanoscale. GO-based sensors have also been demonstrated for early diagnosis of Aβ peptides in cerebrospinal fluid due to their strong fluorescence quenching.

Although they have many benefits, carbon-based nanomaterials pose a range of challenges. Toxicity and biodegradability are the major issues, especially for CNTs and pristine graphene, which can aggregate in tissues and cause inflammation or cytotoxicity unless well functionalized. Surface modifications, including carboxylation and PEGylation, to improve their biocompatibility and clearance are the focus of ongoing research.

QUANTUM DOTS

Quantum dots (QDs) are semiconductor nanocrystals, typically ranging from 2-10 nanometers in diameter. Their tunable fluorescence, as well as their enhanced photostability and wide range of absorption and narrow emission spectra, have made them a precious resource to be used for imaging and promising therapeutic agents for neurodegenerative disorders.

In diagnostic applications, QDs hold great promise as fluorescent probes for high-resolution, real-time imaging of brain structures and processes. The resistance to photobleaching and brightness of QDs render them superior to traditional dyes in applications such as amyloid-beta (Aβ) plaque imaging in Alzheimer's disease (AD).

For example, in a 2019 Kim et al. study, QDs labeled with anti-Aβ antibodies allowed precise imaging of Aβ deposits in brain slices from transgenic AD mice. The high signal-to-noise ratio of QDs allowed early-stage plaque detection, enhancing the sensitivity of diagnostic procedures.

QDs have also been utilized in PD research to image the aggregation and intracellular trafficking of α-synuclein. This has enabled researchers to monitor disease onset at the molecular level. Aptamer- or peptide-functionalized QDs have also been found to be useful in the detection of various conformations of misfolded proteins—a function valuable for differential diagnosis in neurodegenerative illnesses.

Aside from diagnostics, theranostic QDs are being engineered for drug delivery and ROS scavenging. Cadmium-free QDs (such as indium phosphide or carbon-based QDs) are also becoming of increasing interest because they pose lower toxicity issues. Surface-functionalized nanoparticles may be loaded with drug, siRNA, or neurotrophic factors and directed to the CNS by conjugating targeting ligands such as transferrin or lactoferrin. Their fluorescence can be utilized, after delivery, for real-time imaging of distribution and uptake.

One new application is photodynamic therapy (PDT), in which QDs are employed to create reactive oxygen species under the activating effect of light so as to specifically target and destroy diseased cells. Although in its infancy, this approach has promise for targeting dysfunctional neurons or glial cells that are responsible for neurodegeneration.

Though they are valuable, quantum dots also raise extreme toxicity concerns, largely due to the heavy metals—cadmium and selenium—most frequently utilized in their core composition. This drawback bars them from clinic use, particularly for extended periods of time in the brain. As an alternative, scientists are designing biocompatible shells, including silica, PEG, or peptide layers, as well as investigating metal-free substitutes like carbon or graphene quantum dots that have exhibited lower cytotoxicity and enhanced biodegradability.

GOLD NANOPARTICLES (AuNPs)

Gold nanoparticles (AuNPs) are tiny gold fragments measuring 1 to 100 nanometers in size that have unusual physical and chemical properties that render them suitable for medical use. Their high biocompatibility and surface modifiability have made AuNPs a likely drug and diagnostic delivery vehicle through the blood-brain barrier (BBB).

One of the main benefits of AuNPs is that they may be functionalized with any molecule like an antibody, peptide, or drug that binds to a specific receptor on brain cells. Targeting enables AuNPs to penetrate the BBB more efficiently and bring therapeutic molecules to damaged neurons or protein aggregates. As an example, it is found that AuNPs functionalized with amyloid-beta targeting peptides can bind and destroy plaques in Alzheimer's disease and thereby retard the disease progression (Cheng et al., 2018).

Besides drug delivery, gold nanoparticles (AuNPs) find applications in photothermal therapy (PTT). Upon irradiation with near-infrared light, AuNPs convert light energy into heat and thus facilitate targeted killing of diseased cells without damaging neighboring healthy tissue. The technique has shown promise in killing aberrant protein aggregates in neurodegenerative disease model animals (Li et al., 2020).

Besides, AuNPs also enhance brain imaging methods, such as computed tomography (CT) and photoacoustic imaging, to enable early detection and long-term tracking of brain disorders. Their high optical absorption capabilities render them better contrast agents. While these advantages exist, there remain problems. Some research indicates AuNPs will settle in organs such as the liver and spleen and be harmful (Khlebtsov & Dykman, 2011). Particle size and shape as well as surface chemistry play a significant role in their safety profile. Researchers are working to develop coatings such as polyethylene glycol (PEG) in order to prolong circulation and minimize immune clearance.

CERIUM OXIDE NANOPARTICLES

Cerium oxide nanoparticles, or nanoceria, have unique antioxidant characteristics which have attracted special research focus towards neuroprotection. Nanoceria have the unique characteristic of being in two oxidation states—Ce^{3+} and Ce^{4+}—and, by virtue of this, mimic the activity of endogenous antioxidant enzymes like superoxide dismutase (SOD) and catalase. This activity enables nanoceria to neutralize toxic reactive oxygen species (ROS), a critical contributor to oxidative stress, the main etiology of neuronal damage in neurodegenerative conditions like Alzheimer's and Parkinson's (Das et al., 2013).

Oxidative stress is caused by a lack of balance between ROS generation and the capacity of the body to detoxify the toxic molecules. Excess ROS causes protein, DNA, and lipid damage in brain cells, speeding up disease. Nanoceria can continuously scavenge ROS, making it a renewable antioxidant, in contrast to conventional antioxidants that are oxidized after one reaction.

Animal experiments have yielded encouraging findings. For instance, in one conducted in 2019, nanoceria delivered to Parkinson's model mice inhibited neuroinflammation and shielded dopamine-secreting cells, leading to enhanced motor function (Estevez et al., 2019). In Alzheimer's models, nanoceria inhibited amyloid-beta deposition and oxidative stress, enhancing memory and cognition (Kumar et al., 2020).

Nanoceria surface can be engineered using polymers or targeting ligands to enhance stability, BBB permeability, and targeted delivery to damaged brain regions. Concerns do exist that at high doses or with extended exposure, there may be toxicity.

Some reports indicate that an over-accumulation of nanoceria could lead to inflammation or cell killing, and therefore, controlled dosing and biodegradable coatings must be employed (Heckman et al., 2013). In general, nanoceria are a highly active nanomaterial with robust antioxidant and neuroprotective actions, with promise for the retardation or prevention of neurodegenerative disease onset. Subsequent work will be necessary to optimize their safety and formulate clinically acceptable products.

IRON OXIDE NANOPARTICLES

Iron oxide nanoparticles (IONPs), including magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3), have been of significant interest because of their magnetic properties and biocompatibility, which are of very useful advantage in neurodegenerative disease diagnosis and therapy. The particles, with an overall size of 10–100 nm, can be navigated by external magnetic fields, allowing targeted drug delivery to certain brain regions, which is particularly convenient to circumvent the blood-brain barrier (BBB).

IONPs are used as universal contrast agents in magnetic resonance imaging (MRI) since they can alter magnetic signals, allowing lesions and brain tissues to be more visible. The accomplishment helps in the early detection and tracking of diseases like Alzheimer's and Parkinson's (Lee et al., 2017).

Therapeutically, IONPs can be functionalized with therapeutic drugs or targeting molecules such as antibodies or peptides. Functionalization enables them to bind specifically to diseased neurons or protein aggregates. Additionally, in alternating magnetic fields, IONPs generate localized heat, magnetic hyperthermia, which can destroy diseased cells selectively or reduce protein aggregates in the brain (Gupta & Gupta, 2005).

In animal models of Parkinson's disease, dopamine-loaded IONPs targeted to the brain improved motor function and, concurrently, prevented neurodegeneration (Liu et al., 2021). In Alzheimer's disease, magnetic nanoparticles with amyloid-beta antibodies had promise for detection and plaque removal (Wang et al., 2018).

Although promising, there are potential risks including oxidative stress resulting from iron overload and inflammation from nanoparticle deposition. Surface modification with dextran or PEG improves biocompatibility and reduces immunogenicity. Particle size and dose must be optimized to reduce toxicity (Mahmoudi et al., 2011).

WHICH METHODS ARE MOST EFFECTIVE?

When we consider the wide variety of nanoparticle platforms—lipid-based nanoparticles, plastic-like nanoparticles, dendrimers, carbon nanomaterials, gold nanoparticles, cerium oxide nanoparticles, iron oxide nanoparticles, and quantum dots—each have a unique combination of strengths and weaknesses, based on their inherent nature. Biocompatibility is an inherent need for clinical use; lipid-based nanoparticles are particularly exceptional in this regard, with their lipid composition closely resembling that of natural biological membranes, and this allows for good tolerability and minimal immune reaction. Plastic-like nanoparticles, especially those developed from biodegradable polymers like PLGA and chitosan, have excellent biocompatibility while offering enhanced structural support and controlled degradation, thus enhancing their use in long-term drug release. Dendrimers, on the other hand, provide accurate molecular structure well-adapted for multivalent drug conjugation and targeted delivery, but are plagued by issues of biocompatibility due to potential toxicity associated with charged surface groups, unless highly modified. On the other hand, carbon nanomaterials like graphene and carbon nanotubes are famous for their high surface area and mechanical strength and hence are preferable for drug loading and photothermal therapy; however, their low biodegradability and potential to cause oxidative stress and inflammation hinder their clinical progress.

Among drug targeting and delivery functionalities, dendrimers are exceptional for their unmatched functional diversity; their branched architecture allows for the concurrent attachment of drug and targeting ligand, opening the way to intricate, precision-guided therapies. At the same time, fat-derived and plastic-like nanoparticles are best suited to encapsulate a broad range of hydrophilic and hydrophobic drugs, with modifiable surface chemistry for targeted delivery, although they usually require stealth coatings to avoid rapid clearance. Gold nanoparticles excel by their facile surface functionalization and intrinsic optical properties, which not only improve targeted drug delivery but also photothermal therapy and real-time imaging, making them highly versatile theranostics. On another front, cerium oxide nanoparticles present an interesting mix of delivery ability with intrinsic catalytic antioxidant activity, beneficial in the case of oxidative stress-related diseases, but whose long-term biocompatibility and safety profiles are yet to be fully established. Iron oxide nanoparticles combine diagnostic imaging by MRI with therapeutic potential by magnetic hyperthermia, uniquely placing themselves at the crossroads of treatment and monitoring. Finally, quantum dots are imaging leaders, with size-tunable brightness and fluorescence, although their therapeutic application in the clinic is impaired by issues related to heavy metal toxicity, which requires sophisticated surface engineering.

Stability and clearance further differentiate these platforms. Plastic-like nanoparticles and dendrimers provide tunable degradation rates and stability, whereas fat-based nanoparticles are susceptible to lipid peroxidation and may have shorter half-lives in circulation unless well-stabilized. Carbon-based and metal nanoparticles, including gold and iron oxide, have more intrinsic stability; however, they can accumulate and pose long-term toxicity unless carefully designed for biodegradation or clearance. Quantum dots are equally burdened by their heavy metal content. The toxicity profiles are highly divergent: fat-based and well-designed plastic-like nanoparticles are generally of low toxicity, whereas carbon-based nanomaterials, dendrimers—particularly cationic ones—and quantum dots need surface engineering to prevent off-target effects. Metal-based nanoparticles, like gold, cerium oxide, and iron oxide, are generally well tolerated but require careful control of dose and biocompatible coatings to prevent oxidative damage or undesirable immune responses.

The future of nanomedicine is ever more gravitating towards hybrid and multifunctional nanoparticle systems that synergistically combine the individual merits of distinct platforms, overcoming their respective shortcomings. By combining the biocompatibility and biodegradability of plastic-like or fat-based nanoparticles with the high precision targeting and multivalent drug conjugation ability of dendrimers, one can engineer delivery vehicles that are not only safe but highly selective. Analogously, encapsulation of gold nanoparticles in lipid or polymeric matrices can be leveraged for their outstanding optical and photothermal properties for real-time imaging and therapy, all while stemming toxicity and extending circulation time. Carbon nanomaterials, despite their challenges with toxicity, can be functionalized or hybridized with biocompatible polymers or coated with antioxidants like cerium oxide nanoparticles to reduce oxidative stress and inflammation, thus enhancing safety profiles. Analogously, the magnetic properties of iron oxide nanoparticles can be combined with drug-loaded polymeric carriers to achieve controlled, externally guided delivery along with real-time MRI imaging. Quantum dots could be included in these hybrid constructs to achieve excellent imaging contrast, as long as their heavy metal toxicity is greatly diminished through hardy encapsulation.

These multifunctional nanoplatforms represent the principle of "theranostics"—the synergistic combination of therapy and diagnostics—and they have great promise for personalized medicine through the delivery of personalized treatment regimens that dynamically adapt with disease progression. Further interdisciplinary research into these combinational strategies holds the key to transforming targeted drug delivery and precision oncology ultimately to the benefit of improved patient outcomes while minimizing side effects.

CONCLUSION

Nanomaterials promise new hope for treatment of neurodegenerative diseases like Alzheimer's and Parkinson's, notoriously resistant to cure by the brain's strong blood-brain barrier. The barrier excludes most drugs; but tiny nanoparticles can cross it and deposit drugs in the desired areas. In this review, we wrote about eight leading types of nanomaterials—nanoparticles based on fats, plastic-type nanoparticles, dendrimers, carbon nanomaterials, gold nanoparticles, cerium oxide nanoparticles, iron oxide nanoparticles, and quantum dots—each with advantages and disadvantages.

Fat-based nanoparticles and plastic-like nanoparticles are remarkable in safety and in drug carrying and releasing slowly. Dendrimers, in their capacity for targeted delivery and ability to carry multiple drugs, must be carefully constructed to prevent toxicity. Carbon-based nanomaterials hold vast promise due to their distinctive physical properties, but they are somewhat problematic in terms of safety. Gold nanoparticles excel in imaging and therapy, but they must be used with caution owing to side effects. Cerium oxide nanoparticles are potent antioxidants that can defend brain cells, and iron oxide nanoparticles have magnetic properties that are beneficial for guided drug delivery and imaging. Quantum dots are excellent for imaging; however, they must be improved to decrease their toxicity.

A comparison of these materials reveals that there is no such nanomaterial that is ideal. But if their best qualities are integrated into hybrid nanomaterials, the result might be safer, more efficient treatments that deliver drugs in the right place and give diagnostic information simultaneously. As research is ongoing, nanotechnology promises much in terms of creating new neuroprotective therapies that may enhance the quality of life in millions of brain disease patients. Further studies and rigorous testing are still required to confirm that these technologies are safe and efficient for human use. With continuous innovation, nanomaterials may transform the diagnosis and treatment of neurodegenerative diseases in the years to come.

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