Journal of Namibian Studies, 31 S3 (2022): 911-923 ISSN: 2197-5523 (online)

The Effectiveness Of Interventional Radiology Procedures In Treating Specific Conditions

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Abstract

The progress of vascular as well as interventional radiation therapy has been greatly expedited by the study of nanomaterials. The integration of nanoparticles with distinctive and practical characteristics into medical instruments and delivery methods has facilitated the development of innovative diagnostic and treatment techniques for a range of clinical illnesses. This paper examines the progress made in the area of interventional radiography and the use of nanotechnology to enhance the advantages and minimize the drawbacks of diagnostic radiology theranostic treatments. Various nanomaterials have been researched to enhance the effectiveness of interventional radiology procedures, mitigate the risks linked to medical equipment, enhance the precision and efficiency of medication delivery systems, and create novel imaging techniques. In this article, we provide a concise overview of the latest advancements in the field of medical equipment and delivery methods that integrate nanotechnology with vascular and radiation therapy.

Keywords: Interventional radiology, radiation therapy, nanotechnology, medical equipment.

1. Introduction

Interventional radiology (IR) is a modern branch of radiology that uses minimally-invasive techniques guided by medical imaging to diagnose and treat many disorders, such as cancers, cardiovascular conditions, and trauma or bleeding. In the field of Interventional Radiology (IR), there exists a significant historical record of technical advancements and creative breakthroughs that have facilitated the enhancement of medical treatments and equipment. Nanotechnology has had a significant impact on the field of IR because of its flexibility to be adjusted, which is very advantageous for creating and carrying out treatments that are minimally invasive for diagnosing and treating illnesses. Specifically, medical disorders that formerly necessitated invasive vascular surgery are now being more often treated using a minimally invasive interventional radiology (IR) method that is strengthened by nanotechnology.

Nanotechnology-based medical devices used in interventional radiology (IR) applications might be employed for diagnostic purposes, therapeutic purposes, or a combination of both, often known as theranostics. Various techniques have been investigated to create medical devices that include nanoparticles, tailored to the unique requirements of individual patients. Furthermore, many methods of integrating nanoparticles into medical devices have been investigated, contingent upon the properties of the nanoparticles used. Various categories of nanomaterials including nanowires, nanofibers, nanoparticles, quantum dots, and hollow spheres. The diverse physicochemical and mechanical features of these variants may be used to enhance the effectiveness of medical devices and delivery systems employed in interventional radiology procedures (Kargozar & Mozafari, 2018). Quantum dots are preferred over organic dyes for near infrared (NIR) fluorescence because to their superior photostability and ability to penetrate tissues effectively (Brunetti et al., 2018; Gil et al., 2021). Moreover, the minute dimensions of nanoparticles make them very advantageous in the field of drug administration, as they exhibit improved solubility and better bioavailability, enabling them to effectively target specific cells, tissues, or organs at this particular size.

Nevertheless, the implementation of nanotechnology in the realm of infrared (IR) encounters several obstacles. Researchers must still address significant concerns about possible short- and long-term toxicity in live individuals (Zhang, 2017). Although nanodevices have made great progress, their practical use in clinical settings has only improved gradually over the years (Arms et al., 2018; Sercombe et al., 2015). Kaushik (2019) proposed the need to reassess and enhance the development techniques used in nanomedicine via the establishment of partnerships between academia, industry, consortia, and research hospitals, as well as the regulatory framework governing advanced nanotechnology research. The rapid advancement of technology, together with the ongoing quest of scientific innovation, will accelerate the growth of nanotechnology in order to improve theranostic techniques and approaches in the field of infrared (IR) technology. This study focuses on various nanomaterials and nanodevices used in the field of infrared (IR) practice, specifically in the context of vascular applications.

2. Interventional radiology

Since Charles Dotter performed the first percutaneous angioplasty in 1964, the area of Interventional Radiology (IR) has continuously grown and now includes a wide range of techniques that address almost every system in the human body. Figure 1 depicts many prevalent pathological diseases that are treated using interventional radiology procedures .

The majority of procedures in interventional radiology (IR) utilize small, specialized instruments like needles, guidewires, sheaths, and catheters. These instruments are inserted through the skin and blood vessels to access the specific organ being targeted. The process is guided by advanced imaging techniques such as fluoroscopy, ultrasound, computerized tomography (CT), and magnetic resonance imaging (MRI). Due to its minimally invasive nature, IR techniques have the potential to decrease complications, shorten recovery time, and save healthcare costs, while yet achieving greater success rates compared to standard surgical methods. For instance, needle-access and imaging guidance may be used to substitute open operations for peripheral artery disorders (PAD) in some individuals, particularly for stenting and angioplasty procedures. Furthermore, the distinctive capability of infrared (IR) procedures to administer treatment directly into or near the target organ yields therapeutic advantages that cannot be achieved with conventional medical approaches.

Hepatocellular carcinoma often presents with the option of surgical resection or other interventional radiology therapies such microwave ablation or chemoembolization. Several studies have shown that endovascular techniques provide superior benefits compared to surgery for vascular diseases. The results of randomized clinical studies indicate that endovascular repair of abdominal aortic aneurysms leads to considerably reduced rates of death during the perioperative period and early stages, while maintaining comparable overall survival rates after 8 years of follow-up compared to open repair (Lederle et al., 2019). Endovascular procedures for treating varicose veins have shown high success rates (Kheirelseid et al., 2018), and there is emerging evidence to suggest a lower occurrence of postoperative complications, such as hematomas, infections, and paresthesia, compared to open surgery (Pan et al., 2014).

However, the execution of minimally invasive operations requires a distinct skill set possessed by a proficient surgeon, which may be restricted to specialist institutes exclusively (Pahwa et al., 2014). Although there is limited data on other interventional radiology procedures such as bronchial artery embolization for hemoptysis, CT-guided drainage of mediastinal abscesses, and emergency treatment of arterial injury following orthopedic surgery, studies have reported high success rates. In addition, catheter-directed thrombolysis for pulmonary embolism (PE) has been shown to result in fewer consequences compared to anti-coagulation alone, as revealed by Bloomer et al. in 2017.

Liu et al. (2020) revealed that uterine artery embolization is associated with less blood loss, shorter operating time, and reduced hospital stay compared to hysterectomy for postpartum hemorrhage. Significant cost savings have been observed in healthcare for the maintenance of dialysis access through interventional radiology procedures (Trivedi et al., 2020), the use of image-guided percutaneous drainage for gastrointestinal anastomotic leaks instead of surgical repair (Burke et al., 2015), and the insertion of chest ports in the interventional radiology suite (LaRoy et al., 2015).

IR techniques can come with drawbacks. Under some circumstances, the therapeutic efficacy of the treatments may be transient or of shorter duration compared to the surgical alternative. According to a research conducted by Gupta et al. in 2012, patients who received uterine artery embolization had a greater probability of requiring further surgical intervention at the two-year and five-year follow-up compared to those who underwent surgery. A meta-analysis found that percutaneous coronary intervention is linked to a decreased risk of major cardiovascular events in the short term, but an increased risk of long-term major adverse cardiac and cerebrovascular events in patients with left main coronary artery disease (Laukkanen et al., 2017). In addition, adverse events (AE) associated with interventional radiology (IR) procedures are few, but may nonetheless happen.

AEs often reported in the literature for IR treatments including poor device installation leading to infections (Higgins & Herpy, 2021), inappropriate procedures, and unnecessary radiation exposure (Tarkiainen et al., 2020). The occurrence of adverse events (AEs) resulting from medical mistakes may be avoided, and ongoing research in interventional radiology (IR) is primarily focused on reducing recognized clinical risks and devising innovative therapeutic approaches that have minimum negative consequences.

However, the discipline of interventional radiology (IR) is still growing and broadening the range of therapeutic possibilities, particularly for disorders that have few therapy alternatives available. Currently, many techniques including embolization, targeted administration of chemotherapy and radiation therapy, ablation methods, and electroporation are being studied for the treatment of solid tumors. Furthermore, these methods, in addition to drainage, stenting, shunt installation, vertebroplasty, and kyphoplasty, are used as palliative measures to enhance the quality of life for patients in late stages of cancer.

3. Nanotechnology is being used in the field of interventional radiology

Nanotechnology involves the creation of materials at the nanoscale size, which has several uses in medicine, including biosensors, microfluidics, drug delivery, microarray testing, and tissue engineering (Patra et al., 2018). In the field of interventional radiology (IR), nanotechnology is used to improve the effectiveness and efficiency of treatments by using innovative tools, imaging methods, and drug delivery systems that are minimally invasive.

Utilizing nanotechnology in infrared (IR) applications offers several benefits. Nanoparticles possess several advantageous characteristics due to their small size. Firstly, they have a high surface-to-volume ratio and large surface area, which leads to a high signal-to-noise ratio for imaging and medical device visualization. Secondly, they exhibit multifunctionality within a single carrier, resulting in longer circulation times and the ability to perform multimodal imaging. Lastly, nanoparticles can be specifically targeted to deliver high concentrations of contrast or therapeutic agents to a particular area of interest (Monsky et al., 2011). The integration of nanotechnology with infrared (IR) technology has significant promise in the field of customized medicine, enabling the precise treatment of specific medical conditions in individual patients at the optimal moment.

The literature search for this review was restricted to original studies published in 2017. Nanomaterials have often been used for imaging or treating different illnesses via medication delivery systems or improved medical equipment. Nanoparticles exhibit variations in their composition, physical and chemical attributes, as well as targeting qualities and potential metabolic consequences. Nevertheless, their overall adaptability enables advantageous and precise use in therapeutic settings. Various nanoparticles have been used as contrast agents, exhibiting exceptional sensitivity for diverse imaging techniques, including X-ray, CT, MRI, and optical or fluorescence imaging. For instance, artificial metal nanoparticles like bismuth, gadolinium, and tantalum have been widely used in X-ray and CT imaging. These elements possess large atomic numbers and exhibit great X-ray efficiency, making them appropriate for use as contrast agents.

Nanoparticles have been included into several medical devices, such as polymeric inferior vena cava filters (IVCFs), to enhance their visibility under X-ray imaging. Iron oxide nanoparticles are often used as contrast agents in MRI due to their distinctive superparamagnetic characteristics. Iron oxides are composed of either maghemite or magnetite (Ali et al., 2016). An illustrative instance is SPIOs, typically consisting of magnetite cores in nanoparticle size, covered with compounds like polysaccharide (Monsky et al., 2011). SPIO tracers have effectively detected gut bleeding in mouse models, indicating their potential utility as clinical diagnostic tools for gastrointestinal bleeding.

Due to their small size, ratio of surface area to mass, and capacity to bind, adsorb, and transport other substances; nanoparticles have been extensively used as therapeutic delivery systems. When developing nanoparticles for treatment, crucial factors to consider include biodistribution, excretion, and target site accumulation. Most therapeutic nanoparticles consist of chemotherapeutic medicines that are blended with polymeric nanoparticles. An example is the amalgamation of polymeric micellar paclitaxel and cisplatin for the therapy of non-small cell lung cancer, where the nanoparticles facilitated swifter and more profound infiltration of the tumor compared to solely albumin-bound nab-paclitaxel (Shi et al., 2021). Additional polymers used as nanoparticles include polyglycolic acid, mesoporous silica (Lu et al., 2018; Zhang et al., 2019), and hydrogels (He et al., 2020; Mannarino et al., 2020). The use of hydrogel coating has been utilized in vascular catheter access to decrease the deposition of thrombus (Mannarino et al., 2020). Metallic nanoparticles, including gold, silver, and iron, have been used as medication transporters, mediators for ablation, and aids in radiofrequency radiation treatment.

4. Summary

Nanotechnology's use in medicine has significant potential to profoundly influence human health by revolutionizing illness diagnosis, treatment, and prevention. Various nanoparticles and nanomaterials have been created and are still being developed to overcome the constraints of conventional techniques and technologies used in infrared (IR) applications. This study focuses on the use of nanoparticles in medical devices for enhanced diagnosis, therapy, and theranostic alternatives in the field of vascular radiology. Our main emphasis was on the use of nanotechnology in current vascular medical devices, including IVC filters, vascular access, and arteriovenous grafts. A number of these nanodevices have received FDA approval for their use in clinical settings, namely for applications such as drug-eluting vascular catheters and aneurysm coils. However, the majority of nanodevices and nano-drug delivery systems that have been examined in the last five years are still undergoing preclinical research.

Although there have been advancements in the use of nanoparticles in infrared (IR) applications, the bulk of these innovations that have been generated in the laboratory still need further improvement before they can be effectively applied in clinical practice. Significant endeavors have been undertaken in the field of oncology over the past 15 years to develop nanodevices capable of targeting tumor masses (Hernandez-Camarero et al., 2020). However, only a limited number of nanoformulations have received approval from the USFDA for clinical application. These include ONPATTRO Patisiran ALN-TTR02 (developed by Alnulam Pharmaceuticals) and VYXEOS CPX-351 (developed by Jazz Pharmaceuticals)

(Anselmo & Mitragotri, 2019). To enhance the translation efficiency of nanodevices, it is crucial to tackle difficulties related to formulation, standardization of procedures, toxicity, biocompatibility, and manufacturing costs.

However, the combination of infrared (IR) and nanotechnology enables a wide range of applications within the growing field of IR. The use of nanoparticle imaging contrasts, such as SPIONs, has proven effective. However, the integration of image fusion with these contrasts has great potential in medical imaging. This combination has the capability to detect diseases that are smaller than 1 nm in size (Manson et al., 2020). An additional promising prospect for the field of information retrieval (IR) is the synergistic use of nanotechnology and artificial intelligence (AI), particularly in the realm of medicine delivery systems. Nanotechnology has the capacity to develop adaptable carriers that may enhance the targeting of diseases in various locations. Similarly, AI has the ability to optimize medicine and dosage parameters tailored to individual patients or unique situations (Ho et al., 2019).

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