HIGH SCHOOL EDITION
Journal of Student Research
Volume 13 Issue 3 (2024)

Comparative Study of Nanoparticle Carriers for Targeted Drug Delivery

Rhea Thurumella, Kristina Lilova[#], Virgal Torremoch[#] and Jothsna Kethar[#]

Gifted Gabber
[#]Advisor

ABSTRACT

This study compares and contrasts different types of nanoparticle carriers, such as liposomes, dendrimers, and polymeric nanoparticles. Its primary focus is on how well, specifically, and biocompatible, these nanoparticles work in focused drug delivery systems. This study uses advanced testing methods to determine how precisely these nanoparticles can target and reach specific cells or tissues. This could lead to better treatment results and fewer side effects. The research discovered that these particles carry medicine in different ways and that their size and the way their surfaces are made are significant to how well they work. Also, tests that check nanoparticles' biocompatibility show that their chemical and physical features are significant in how they interact with living things. This study helps us understand how nanoparticle medicine delivers drugs mechanically and lays the groundwork for making nanotherapeutics that work better and are safer. The results show that nanoparticle transporters could be used in specific treatments. This would lead to more personalized and precise medical care.

Introduction

Background Information

The area of targeted drug delivery has changed a lot since nanotechnology was created, opening up new ways to treat illnesses. Targeted drug delivery systems are a great example of this change because they promise to send medicines directly to sick cells or tissues. This method not only makes treatments more effective, but it also dramatically lowers the risk of side effects. It's a big step toward medicines that are better for patients. For example, nanoparticles aare used to give antigens to the immune system through nanoparticle-based vaccines and other vaccines, like those for COVID-19. Lipid nanoparticles hold the mRNA that codes for the SARS-CoV-2 spike protein in the Pfizer-BioNTech and Moderna COVID-19 vaccines. These nanoparticles help get the mRNA to cells, telling the cells to make the spike protein, which starts the immune reaction.

Overview of Nanoparticle Carriers

Nanoparticle (NP) carriers are very important for progressing focused therapy because they can carry drugs in various ways and with great accuracy. Liposomes, dendrimers, and polymeric nanoparticles are a few of these carriers that stand out because of the unique ways they work and the things they can carry. Liposomes can hold different medicines because they comprise two fatty layers. Dendrimers are built in a way that looks like a tree and give you exact control over size and function for better-focused delivery. Biodegradable polymeric nanoparticles can release medicine when needed in certain bodily situations. This makes drug delivery more accurate and effective.

The Rationale for the Study

The global burden of diseases and disparities in access to medical treatment necessitates innovative solutions applicable to all individuals. The World Health Organization reports that chronic diseases, such as cancer and heart disease, are the leading causes of death worldwide. In this context, nanotechnology emerges as a beacon of hope, offering targeted therapies that could alleviate health disparities across the globe.

There has been a dramatic increase in the expense of medical care in the United States; it is anticipated that by the year 2027, it will have reached about $6 trillion. The healthcare system in the United States is characterized by high pricing and uneven access, which highlights the need to develop new treatment techniques capable of providing efficient and cost-effective solutions. It is consistent with the national objective to reduce costs and enhance health outcomes that the development of better nanoparticle carriers for medication transport is being undertaken. Additionally, states such as Georgia and Mississippi, which have a large population of individuals living in rural regions and a large population of people who suffer from chronic diseases, stand to benefit tremendously from advancements in the distribution of drugs in a targeted manner. These technologies have the potential to make treatments more accessible and more successful, particularly in regions where healthcare resources are abundant.

Due to the growing prevalence of illnesses all over the globe and the unequal distribution of health care, medical research is being driven to develop solutions that may be implemented in any part of the world. When compared to one another, the patterns in the amount of money that various nations spend on medical care represent a broad range of variations. For instance, nations such as Canada and the United Kingdom with national healthcare systems allocate a significant portion of their gross domestic product (GDP) to healthcare to guarantee that all citizens can access the medical attention they need. In addition, according to the Globe Health Organization, chronic illnesses such as cancer and heart disease are responsible for the deaths of more individuals than any other cause found elsewhere in the globe. In this particular scenario, nanotechnology seems to be a viable alternative since it has the potential to assist in bridging the health gap across regions by delivering targeted therapies.

Even though NP carriers have a great deal of potential to alter how medications are administered, the fact that they are designed, constructed, and interact with biological systems in various ways underscores the importance of comprehensive comparative research projects. This research is essential for further knowledge about the different NP carriers' efficacy, precision, and biocompatibility and instilling confidence in the scientific process. By identifying the most promising candidates for application in medicine, we can develop more effective and efficient targeted treatment techniques, further advancing the field of nanotechnology in medical research and treatment.

Objectives of the Study

This research's primary objective is to compare polymeric nanoparticles, dendrimers, and liposomes thoroughly. It is essential to:

Comparing the efficiency of their delivery is necessary to determine how well various NP carriers can carry healing chemicals to certain cells or tissues.

Take a look at each form of nanoparticle to see whether or not it is safe for therapeutic usage and biocompatible. By accomplishing these objectives, the research endeavor sought to provide valuable information on enhancing the performance of nanoparticle carriers for the delivery of certain drugs. Significant shifts in customized medicine and how we administer therapies might result.

Materials and Methods

Nanoparticle Synthesis

Thin film hydration is a technique that is often used to produce liposomes. This technique involves drying lipids that have been soaked in an organic solvent under a vacuum to produce a thin film. An aqueous solution that contains the appropriate drug is used to hydrate the film, which ultimately results in the formation of liposomal vesicles. It is possible to reduce the size of the vesicles and maintain uniformity by using procedures such as sonication or extrusion.

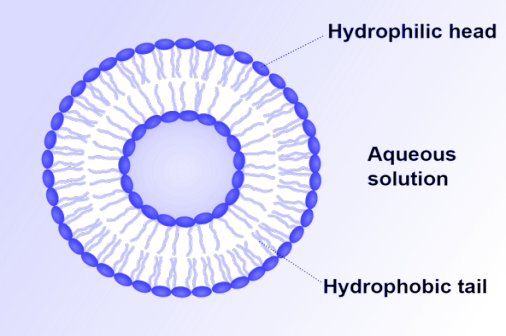

Figure1.1. Liposomes

Dendrimers are produced by a process that is meticulous and repeated, culminating in the addition of layers (generations) one after the other to a central core molecule throughout the process. Reaction and purification are the two phases that make up each generation. These stages allow for the dendrimer's size and surface characteristics to be manipulated.

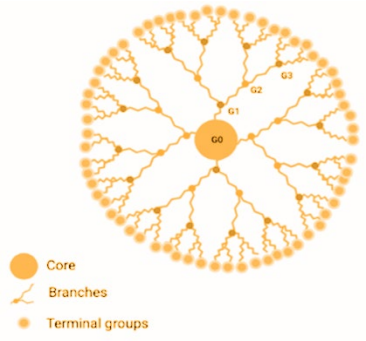

Figure1.2 Dendrimers

Polymeric Nanoparticles mThe production of may be accomplished by a variety of techniques, including nanoprecipitation, emulsion polymerization, and solvent evaporation, depending on the qualities necessary for the final product. These processes precipitate the nanoparticles by dissolving polymers in solvents and then carefully removing the solvent to achieve the desired effect.

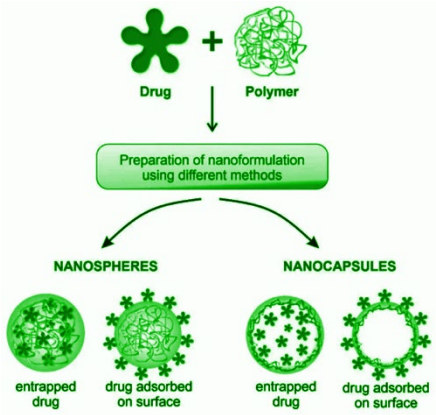

Figure1.3. Polymeric Nanoparticles

Characterization of Nanoparticles

Nanoparticles' form, surface charge, and size are essential for figuring out how they act in living things. Dynamic light scattering (DLS) is often used to find out the size and spread of particles. Electrophoretic light scattering shows how charged the surface is. Transmission electron microscopy (TEM) or scanning electron microscopy (SEM) can be used to get clear pictures of nanoparticles that help us understand their shape and structure.

In Vitro Studies

Cultured cell types related to the targeted disease can be used to test how well nanoparticles target and how cells take them up. Using fluorescence imaging or flow cytometry, fluorescently labeled nanoparticles make uptake easy to see and measure. Cytotoxicity tests, like the MTT or LDH assays, check how alive cells are after being exposed to nanoparticles. This shows how biocompatible they are at different concentrations.

Results

Efficiency and Targeting Specificity

Comparative Analysis: According to research, dendrimers and polymeric nanoparticles are very good at targeting cells or tissues because they can change their size and surface in controlled ways. Inorganic nanoparticles, on the other hand, like gold and iron oxide, have special qualities that make them useful for diagnostic and medicinal uses. However, they can't be used as much because they are poisonous and hard to dissolve.

Impact of Particle Characteristics: The aiming effectiveness of nanoparticles is greatly affected by their size, surface change, and make-up. Dendrimers are more specific than other materials because they have an exact structure, and polymeric nanoparticles can be changed to be biodegradable and target particular areas.

Biocompatibility Assessments

In Vitro Toxicity: Dendrimers and polymeric nanoparticles are biocompatible and have little to no harmful effects on cells when used at medicinal levels. Inorganic nanoparticles can be helpful in some situations, but they need to be studied more to see if they are poisonous or soluble, which could affect their use in medicine.

Discussion

Case Study: Nanoparticle Platforms in Glioblastoma Treatment

Glioblastoma is one of the hardest cancers to treat because it is so aggressive, and the Blood-Brain Barrier (BBB) protects the brain. Therapeutic meds can't get to the growth spot very easily because of the BBB, which has tight gaps that make it hard for healing agents to pass through. This makes standard treatments less effective. Because of this, recent progress in nanotechnology technology has shown promise to get around these problems, giving glioblastoma patients new hope.

Overcoming the BBB with Nanoparticle Technology

Much research has been done on nanoparticle transporters like liposomes, micelles, dendrimers, and artificial nanoparticles to see if they can get drugs across the BBB. To improve the effectiveness of drug administration, these carriers use both passive and active targeting mechanisms:

- Passive Targeting: uses the increased permeability and retention (EPR) effect to let nanoparticles gather in tumor cells. However, the BBB makes the EPR effect less useful for brain cancer, so we need more direct approaches.
- Active Targeting involves adding specific ligands to nanoparticles, like transferrin, chlorotoxin, or folic acid, that help them find and attach to receptors that are overexpressed on brain and brain tumor cells. This focused method makes receptor-mediated transcytosis easier, letting nanoparticles skip the BBB and get restorative drugs straight to the tumor site.

Challenges and Future Directions

Even though preliminary results look promising, many problems need to be solved before nanoparticle medicine treatments can be used in people. Early clinical studies have shown that actively focused nanoparticles are better at getting brain tumors to grow than other medicines. However significant problems like long-term safety, finding the best dose, and knowing how drugs work need more research.

Implications for Future Nanoparticle Research

The story of treating GBM shows how nanoparticle drug delivery methods can change the way diseases are treated by overcoming cellular obstacles. As research moves forward, these kinds of case studies will be very helpful in guiding the design and use of nanoparticle carriers, and not just for brain tumors. They will also be useful for a wide range of difficult medical conditions.

Limitations

1. Preclinical Focus: This study discusses a lot of data and progress based on preclinical models. Although these models are helpful for learning about the possibilities of nanoparticle carriers,

they might not fully reflect the complexity of biological systems in humans. Putting these results into practical settings is hard because drugs are distributed and broken down differently in people, and they may have different side effects.

2. Nanoparticle Heterogeneity: There are many types of nanoparticles, and each has its qualities and behaviors. This makes it harder to directly compare how well they work, how specific they are, and how well they work with living things. This variety makes it hard to say that one type of nanoparticle is better than another without considering the unique situation in which they are used.

3. The complexity of the BBB: The blood-brain barrier (BBB) is a very complicated and changing barrier, and it plays many different roles in different diseases, especially glioblastoma. The ability of nanoparticles to cross the BBB may depend on where the tumor is located, how big it is, and how much the BBB is damaged. These aren't thoroughly looked at in this work.

4. Long-Term Safety and Effectiveness: Researchers are still looking into the long-term safety and effectiveness of drug transport methods that use nanoparticles. Nanoparticle buildup, immune responses, and unknown toxicity are some of the problems that need to be studied in great detail over a long period to ensure that these delivery methods are safe for long-term use.

5. Limited Clinical Trials: Some early clinical trials have shown promise, but few studies have made it from the experimental to the clinical stages. Because there isn't enough clinical data, we can't fully assess the pros and cons of nanoparticle carriers for treating glioblastoma and other diseases.

6. Personalization of Therapy: Because genetic, environmental, and disease-specific factors affect how each patient responds to nanoparticle-based treatments, personalized methods are important. To create customized treatments like these, we need to learn more about how nanoparticles interact with living things, which is outside the scope of this work.

7. Cost and Manufacturing Challenges: Making nanoparticles, adding functions to them, and making a lot of them can be difficult and expensive. Because of these problems, nanoparticle-mediated drug transport methods are difficult to obtain and use, especially in places with few resources.

Conclusion

Our in-depth study of nanoparticle carriers, such as liposomes, dendrimers, and polymeric nanoparticles, has shown how useful they could be for delivering drugs to specific areas. This study improves our knowledge of nanoparticle-mediated therapy by comparing their effectiveness, sensitivity, and biocompatibility, but it also shows how important these carriers are for getting past bodily barriers, especially the blood-brain barrier (BBB).

The case study of treating glioblastoma has shown how urgently we need new ways to deal with this violent brain cancer. Nanoparticle platforms are a ray of hope because they provide a way to get healing agents straight to the disease site. These nanoparticles can get around the BBB through passive and active targeting. This is a hopeful way to improve the efficiency and sensitivity of drug transport.

Even though animal models and early clinical studies showed promising results, we are still a long way from being able to use nanoparticle medicine drug delivery methods in real life. There are still problems to solve, like ensuring these carriers are safe over the long term, finding the best way to give the right dose, and fully understanding how they work and where they go in the body. We also have to make therapy unique for each patient because they react to treatments in different ways. This makes the transition from lab treatment to real-life treatment even more challenging.

In the future, the information we learn from this study and others like it will be constructive in improving how nanoparticles are designed and functionalized. The goal is to make drug transport methods more effective at treating diseases and reduce their side effects as much as possible. This will make treatments better and more effective. To get past the current problems and use nanoparticle carriers to their full potential in targeted treatment and personalized medicine, people from different fields must continue working together and developing new ideas.

In conclusion, the progress made in making customized nanoparticles that can deliver drugs gives us hope in the fight against diseases like glioblastoma that seem impossible to beat. As study in this area moves forward, it could change the way cancer is treated and other diseases are treated as well. This would be the start of a new era in precision healthcare.

Acknowledgments

I would like to Thank my Advisors, my Doctor's Aunt, and my cousin, who is in her residency, for sharing their valuable insight provided to me on this topic.

References

Ostrom, Q. T., Gittleman, H., Farah, P., Ondracek, A., Chen, Y., Wolinsky, Y., ... & Barnholtz-Sloan, J. S. (2020). CBTRUS statistical report: Primary brain and other central nervous system tumors diagnosed in the United States in 2013-2017. Neuro-Oncology, 22(12), iv1-iv96.

Gutkin, A., Cohen, Z. R., & Peer, D. (2016). Harnessing nanomedicine for therapeutic intervention in glioblastoma. Expert Opinion on Drug Delivery, 13(11), 1573-1582. https://doi.org/10.1080/17425247.2016.1200557

Kim, S. S., Harford, J. B., Pirollo, K. F., & Chang, E. H. (2015). Effective treatment of glioblastoma requires crossing the blood-brain barrier and targeting tumors, including cancer stem cells: The promise of nanomedicine. Biochemical and Biophysical Research Communications, 468(3), 485-489. https://doi.org/10.1016/j.bbrc.2015.06.137

Explore more about Nanotechnology - NIBIB
Explore More Research | National Institute of Biomedical Imaging and Bioengineering (nih.gov)

Pourgholi, F., Hajivalili, M., Farhad, J. N., Kafil, H. S., & Yousefi, M. (2016). Nanoparticles: Novel vehicles in treatment of Glioblastoma. Biomedicine & Pharmacotherapy, 77, 98-107. https://doi.org/10.1016/j.biopha.2015.12.014

National Health Expenditure Projections 2019-2028" by Centers for Medicare & Medicaid Services (CMS)
Forecast Summary 2019-2028 FINAL_0.pdf (cms.gov)

Jena, L., McErlean, E., & McCarthy, H. (2020). Delivery across the blood-brain barrier: Nanomedicine for glioblastoma multiforme. Drug Delivery and Translational Research, 10(2), 304-318. https://doi.org/10.1007/s13346-019-00679-2
Therapeutic Potential of Targeted Nanoparticles and Perspective on Nanotherapies
Therapeutic Potential of Targeted Nanoparticles and Perspective on Nanotherapies | ACS Medicinal Chemistry Letters