Volume 1 | issue 1
Review Article
JOURNAL OF PHYSICS AND CHEMISTRY

Nanomaterials for Biomedical Applications: Current Trends and Future Prospects

AFAM UZORKA[1]*, DAVID MAKUMBI[1], DAVID KIBIRIGE[1]

Kampala International University Kampala Uganda

***Corresponding Author:** Afam Uzorka, Kampala International University Kampala Uganda.

Submitted: 29 Sep 2023 **Accepted:** 03 Oct 2023 **Published:** 09 Oct 2023

Citation: *Afam Uzorka, David Makumb, David Kibirige (2023), Nanomaterials for Biomedical Applications: Current Trends and Future Prospects, J of Surgery & Anesthesia. Review article,1(1).01-09.*

Abstract

In the realm of biomedicine, nanomaterials have become ground-breaking instruments with a variety of uses including drug transport, imaging, diagnostics, and therapies. This study highlights the potential advantages and difficulties of the most recent developments in nanomaterials for biomedical applications. Nanomaterials offer targeted and regulated release of therapeutic molecules during drug delivery, increasing treatment effectiveness while lowering side effects. Nanomaterials improve imaging modalities for medical imaging, offering greater resolution and specificity for disease monitoring. Early disease diagnosis and individualized medications are made possible by the rapid and sensitive biomarker identification provided by nanomaterial-based diagnostics. Furthermore, targeted therapy, immunomodulation, and gene delivery are made possible by nanomaterials. To fully realize the potential of nanomaterials in biomedical applications, a number of issues, such as biocompatibility, regulatory approval, and scalability, must be resolved. Nanomaterials have the potential to change biomedicine and improve patient care in the future. Nanomaterials present a wide range of opportunities for enhancing disease diagnosis and treatment, from customized medicine and combination medicines to smart theranostics and AI integration.

Keywords: Nanomaterials, Biomedical Applications, Drug Delivery, Imaging, Therapeutics

Introduction

Nanotechnology has transformed the field of biomedicine in recent years by providing innovative approaches to medicines medical imaging medication delivery and diagnostics [1-5]. Engineered structures called nanomaterials, which exhibit special qualities at the nanoscale, have become important players in the development of biomedical applications. They provide new opportunities for precise and focused therapies in a variety of diseases because of their capacity to interact with biological systems at the cellular and molecular level [5]. This study will examine the most recent developments in nanomaterials used in biomedicine for drug administration, imaging, diagnostics, and therapies, as well as their potential advantages and drawbacks. This study will also highlight the future prospects of nanomaterials for biomedical applications.

Nanomaterials for Targeted Drug Delivery

A novel strategy used in contemporary medicine to increase the effectiveness and lessen the negative effects of medicinal drugs is called targeted medication delivery [3,4]. Due to their distinct physicochemical features, which enable precise and controlled drug release at certain places inside the body, nanomaterials have emerged as intriguing candidates for targeted drug delivery systems [3,4,6].

There have been many different nanomaterials studied for drug delivery applications, and each one has unique benefits in terms of stability, biocompatibility, and drug-carrying ability. Liposomes and other lipid-based nanoparticles are well-known carriers that can encapsulate both hydrophilic and hydrophobic medications [7,8]. Dendrimers and polymeric nanoparticles like poly-lactic-co-glycolic acid (PLGA) offer customizable surface modifications and release profiles for targeted distribution [9,10]. Additionally, inorganic nanoparticles like gold and mesoporous silica nanoparticles have demonstrated potential as drug delivery systems [11].

Active and Passive Targeting Strategies

In order to improve their selective accumulation at the intended region, nanomaterials might be functionalized to actively target particular cells or tissues. In active targeting, ligands, antibodies, or peptides are attached to the surface of nanoparticles to help target cells with overexpressed receptors recognize and internalize the particles [12]. The enhanced permeability and retention (EPR) effect, which enables nanoparticles to passively accumulate at tumor locations with leaky vasculature, is used in passive targeting [13]. The effectiveness of drug delivery can be considerably increased by combining active and passive targeting tactics.

Overcoming Biological Barriers

Nanomaterials must successfully navigate through a number of biological obstacles, including as enzymatic breakdown, immunological clearance, and cellular internalization, in order to achieve drug delivery [14,15]. PEGylation, a polyethylene glycol coating that reduces protein adsorption and delays immune system recognition, is one type of surface modification that can prolong circulation duration [16]. Additionally, logical nanocarrier design can maximize therapeutic benefits by enhancing endocytosis and intracellular drug release [17].

Controlled Drug Release

The benefit of regulated drug release provided by nanomaterials ensures a prolonged and focused therapeutic impact. This can be accomplished by using nanocarriers that are stimuli-responsive to certain triggers, such as pH, temperature, enzymes, or light [18]. These triggers can cause medication release at the intended site, decreasing side effects and drug exposure to healthy tissues.

Challenges of Nanomaterials for Targeted Drug Delivery

Although targeted medication delivery using nanomaterials has enormous potential, there are still a number of issues that need to be resolved before they are widely used in clinical settings.

Toxicology and Biocompatibility: Toxicology and biocompatibility studies are crucial to guarantee the safety of nanomaterials since they may interact with biological systems differently than bulk materials do [19].

Scale-Up and Manufacturing: To satisfy the requirements of large-scale drug production, it is necessary to address the scalability and repeatability of nanomaterial synthesis [20].

Regulatory Approval: To ensure the safety and efficacy of nanomaterial-based drug delivery systems for human use, a thorough review and regulatory approval are required [21].

Pharmacokinetics and Biodistribution: To optimize medication delivery and prevent potential buildup in non-target organs, it is essential to understand the pharmacokinetics and biodistribution of nanocarriers [22].

Overall, targeted medication delivery has entered a new era thanks to nanomaterials, which has the potential to transform medical procedures and enhance patient outcomes. Exciting potential for customized treatment arises from the ability to construct nanocarriers for active targeting, regulated drug release, and evasion of biological barriers. However, multidisciplinary efforts are required to overcome the issues associated to safety, scalability, and regulatory approval in order to fully realize the potential of nanomaterials for medication delivery. Nanomaterial-based drug delivery systems have the potential to revolutionize healthcare and enable the development of targeted medicines for a variety of ailments with sustained study and collaboration.

Nanomaterials in Medical Imaging

In the early detection, diagnosis, and follow-up of many diseases, medical imaging is crucial. Nanomaterials have been effective instruments for improving medical imaging procedures in recent years [23]. High surface area, variable optical characteristics, and surface functionalization, among other distinctive properties at the nanoscale, have transformed imaging modalities and enhanced their resolution, sensitivity, and specificity [24].

Contrast Agents for Enhanced Imaging

In numerous imaging modalities, nanomaterials have been thoroughly investigated as contrast agents to enhance the visibility of anatomical structures and clinical abnormalities [24,25]. Due to its potent magnetic characteristics and biocompatibility, superparamagnetic iron oxide nanoparticles (SPIONs) have emerged as a leading contender in magnetic resonance imaging (MRI) [26]. Well-known fluorophores used in fluorescence imaging include quantum dots and upconversion nanoparticles, which provide greater brightness and stability than conventional organic dyes [27]. The sensitivity and precision of imaging techniques are considerably improved by these nanomaterials.

Targeted Imaging with Functionalized Nanoparticles

Precision medicine uses nanomaterials that have been functionalized with particular ligands, antibodies, or peptides to actively target sick tissues [28]. Targeted nanoparticles can concentrate at the place of interest by attaching specifically to cell surface indicators or receptors enabling early diagnosis and improved monitoring of diseases including cancer and cardiovascular conditions [29]. With this focused approach, non-specific signals are reduced, and the overall imaging signal-to-noise ratio is improved.

Theranostic Nanoparticles

A brand-new class of nanomaterials called theranostic nanoparticles combines medicinal and diagnostic properties. These nanoparticles provide real-time monitoring of treatment response by combining imaging agents with therapeutic payloads, such as medications or gene treatments [30]. Theranostic nanomaterials have particular promise for image-guided therapeutics because they enable individualized treatment plans and minimize side effects [30].

Nanoparticles for Molecular Imaging

Through the visualization and measurement of particular molecular processes occurring within the body, molecular imaging attempts to shed light on disease mechanisms and therapy effectiveness. Nanomaterials have made multimodal molecular imaging techniques possible since they can transport many imaging moieties and ligands [31]. Researchers can develop a thorough understanding of disease pathophysiology at the molecular level by combining several imaging modalities like positron emission tomography (PET), single-photon emission computed tomography (SPECT), and fluorescence imaging.

Challenges of Nanomaterials in Medical Imaging

Although nanoparticles have showed considerable promise in medical imaging, numerous issues must be resolved for their successful clinical translation:

Biocompatibility and Toxicity: To guarantee the security of nanomaterials for in vivo imaging applications, thorough biocompatibility studies are necessary.

Regulatory Approval: To guarantee the efficacy and safety of nanomaterial-based imaging agents in clinical settings, they must undergo thorough examination and regulatory approval.

Biodistribution and Clearance: In order to maximize the imaging capabilities of nanomaterials and reduce potential toxicity, it is essential to understand the biodistribution and clearance pathways of these substances.

Standardization and Reproducibility: For the synthesis, characterization, and application of nanomaterials in medical imaging, the development of standard protocols is crucial for the consistency and comparability of results across various investigations.

Overall, nanomaterials have become important tools in medical imaging, providing previously unheard-of possibilities for early and accurate disease diagnosis, individualized treatment plans, and image-guided therapies. Healthcare advancement and patient outcomes hold significant potential from the ability to functionalize and customize nanomaterials for targeted imaging and theranostic applications. To fully realize the potential of nanomaterials in medical imaging and advance the science towards a new era of precision medicine, it is imperative to overcome the issues of biocompatibility, regulatory approval, and standardization.

Nanomaterials for Diagnostics

In order to enable prompt interventions and better patient outcomes, diagnostic technologies are crucial in the early diagnosis and monitoring of diseases. Nanomaterials have recently become effective diagnostic tools, allowing for the quick, accurate, and focused detection of infections and biomarkers [32].

Nanobiosensors for Biomarker Detection

Nanobiosensors are devices based on nanomaterials that can specifically find and measure particular biomolecules indicative of disease conditions. Incorporating functionalized nanomaterials into sensor platforms improves sensitivity and specificity. Examples include carbon nanotubes, quantum dots, and gold nanoparticles. In comparison to traditional diagnostic techniques, these nanobiosensors allow for the early diagnosis of diseases like cancer, infectious diseases, and neurological disorders [32].

Lateral Flow Assays and Nanoparticle Probes

For point-of-care diagnostics, lateral flow assays (LFAs) are straightforward, quick, and reasonably priced diagnostic procedures. When specific antibodies or nucleic acid sequences are coupled to nanoparticle probes, such as gold or upconversion nanoparticles, the target analytes can be seen within minutes [33]. LFAs are useful instruments in distant and resource-constrained environments because they can be used to identify pathogenic pathogens, pregnancy hormones, and cardiac biomarkers [33].

Multimodal Imaging Agents for Molecular Diagnostics

Fluorescence, magnetic resonance, and positron emission tomography are just a few of the imaging modalities that can be combined into one probe because to the special properties of nanomaterials. These multimodal imaging tools support molecular diagnostics and give researchers real-time visualization and monitoring of cellular and molecular activities. These nanomaterials improve early diagnosis and therapy response evaluation by focusing on disease-specific biomarkers.

Nanopore-Based Diagnostics

The distinctive characteristics of nanomaterials, such as graphene or silicon nitride nanopores, are used by nanopore-based diagnostic tools to detect and classify biomolecules based on variations in electrical conductance. These instruments exhibit promise in protein analysis, pathogen detection, and DNA sequencing, providing quick and label-free detection techniques with great sensitivity and specificity [34].

Challenges of Nanomaterials for Diagnostics

Nanomaterials provide a variety of options for diagnostic applications, but before they can be widely used, a number of issues must be resolved.

Biocompatibility and Safety: The biocompatibility and safety of nanomaterials must be guaranteed in order for them to be used in diagnostic applications, particularly for in vivo diagnostics.

Standardization and Reproducibility: To provide repeatable outcomes across various diagnostic platforms, standard methods and quality control mechanisms for nanomaterial production and functionalization must be developed.

Regulatory Permission: To ensure the accuracy, dependability, and safety of diagnostic tests based on nanomaterials in clinical settings, regulatory permission is required.

Cost-Effectiveness and Scalability: To make nanomaterial-based diagnostics available in a variety of healthcare settings, cost-effectiveness and scalability must be taken into account.

Overall, nanomaterials have the potential to completely transform disease diagnostics by providing quick, accurate, and targeted ways of disease detection. Nanomaterial-based platforms hold great potential for enhancing early disease diagnosis and facilitating tailored medicine. These platforms range from point-of-care testing to molecular imaging and nanopore-based diagnostics. Harnessing the full potential of nanomaterials for diagnostics would advance the field of medicine and pave the way for more effective and tailored therapies. However, significant hurdles remain, including those relating to biocompatibility, standardization, regulatory approval, and cost-effectiveness.

Nanomaterials for Therapeutics

The science of therapeutics has undergone a revolution thanks to nanotechnology, which now provides creative methods for curing a wide range of diseasees. Nanomaterials have shown great promise for delivering therapeutic agents, improving drug efficacy, and creating novel therapeutic techniques due to their distinctive physicochemical features and adjustable qualities [32].

Nanoparticles for Targeted Therapy

Targeted therapy now has new avenues to explore because to nanoparticles, which enable precise delivery of therapeutic chemicals to particular cells or tissues. They can actively target disease-specific receptors, facilitating increased accumulation and internalization at the targeted region, by functionalizing the surfaces of nanoparticles with ligands or antibodies [35]. In especially for cancer and inflammatory diseasees, this focused strategy minimizes systemic adverse effects and maximizes therapeutic efficacy [36].

Nanocarriers for Controlled Drug Release

Therapeutic substances can be released gradually and under control using drug carriers made of nanomaterials. Drugs can be released in reaction to particular triggers, such as pH, temperature, enzymes, or light, using stimuli-responsive nanocarriers [35]. This controlled drug release provides better pharmacokinetics, less frequent dosage, and superior therapeutic results.

Photothermal and Photodynamic Therapies

When exposed to laser irradiation, several nanomaterials, including carbon nanotubes and gold nanoparticles, exhibit photothermal characteristics, which turn light into heat [37]. Cancer cells are only targeted and destroyed by photothermal therapy, sparing healthy tissues [38]. Additionally, photodynamic therapy uses photosensitizers, which are frequently integrated into nanoparticles, to produce reactive oxygen species upon light activation, which destroys bacteria and cancer cells [39,40].

Gene Delivery and Gene Editing

For the goal of gene therapy or gene editing, nanomaterials have made it easier to transfer genetic material into cells, such as plasmids or short interfering RNA (siRNA) [41]. It is common practice to transfer genes using viral vectors and lipid-based nanoparticles in an effort to fix genetic flaws or regulate gene expression [41]. These innovations have a lot of potential for treating cancer and genetic problems.

Immunomodulation and Vaccination

When used to interact with the immune system, nanomaterials can either stimulate or decrease immunological responses [42]. In vaccinations, they can serve as adjuvants, fostering stronger and more focused immune responses [42]. Additionally, antigens or immune modulators can be delivered via nanomaterials, resulting in targeted immunotherapy for cancer and infectious disorders [42].

Challenges of Nanomaterials for Therapeutics

Despite the prospective medicinal applications of nanomaterials, successful clinical translation faces a number of obstacles:

Biocompatibility and Safety: A thorough evaluation of biocompatibility is necessary to guarantee the safety of nanoparticles used in therapeutic applications on people.

Pharmacokinetics and Biodistribution: It's essential to comprehend how nanomaterials behave in vivo, particularly their pharmacokinetics and biodistribution, in order to maximize medicine delivery and reduce potential toxicity.

Regulatory Approval: To guarantee the safety and efficacy of nanomaterial-based medicines for clinical application, a thorough review and regulatory approval are required.

Manufacturing and Scalability: For large-scale production and commercialization, the scalability and reproducibility of nanomaterial synthesis need to be addressed.

Overall, nanomaterials have completely changed the therapeutic landscape by providing cutting-edge methods for targeted drug delivery, gene therapy, immunomodulation, and more. Their distinctive qualities and customizable traits enable personalized medicine and the creation of cutting-edge treatment plans for a variety of ailments. To fully utilize the therapeutic potential of nanomaterials, however, regulatory approval, scalability, and biocompatibility issues must be resolved. This will improve patient outcomes and completely transform modern medicine.

Future Prospects

Nanomaterials for biomedical applications are constantly improving, and this holds great potential for the future of healthcare. Several significant future potentials are emerging as scholars continue to study and innovate.

Personalized Medicine

By providing customized and targeted therapy nanomaterials present a special opportunity for personalized medicine [35]. Nanomaterial-based therapeutics have the potential to greatly enhance treatment outcomes and reduce side effects since they can deliver medications precisely to specific disease sites and customize treatments depending on patients' genetic composition and disease features.

Theranostics

Theranostics, an emerging field with immense potential, is the combination of diagnostics and therapies on a single platform. Theranostic agents can concurrently diagnose diseases and deliver therapeutic compounds in a customized and targeted manner [2] thanks to the development of nanomaterials. By allowing real-time monitoring of treatment response and modifying therapy as necessary, theranostic nanomaterials have the potential to change disease management.

Integration of Artificial Intelligence (AI)

AI-based technology and nanomaterials can be used to create better and more effective medical therapies. AI can be used to anticipate patient responses, improve drug release profiles, and analyze intricate imaging data [43]. The creation of precise medicines can be accelerated, and treatment decision-making can be improved, by combining AI and nanomedicine.

Immunotherapy Advancements

Nanomaterials have the potential to significantly advance immunotherapy techniques. Researchers can improve the efficacy of cancer immunotherapies and create brand-new treatments for autoimmune and inflammatory disorders by creating nanocarriers that can control immune responses and transport immunomodulatory drugs.

Non-Invasive Treatments

Nanomaterials have the potential to make non-invasive treatments possible, which would lessen the need for invasive procedures and ease patient discomfort. For instance, using nanomaterials for localized therapies and targeted drug delivery, diseases can be treated directly at the afflicted sites without the need for extensive procedures or systemic medication administration.

Nanomedicine in Global Health

Global health could be dramatically impacted by the creation of scalable, affordable diagnostic and treatment instruments based on nanomaterials. With the use of these technologies, the prevalence of infectious diseases can be decreased and important healthcare services can be more easily accessed in remote and resource-constrained areas.

Conclusions

Nanomaterials have opened up a whole new world of possibilities for biomedical applications, demonstrating their enormous promise for treatments, imaging, and drug transport. Because of their distinctive physicochemical characteristics and adaptability, they have helped researchers come up with creative answers to difficult problems in healthcare. Nanomaterials provide a promising route for accurately delivering therapeutic molecules to disease locations, increasing treatment efficacy, and lowering systemic side effects. This is done by targeted drug delivery. Nanomaterials have improved imaging modalities for use in medical imaging, allowing for the high-resolution and sensitive detection of disease indicators, facilitating early diagnosis and tailored medication.

With the development of nanomaterial-based diagnostics, disease detection has undergone a revolutionary change. These tests are quick and accurate, assisting in early diagnosis and real-time monitoring of treatment response. Additionally, intriguing medicines based on nanomaterials have evolved, opening up new possibilities for gene delivery, immunomodulation, and photothermal and photodynamic therapy.

Nanomaterials have a bright future in biological applications and have the ability to change the face of healthcare. Nanomaterials present a wide range of opportunities for enhancing disease diagnosis and treatment, from customized medicine and combination medicines to smart theranostics and AI integration.
On the road to clinical translation, obstacles persist despite their incredible potential. To reduce potential dangers related to the usage of nanomaterials, it is essential to ensure their biocompatibility and safety. In order to maximize drug delivery and reduce unwanted effects, it will be essential to understand their pharmacokinetics and biodistribution. Additionally, receiving regulatory permission is necessary to ensure the security and effectiveness of nanomaterials for medical applications.

In order to overcome these obstacles and realize the full potential of nanomaterials in biomedical applications, collaboration among scientists, physicians, and regulatory agencies will be essential. The development and commercialization of nanomaterial-based technologies will be accelerated by standardizing methods and ensuring reproducibility. The progress of healthcare through continued research and funding in nanotechnology will ultimately improve patient outcomes and change how diseases are identified and treated.

In conclusion, the use of nanomaterials in biomedical applications represents an exciting new area in contemporary medicine. Nanomaterials hold the key to revolutionizing healthcare and providing more effective, focused, and safe therapies for a wide range of ailments because of their potential benefits in precision medicine, tailored therapy, and improved diagnostics. We are on the verge of a new age in biomedicine, where nanotechnology will play a crucial role in determining the future of healthcare, as we continue to explore the potential of nanomaterials.

Conflict of Interest

None

References

1. Banerjee P, Qamar I (2022) Nanobiomaterials in biomedicine: Designing approaches and critical concepts. In Nanobioanalytical Approaches to Medical Diagnostics Woodhead Publishing 345-361.
2. Li X, Li W, Wang M, Liao Z (2021) Magnetic nanoparticles for cancer theranostics: Advances and prospects. Journal of Controlled Release 335: 437-448.
3. Li S, Chen L, Fu Y (2023) Nanotechnology-based ocular drug delivery systems: recent advances and future prospects. Journal of Nanobiotechnology 21: 1-39.
4. Patra J K, Das G, Fraceto L F, Campos E V R, Rodriguez Torres (2018) Nano based drug delivery systems: recent developments and future prospects. Journal of nanobiotechnology 16: 1-33.
5. Kong X, Gao P, Wang J, Fang Y, Hwang K C (2023) Advances of medical nanorobots for future cancer treatments. Journal of Hematology & Oncology 16: 74.
6. Tiwari H, Rai N, Singh S, Gupta P, Verma A (2023) Recent Advances in Nanomaterials-Based Targeted Drug Delivery for Preclinical Cancer Diagnosis and Therapeutics. Bioengineering 10: 760.
7. Pucci C, Martinelli C, Ciofani G (2020) What does the future hold for chemotherapy with the use of lipid-based nanocarriers? Future Oncology 16: 81-84.
8. Safaeian Laein S, Katouzian I, Mozafari M R, Farnudiyan Habibi A, Akbarbaglu Z (2023) Biological and thermodynamic stabilization of lipid-based delivery systems through natural biopolymers; controlled release and molecular dynamics simulations. Critical Reviews in Food Science and Nutrition 1-20.
9. Rout S R, Kenguva G, Sharma D, Sahebkar A, Aeri, V (2023) Gene therapy using PLGA nanoparticles. In Poly (Lactic-Co-glycolic Acid) (PLGA) Nanoparticles for Drug Delivery Elsevier 393-414.
10. Sheffey V V, Siew E B, Tanner E E, Eniola Adefeso O (2022) PLGA's plight and the role of stealth surface modification strategies in its use for intravenous particulate drug delivery. Advanced Healthcare Materials 11: 2101536.
11. Garcia-Fernandez A, Sancenon F, Martinez Manez, R (2021) Mesoporous silica nanoparticles for pulmonary drug delivery. Advanced Drug Delivery Reviews, 177: 113953.
12. Anarjan, F S (2019) Active targeting drug delivery nanocarriers: Ligands. Nano-Structures & Nano-Objects 19: 100370.
13. Shinde V R, Revi N, Murugappan S, Singh S P, Rengan A K (2022) Enhanced permeability and retention effect: A key facilitator for solid tumor targeting by nanoparticles. Photodiagnosis and Photodynamic Therapy 39: 102915.
14. Finbloom J A, Sousa F, Stevens M M, Desai T A (2020) Engineering the drug carrier biointerface to overcome biological barriers to drug delivery. Advanced Drug Delivery Reviews 167: 89-108.
15. Mitchell M J, Billingsley M M, Haley R M., Wechsler M E, Peppas N A (2021) Engineering precision nanoparticles for drug delivery. Nature reviews drug discovery 20: 101-124.
16. Shi D, Beasock D, Fessler A, Szebeni J, Ljubimova J Y (2022) To PEGylate or not to PEGylate: Immunological properties of nanomedicine's most popular component, polyethylene glycol and its alternatives. Advanced drug delivery reviews 180: 114079.
17. Tian T, Ruan J, Zhang J, Zhao C X, Chen D (2022) Nanocarrier-based tumor-targeting drug delivery systems for hepatocellular carcinoma treatments: Enhanced therapeutic efficacy and reduced drug toxicity. Journal of biomedical nanotechnology 18: 660-676.
18. Alsehli M (2020) Polymeric nanocarriers as stimuli-responsive systems for targeted tumor (cancer) therapy: Recent advances in drug delivery. Saudi Pharmaceutical Journal 28: 255-265.
19. Ayubi, M., Karimi M, Abdpour S, Rostamizadeh, K, Parsa M, et al. (2019) Magnetic nanoparticles decorated with PEGylated curcumin as dual targeted drug delivery: Synthesis, toxicity and biocompatibility study. Materials Science and Engineering: C 104: 109810.
20. Banthia P, Gambhir L, Sharma A, Daga D, Kapoor N (2022) Nano to rescue: repository of nanocarriers for targeted

drug delivery to curb breast cancer. 3 Biotech 12: 70.
21. Suri R, Beg S, Kohli K (2020) Target strategies for drug delivery bypassing ocular barriers. Journal of Drug Delivery Science and Technology 55: 101389.
22. Karami Z, Sadighian S, Rostamizadeh K, Hosseini S H, Rezaee S (2019) Magnetic brain targeting of naproxen-loaded polymeric micelles: pharmacokinetics and biodistribution study. Materials Science and Engineering: C 100: 771-780.
23. Farzin A, Etesami S A, Quint J, Memic A, Tamayol A (2020) Magnetic nanoparticles in cancer therapy and diagnosis. Advanced healthcare materials 9: 1901058.
24. Li S, Tan L, Meng X (2020) Nanoscale metal-organic frameworks: synthesis, biocompatibility, imaging applications, and thermal and dynamic therapy of tumors. Advanced Functional Materials 30: 1908924.
25. Mohapatra J, Nigam S, George J, Arellano A C, Wang P (2023) Principles and applications of magnetic nanomaterials in magnetically guided bioimaging. Materials Today Physics 32: 101003.
26. Hooshmand S, Hayat S M, Ghorbani A, Khatami M, Pakravanan K (2021) Preparation and applications of superparamagnetic iron oxide nanoparticles in novel drug delivery systems: An overview. Current medicinal chemistry 28: 777-799.
27. Gowtham P, Harini K, Pallavi P, Girigoswami K, Girigoswami A (2022) Nano-fluorophores as enhanced diagnostic tools to improve cellular imaging. Nanomedicine Journal 9: 281-295.
28. Mohammad Rafiei F, Khojini J Y, Ghazvinian F, Alimardan S, Norioun H (2023) Cell membrane biomimetic nanoparticles in drug delivery. Biotechnology and Applied Biochemistry https://iubmb.onlinelibrary.wiley.com/doi/epdf/10.1002/bab.2487.
29. Nitheesh Y, Pradhan R., Hejmad S, Taliyan R., Singhvi G (2021) Surface engineered nanocarriers for the management of breast cancer. Materials Science and Engineering: C 130: 112441.
30. Lee Y, Kang T, Cho H R., Lee G J, Park O K (2021) Localized delivery of theranostic nanoparticles and high-energy photons using microneedles-on-bioelectronics. Advanced Materials 33: 2100425.
31. Cheng P, Pu K (2021) Molecular imaging and disease theranostics with renal-clearable optical agents. Nature Reviews Materials 6: 1095-1113.
32. Xie S, Ai L, Cui C, Fu T, Cheng X (2021) Functional aptamer-embedded nanomaterials for diagnostics and therapeutics. ACS Applied Materials & Interfaces 13: 9542-9560.
33. Reid R, Chatterjee B, Das S J, Ghosh S, Sharma T K (2020) Application of aptamers as molecular recognition elements in lateral flow assays. Analytical biochemistry 593: 113574.
34. Ding T, Yang J, Pan V, Zhao N, Lu Z (2020) DNA nanotechnology assisted nanopore-based analysis. Nucleic acids research 48: 2791-2806.
35. Luo M., Lewik G, Ratcliffe J C, Choi C H J, Mäkilä E (2019) Systematic evaluation of transferrin-modified porous silicon nanoparticles for targeted delivery of doxorubicin to glioblastoma. ACS applied materials & interfaces 11: 33637-33649.
36. Li D F, Yang M F, Xu H M, Zhu M Z, Zhang Y (2022) Nanoparticles for oral delivery: targeted therapy for inflammatory bowel disease. Journal of Materials Chemistry B 10: 5853-5872.
37. Naief, M F, Khalaf Y H, Mohammed A M (2022) Novel photothermal therapy using multi-walled carbon nanotubes and platinum nanocomposite for human prostate cancer PC3 cell line. Journal of Organometallic Chemistry 975: 122422.
38. West C L, Doughty A C, Liu K, Chen W R. (2019) Monitoring tissue temperature during photothermal therapy for cancer. Journal of bio-X research, 2: 159-168.
39. Singh S K, Mazumder S, Vincy A, Hiremath N, Kumar R. (2023) Review of Photoresponsive Plasmonic Nanoparticles That Produce Reactive Chemical Species for Photodynamic Therapy of Cancer and Bacterial Infections. ACS Applied Nano Materials 6: 1508-1521.
40. Yu H, Chen B, Huang H., He Z, Sun J (2022) AIE-active photosensitizers: Manipulation of reactive oxygen species generation and applications in photodynamic therapy. Biosensors 12: 348.
41. Tsai H C, Pietrobon V, Peng M, Wang S, Zhao L (2022) Current strategies employed in the manipulation of gene

expression for clinical purposes. Journal of Translational Medicine 20: 535.
42. Deng J, Wang J, Shi J, Li H, Lu M (2022) Tailoring the physicochemical properties of nanomaterials for immunomodulation. Advanced drug delivery reviews 180: 114039.
43. Hassanzadeh P, Atyabi F, Dinarvand R (2019) The significance of artificial intelligence in drug delivery system design. Advanced drug delivery reviews 151: 169-190.