Advancing Medical Science through Nanobiotechnology: Prospects, Applications, and Future Directions

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Abstract

Background: Nanobiotechnology brings together the fascinating world of nanotechnology and the field of biology, creating exciting possibilities for advancing medicine. This innovative area draws upon a wide range of knowledge and techniques from disciplines like engineering, physics, chemistry, and biology. Method: To understand how nanotechnology can enhance medical science, we conducted a thorough review of existing literature. This included examining its principles, the limitations it faces, the challenges researchers encounter, and the various applications it may have in healthcare. Results: Nanobiotechnology holds great promise for improving healthcare globally. Researchers are working on developing novel nanoparticles and nanodevices that could profoundly benefit human health. While we're not yet seeing widespread clinical applications of these technologies, many promising projects are making significant strides in the experimental stages. When nanotechnology is applied in medicine, it allows for highly precise interactions with the body's cellular and molecular structures. This level of specificity means that treatments can be more effective while minimizing side effects, and targeting specific cells or tissues in need. Conclusion: Despite the exciting potential of nanobiotechnology, there is still a lot of work to be done. We need more detailed research and thorough clinical trials to successfully integrate these innovations into everyday medical practice. Additionally, as we explore these new frontiers, it's crucial to address ethical and moral concerns related to the use of these technologies in healthcare.

Keywords: Nanobiotechnology, Applications, Medical, Molecular Diagnostics, Biomedical Innovation

Significance | Nanobiotechnology advances healthcare through precise diagnostics, targeted therapies, early detection, personalized treatments, and minimally invasive procedures, enhancing patient outcomes and transforming medical science globally.

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Introduction

Nanobiotechnology is an exciting and innovative field that combines the principles of nanotechnology and biotechnology to create groundbreaking ways to explore and interact with biological systems on a tiny scale at the molecular level. Biotechnology has long focused on harnessing the natural processes of living organisms to make advancements in areas like medicine and agriculture (Emerich et al.,2003). In contrast, nanotechnology digs into the realm of materials and devices that are incredibly small, typically ranging from 1 to 100 nanometers. By merging these two disciplines, nanobiotechnology opens up a world of possibilities for developing tools and systems that can engage with biological structures in ways never thought possible (Sahoo et al.,2003). This blend of science disciplines helps researchers tackle complex biological problems with a level of precision and efficiency that was previously unattainable (Vasir et al.,2005). For instance, scientists

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can create nanoscale devices that can imitate or boost cellular functions, leading to targeted drug delivery, real-time imaging of biological processes, and even the early detection of diseases (Vasir et al.,2005). Moreover, nanobiotechnology has the potential to break through current barriers in medicine, such as enhancing how well drugs work in the body, minimizing unwanted side effects, and tailoring treatments to fit each patient's unique genetic makeup (Maeda et al.,2000). At its essence, this field leverages the unique traits of nanoscale materials like their increased surface area and better reactivity to design nanoparticles capable of slipping through cellular membranes, delivering treatments straight to affected areas, and providing highly sensitive diagnostic tools (Allen et al.,2004). For example, quantum dots and other tiny crystals can serve as bright fluorescent markers, helping detect specific biomolecules, while magnetic nanoparticles enable less invasive imaging and targeted heat treatments for tumors. We're already seeing the benefits of integrating nanobiotechnology into medical science in both research labs and clinical settings (Garcia et al.,2005). Scientists are hard at work creating advanced diagnostic tools, like biosensors that can find biomarkers even in incredibly low concentrations, and nanocarriers designed to help drugs cross the blood-brain barrier (Feng et al.,2004). Additionally, progress in nanomaterials is boosting regenerative medicine through tissue engineering and stem cell therapies, creating new pathways to treat diseases that once seemed impossible to manage. However, to fully realize the benefits of nanobiotechnology in healthcare, we need to tackle a few challenges. Ensuring the safety and compatibility of nanomaterials with the human body is crucial, as is figuring out how these materials behave over time and reducing any potential side effects (De et al.,2004). Ethical considerations and regulatory guidelines also play a significant role in developing and applying nanobiotechnology responsibly in clinical practices (Moghimi et al.,2005). In this review, we'll dive into the core principles of nanobiotechnology, examine its current applications in medicine, and look toward future opportunities in this fast-evolving field. We'll highlight the unique advantages of using nanoscale approaches, explore their impact on diagnosing and treating diseases, and discuss the ongoing research aimed at overcoming current limitations. As we move forward, nanobiotechnology holds great promise for transforming healthcare, making treatments more effective, personalized, and less invasive ultimately leading to better patient outcomes and enhancing the quality of life for many.

Nanobiotechnology at a glance

Biotechnology and nanotechnology are among the most exciting advancements of the 21st century. At its core, nanotechnology often called nanotech involves creating and using materials and devices built on an incredibly tiny scale, typically measuring between 1 to 100 nanometers (Lee et al.,2002). This technology allows scientists to innovate in ways we've never seen before, crafting materials and devices that can function at a scale smaller than a single cell (NBTC ,2004). On the other hand, biotechnology focuses on understanding the biological processes of living organisms, including microorganisms (Lin et al.,2006). When these two fields come together forming what we call nanobiotechnology they open up a world of possibilities for enhancing our ability to study life and tackle various challenges in medicine, environmental science, and beyond (Guccione et al.,2004). Nanotechnology itself is diverse, touching on everything from conventional physics to groundbreaking concepts like molecular self-assembly (LaVan et al.,2002). It encompasses the creation of novel materials at the nanoscale and the exploration of how we might manipulate matter at the atomic level. This exciting interplay of disciplines such as surface science, organic chemistry, molecular biology, and semiconductor physics drives innovation and could lead to transformative technologies that improve our quality of life (E1 et al.,2002).

Advantages of nanobiotechnology

The ways that diseased or inflamed tissues change can open up exciting possibilities for developing targeted nanotechnology products (Hu et al.,2004). Here are some advantages of this approach:

1. We can target drugs more effectively by taking advantage of the unique features of unhealthy tissues.2. These nanoproducts can gather in much higher concentrations compared to traditional drugs.3. In tumors, increased permeability of blood vessels and compromised lymphatic drainage helps nanosystems work better by enhancing their ability to penetrate and remain in these areas (Arangoa et al.,2001).4. Nanosystems can specifically localize in inflamed tissues, improving treatment effectiveness.5. Nanoparticles are great for delivering drugs to the brain, making it possible to bypass the challenging blood-brain barrier (Arbos et al.,2004).6. Loading drugs onto nanoparticles changes how they distribute in the body, allowing for more precise delivery of active compounds, which can enhance their effectiveness while reducing side effects (Diwan et al.,2003). Overall, this targeted approach could lead to significant improvements in how we treat diseases.

Applications of nanobiotechnology in medical and clinical fields

Nanobiotechnology is opening up exciting new possibilities in clinical applications, especially in areas like disease diagnosis, targeted drug delivery, and molecular imaging (Koping et al.,2005). Researchers are actively exploring these innovative methods, and some promising products are currently in clinical trials. Ultimately, the advancements in this field are set to revolutionize how we diagnose, treat, and prevent diseases.

(A)Diagnostic Application

Traditionally, diagnosing many diseases relies on visible symptoms appearing, but by then, effective treatment can be harder to achieve. It's crucial to detect diseases earlier, ideally even before symptoms show up, to increase the chances of successful treatment. Nucleic acid diagnostics can help with this by identifying pathogens and diseased cells at stages where symptoms aren't present yet (Lutsiak et al.,2002). While existing technologies like polymerase chain reaction (PCR) are valuable, nanotechnology is enhancing diagnostic methods to improve sensitivity, efficiency, and cost-effectiveness (Young et al.,2006).

1. Detection

Current clinical tests often spot diseases by detecting the binding of specific antibodies to targeted molecules (Hart et al.,2005). This process usually involves conjugating antibodies with dyes and visualizing the results under a microscope. However, dyes can sometimes limit the specificity of tests (Zhang et al.,2003). That's where nanobiotechnology shines using tiny semiconductor nanocrystals known as quantum dots improves the detection process (Elan Corporation,2004). These quantum dots can endure more cycles of excitation and light emissions compared to typical organic dyes, making them a game changer (Wickline et al.,2006).

2. Individual Target Probes

Although magnetic detection methods have their strengths, optical and colorimetric approaches are still favored by many in the medical field (Panyam et al.,2003). A company named Nanosphere has developed techniques enabling the optical detection of genetic material in biological samples (West et al.,2000). For instance, gold nanoparticles attached with short DNA segments show great promise in identifying pathogens like anthrax, offering much higher sensitivity than many current tests (Ure et al.,2003).

3. Protein Chips

Proteins play a crucial role in defining the biological state of organisms, whether they are healthy or ill (Webster e al.,2004). As a result, understanding proteomics is essential in disease diagnostics and drug development. Protein chips can be treated with specific chemicals that bind to proteins with certain characteristics. Companies like Agilent and NanoInk are utilizing cutting-edge techniques, such as ink-jet printing and dip-pen nanolithography, to create these detailed microarrays at the nanoscale (Price et al.,2003).

4. Sparse Cell Detection:

Some cells, like cancer cells or fetal cells, are rare yet significantly different from their surrounding cells in normal conditions (Buzea et al.,2007). These sparse cells can be crucial for identifying genetic defects, but they often pose a challenge for detection and isolation. Nanobiotechnology is advancing our capabilities in this area (Milunovich et al.,2001). Researchers have developed nanosystems that sort sparse cells from blood and other tissues by leveraging unique properties like surface charge and deformation (Hamad et al.,2002). For example, specific microchannels with electrodes can precisely sort cells based on their charge characteristics. Cornell University's nano-biotechnology center is actively using these technologies to create powerful diagnostic tools (Li et al.,2007).

5. Nanotechnology in Imaging

For intracellular imaging, scientists can label target molecules with quantum dots or synthetic chromophores, such as fluorescent proteins, which help detect specific genetic sequences (Nijhara et al.,2006). This approach lays the groundwork for developing simple, reliable tests to identify genetic material, enhancing our ability to diagnose and treat diseases efficiently (Lam et al.,2004).

These innovations in nanobiotechnology represent a promising frontier in medicine, allowing us to approach disease detection and treatment with increased precision and effectiveness (Williams et al.,2004).

(B) Therapeutic Applications of Nanotechnology

Nanotechnology is making waves in the field of medicine by allowing for the creation of new drug formulations that have fewer side effects and more effective delivery methods (Elder et al.,2006).

1. Drug Delivery

One of the most exciting uses of nanotechnology is in drug delivery. Nanoparticles can be engineered to transport medications directly to the exact location in the body where they are needed, including areas that standard drugs have difficulty reaching (Radomski et al.,2005). For example, if a medicine is attached to a nanoparticle, it can be directed to a disease site using radio or magnetic signals. These nanodrugs can be specially designed to release their therapeutic contents only when certain molecules are present or when specific external triggers, such as infrared heat, are applied (Medina et a.,2007). This allows for a precise treatment approach where the overall dosage can be minimized, thereby reducing harmful side effects. By wrapping drugs in nanosized materials like organic dendrimers or hollow polymer capsules, the release can be finely controlled (Chen e al.,2006). This advancement is crucial, particularly for drugs that cannot be taken orally due to poor absorption, as nanotechnology can protect them from breakdowns in the body. Additionally, nanoparticles are being explored for delivering antigens in vaccines, enhancing the effectiveness of immunization by making use of advanced encapsulation techniques.

2. Gene Delivery

Gene therapy holds great promise, but it has faced hurdles, especially with conventional delivery systems that can be difficult to work with and may provoke immune responses. Nanotechnology offers a fresh perspective here by employing nanoparticle-based, non-viral methods to transport plasmid DNA (Jain et al.,2003). These nanoparticles, sized between 50 to 500 nanometers, can help in successfully introducing less immunogenic gene carriers. This innovative approach stands to significantly improve the methods used to repair or replace defective genes in patients.

3. Liposomes

Liposomestiny spheres made up of lipid bilayers are another exciting component of gene therapy. They can navigate through cell membranes easily, making them valuable for targeted delivery. Recent studies have shown that certain types of liposomes can effectively deliver genes directly to specific areas in the body. For instance, by attaching a liposome to a monoclonal antibody targeting human insulin, researchers demonstrated successful gene expression in the brains of monkeys. Such findings indicate a promising direction for future targeted therapies (Jain et al.,2007).

4. Surfaces

In nature, the interactions between cells and their surfaces are intricate and can define how biological processes occur like how blood cells interact with the brain or how pathogens invade tissues. With nanofabrication, scientists can enhance our understanding of these interactions by modifying surface properties at the nanoscale (Jain et al.,2006). Such innovations can lead to the development of hybrid biological systems that can be utilized for drug screening, sensors, or even as implants and medical devices. For example, a polymer coating developed by Elan Pharmaceuticals successfully altered the properties of drugs that typically struggle with poor water solubility.

5. Biomolecular Engineering

Traditional methods for designing bioactive molecules can be expensive and time-consuming, which restricts their accessibility. Fortunately, nanoscale assembly techniques provide an alternative, enabling chemical and biological reactions to occur on solid surfaces. This method tends to generate less waste and allows for more precise control over the biomolecules involved. Companies like EngeneOS are at the forefront of biomolecular engineering, creating programmable biomolecular machines that utilize both natural and synthetic components (Jain et al.,2005). These machines hold a wide array of applications, including biosensors, chemical manufacturing, and drug discovery.

6. Biopharmaceuticals

Lastly, nanobiotechnology holds incredible potential for developing new medications to treat diseases that conventional drugs cannot effectively target. Traditionally, the pharmaceutical industry has focused on a limited range of diseases, but with the advancements brought about by nanotechnology, new therapeutic options are emerging for conditions that were once deemed challenging to address (Jain et al.,2005).

7. Nanotechnology in Cardiac Therapy

Nanotechnology is opening up exciting possibilities in the field of cardiovascular medicine by allowing us to explore and address issues at a cellular level (Fan et al.,2005). This emerging technology offers innovative tools for diagnosing and imaging heart conditions, as well as for tissue engineering. For instance, tiny sensors like quantum dots and nanocrystals can effectively monitor complex immune responses related to heart problems or inflammation.

Moreover, nanotechnology helps identify and understand the specific mechanisms behind various heart disorders, which is crucial for targeted treatment. It even allows for the creation of atomic-scale machines that can be integrated into biological systems (Ramachandran et al.,2004). These advanced nanomachines hold the potential to reshape our current strategies for treating serious cardiovascular conditions. Additionally, nanotechnology provides solutions for tackling problems like unstable plaques and valve clarifications, offering hope for more localized and sustained drug delivery methods in managing heart diseases.

8. Nanotechnology in Dental Care

The future of dentistry looks bright with the help of nanotechnology. The innovations in this field, often referred to as nano dentistry, will leverage nanomaterials and advanced biotechnological approaches to promote better oral health (Chan et al.,2005). This breakthrough could be a game-changer for millions who currently receive inadequate dental care. Nanodental techniques are expected to evolve significantly, with reconstructive nanorobots targeting specific channels in teeth for swift and effective repair. The benefits of nanotechnology in maintaining natural teeth could be tremendous, too. For example, advanced materials like sapphire can be used to replace the upper enamel layer, enhancing both the appearance and durability of teeth.

9. Nanotechnology in Orthopedic Applications

In orthopedics, nanotechnology is paving the way for new treatments by using materials that are on a nanoscale, specifically between 1 and 100 nanometers. These nanomaterials, which include polymers, carbon nanofibers, nanotubes, and ceramic composites, can effectively promote better integration of calcium minerals onto implants (Bentolila et al.,2006). This leads to improved interactions between the implant and surrounding bone tissue, potentially enhancing the success of orthopedic implants. By bettering the attachment process and reducing complications, these nanostructured materials represent a promising area of research that could greatly improve patient outcomes and joint functionality.

Future prospects of nanobiotechnology

There's a growing conversation about what the future might hold for nanobiotechnology. This exciting field promises new materials and devices that could revolutionize areas like medicine, electronics, biomaterials, and energy production. However, alongside its potential, there are valid concerns regarding toxicity and environmental impact, as well as possible effects on the global economy and various alarming future scenarios (Partlow et al.,2007). These worries have sparked discussions among advocacy groups and governments about whether nanobiotechnology needs specific regulations.

Despite these debates, the technology holds great promise. It could lead to groundbreaking advancements in biomedical applications, ranging from targeted drug delivery and gene therapy to innovative molecular imaging and biosensors. One focal point of current research is developing therapies tailored to specific targets and methods for early disease diagnosis (Gourley et al.,2005). There are already two main categories of medical applications taking shape: one involves imaging technologies like quantum dots, which are starting to be commercially licensed, while the other focuses on sensitive ways to detect nucleic acids and proteins. By the years 2015 to 2020, we were expected to see some products from academic and government labs make their way into the marketplace. Innovations in cell isolation and molecular filtration were anticipated to emerge, and certain drug delivery systems were on the brink of commercialization or advanced clinical trials (Bao et al.,2005). For instance, companies like NanoSystems and American Pharmaceutical Partners were working on encapsulating cancer drugs, such as Taxol, in nanopolymers . However, it's important to note that many medical devices and therapies may still take over a decade to reach consumers. This highlights the need for a complex infrastructure in nanotechnology and careful regulatory management. As nanomedicine continues to evolve, its applications in various medical fields are being explored. In diagnostics, it could enable faster detection of diseased cells allowing for treatment before they can spread. Patients with severe injuries or organ dysfunctions could also see significant benefits from nanomedicine techniques (Robertson et al.,2007). However, there are significant challenges to address. No single individual or group can tackle all the questions that arise from using nanotechnology. There are five main hurdles to overcome. First, we need tools to assess exposure to engineered nanomaterials in our air and water. Monitoring potential contamination in the environment is crucial, especially as it relates to food safety. The second challenge is developing ways to effectively detect and determine the toxicity of engineered nanomaterials over the next 5 to 15 years. Additionally, we need predictive models to understand how these materials could affect human health and the environment. Another hurdle is creating systems to evaluate the long-term impacts of these nanomaterials throughout their life cycle. Finally, a broader challenge is designing the necessary tools to assess the potential risks posed to both human health and the environment. On the commercialization front, uncertainties around the effectiveness of innovations, scaling challenges, funding limitations, and the need for time and resources can all be barriers (Geho et al.,2006). Many companies see the potential in nanotechnology for developing new products and enhancing existing ones, but introducing a groundbreaking technology like nanotechnology raises pressing questions about regulation. It's essential for authorities worldwide to evaluate possible risks and establish appropriate regulations as this advanced technology becomes more widely used.

Potential hazards of nanoparticles

Nanoparticles, due to their incredibly small size, have some unique advantages, but they also come with potential health risks similar to those associated with particulate matter. These tiny particles can impact various bodily systems, including respiratory, cardiovascular, and gastrointestinal health. For instance, studies involving carbon nanotubes in mice have revealed that these particles can lead to serious lung issues like inflammation and tissue damage (Agrawal et al.,2005). One concerning aspect of nanoparticles is their ability to enter the human body through different pathways. The most common route of exposure seems to be through the lungs, especially during their production or use. Once inhaled, nanoparticles can quickly move into the bloodstream and affect other vital organs. Interestingly, they also show promise in biotechnology, as they can act as gene-delivery vehicles. Research has demonstrated that nanoparticles can reach the brain through the olfactory pathway, which is a direct route connected to smell. Studies with monkeys and rats have shown that carbon and manganese nanoparticles can accumulate in the olfactory bulb, suggesting a potential method for bypassing the blood-brain barrier (Bentzen et al.,2005). While this could lead to innovative medical treatments, it also raises concerns about possible inflammatory responses in the brain that need further investigation.

In laboratory studies, nanoparticles have been shown to have certain effects on blood platelets, which could increase the risk of blood clotting. However, fullerenes, another type of nanoparticle, seem to be safer in this context as they do not promote platelet aggregation. This makes them a more appealing option for developing drug delivery systems. There are also worries about the effects of nanoparticles on the gastrointestinal system, which could lead to inflammatory bowel diseases. The toxicity may stem from their ability to trigger the release of pro-inflammatory substances, leading to inflammation and damage in various organs (Maeda et al.,2006). While much of this research has been conducted in lab settings or animal models, translating these findings to humans is complex and requires further study. Thus, using nanoparticles in human applications must be approached with caution and thorough research.

Conclusion

Nanobiotechnology has the potential to change the way we think about medicine and our health in some truly exciting ways. Imagine being able to deliver drugs precisely where they're needed in the body or finding cures for diseases that currently have no solution. It's a field filled with hope and promise. However, along with these advancements come important questions about safety and ethics. It's crucial that we take a careful look at how we use nanomedicine to make sure we're doing it responsibly. While some scientists have raised concerns, a lot of experts believe we should keep pushing forward, as long as we prioritize thorough testing to protect people's health. As we continue to research and improve safety protocols, nanobiotechnology could become a key player in healthcare, offering innovative solutions and enhancing our well-being. If we handle its development wisely, this incredible technology could save many lives and become a vital part of our daily lives and modern medicine.

Author contributions

M.A.B.S. conceptualized and designed the study, supervised the review process, and contributed to the manuscript's finalization. A.D. conducted the literature review, analyzed relevant studies, and contributed to manuscript drafting. N.D.N. assisted in data collection, critical analysis, and manuscript editing. M.A.R.B. contributed to the discussion on nanobiotechnology applications and future directions. T. assisted in manuscript formatting, reference management, and proofreading. All authors reviewed and approved the final manuscript.

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References

Emerich, D. F., & Thanos, C. G. (2003). Nanotechnology and medicine. Expert Opinion on Biological Therapy, 3(4), 655–663.

Sahoo, K. S., & Labhasetwar, V. (2003). Nanotech approaches to drug delivery and imaging. Drug Discovery Today, 8(24), 1112–1120.

Vasir, J. K., & Labhasetwar, V. (2005). Targeted drug delivery in cancer therapy. Technology in Cancer Research & Treatment, 4(4), 363–374.

Vasir, J. K., Reddy, M. K., & Labhasetwar, V. (2005). Nanosystems in drug targeting: Opportunities and challenges. Current Nanoscience, 1(1), 47–64.

Maeda, H., Wu, J., Sawa, T., Matsumura, Y., & Hori, K. (2000). Tumor vascular permeability and the EPR effect in macromolecular therapeutics: A review. Journal of Controlled Release, 65(1-2), 271–284.

Allen, T. M., & Cullis, P. R. (2004). Drug delivery systems: Entering the mainstream. Science, 303(5665), 1818–1822.

Garcia-Garcia, E., Gil, S., Andrieux, K., Desmaële, D., Nicolas, V., Taran, F., Georgin, D., Andreux, J. P., Roux, F., & Couvreur, P. (2005). A relevant in vitro rat model for the evaluation of blood–brain barrier translocation of nanoparticles. Cellular and Molecular Life Sciences, 62(12), 1400–1408.

Feng, S. S., Mu, L., & Win, K. Y. (2004). Nanoparticles of biodegradable polymers for clinical administration of paclitaxel. Current Medicinal Chemistry, 11(4), 413–424.

De Kozak, Y., Andrieux, K., Villarroya, H., Klein, C., Thillaye-Goldenberg, B., & Naud, M. C. (2004). Intraocular injection of tamoxifen-loaded nanoparticles: A new treatment of experimental autoimmune uveoretinitis. European Journal of Immunology, 34(12), 3702–3712.

Shaffer, C. (2005). Nanomedicine transforms drug delivery. Drug Discovery Today, 10(21), 1581–1582.

Moghimi, S. M., Hunter, A. C., & Murray, J. C. (2005). Nanomedicine: Current status and future prospects. FASEB Journal, 19(3), 311–330.

Lee, K. B., Park, S. J., Mirkin, C., Smith, J., & Mrkisch, M. A. (2002). Protein nanoarrays generated by dip-pen nanolithography. Science, 295(5560), 1702–1705.

NBTC (Nano-biotechnology Center, Cornell University). (2004). Home page. http://www.nbtc.cornell.edu/default.htm

Lin, H., & Datar, R. H. (2006). Medical applications of nanotechnology. National Medical Journal of India, 19(1), 27–32.

Guccione, S., Li, K. C., & Bednarski, M. D. (2004). Vascular-targeted nanoparticles for molecular imaging and therapy. Methods in Enzymology, 386, 219–236.

LaVan, D. A., Lynn, D. M., & Langer, R. (2002). Timeline: Moving smaller in drug discovery and delivery. Nature Reviews Drug Discovery, 1(1), 77–84.

El-Shabouri, M. H. (2002). Positively charged nanoparticles for improving the oral bioavailability of cyclosporin-A. International Journal of Pharmaceutics, 249(1-2), 101–118.

Hu, L., Tang, X., & Cui, F. (2004). Solid lipid nanoparticles (SLNs) to improve oral bioavailability of poorly soluble drugs. Journal of Pharmacy and Pharmacology, 56(12), 1527–1535.

Arangoa, M. A., Campanero, M. A., Renedo, M. J., Ponchel, G., & Irache, J. M. (2001). Gliadin nanoparticles as carriers for the oral administration of lipophilic drugs: Relationships between bioadhesion and pharmacokinetics. Pharmaceutical Research, 18(10), 1521–1527.

Arbos, P., Campanero, M. A., Arangoa, M. A., & Irache, J. M. (2004). Nanoparticles with specific bioadhesive properties to circumvent the pre-systemic degradation of fluorinated pyrimidines. Journal of Controlled Release, 96(1), 55–65.

Diwan, M., Elamanchili, P., Lane, H., Gainer, A., & Samuel, J. (2003). Biodegradable nanoparticle-mediated antigen delivery to human cord blood-derived dendritic cells for induction of primary T cell responses. Journal of Drug Targeting, 11(8-10), 495–507.

Koping-Hoggard, M., Sanchez, A., & Alonso, M. J. (2005). Nanoparticles as carriers for nasal vaccine delivery. Expert Review of Vaccines, 4(2), 185–196.

Lutsiak, M. E., Robinson, D. R., Coester, C., Kwon, G. S., & Samuel, J. (2002). Analysis of poly(d,l-lactic-co-glycolic acid) nanosphere uptake by human dendritic cells and macrophages in vitro. Pharmaceutical Research, 19(10), 1480–1487.

Young, L. S., Searle, P. F., Onion, D., & Mautner, V. (2006). Viral gene therapy strategies: From basic science to clinical application. Journal of Pathology, 208(3), 299–318.

Hart, S. L. (2005). Lipid carriers for gene therapy. Current Drug Delivery, 2(4), 423–428.

Ewert, K., Evans, H. M., Ahmad, A., Slack, N. L., Lin, A. J., Martin-Herranz, A., et al. (2005). Lipoplex structures and their distinct cellular pathways. Advances in Genetics, 53, 119–155.

Zhang, Y., Schlachetzki, F., Li, J. Y., Boado, R. J., Pardridge, W. M., et al. (2003). Organ-specific gene expression in the rhesus monkey eye following intravenous nonviral gene transfer. Molecular Vision, 9, 465–472.

Elan Corporation, PLC. (2004). Available at http://www.elan.com/DrugDelivery

Wickline, S. A., Neubauer, A. M., Winter, P., Caruthers, S., & Lanza, G. (2006). Applications of nanotechnology to atherosclerosis, thrombosis, and vascular biology. Arteriosclerosis, Thrombosis, and Vascular Biology, 26(3), 435–441.

Panyam, J., & Labhasetwar, V. (2003). Biodegradable nanoparticles for drug and gene delivery to cells and tissue. Advanced Drug Delivery Reviews, 55(3), 329–347.

West, J. L., & Halas, N. J. (2000). Applications of nanotechnology to biotechnology commentary. Current Opinion in Biotechnology, 11(2), 215–217.

Ure, D., & Harris, J. (2003). Nanotechnology in dentistry: Reduction to practice. Dental Update, 30(1), 10–15.

Webster, T. J., Waid, M. C., McKenzie, J. L., Price, R. L., & Ejiofor, J. U. (2004). Nanobiotechnology: Carbon nanofibres as improved neural and orthopedic implants. Nanotechnology, 15(1), 48–54.

Price, R. L., Waid, M. C., Haberstroh, K. M., & Webster, T. J. (2003). Selective bone cell adhesion on formulations containing carbon nanofibers. Biomaterials, 24(11), 1877–1887.

Buzea, C., Pacheco, I., & Robbie, K. (2007). Nanomaterials and nanoparticles: Sources and toxicity. Biointerphases, 2(4), MR17.

Milunovich, S., & Roy, J. (2001). The next small thing: An introduction to nanotechnology. Merrill Lynch Report, September 4.

Hamad-Schifferli, K., Schwartz, J., Santos, A. T., Zhang, S., & Jacobson, J. (2002). Remote electronic control of DNA hybridization through inductive coupling to an attached metal nanocrystal antenna. Nature, 415(6869), 152–155.

Li, Z., Hulderman, T., Salmen, R., Chapman, R., Leonard, S. S., Young, S. H., et al. (2007). Cardiovascular effects of pulmonary exposure to single-wall carbon nanotubes. Environmental Health Perspectives, 115(3), 377–382.

Nijhara, R., & Balakrishnan, K. (2006). Bringing nanomedicines to market: Regulatory challenges, opportunities, and uncertainties. Nanomedicine, 2(2), 127–136.

Lam, C. W., James, J. T., McCluskey, R., & Hunter, R. L. (2004). Pulmonary toxicity of single-wall carbon nanotubes in mice 7 and 90 days after intratracheal instillation. Toxicological Sciences, 77(1), 126–134.

Williams, D. (2004). The risks of nanotechnology. Medical Device Technology, 15(5), 9–10.

Oberdörster, E. (2004). Manufactured nanomaterials (fullerenes, C60) induce oxidative stress in the brain of juvenile largemouth bass. Environmental Health Perspectives, 112(10), 1058–1062.

Elder, A., Gelein, R., Silva, V., Feikert, T., Opanashuk, L., Carter, J., et al. (2006). Translocation of inhaled ultrafine manganese oxide particles to the central nervous system. Environmental Health Perspectives, 114(8), 1172–1178.

Radomski, A., Jurasz, P., Onso-Escolano, D., Drews, M., Morandi, M., Malinski, T., et al. (2005). Nanoparticle-induced platelet aggregation and vascular thrombosis. British Journal of Pharmacology, 146(6), 882–893.

Medina, C., Santos-Martinez, M. J., Radomski, A., Corrigan, O. I., & Radomski, M. W. (2007). Nanoparticles: Pharmacological and toxicological significance. British Journal of Pharmacology, 150(5), 552–558.

Chen, Z., Meng, H., Xing, G., Chen, C., Zhao, Y., Jia, G., et al. (2006). Acute toxicological effects of copper nanoparticles in vivo. Toxicology Letters, 163(2), 109–120.

Jain, K. K. (2003). Nanodiagnostics: Application of nanotechnology in molecular diagnostics. Expert Review of Molecular Diagnostics, 3(2), 153–161.

Jain, K. K. (2007). Nanobiotechnology: Applications, markets and companies. Basel: Jain PharmaBiotech Publications.

Jain, K. K. (2006). Nanobiotechnology in molecular diagnostics. Norwich, United Kingdom: Horizon Scientific Press.

Jain, K. K. (2005). Nanotechnology in clinical laboratory diagnostics. Clinica Chimica Acta, 358(1-2), 37–54.

Jain, K. K. (2005). Nanotechnology-based lab-on-a-chip devices. In Fuchs, J. & Podda, M. (Eds.), Encyclopedia of Diagnostic Genomics and Proteomics (pp. 891–895). New York: Marcel Dekker Inc.

Fan, R., Karnik, R., Yue, M., Li, D., Majumdar, A., & Yang, P. (2005). DNA translocation in inorganic nanotubes. Nano Letters, 5(9), 1633–1637.

Ramachandran, N., Hainsworth, E., Bhullar, B., Eisenstein, S., Rosen, B., Lau, A. Y., et al. (2004). Self-assembling protein microarrays. Science, 305(5689), 86–90.

Chan, P., Yuen, T., Ruf, F., Gonzalez-Maeso, J., & Sealfon, S. C. (2005). Method for multiplex cellular detection of mRNAs using quantum dot fluorescent in situ hybridization. Nucleic Acids Research, 33(18), e161.

Bentolila, L. A., & Weiss, S. (2006). Single-step multicolor fluorescence in situ hybridization using semiconductor quantum dot-DNA conjugates. Cell Biochemistry and Biophysics, 45(1), 59–70.

Partlow, K. C., Chen, J., Brant, J. A., Neubauer, A. M., Meyerrose, T. E., & Creer, M. H., et al. (2007). 19F magnetic resonance imaging for stem/progenitor cell tracking with multiple unique perfluorocarbon nanobeacons. The FASEB Journal, 21(8), 1647–1654.

Gourley, P. L., Hendricks, J. K., McDonald, A. E., Copeland, R. G., Barrett, K. E., & Gourley, C. R., et al. (2005). Mitochondrial correlation microscopy and nanolaser spectroscopy: New tools for biphotonic detection of cancer in single cells. Technology in Cancer Research & Treatment, 4(6), 585–592.

Bao, Y. P., Wei, T. F., Lefebvre, P. A., An, H., He, L., & Kunkel, G. T., et al. (2006). Detection of protein analytes via nanoparticle-based bio bar code technology. Analytical Chemistry, 78(7), 2055–2059.

Robertson, J. W., Rodrigues, C. G., Stanford, V. M., Rubinson, K. A., Krasilnikov, O. V., & Kasianowicz, J. J. (2007). Single-molecule mass spectrometry in solution using a solitary nanopore. Proceedings of the National Academy of Sciences of the United States of America, 104(21), 8207–8211.

Geho, D. H., Jones, C. D., Petricoin, E. F., & Liotta, L. A. (2006). Nanoparticles: Potential biomarker harvesters. Current Opinion in Chemical Biology, 10(1), 56–61.

Agrawal, A., Tripp, R. A., Anderson, L. J., & Nie, S. (2005). Real-time detection of virus particles and viral protein expression with two-color nanoparticle probes. Journal of Virology, 79(13), 8625–8628.

Bentzen, E. L., House, F., Utley, T. J., Crowe, J. E., & Wright, D. W. (2005). Progression of respiratory syncytial virus infection monitored by fluorescent quantum dot probes. Nano Letters, 5(4), 591–595.

Maeda, M., Kuroda, C. S., Shimura, T., Tada, M., Abe, M., & Yamamuro, S., et al. (2006). Magnetic carriers of iron nanoparticles coated with a functional polymer for high throughput bioscreening. Journal of Applied Physics, 99(8), 08H103.