Integration of Nanotechnology and Physics in Clinical Practice and medical devices: Insights from Optometry, Radiology, Anesthesia, Dentistry, and Nursing

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1. Introduction to Nanotechnology and Physics in Clinical Practice

The interface between nanotechnology and physics is a fascinating one, particularly with regards to clinical practice. Both disciplines at their nanoscale and quantum levels can play an enormously significant role in diagnosis, treatment and improvement of patient outcomes. Optometry, radiology, anesthesia, dentistry and nursing are some of the fields aimed to be deliberated here. A clinical perspective of recent discoveries in nanotechnology and quantum physics at their relevant domains has been placed for one and all involved in healthcare (A Saunders, 2009). Nanotechnology is defined as the design, characterization and application of structures, devices and systems by controlling shape and size at nanometer scale level (K. Y. Wong & L. Liu, 2012). Of all the possible medical technologies, integration of nanotechnology and quantum physics concomitantly is covalently bonded and eye care technology takes the privilege of deliberating it first. Further, quantum physics and optometry takes the precedence over rest of the disciplines. A broad propagation of near infra-red quantum beam can be taken as an example of optometry and nanotechnology mostly employed in fabrication of nanostructured materials having optometric application such as waveguides, lenses, transceiver, etc., for radiometry. A hope and challenge placed here is that the integration of nanotechnology and quantum physics can play pivotal role in health care nanomedicine technology. A simple overview on how the ongoing horizon discoveries at nano and quantum level presently being and can be clinically practiced have been placed. A simple introduction nano and quantum horizon discoveries on broadly five domains of clinical practice is discussed here and each topic is crafted on its own merit in a detail.

2. Fundamental Concepts of Nanotechnology and Physics

To understand the applied aspects of nanotechnology and physics, it is essential to grasp the fundamental concepts. This section covers the basic principles of nanoparticles and quantum mechanics, establishing the groundwork for their clinical applications in optometry, radiology, anesthesia, dentistry, and nursing. Starting with nanoparticles, the discussion focuses on their definition, development methods, properties, biomedical applications, and toxicity assessment. The unique significance of nanoparticles and nanomedicine in healthcare is highlighted, along with their revolutionary potential for diagnosis, treatment, and prevention of various illnesses (K. Y. Wong & L. Liu, 2012). By bridging the gap between fundamental theories and real-world applications, this chapter connects theoretical knowledge with practical outcomes. It also sets the stage for in-depth discussions on specific case studies and applications in clinical practice in the next chapter.

Nanoparticles are defined as solid particles with a size range of 1 to 100 nanometers. Nanoparticle development methods are categorized into top-down and bottom-up approaches. In the top-down method, larger bulk materials are reduced to nanosized particles, while the bottom-up method involves assembling individual atoms or molecules to form nanoparticles. Nanoparticles can also be classified based on composition, including metals, semiconductors, lipids, polymers, and dendrimers. Transitioning materials from macro- to nano-scale alters their surface area to volume ratio, resulting in unique properties. At the nano-scale, high surface area affects chemical interactions and changes physical properties such as color and solubility. Nanoparticles can penetrate biological barriers due to their small size, demonstrating quantum effect, which refers to changes in a particle's energy state concerning confinement and size. Quantum dots are nanometer-sized semiconductor crystals that exhibit quantum confinement and unique optical properties, making them valuable in biology and medicine. These nanoparticles absorb and emit energy in the visible spectrum, with size-affecting photoluminescence wavelength (Abdul Salam Selim et al., 2015).

2.1. Nanoparticles and Their Properties

Nanoparticles, or nanomaterials, are particulate dispersions of solid particles that range in size from 10 to 100 nm. Particles within this size range exhibit unique physical, chemical, biological, and toxicological properties compared to bulk materials, which greatly expand their applicability in various fields. Nanoparticles have found extensive applications across several disciplines, including molecular biology, physics, organic and inorganic chemistry, medicine, and material science, because of their unique chemical, optical, electrical, and magnetic characteristics (Chakraborty et al., 2023). The design and use of structures with nanoscale dimensions are at the heart of nanotechnology and have widespread applications in medicine to create nanomedicine or involves the use of nanomaterials for the diagnosis, prevention, and treatment of diseases.

It has been shown that reducing bulk materials to nano-size changes their physicochemical properties. Nanomaterials possess large surface area, high reactivity, and greater solubility compared to their bulk equivalent. These nanometre-sized materials exhibit size-dependent optical, electrical, magnetic, and catalytic properties effect that can be exploited in a variety of biomedical applications. For instance, gold nanoparticles of <20 nm exhibited a size-dependent antibacterial effect against a variety of Gram positive and Gram negative bacteria. The large surface area-to-volume ratio of nanoparticles generally makes them highly reactive and confers a high adsorption capacity, which allows them to transport or interact with other molecules. Moreover, these interactions modulate the molecular or cellular activities, which make them a promising candidate for various biological applications.

Drug delivery systems are one of the most promising areas in healthcare and biomedical research that involve the use of drug delivery systems on a nanoscale to minimize chemotherapy-related adverse effects while boosting the overall effectiveness of the treatment. The utilization of nanomaterials offers unrivaled flexibility to tailor the characteristics of the therapeutics. As numerous physiological processes occur at nanoscales, the comparable size of nanomaterials to human cell organelles makes them a potent carrier for delivering drug molecules. Nanoparticles (NPs) are favorable platforms for the target-specific and controlled delivery of therapeutic micro- and macromolecules due to their ability to form stable interactions with ligands, variability in size and shape, and high carrier capacity (I. Ramos et al., 2022).

2.2. Quantum Mechanics in Clinical Applications

An exploration of emerging technologies that employ aspects of physics and nanotechnology in their design and clinical application in optometry, radiology, anesthesiology, dentistry, and nursing provides insight into the novel convergence of these subjects in clinical practice.

Consideration is given to the integration of principles and nanotechnology from emerging areas of physics—particularly relativistic, quantum, and biophysics—into novel devices and technologies with clinical application. A brief overview of an emerging technology from each of the five fields follows that illustrates this convergence, and their newly considerated application (Shams et al., 2023). Topics include imaging technologies that utilize relativistic or quantum principles; drug delivery systems that harness quantum or biophysical effects; diagnostic devices that consider quantum, biophysical, or relativistic principles; and novel therapeutic treatments that employ principles of biophysics or relativity.

Quantum mechanics describes the behavior of matter and light at the atomic and subatomic scale. This esoteric domain of reality shapes the very fabric of existence, underpinning atoms, molecules, and fundamental forces. It has liberating ideas counterintuitive to the macroscopic world, such as the bizarre notion that particles can exist in multiple states or locations simultaneously (superposition). An effect so strange that entangled pairs of particles dictate each other's states instantaneously, regardless of the distance separating them. Quantum tunneling allows particles to appear on the other side of an energy barrier without traversing it, exposing nonclassical pathways. The macroscopic world emerges as an apparent continuum when collections of particles cohere. Global states represent mass, momentum, and charge, leading to classical fields governed by macroscopic equations. Quantum mechanics is the most accurately tested theory of nature, with pivotal experiments validating its predictions.

3. Applications in Optometry

3.1. Nanotechnology in Contact Lenses

3.2. Optical Coherence Tomography

4. Applications in Radiology

The focus of this article is on application of nanotechnology and physics approach in clinical practice. Five different professions were selected to underline how nano devices or physic approach is used or can be use in future on clinical practice. Optometry uses nano devices for drug delivery to eye tissues and it provides localized drug action with low side effects. Nanotechnology also uses in contact lens for drug delivery which provide long duration action compared to eye drop. Physics approach in optometry helps to diagnose eye strabismus more accurate and early detection. In case of nursing profession, nano devices can be used in development of bandage which provides localized drug action on wound. Bandage integrated with nanotechnology can provide faster healing with minimal scar formation. Bandage can be added with detecting agent which will detect infection and change color of bandage which will alert nurses. Also nanotechnology can be used for smart pill which can detect diseases inside body and send information outside the body. Smart pill integrated with drug delivery system can deliver drug to specific location and provide side effects free action. There is huge scope of research in nanotechnology in integration with nursing profession. In case of clinical radiology, nano device can be used as contrast agent which will enhance quality of image. Clinical radiology can be enhanced with convergence of existing practice and nanotechnology which will detect disease earlier. Different types of nanoparticle agents are discussed which can be used in MRI or CT scan. Nanoparticle such as silica, gold, polymer has been explored as contrast agent during CT scan and have shown better image quality compared to existing agent. Safety and bio compatibility is the major concern in use of nanoparticles in clinical imaging. Nanoparticle based agent can be used in personalized medicine where patient DNA seq is analyzed and radiological agent is designed which uses DNA seq as input and generates agent which will precisely act on target site. There is scope of future research in utilization of nanoparticle in radiology (Siddique & C. L. Chow, 2020).

4.1. Nanoparticle Contrast Agents

Nanoparticle contrast agents are emerging as the most promising development, especially in enhancing the quality of radiological images. Introduction of imaging agent in the body increases the contrast between the area of interest and background in the images so that the observations can be much more accurate. Generally, contrast materials have low atomic number than surrounding tissues in X-ray radiology because X-rays are mostly absorbed by heavy elements. The would-be nanoparticle agents are novel materials with dimensions in the nanometer size range that possess unusual properties differing dramatically from bulk materials. On the other hand, traditional contrast materials are largely only salt of heavy metals. States of the art of nanoparticle agents composed of metals or metal oxides will be reviewed here focused on their principles, preparation methods and applications in enhancing the imaging quality and precision mainly of X-ray radiology (Siddique & C. L. Chow, 2020). Gold nanoparticles (AuNPs) can be designed and synthesized with great control over size, shape and surface properties that are crucial parameters to dictate the contrast enhancement in imaging applications. Silica nanoparticles (SiNPs) are another kind of widely studied candidate in biomedical applications owing to their advantageous characteristics such as ease of preparation, particle size tunability, high stability, easy bioconjugation and low toxicity. On the other hand, clinical application of silica based agents could be more favorable because no safety problem has been concerned due to the wide use of silica in food and nano-silicac gel in medicine. SiNPs have been studied to improve the contrast resolution of the X-ray images taken at different excitation energies. Because nanoparticle agent has large number of atoms providing high dose of attenuation even at low concentration, it is absolutely superior in sensitivity of detection. Biocompatibility is one of the most important factors of cooperative nanoparticles in clinical applications. Although AuNPs could induce some side effects such as inflammation response and cytotoxicity, they are still widely explored because gold has been used for a long time in body implants with no side effect. Biocompatibility of SiNPs is proved because silica gel has been widely used in food and medicine with no adverse effect. With the advanced imaging instruments, diseases detection and monitoring could be performed in vivo and at early stage with the aid of widely biomarker-absorption-directed nanoparticles agents.

4.2. Nanotechnology in Imaging Techniques

This review focusses on the implications of nanotechnology on imaging techniques under the broad field of radiology. With the advent of nanoscale innovations, such techniques have undergone a remarkable transformation in terms of image acquisition, processing and interpretation. Several research and development works across the globe involve the integration of advanced nanomaterials with imaging techniques spanning across different modalities such as magnetic resonance (MR) imaging, computed tomography (CT), ultrasound and so on. These novels materials usually enhance the imaging sensitivity and specificity through the upgradation of the existing hardware, chemical alteration of the contrast agent or the rational combination of both (Bonlawar et al., 2024). In addition, imaging experiments driven by computational tools involving artificial intelligence and machine learning are also explored in conjunction with nanotechnology and said to refine the imaging techniques. Although these advanced imaging techniques are proven to be effective in preclinical scenarios, clinical application is associated with challenges. Nonetheless, nanotechnology could pave the way to personalized imaging techniques that would affect both diagnosis and treatment planning (Rahman, 2023). A survey of the advancements on nanotechnology-based imaging techniques is presented here, focussing on the modality-wise approach and future directional research.

Imaging techniques are vital for the qualitative and quantitative assessment of bio-morphological characteristics of tissues/cells either in normal or pathological states. Several imaging modalities operating in different spectral/energy windows have been explored in medical practice for image acquisition, and each has its own advantages and disadvantages. Nonetheless, all these modalities are upgradable refinement/improvement of the image acquisition outcome, particularly the resolution and efficiency, which has a direct impact on post-processing and interpretation. So far, imaging techniques have been improved either through hardware upgradation or post-acquisition data processing. During the last two decades, the concept of imaging technique refinement/upgradation driven by computational tools involving artificial intelligence and machine learning has gained immense popularity among the research community. Such techniques are proven effective in enhancing the resolution of images acquired through visible/NIR spectral techniques. Even prior to this, nanotechnology-driven advancements in imaging techniques are reported and said to improve the sensitivity and efficacy of the imaging outcomes.

5. Applications in Anesthesia

Nanotechnology and physics have contributed to the clinical practice of anesthesia. These innovations are relevant to anesthesiology for improved patient outcomes. Physiological monitoring is essential for anesthesia safety and effectiveness. The introduction of advanced capabilities has largely relied on nanotechnology and smart sensor systems grounded in physics principles. In recent decades, nanoparticles have been developed as drug delivery systems, known as nanomedicine, and their clinical translations are anticipated (Gu et al., 2023). Anesthetic agents are pharmaceuticals that induce effects like sedation, amnesia, hypnosis, analgesia, and muscle relaxation. Controlling these effects during perioperative periods is a routine practice in anesthesia.

These advancements can profoundly impact drug delivery precision and safety. A major concern in drug delivery is dosage. The conventional method of administering drugs without real-time feedback on drug effects may induce underdosing or overdosing. Engineered nanoparticles embed drugs that remain inactive until they target intended tissues. Considering patient-specific characteristics, targeting ligands on nanoparticles ensure receptor-mediated endocytosis, releasing drugs selectively inside tissues. Anesthetics have vasodilative effects on blood vessels, increasing local blood flow, which can eliminate perfusion site drugs. Anesthesia's plasma half-life is critical for rapid recovery, as excessively long half-lives can lead to accumulation toxicity. To address this, short-acting or ultra-short-acting agents are necessary. For neuroaxial anesthesia, delivered drugs can diffuse throughout the whole neuraxis due to cerebrospinal fluid circulations. This necessitates molecules larger than 250 Da.

Furthermore, nanosensors have emerged as revolutionary technology for detecting various analytes, using nanoparticles to translate interaction responses into signal variations. Infiltration anesthesia and nerve blocks are numerical techniques wherein anesthetic drugs are locally delivered to specific nerves to induce physiological blocks. These advances integrate smart monitoring alongside anesthetic delivery systems, providing real-time feedback on patient responses. A preliminary closed-loop system that combines drug delivery devices with monitoring technologies can adjust drug doses based on detection results. These innovations can significantly impact the individualization of anesthesia protocols during surgery, allowing for more sophisticated and complex monitoring beyond physiological parameters. This review aims to provide an overview of nanotechnology and physics applications in drug delivery and monitoring technologies in anesthesia, along with innovations currently translated into clinical practice or under investigations. The innovations in anesthesia are applied in different surgical specialties, and future studies focusing on optimizing these technologies for clinical use are anticipated.

5.1. Nanoparticles in Drug Delivery Systems

Among all the nanoparticles used in drug delivery systems, lipid nanoparticles and polymer nanoparticles are the most studied in order to deliver anesthetic agents. During the last decade, lipid-based systems emerged as promising delivery platforms for anesthetics. In particular, nanoemulsions or selfnanoemulsifying drug delivery systems (SNEDDS) have been investigated to tackle the challenges of intravenous anesthetics, via ensuring a safe and quick recovery. Nanoemulsions containing propofol, the most widely used intravenous anesthetic, have shown enhanced anesthetic effect and reduced hypoxia risk. Similar findings have been reported for other lipid-based agents, e.g. short-chain triglyceride nanoemulsions as alternative propofol formulation, or using medium-chain triglyceride nanoemulsion of etomidate for improved cardiopulmonary stability.

Polymer nanoparticles are another widely studied platform to deliver anesthetic agents. Poly(lactic-co-glycolic acid) (PLGA) nanoparticles allowing controlled delivery of propofol have been successfully prepared and characterized. Anesthetic effect was nanoparticle size-dependent, thus enabling tuning drug efficacy through formulation design. In a more recent study, ethyl cellulose nanoparticles were explored to deliver isoflurane. Larger particles (1.5–3.0 μm) showed better stability and slower isoflurane release than smaller nanoparticles, leading to prolonged drug action. Apparently, particulate systems carrying inhaled anesthetics could also be developed to enhance drug delivery efficiency through respiratory targeting.

The advent of nanoparticles-based delivery systems for anesthetic agents has the potential to enhance the quality of care for patients undergoing surgery. Such development is not only beneficial for surgical procedures, but also for non-surgical interventions requiring anesthesia. In addition to bioavailability, safety and toxicity concerns across the entire lifecycle of nanoparticles remain challenging yet critical for their development. The production process, particle size, particle shape, surface charge, surface chemistry, and agglomeration could all affect nanoparticles-induced toxicity. Proper design and characterization of nanoparticles are essential for maximizing their therapeutic index. Robust stability is pivotal for ensuring safe storage and administration. Anesthetic nanoparticles are typically designed to achieve a zero-order release kinetics. Strategies to measure and optimize release kinetics require further exploration. Based on the methodologies, toxicity and efficacy studies of clinical relevant drug doses should be conducted for nanoparticle candidates prior to in vivo evaluation. Most currently, efforts are focused on optimizing drug formulation and delivery method for a specific nanoparticle platform. With the advancement of nanotechnology, it is anticipated that practices of anesthesia in clinics could become personalized protocols due to the particulate systems, similar to what are being developed for analgesics (Lu et al., 2024).

5.2. Nanosensors for Anesthetic Monitoring

5.2. Nanosensors for Anesthetic Monitoring One of the most exciting applications of nanotechnology is the development of nanosensors capable of monitoring anesthetic agents. Anesthetics are essential to surgery or intensive care; they provide anesthesia, analgesia, and sedation, and muscle relaxants are meant to control neuromuscular blockade. Some anesthetics are also used in non-surgical procedures such as endoscopy and catheter insertion. However, they all have the potential to cause serious side effects, which can alert pre-administration monitoring of patient conditions. The widespread introduction of closed-loop systems for providing anesthesia in an individual mode is impossible without flexible, intelligent, and compact sensor systems for monitoring anesthetic agents. Therefore, the application of nanotechnology in producing sensors is a great hope for the safety of patients undergoing surgery or care in the intensive care unit (ICU). The concentration and effects of anesthetic drugs can be continuously monitored, providing real-time data on the degree of impact on the patient's system. This enhanced monitoring capability will pave the way for more individually tailored anesthesia management, drastically reducing potential complications and improving patient outcomes (Gu et al., 2023). Several types of nanosensors are being researched and developed for monitoring injectable or inhaled anesthetics. These include fluorescent nanosensors based on quantum dots and upconversion nanoparticles, luminescent nanosensors based on metallophthalocyanines, surface plasmon resonance (SPR) nanosensors, and electrochemical nanosensors. In most cases, sensitivity is achieved at the expense of inadequate specificity. Despite the many available approaches, the main issues regarding the practical implementation of these monitoring technologies in clinical practice remain regulatory approvals and the necessity of clinical validation. However, as with laboratory tests of new pharmaceuticals, the development of a widely used method for monitoring new drugs is essential to carry out epidemiological studies. The application of nanotechnology provides opportunities in this direction. Future studies of NMs as monitoring tools should focus on expanding knowledge of their behavior in biological systems, developing mathematical models for describing NM distribution and drug delivery, and optimizing multi-route exposure in vivo experiments. Considerable changes in the application of NMs in safety assessment and toxicity of chemicals move, in part, from single-route exposure studies toward more relevant multi-route exposure scenarios. NMs must be applied to enhance computational techniques, limiting experimental efforts to keep them in reasonable ranges of time and costs. In bioassays, collaborative efforts between chemists, biologists, and modelers must develop NMs as sensing elements and unravel fundamental biophysical mechanisms in assays based on molecular multiplexing. Good collaboration between basic research and technology transfer to end-users is crucial for successful implementation.

6. Applications in Dentistry

Current innovations in clinical practice using nanotechnology and physics in conjunction with their implementation in fields of optometry, radiology, anesthesia, dentistry and nursing are highlighted. Teaching and research initiatives in these merged disciplines are discussed. Future perspective is also described. Dentistry is going through a paradigm shift from conventional treatments to a more engineered approach with the integration of art and science. Nanotechnology and physics are changing the canvas of dentistry by designing materials from the nanoscale to macroscale improving clinical practice. A thorough overview of the current applications and future perspective of nanotechnology and physics in integration and advancement of clinical practice in restorative dentistry, preventive dentistry, oral imaging technologies and ongoing research is discussed (S. Mantri & P. Mantri, 2013).

Nanomaterials have found their way to clinical practice in the field of restorative dentistry. Nanocomposites are the class of dental restorative materials comprised of nanoparticles/nanoclusters as a filler which was pioneered in the year 2000. However, the research on composites from 1970's led to invention of macrohybrid composites having the fillers size in micrometers (Uskoković & Eduardo Bertassoni, 2010). There are three generations of composites, macrocomposites, microcomposites and nanocomposites. Macrocomposites were widely used in clinical practice because they outperform dental amalgam in mechanical properties and longevity. However, macrocomposites leave gaps at the interface with tooth structure due to the mismatch in their size with the tooth structure which is at microscale. Thus a second generation of microcomposites was developed with fillers of size 15 um to 1 um which improved the marginal integrity and microleakage as the size of filler was close to the size of probing spaces of tooth structure. But they did not improve much on longevity as still gaps were left at the interface.

6.1. Nanomaterials in Restorative Dentistry

Advancements in nanotechnology have seen its application spans across various fields of science and professions such as Optometry, Radiology, Anesthesia, Dentistry, Nursing etc. Nanotechnology, simply put, refers to study and manipulation of materials at molecular level, focusing on dimensions and tolerances of between 1 and 100 nanometers (A Saunders, 2009). Nanomaterials are materials that have been engineered with nanotechnology at atomic, molecular and macromolecular scales. Integrating Nanotechnology and Physics in clinical practice can result in exponentially higher quality and long-lasting durability of treatments, materials and appliances. This proposal intends to examine how Nanotechnology and Physics is currently being integrated into clinical practice and how this could be further built upon in the future. Initial focus will be on optometry and the use of nanomaterials in eyeglasses and contact lenses. Then proceeding into radiology and how nanoscience and nano imaging could change the landscape of treatment and detection of cancerous cells. Next focus would be on the field of Anesthesia and possible use of nanobots and application of nano science in drugs used. Following this is Dentistry and the use of nanomaterials in restorative and preventive care. Finally, discussion would lead to Nursing and detection of diseases and nano drugs used in treatment. Concepts and current applications in place will then be discussed and elaborate future possibilities. Each profession will begin with a brief background explaining current technologies in use and possible use of Nanotechnology and Physics advancements. There is growing need for advancement in technologies used in Dentistry and overall healthcare ensuring long lasting and stable materials used. Nanotechnology could provide an effective solution to this need.

6.2. Nanotechnology in Oral Imaging

This subsection discusses the integration of nanotechnology in oral imaging techniques, reviewed from a clinical optometrist perspective. The early detection and monitoring of oral diseases, progress in the treatment, and planning of surgical interventions rely largely on the precision of imaging techniques in visualizing the desired structures. Over the past decades, a wide variety of imaging modalities have been developed, and some of them have been commercially available, which utilize different mechanisms for oral structures imaging, boosting the resolution, accuracy, and sensitivity of visualizing the desired structures (S. Mantri & P. Mantri, 2013). Nevertheless, most of them are based on macroscale techniques, which restrict their performance when applied to small or early-stage lesions. Apart from this, some imaging techniques involve the use of high radiation dosage to achieve contrast and clarity, making the patients prone to hazards. Until now, clinical oral imaging mostly relies on plain radiography, optical imaging, and computed tomography techniques.

Combined with the advance on the nanoscale materials, oral imaging techniques based on nano-enabled technologies have drawn increasing attention that may address the aforementioned issues of current imaging techniques. The design and application of nanoscale materials could enhance the performance of the oral imaging techniques by providing a new imaging mechanism or acting as contrast agents. Potential benefits of nano-enabled oral imaging techniques include the capability to visualize small (or early-stage) lesions that can hardly be detected by the current techniques, significant decrease of radiation exposure for the patients, and the necessity for less complicated imaging procedures. The imaging techniques are discussed in the order of mechanisms from which the oral disease is detected, including techniques that passively rely on the diseased-targeted nanoparticles to improve the imaging contrast, techniques that take advantage of the in vitro diseased-targeted nanoparticles to upconvert the excitation signal into fluorescence or the imaging signal into a high harmonic signal, and techniques that actively apply nanoparticles in the imaging progress. Some efforts for the early detection of disease, monitoring of the treatment progress, and planning of surgical interventions are also reviewed. Finally, the issues that should be addressed before these advanced oral imaging technologies are translated from bench to bedside are briefly discussed. This review of the state-of-the-art of the nano-enabled oral imaging techniques is believed to promote more research efforts on the refinement of these techniques to be more widely applicable and effective in clinical use.

7. Applications in Nursing

Nanotechnology and physics have a vital impact on nursing practice. Nanoparticle application is the latest development in drug delivery systems, enhancing nursing care by improving precision in care delivery. Drugs administered through this technique take the form of nanoparticles like gold and silica. They are a few nanometers in size with a strong charge, allowing attachment with drugs and controlling their release. Nanoparticle-embedded drugs can detect the tumor cells and directly deliver the drug to the target site, minimizing side effects. This novel concept in biomedicine facilitates easier data management for nurses and reduces the risk of medication errors (Kapil et al., 2014).

Nanotechnology can transform wound healing nursing practices with the help of advanced nanotechnology-enabled materials. Chronic wounds require extensive nursing care, taking up to months for recovery and demanding several nursing hours. Designing nanostructured surfaces for dressing can prevent biofilm formation and bacterial attachment, hastening healing time and reducing the number of dress changes required. The healing process can be enhanced through the controlled delivery of growth factors for rapid tissue regeneration. These innovations minimize care time by nurses and provide better management of patients with chronic wounds (Salehahmadi & Hajiliasgari, 2013).

Nursing research focuses on the integration of nanotechnology innovations for regular tank monitoring of patients and their conditions using nanoscale monitoring devices. Nano-sized sensors assess body fluids like blood, urine, and sweat for monitoring patient conditions in real-time and alert nurses when attention is needed. Nanotechnology profoundly impacts nursing practices with ongoing research efforts in this integration. Nursing models would be based on the rapid assessment of changes in health conditions by integrating point-of-care testing with care delivery. Nursing care would be more personalized with the advancement of nursing practice in nanotechnology, predicting health conditions before the onset of the disease. Overall, nursing practice would be revolutionized with significant impacts from these technologies in the future.

7.1. Nanoparticles for Drug Delivery in Nursing Care

Nursing care is vital for patients receiving medication treatments. However, conventional systemic administration often leads drugs to non-target tissues, resulting in adverse effects. Local administration of medication avoids systemic delivery, but many drugs cannot permeate biologically protective barriers. Nanoparticles can encapsulate medications and deliver them through different parenteral routes to targeted tissues due to unique permeability. Targeted delivery enhances the effectiveness of medications and minimizes adverse effects. Nanoparticle-based drug delivery systems consist of nanoparticles with sizes ranging from 1-100 nm and can be hydrophilic or hydrophobic. Drugs are incorporated into nanoparticles via covalent linkage or simple encapsulation. Hydrophilic drugs are encapsulated in a hydrophilic polymer matrix or are polymer-drug conjugates, while hydrophobic drugs are linked to hydrophobic polymers or surfactants. Nanoparticles can passively accumulate at the target site through enhanced permeation and retention (EPR) effects or actively target tissues via ligands (Sonamuthu, 2019).

Nursing practice uses liposomes, nanospheres, polymeric nanoparticles, dendrimers, nanoemulsions, and others for drug delivery. Liposomes (50 nm-1.0 µm) are amphiphilic phospholipid nanoparticles approved for use in parenteral nutrition. Liposomal-encapsulated amphotericin B is a first-line antifungal for immunocompromised patients. Nanospheres are solid polymeric matrices for hydrophilic and lipophilic drug delivery. Biodegradable nanosphere-based fenoldopam mesylate delivery lowers hypotension and increases renal perfusion in acute renal failure. Polymeric nanoparticles (100 nm-1.0 μm) encapsulate hydrophilic drugs in biodegradable polymers. Bupivacaine nanoparticles prolong analgesic duration and hinder motor block in phrenic nerve blocks. Dendrimers (1-100 nm) are nanocarriers formed by repetitively branched polymers. Dendrimer-encapsulated ibuprofen outperforms free ibuprofen in articular pain models. Dendrimers target blood-brain barriers to treat neurological disorders. Nanoemulsions (50-500 nm) comprise oil, surfactant, and co-surfactant, enhancing solubility and stability of lipophilic drugs in parenteral and oral administration. These technologies can be implemented in nursing care, benefiting patients by reducing toxicity and improving treatment adherence.

Target tissues often require drug administration more than once a day. Nanoparticles can prolong drug delivery, permitting one or twice-a-day administration instead of multiple regimen steps. Subcutaneous injection of nanoparticle-encapsulated narcotics for pain relief can be adjusted upon assessing analgesia depth. However, development, fabrication, characterization, stability testing, and regulatory approval of nanoparticle-based delivery systems remain challenging. Most research is preclinical; clinical testing of nanoparticle-based delivery systems is rare. Nanoparticle physicochemical characteristics affect safety and biological action. Drug-free nanoparticles are tested for safety and biocompatibility before drugs are introduced into the delivery system. Nanoparticle size significantly impacts biodistribution. Travelling through blood circulation, larger nanoparticles accumulate in the liver and spleen, while smaller nanoparticles pass blood-brain barriers.

7.2. Nanotechnology in Wound Healing

Nanotechnology encompasses the design and application of structures, devices, and systems via the manipulation of matter on the nanoscale (1–100 nm). Nanotechnology has recently been integrated into modern nursing practices. Nanoparticles and nanomaterials exhibiting antimicrobial properties can promote faster recovery of patients with wounds. Different metals produce nanoparticles that can be used for wound care. Silver (Ag) is a widely used metallic nanoparticle due to its antibacterial properties. There are various forms of silver used for wound care, such as hydrogel, foam, cream, ointment, and non-adherent dressings. In addition, biopolymer-based hydrogel dressings containing silver nanoparticles have been developed. Zinc oxide (ZnO) nanoparticles also exhibit good antibacterial properties against a wide range of pathogens that can cause infection in chronic wounds. Hydrogel-based dressings with embedded ZnO nanoparticles have also been investigated. Copper oxide (CuO) nanoparticles can inhibit bacterial growth, promoting healing in diabetic rats. Mullite nanoceramic particles can inhibit bacterial biofilm formation, which is required for chronic wound care. Hydroxyapatite nanoparticles incorporated into polyvinyl alcohol dressings can reduce the bacterial count in infected wounds. This wide range of nanomaterials can create improved healing environments for patients with wounds (1).

Recent advances in nanotechnology have made it possible to develop smart dressings that can monitor wounds using wireless transmission of data. These dressings use a combination of materials, such as polymers and metal nanoparticles, that can change the conductivity based on the wound condition. Bandage materials can also release drugs in response to pH changes in the wound environment like smart hydrogel bandages. These innovations in nanotechnology can be greatly beneficial to patients. Most importantly, the smart dressings will be able to notify the caregiver regarding the status of the wound site, improving patient comfort. In addition, the bandages will be able to release drugs automatically without caregiver intervention. The current bandages used for chronic wounds usually require daily changes, which can be painful for patients. Using these smart dressing systems will lessen the needed frequency of dressing changes, as the caregiver will be informed only when it is necessary (Naskar & Kim, 2020). There are several benefits and potentials brought about by innovations in nanotechnology in the field of nursing. However, new technologies face challenges in clinical acceptance and need to overcome existing regulatory hurdles. The knowledge gap between engineers and health care professionals is another challenge to implementing new technologies in clinical practice. Nevertheless, thorough investigations of these issues and ongoing research efforts can lead to the development of novel solutions. For example, strategies to optimize the formulation of nanoparticles addressing a range of issues like effectiveness, safety, and the type of wound are being evaluated.

8. Challenges and Future Directions in Integrating Nanotechnology and Physics in Clinical Practice

The integration of nanotechnology and physics into medical practice is approached from the perspective of optometry, radiology, anesthesia, dentistry, and nursing. Examples are provided to demonstrate how these integrations can become part of everyday clinical practice. The selected areas of optometry, radiology, anesthesia, dentistry, and nursing represent a broader spectrum of currently integrated technologies and an insight into the future requirements and development of other clinical practices. While the integration of nanotechnology and physics is well established and ahead of the curve in some aspects, others are just developing or not addressed at all. These examples highlight the advances possible through integration and encourage others to adopt similar approaches. Each of the contributions addresses the integration of nanotechnology and physics from the clinical perspective of the discipline but also provides an insight into the discussion to other clinicians and the application of combined technologies in their practice.

Over the past two decades, nanotechnology has permeated various disciplines in science, engineering, and clinical practice. Nanotechnology is defined as technology that deals with materials at the nanoscale, typically between 1 and 100 nanometers. Materials in this size range exhibit unique physical and chemical properties differing from their bulk counterparts. Nanomaterials are routinely used in clinical practice, sometimes without consideration of their nanoscale properties. Nanotechnology-based innovations in health care have become a multibillion-dollar industry. It is expected to exceed USD 200 billion by 2025, with a significant proportion allocated to therapeutics and drug delivery. While currently marketed nanomedicines have a broad range of clinical applications, there are still unmet needs and diseases nanotechnology has yet to address (Đorđević et al., 2021).

Significant advances in research efforts have been made to develop novel biopharmaceuticals and optimize current ones using nanotechnology-based approaches. However, many of these developments still need to be translated into clinical settings. Beyond pharmacology, nanotechnology-based research and innovations have vast applications in the prevention, diagnosis, and treatment of diseases in other medical fields. Most research and development efforts focus on the design and optimization of nanoparticles with therapeutic effects, neglecting their engineering for safe and effective application in the clinic (I. Ramos et al., 2022). Currently, the most significant limitations to the translation of nanotechnology-based innovations into clinical practice are associated with the lack of understanding of nanomaterials' biological effects and interactions and the absence of standardization and regulation of nanotechnology-based systems and treatments. Also critical for translation is the complexity of bridging the gap between physicists, engineers, material scientists, and healthcare professionals who need to collaborate to successfully develop and implement nanotechnology-based systems and treatments.

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