Review Article

A Review of Diagnostic Nano Stents: Part (I)

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ABSTRACT

The development of diagnostic nanostents, which blend stent design with nanotechnology to offer multipurpose capabilities, has greatly revolutionized medical diagnostics. Blood vessels can receive structural support and we have real-time diagnosis data from these state-of-art devices. To enhance the precision and efficacy of cardiovascular therapy, diagnostic nanostents are devices that incorporate imaging and diagnostic-oriented nanoparticles. Imaging agents, such as nanoparticles that respond to various imaging modalities, are included in medical imaging procedures to improve the visualization of blood vessels and surrounding tissues. Better diagnostic accuracy and early problem discovery are made possible for greater visibility. This review explores the potential benefits of diagnostic nanostents, including their dual ability to provide structural support and diagnostic skills. The use of nanomaterials that can enhance contrast makes real-time imaging during medical procedures possible and provides immediate feedback to healthcare professionals. Moreover, diagnostic nanostents advance the ideas of personalized medicine. Preclinical research, clinical trials, and more studies are required to verify the safety, efficacy, and utility of these diagnostic nanostents in medicine, despite their many potential advantages. Because of the interdisciplinary nature of research and the dynamic character of nanomedicine, diagnostic nanostents are positioned as a transformative technology that could completely change medical diagnostics in cardiovascular therapy.

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Content

1. Introduction

Cardiovascular diseases remain a global health challenge, necessitating continuous advancements in diagnostic and therapeutic approaches [1]. Diagnostic nanostents represent a revolutionary fusion of nanotechnology and interventional cardiology, offering a paradigm shift in the way we perceive and manage vascular conditions [2]. These innovative devices go beyond traditional stents, seamlessly integrating diagnostic capabilities into their structural support functions. The integration of nanotechnology into diagnostic nanostents brings unprecedented precision and versatility to cardiovascular diagnostics [3]. Nanomaterials, engineered at the nanoscale, not only provide mechanical reinforcement to blood vessels, but also serve as carriers for imaging agents and diagnostic functionalities [4]. This convergence of structural support and real-time diagnostic capabilities holds the potential to transform the landscape of cardiovascular interventions [5].

Diagnostic nanostents leverage nanotechnology to design stent materials with enhanced properties, including biocompatibility and imaging capabilities. Nanoscale engineering allows for the precise manipulation of material characteristics, contributing to the multifunctionality of these advanced medical devices [6]. Nanoparticles with imaging properties are seamlessly integrated into the stent design, serving as contrast agents for various imaging modalities. These imaging agents enhance the visibility of blood vessels and surrounding tissues, providing detailed and real-time diagnostic information during medical imaging procedures [7].

Diagnostic nanostents enable real-time imaging during interventions, offering immediate feedback to healthcare providers. This real-time diagnostic capability enhances the accuracy of procedures and contributes to early detection, thus, potentially improving patient outcomes [8]. By combining structural support with diagnostic functionalities, diagnostic nanostents offer a multifunctional approach to cardiovascular interventions. These devices aim to streamline the diagnostic workflow, reducing the need for separate diagnostic procedures and enhancing the efficiency of patient care [9].

The primary objective is to enhance the visualization of blood vessels and adjacent tissues during diagnostic procedures. Improved visibility contributes to accurate assessments of vascular conditions, enabling timely and targeted interventions [10]. Diagnostic nanostents aim to provide real-time diagnostic feedback to healthcare providers during interventions. This immediate feedback enhances decision-making, allowing for adjustments in real time based on the evolving diagnostic information [11]. The integration of nanotechnology allows for the customization of diagnostic approaches, aligning with the principles of personalized medicine. Diagnostic nano stents aim to tailor diagnostic procedures to individual patient characteristics, optimizing the diagnostic yield [12].

Despite the promising potential of diagnostic nanostents, challenges such as biocompatibility, regulatory approvals, and long-term safety need to be addressed. Ongoing research, interdisciplinary collaboration, and rigorous clinical testing are imperative to validate the safety, efficacy, and clinical utility of these innovative devices [13]. The introduction of diagnostic nanostents marks a significant leap forward in cardiovascular diagnostics, merging structural support with real-time imaging capabilities. As research progresses, the integration of nanotechnology into stent design is poised to redefine diagnostic precision and efficiency in cardiovascular interventions [14].

1.2. Research and methodologies

Research on diagnostic nanostents involves a multifaceted approach, combining principles from nanotechnology, materials science, imaging sciences, and clinical research [15]. The methodologies employed in studying diagnostic nanostents encompass a range of techniques, from the engineering of nanomaterials to preclinical and clinical evaluations. Material Selection: Researchers explore biocompatible nanomaterials suitable for stent construction, considering factors such as mechanical strength, degradation properties, and imaging capabilities [16].

Surface Modification: Nanomaterial surfaces may be engineered to enhance biocompatibility, reduce thrombogenicity, and improve imaging agent adherence. Nanoparticles or nanomaterials with imaging properties (e.g., magnetic, fluorescent, or radiopaque) are chosen as contrast agents. Methods for effectively loading imaging agents onto or into nanomaterials are explored, ensuring stability and sustained release during diagnostic procedures [17]. Nanotechnology-based fabrication techniques, such as lithography, self-assembly, or layer-by-layer assembly, are employed to create diagnostic nano stents with precise structural and imaging features [18] (Figure 1). Cell culture experiments assess the biocompatibility of diagnostic nanostents, examining cell adhesion, viability, and inflammatory responses. Animal Studies: Implantation of diagnostic nanostents in animal models provides insights into their biocompatibility within a living organism [19]. *In* vitro Imaging Studies: Researchers perform controlled imaging studies in simulated physiological conditions to evaluate the visibility and diagnostic efficacy of diagnostic nano stents. *Preclinical Imaging*: Animal studies involving diagnostic procedures (e.g., angiography, CT scans, MRI) assess the real-time diagnostic capabilities of the stents in a physiological context [20] (Table 1). The mechanical properties of diagnostic nanostents, including radial strength, flexibility, and durability, are evaluated through standardized testing methods [21]. Computational modeling helps predict and optimize the mechanical behavior of diagnostic nanostents under various physiological conditions [22]. Diagnostic nanostents may incorporate therapeutic agents for localized treatment. Methods for loading and releasing these agents are explored.

In vivo studies assess the release kinetics and systemic distribution of imaging and therapeutic agents, contributing to optimized diagnostic and therapeutic outcomes. Long-term studies in animal models evaluate the long-term safety, imaging performance, and biocompatibility of diagnostic nanostents [23-33] (Figure 2).

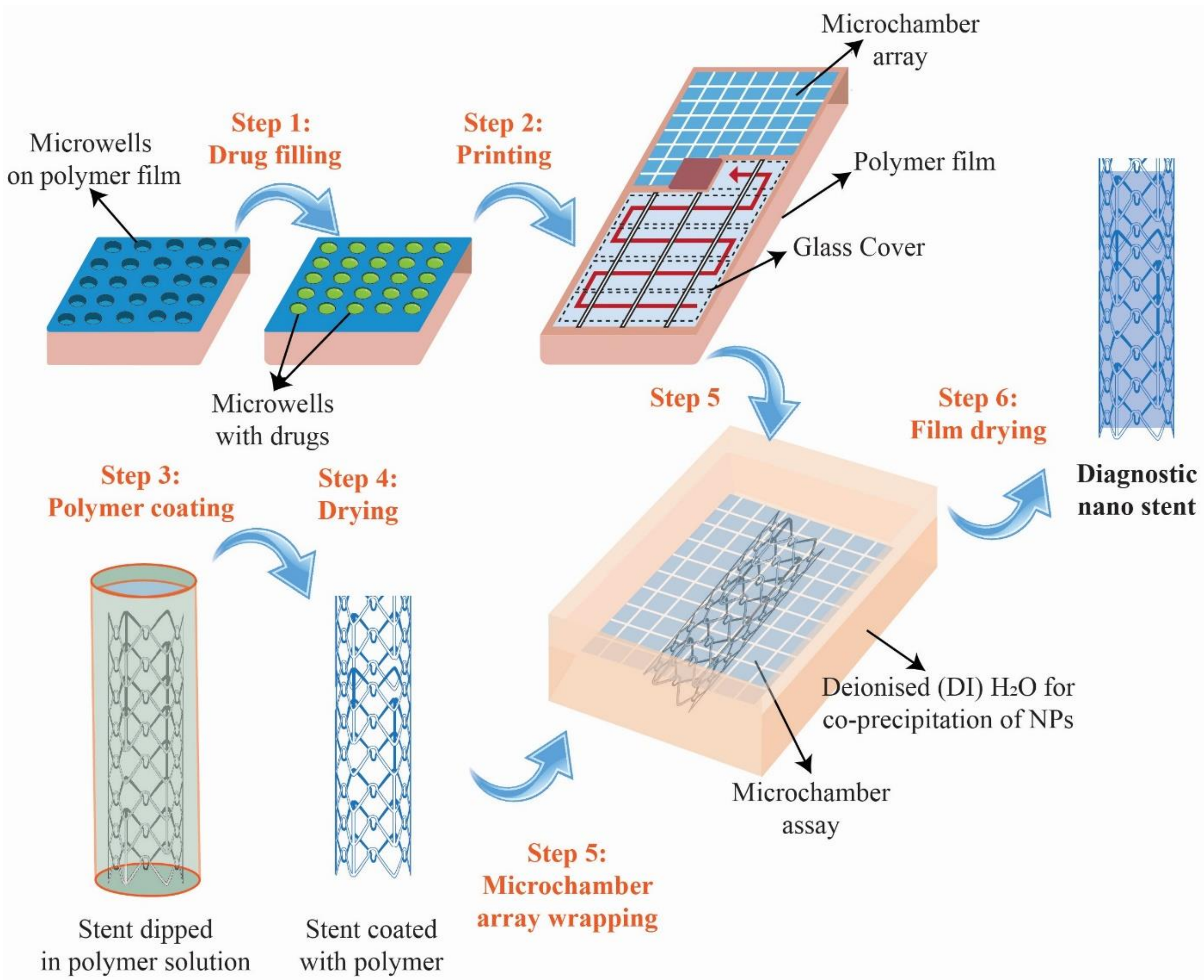

Figure 1. Diagnostic nano stent leverage nanotechnology to design drug loaded stent materials with enhanced biocompatibility

Table 1. Nanotechnology-based biosensors to detect biomarkers of CADs

Biomarker	Recognition	Nanomaterials	Methods	Linear range	LOD	Time [min]	Samples
Cardiac troponins(cTns)	Antibody	AuNP-Hep-xGnP	DPV	0.050-0.35 ng/mL	0.016 ng/mL	20	Whole blood
cTns	Antibody	Ag/CoSnanoflowers	ECL	0.1 fg/mL - 100 pg/mL	0.03 fg/mL	—	Human serum
Myoglobin	Antibody	Ag NPT/ITO	SERS	10 ng/mL - 5 µg/mL	10 ng/mL	—	Buffer, Urine
CK-MB	Antibody	Polypyrrole@Bi_2WO_6	PEC	0.5-2000 ng/mL	0.16 ng/mL	—	Blood
Multitargets	Antibody (cTnI, CRP)	TiO_2 nanofibrous	ELISA	10 pg/mL - 100 ng/mL	Multitarget	antibody [cTnI, CRP]	TiO_2 nano-fibrous
miRNAs	Complementary strands	Hollow Ag/Au NS	SERS with CHA	1 fM-10 nM	0.306 fM	—	Blood

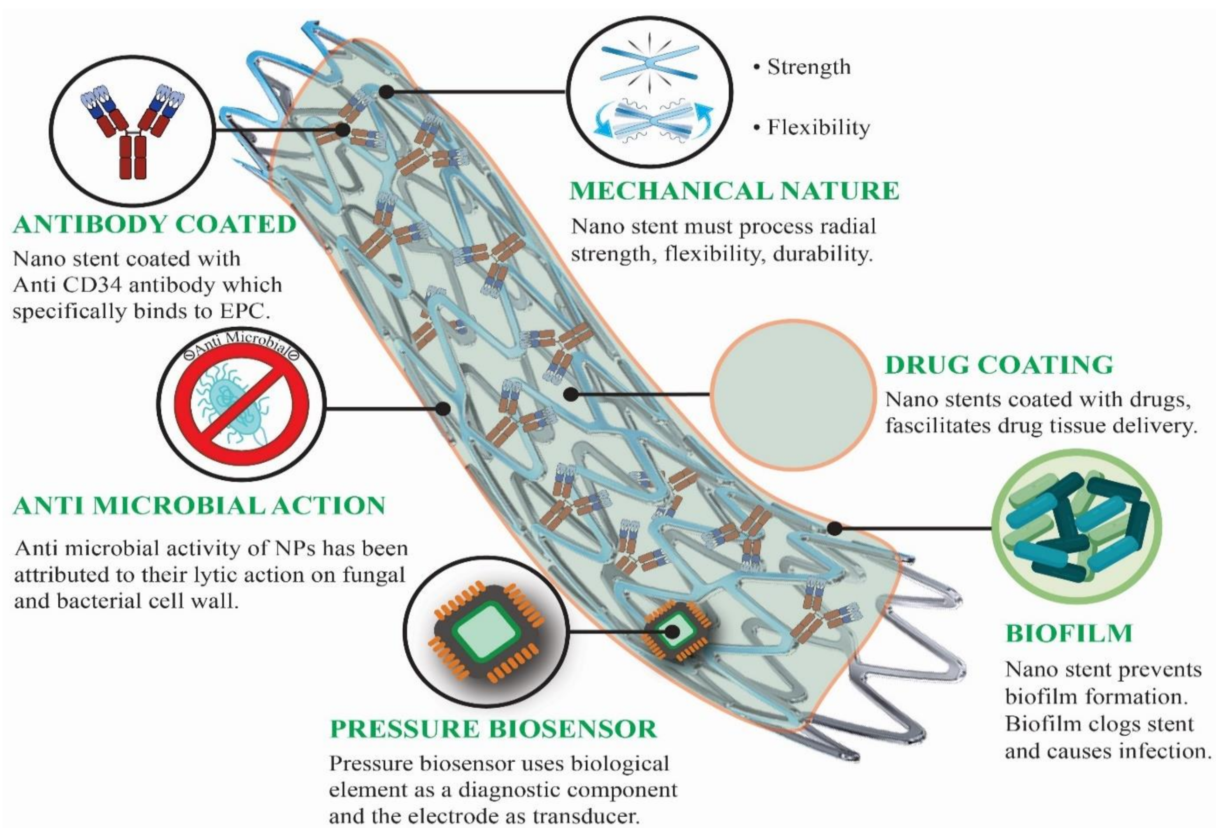

Figure 2. Properties of nano stents includes its mechanical nature (radial strength & flexibility) and its biochemical properties (antibody coated, anti-microbial action, drug coating, pressure biosensor, biofilm inhibition, *etc*.).

Phase I to III clinical trials involve human subjects to assess safety, diagnostic efficacy, and potential therapeutic benefits in real-world scenarios. *Post-Market Surveillance*: Continuous monitoring of patients who have received diagnostic nanostents provides data on their long-term safety, imaging performance, and clinical utility. Collaboration with regulatory agencies is essential to ensure compliance with safety and efficacy standards, leading to regulatory approvals for clinical use. The research methodologies employed in the development of diagnostic nanostents involve a combination of material engineering, imaging agent integration, biocompatibility assessments, mechanical testing, and comprehensive preclinical and clinical evaluations. These methods collectively contribute to advancing the understanding and application of diagnostic nanostents in cardiovascular interventions [34]. Nanotechnology may be employed to enhance the diagnostic capabilities of stents. For example, incorporating nanomaterials with imaging properties could improve visualization during medical imaging procedures. It is important to note that the development of nanostents is an active area of research, and specific types may emerge over time as researchers make advancements in nanotechnology and its application to medical devices [35].

The statement succinctly captures the essence of how nanotechnology can be harnessed to enhance the diagnostic capabilities of stents. By incorporating nanomaterials with imaging properties, such as nanoparticles that respond to imaging modalities like MRI or ultrasound, researchers aim to improve the visualization of blood vessels and surrounding tissues during medical imaging procedures. Accurately encapsulates the role of nanotechnology in enhancing the diagnostic capabilities of stents. The incorporation of nanomaterials with imaging properties, such as nanoparticles responsive to modalities like MRI or ultrasound, is a strategy aimed at improving the visualization of blood vessels and surrounding tissues during medical imaging procedures.

2. Nanotechnology Integration

The integration of nanotechnology into stent design involves incorporating nanomaterials with specific properties, such as imaging capabilities, to augment their functionality. The statement succinctly captures a key aspect of the integration of nanotechnology into stent design. The incorporation of nanomaterials with specific properties, particularly imaging capabilities, is a strategic approach to enhance the overall functionality of stents. Nanotechnology enables the design and engineering of materials at the nanoscale with tailored properties. This customization allows stent developers to choose materials that serve specific functions, such as imaging, drug delivery, or biocompatibility [36-52]. Nanomaterials encompass a wide range of substances, including nanoparticles, nanotubes, and nanocomposites. Each type of nanomaterial offers unique properties that can be harnessed to enhance various aspects of stent functionality. The integration of nanomaterials with imaging capabilities directly contributes to improved diagnostic capabilities [53]. For instance, nanoparticles designed for contrast enhancement can enhance the visibility of blood vessels and surrounding tissues during medical imaging procedures. Some nanomaterials can be engineered to respond to specific stimuli, such as magnetic fields or ultrasound waves. This responsiveness can be utilized to create smart stents that actively contribute to diagnostics or therapeutic interventions. Nanotechnology facilitates the development of multifunctional stents that can perform several tasks simultaneously [54-70].

For example, a stent may incorporate nanomaterials for drug delivery, imaging enhancement, and surface modification to improve biocompatibility. Nanoscale engineering allows for precise control over the properties of the incorporated nanomaterials. This precision enables stent designers to fine-tune the functionality of the stent according to specific medical requirements [71-90]. The choice of nanomaterials is crucial for ensuring biocompatibility. While enhancing functionality, the nanomaterials used in stents mustn't induce adverse reactions or immune responses within the body. Nanotechnology can be applied to develop advanced coatings for stents. These coatings may have properties such as hydrophilicity, anti-thrombogenicity, or anti-inflammatory effects, contributing to the overall performance and safety of the stent. Beyond imaging, nanotechnology plays a significant role in targeted drug delivery [91].

Stents can be designed to release therapeutic agents precisely at the site of action, preventing restenosis or promoting healing after interventions. The field of nanotechnology in stent design is dynamic, with ongoing research focusing on optimizing nanomaterial properties and exploring new functionalities. This continuous innovation contributes to the evolution of stent technology. The integration of nanotechnology into stent design is a promising avenue that allows for the incorporation of nanomaterials with specific properties, especially imaging capabilities, to enhance the overall functionality of stents. This approach holds great potential for advancing both diagnostics and therapeutic interventions in the field of interventional medicine [92] (Figure 3).

2.2. Imaging nanoparticles

Nanoparticles engineered with imaging properties play a crucial role in enhancing diagnostic capabilities. These nanoparticles can respond to various imaging modalities, including magnetic resonance imaging [MRI], ultrasound, or other techniques used in medical imaging. The statement accurately highlights the critical role that nanoparticles with imaging properties play in advancing diagnostic capabilities. Nanoparticles designed for imaging often serve as contrast agents, enhancing the contrast between tissues of interest and their surroundings (Tables 2 and 3).

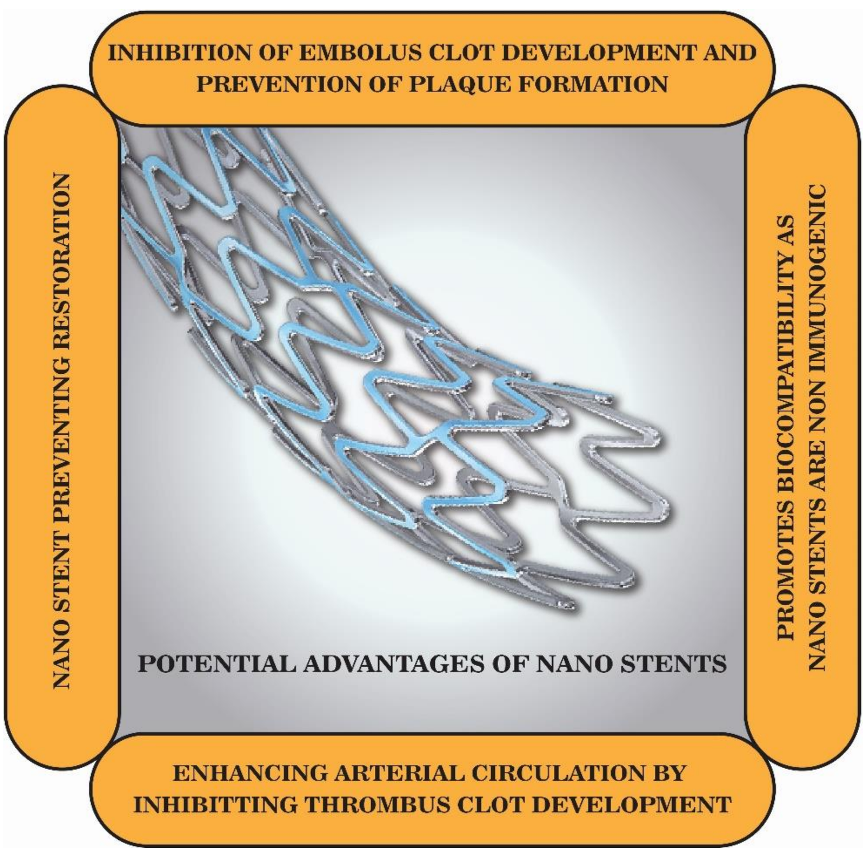

Figure 3. Integration of nanotechnology in stent design allows the incorporation of nanomaterials with specific properties, especially imaging capabilities, to enhance the overall functionality of stents.

Table 2. Nanoparticles designed for imaging often serve as contrast agents, enhancing the contrast between tissues or structures of interest and their surroundings by Bottom-Up method

S. No.	Bottom-up method	Merits	Demerits	General remarks
1	Atomic layer deposition	Allows digital thickness control to the atomic level precision by depositing one atomic layer at a time, pin-hole free nanostructured films over large areas, good reproducibility, and adhesion due to the formation of chemical bonds at the first atomic layer	Usually a slow process, also an expensive method due to the involvement of vacuum components, difficulty in depositing certain metals, multicomponent oxides, and certain technologically important semiconductors (Si, Ge, *etc.*) in a cost-effective way	Although a slow process, it is not detrimental to the fabrication of future-generation ultra-thin ICs. The stringent requirements for the metal barriers (pure; dense; conductive; conformal; and thin) that are employed in modern Cu-based chips can be fulfilled by atomic layer deposition
2	Sol gel nanofabrication	A low-cost chemical synthesis process-based method, fabrication of a wide variety of nanomaterials including multicomponent materials (glass, ceramic, film, fiber, and composite materials)	Not easily scalable, usually difficult to control synthesis and the subsequent drying steps	A versatile nanofabrication method that can be made scalable with further advances in the synthesis steps
3	Molecular self-assembly	Allows self-assembly of deep molecular nanopatterns of width less than 20 nm and with the large pattern stretches, generates atomically precise nanosystems	Difficult to design and fabricate nanosystems unlike mechanically directed assembly	Molecular self-assembly of multiple materials may be a useful approach in developing multifunctional nanosystems and devices
4	Physical and chemical vapor-phase deposition	Versatile nanofabrication tools for fabrication of nanomaterials including complex multicomponent nanosystems (e.g., nanocomposites), controlled simultaneous deposition of several materials including metal, ceramics, semiconductors, insulators and polymers, high purity nanofilms, a scalable process, possibility to deposit porous nanofilms	Not cost-effective because of the expensive vacuum components, high-temperature process, and toxic and corrosive gases particularly in the case of chemical vapor deposition	It provides a unique opportunity for the nanofabrication of highly complex nanostructures made of distinctly different materials with different properties that are not possible to accomplish using most of the other nanofabrication techniques. New advances in chemical vapor deposition such as 'initiated chemical vapor deposition' [i-CVD] provide unprecedented opportunities for depositing polymers without reduction in the molecular weights

Table 2. Continued

S. No.	Bottom-up method	Merits	Demerits	General remarks
5	DNA-scaffolding	Allows high-precision assembling of nanoscale components into programmable arrangements with much smaller dimensions (less than 10 nm in half-pitch)	Many issues need to be explored, such as novel unit and integration processes, compatibility with CMOS fabrication, line edge roughness, throughput, and cost	Very early stage. Ultimate success depends on the willingness of the semiconductor industry in terms of need, infrastructural capital investment, yield, and manufacturing cost
6	Atomic layer deposition	Allows digital thickness control to the atomic level precision by depositing one atomic layer at a time, pin-hole free nanostructured films over large areas, good reproducibility, and adhesion due to the formation of chemical bonds at the first atomic layer	Usually a slow process, also an expensive method due to the involvement of vacuum components, difficulty in depositing certain metals, multicomponent oxides, and certain technologically important semiconductors (Si, Ge, etc.) in a cost-effective way	Although a slow process, it is not detrimental to the fabrication of future-generation ultra-thin ICs. The stringent requirements for the metal barriers (pure; dense; conductive; conformal; and thin) that are employed in modern Cu-based chips can be fulfilled by atomic layer deposition
7	Sol gel nanofabrication	A low-cost chemical synthesis process-based method, fabrication of a wide variety of nanomaterials including multicomponent materials (glass, ceramic, film, fiber, composite materials)	Not easily scalable, usually difficult to control synthesis and the subsequent drying steps	A versatile nanofabrication method that can be made scalable with further advances in the synthesis steps
8	Molecular self-assembly	Allows self-assembly of deep molecular nanopatterns of width less than 20 nm and with the large pattern stretches, generates atomically precise nanosystems	Difficult to design and fabricate nanosystems unlike mechanically directed assembly	Molecular self-assembly of multiple materials may be a useful approach in developing multifunctional nanosystems and devices

Table 2. Continued

9	Physical and chemical vapor-phase deposition	Versatile nanofabrication tools for fabrication of nanomaterials including complex multicomponent nanosystems (e.g., nanocomposites), controlled simultaneous deposition of several materials including metal, ceramics, semiconductors, insulators and polymers, high purity nanofilms, a scalable process, possibility to deposit porous nanofilms	Not cost-effective because of the expensive vacuum components, high-temperature process, and toxic and corrosive gases particularly in the case of chemical vapor deposition	It provides a unique opportunity for nanofabrication of highly complex nanostructures made of distinctly different materials with different properties that are not possible to accomplish using most of the other nanofabrication techniques. New advances in chemical vapor deposition such as 'initiated chemical vapor deposition' (i-CVD) provide unprecedented opportunities for depositing polymers without reduction in the molecular weights

Table 3. Nanoparticles designed for imaging often serve as contrast agents, enhancing the contrast between tissues or structures of interest and their surroundings by Top-Down method

S. No.	The top–down method	Merits	Demerits	General remarks
1	Optical lithography	Long-standing, established micro/nanofabrication tool especially for chip production, sufficient level of resolution at high throughputs	Tradeoff between resist process sensitivity and resolution involves state-of-the-art expensive clean room-based complex operations	The 193 nm lithography infrastructure already reached a certain level of maturity and sophistication, and the approach could be extended to extreme ultraviolet (EUV) sources to shrink the dimension. Also, future developments need to address the growing cost of a mask set
2	E-beam lithography	Popular in research environments, an extremely accurate method and effective nanofabrication tool for <20 nm nanostructure fabrication with desired shape	Expensive, low throughput and a slow process (serial writing process), difficult for <5 nm nanofabrication	E-beam lithography beats the diffraction limit of light, capable of making periodic nanostructure features. In the future, multiple electron beam approaches to lithography would be required to increase the throughput and degree of parallelism

Table 3. Continued

S. No.	The top–down method	Merits	Demerits	General remarks
3	Soft and nanoimprint lithography	Pattern transfer-based simple, effective nanofabrication tool for fabricating ultra-small features (<10 nm)	Difficult for large-scale production of densely packed nanostructures, also dependent on other lithography techniques to generate the template, and usually not cost-effective	Self-assembled nanostructures could be a viable solution to the problem of complex and costly template generation and for templates of periodic patterns of <10 nm
4	Block co-polymer lithography	A high-throughput, low-cost method, suitable for large-scale densely packed nanostructures, diverse shapes of nanostructures, including spheres, cylinders, and lamellae possible to fabricate including parallel assembly	Difficult to make self-assembled nanopatterns with variable periodicity required for many functional applications, usually high defect densities in block copolymer self-assembled patterns	The use of triblock copolymers is promising to generate more exotic nanopattern geometries. Likewise, functionalization of parts of the block copolymer could be done to achieve a hierarchy of nanopatterning in a single-step nanofabrication process
5	Scanning probe lithography	High-resolution chemical, molecular and mechanical nanopatterning capabilities, accurately controlled nanopatterns in resists for transfer to silicon, ability to manipulate big molecules and individual atoms	Limited for high throughput applications and manufacturing, an expensive process, particularly in the case of ultra-high-vacuum-based scanning probe lithography	Scanning probe lithography can be leveraged for advanced bio nanofabrication that involves the fabrication of highly periodic biomolecular nanostructures

This increased contrast improves the visibility of specific areas during diagnostic imaging. Nanoparticles can be tailored to respond to magnetic fields, making them suitable for enhancing images in MRI scans. Magnetic nanoparticles, in particular, exhibit unique properties that make them effective as contrast agents in MRI procedures. *Ultrasound Imaging*: Nanoparticles can be engineered to enhance ultrasound imaging, providing improved resolution and clarity. Contrast agents composed of microbubbles or nanobubbles, for example, can enhance the visibility of blood vessels and tissues during ultrasound examinations.

Some nanoparticles exhibit fluorescence properties, allowing them to emit light when exposed to specific wavelengths. This property is valuable for fluorescence imaging techniques, providing a visual indicator for the presence of certain structures or molecules. Nanoparticles can be utilized in photoacoustic imaging, a technique that combines laser-induced ultrasound and optical imaging. This approach allows for the visualization of structures with high resolution and sensitivity. Engineered nanoparticles can be designed to respond to external stimuli, such as light, heat, or magnetic fields.

This responsiveness can be exploited to control the release of imaging signals or to modulate contrast during imaging procedures. Nanoparticles can be functionalized by targeting ligands, allowing for targeted imaging of specific cells or tissues. This targeted approach improves the accuracy of diagnostics by focusing on areas of interest. Engineered nanoparticles are valuable tools in studying the biodistribution of drugs or contrast agents in the body. They can be labeled with imaging moieties, allowing researchers to track their movement and accumulation in real time. The integration of therapeutic and diagnostic functions, known as theragnostic, involves using nanoparticles for both imaging and drug delivery.

This approach enables personalized medicine by tailoring treatments based on real-time imaging data. Engineered nanoparticles can contribute to non-invasive imaging methods, reducing the need for more invasive diagnostic procedures. This is particularly advantageous for patient comfort and safety. Nanoparticles with imaging properties enable real-time monitoring of biological processes. This capability is crucial for dynamic studies, such as tracking the movement of drugs or visualizing changes in tissues over time. Engineered nanoparticles for imaging have applications in both research and clinical settings. In research, they contribute to understanding disease mechanisms, while in clinical practice; they enhance the accuracy of diagnostic procedures.

Nanoparticles with imaging properties represent a powerful tool in medical imaging, contributing to enhanced diagnostic capabilities across various modalities. Their versatility and ability to respond to specific imaging techniques make them valuable assets in advancing the field of diagnostic medicine [93].

2.3. Improved visualization

The primary goal of incorporating imaging nanomaterials is to enhance the visualization of blood vessels and surrounding tissues. This improvement is particularly important for obtaining detailed and clear images during diagnostic procedures. Accurately emphasizes the primary goal of incorporating imaging nanomaterials in medical applications, especially in the context of enhancing the visualization of blood vessels and surrounding tissues. Improved Resolution: Imaging nanomaterials contributes to improved resolution in diagnostic imaging. The smaller size and specific properties of these nanomaterials enhance the clarity and sharpness of images, allowing for a more detailed view of anatomical structures. The incorporation of imaging nanomaterials as contrast agents significantly enhances the contrast between blood vessels or tissues of interest and their surroundings. This heightened contrast is crucial for distinguishing subtle differences and abnormalities in diagnostic images. Nanomaterials can be engineered to accumulate specifically in target areas, enabling precise localization during imaging. This targeted approach is valuable for identifying and assessing specific regions of interest within the body. The improved visualization facilitated by imaging nanomaterials contributes to the early detection of abnormalities.

Early identification of conditions such as tumors, lesions, or vascular issues enhances the potential for timely intervention and improved patient outcomes. Some imaging nanomaterials can serve dual roles by providing both structural and functional information. For instance, they may highlight not only the anatomy of blood vessels, but also provide insights into physiological processes such as blood flow or cellular activity. The use of imaging nanomaterials supports non-invasive evaluation of tissues and organs. This is particularly advantageous for patients who may benefit from diagnostic procedures without the need for invasive interventions. Nanomaterials enable real-time monitoring during diagnostic procedures. This capability is essential for dynamic studies, allowing healthcare professionals to observe changes in blood flow, tissue perfusion, or other physiological parameters in real time. The incorporation of imaging nanomaterials facilitates quantitative imaging, allowing for the measurement and analysis of parameters such as blood flow velocity, tissue perfusion, or molecular concentrations. This quantitative information adds precision to diagnostic assessments. Nanomaterials can be designed for multimodal imaging, where they respond to multiple imaging modalities. This approach provides complementary information, improving the overall diagnostic assessment and reducing the reliance on a single imaging technique. The enhanced visualization achieved with imaging nanomaterials contributes to patient-friendly imaging experiences.

It may reduce the need for repeated imaging sessions and enhance the overall efficiency of diagnostic procedures. Imaging nanomaterials are designed to seamlessly integrate with existing imaging technologies, allowing for their widespread adoption in clinical practice without significant modifications to current diagnostic protocols. The incorporation of imaging nanomaterials aims to enhance the visualization of blood vessels and surrounding tissues, thereby improving the quality and informativeness of diagnostic images. This advancement is pivotal for achieving more accurate diagnoses, facilitating early detection, and contributing to the overall effectiveness of diagnostic procedures in healthcare [94].

2.4. Responsive to specific modalities

Nanoparticles can be designed to respond selectively to specific imaging modalities. For instance, magnetic nanoparticles may enhance visibility in MRI scans, while other types of nanoparticles could be tailored for ultrasound imaging highlighting a key aspect of the versatility of nanoparticles in medical imaging namely, their ability to be selectively designed for specific imaging modalities. Nanoparticles can be engineered to respond selectively to distinct imaging modalities, tailoring their properties for optimal enhancement in specific diagnostic techniques. Magnetic nanoparticles, such as superparamagnetic iron oxide nanoparticles, are particularly effective in enhancing visibility in magnetic resonance imaging (MRI). These nanoparticles respond to the magnetic fields generated during an MRI scan, producing contrast that aids in visualizing anatomical structures and detecting abnormalities.

Other types of nanoparticles can be specifically designed for ultrasound imaging. Nanoparticles, including microbubbles or nanobubbles, respond to ultrasound waves by oscillating or bursting, creating a contrast that improves the visibility of tissues and blood vessels during ultrasound examinations. Fluorescent nanoparticles emit light when exposed to specific wavelengths, making them suitable for optical imaging techniques. These nanoparticles are valuable in applications such as fluorescence microscopy or in vivo imaging where their fluorescence enhances visualization.

Nanoparticles can be engineered for photoacoustic imaging, a technique that involves converting laser-induced energy into ultrasound signals. Gold nanoparticles, for example, are often used for their strong photoacoustic response, aiding in the tissues visualization with high resolution. Advances in nanotechnology allow the development of multimodal nanoparticles that respond to multiple imaging modalities. These versatile nanoparticles provide complementary information, improving diagnostic accuracy by combining the strengths of different imaging techniques. Nanoparticles can be designed to respond to external stimuli beyond traditional imaging modalities.

This responsiveness might include reactions to changes in pH, temperature, or specific biochemical environments, enabling tailored imaging responses based on the conditions at the target site. The surface properties of nanoparticles can be customized to achieve optimal interaction with imaging devices. Surface modifications may include the attachment of targeting ligands or coatings that enhance the stability and performance of nanoparticles in specific imaging environments [95] (Figure 4).

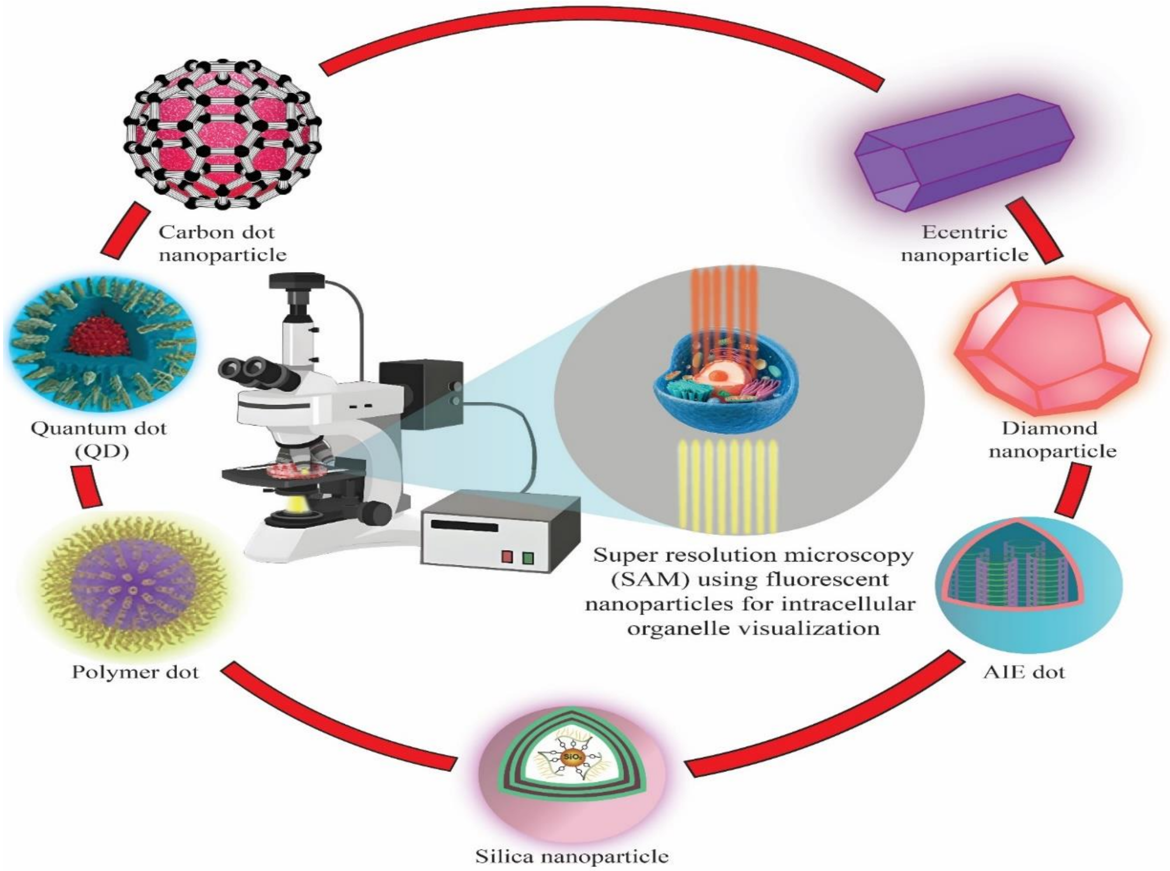

Figure 4. Fluorescent nanoparticles emit light when exposed to specific wavelengths, making them suitable for intracellular optical imaging

Nanoparticles designed for specific imaging modalities contribute to real-time monitoring during the diagnostic procedures. This capability is essential for capturing dynamic changes and assessing physiological processes as they occur. Functionalized nanoparticles can target specific biomarkers associated with diseases. This targeted approach enables the selective imaging of diseased tissues or cells, offering a higher degree of precision in diagnostics.

The continual advancements in nanomedicine contribute to the development of increasingly sophisticated nanoparticles with enhanced imaging capabilities. Ongoing research explores new materials and designs for nanoparticles to further improve their performance in diverse imaging applications. The selective design of nanoparticles for specific imaging modalities showcases the adaptability of nanotechnology in tailoring contrast agents to the unique requirements of each diagnostic technique. This tailored approach contributes to the advancement of imaging technologies, supporting more accurate and detailed diagnostics in various medical applications [96].

2.5. Contrast enhancement

Nanoparticles can serve as contrast agents, enhancing the contrast between blood vessels and adjacent tissues. This heightened contrast improves the clarity of images, aiding healthcare professionals in making accurate diagnoses. Succinctly captures the crucial role that nanoparticles play in medical imaging as contrast agents.

Nanoparticles enhance the contrast in medical images by selectively accumulating in specific tissues or structures. This contrast enhancement is particularly valuable in distinguishing between different types of tissues and highlighting areas of interest. The heightened contrast provided by nanoparticles contributes to improved clarity in diagnostic images. This improved clarity allows healthcare

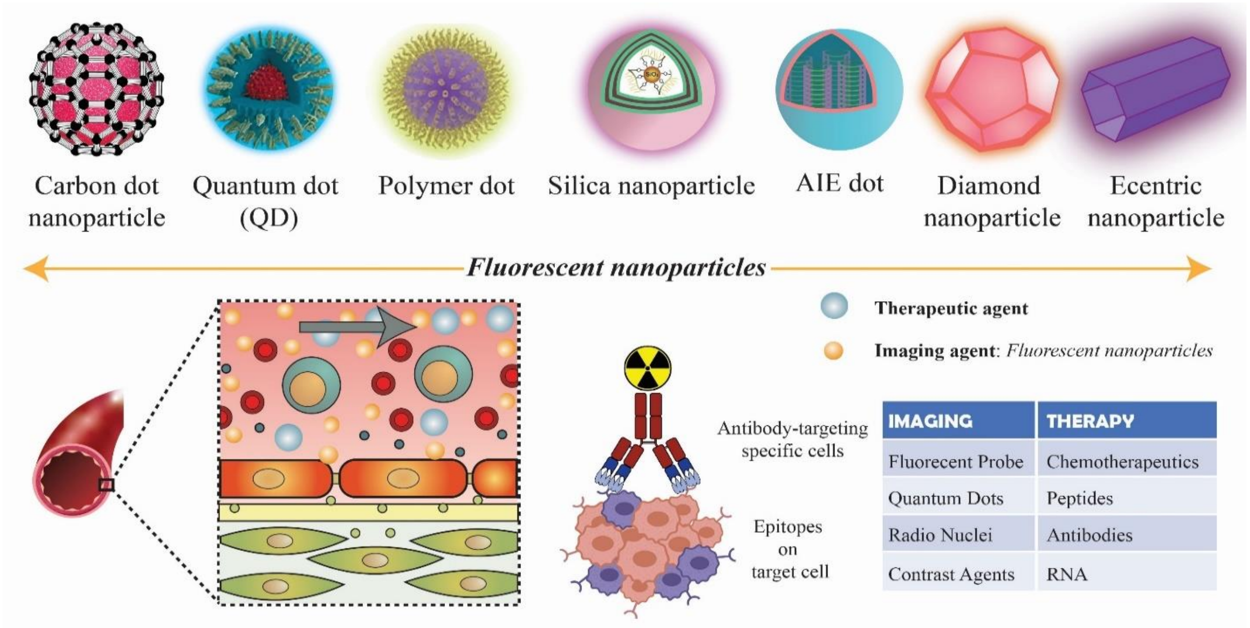

Figure 5. Fluorescent nanoparticles are used to enhance the visualization of blood vessels during imaging procedure

professionals to visualize anatomical structures, blood vessels, and abnormalities with greater precision. Nanoparticles are often utilized to enhance the visualization of blood vessels during imaging procedures (Figure 5).

This is critical in various medical fields, including cardiology, radiology, and vascular surgery where detailed imaging of vascular structures is essential for diagnosis and treatment planning. The enhanced clarity and contrast facilitated by nanoparticle-based contrast agents' aid healthcare professionals in making more accurate and reliable diagnoses. This is particularly beneficial for detecting subtle abnormalities or early signs of diseases. By improving the distinction between different tissues and structures, nanoparticle contrast agents help reduce ambiguity in diagnostic images. This reduction in ambiguity is crucial for avoiding misinterpretations and ensuring the accuracy of diagnostic assessments. Nanoparticles can be tailored to optimize specific imaging modalities, such as magnetic resonance imaging [MRI], computed tomography [CT], ultrasound, and optical imaging.

This versatility allows for the customization of contrast agents based on the requirements of the imaging technique. Functionalized nanoparticles can be designed for targeted contrast enhancement, concentrating the contrast agent specifically in areas of interest. This targeted approach further improves the precision of imaging and reduces the background noise in diagnostic images. The use of nanoparticles as contrast agents enables real-time imaging during medical procedures. This real-time visualization is valuable in interventions, surgeries, and other dynamic processes where immediate feedback is essential for decision-making. The use of nanoparticle-based contrast agents contributes to patient-friendly imaging experiences. The enhanced clarity and reduced ambiguity in images may decrease the need for additional imaging sessions, minimizing inconvenience for patients. Some nanoparticles used as contrast agents may have theragnostic capabilities, combining both diagnostic and therapeutic functions. This approach allows for simultaneous imaging and targeted therapy, fostering a personalized medicine approach. The development of biocompatible nanoparticle contrast agents is crucial to ensure their safe use in medical imaging. Biocompatible materials help minimize adverse reactions and ensure the overall safety of the imaging procedure.

Nanoparticles serving as contrast agents significantly contribute to the field of medical imaging by enhancing contrast, improving clarity, and aiding in accurate diagnoses. Their versatility and adaptability across various imaging modalities make them valuable tools for healthcare professionals seeking detailed and reliable information during diagnostic procedures [97].

2.6. Real-time imaging

The use of nanomaterials allows for real-time imaging during medical procedures. This capability is valuable for monitoring changes in blood vessels or tissues dynamically, providing immediate feedback to healthcare providers. Accurately highlights a significant advantage of using nanomaterials in medical imaging the ability to enable real-time imaging during medical procedures. Nanomaterials contribute to real-time imaging by providing continuous and dynamic monitoring of changes in blood vessels, tissues, or other relevant biological structures. This capability allows healthcare providers to observe and analyze dynamic processes as they occur. Real-time imaging with nanomaterials offers healthcare providers immediate feedback during medical procedures.

This prompt information is crucial for making timely decisions, adjusting interventions, or addressing unexpected changes in real time. In surgical settings, real-time imaging facilitated by nanomaterials is particularly valuable. Surgeons can visualize the targeted area with enhanced clarity and make precise adjustments during procedures, potentially improving the overall surgical outcome. In interventional radiology procedures, where minimally invasive interventions are performed under imaging guidance, real-time imaging allows for precise navigation of catheters or devices to the target site. This enhances the accuracy of interventions such as angioplasty, stent placement, or embolization. Nanomaterial-enhanced real-time imaging provides intraoperative guidance, helping surgeons navigate through complex anatomical structures. This is beneficial for procedures that require a high degree of precision, such as tumor resections or vascular surgeries. In cardiac interventions, real-time imaging with nanomaterials can be vital for visualizing blood flow, assessing valve function, or guiding the placement of devices like stents.

This capability contributes to the success and safety of cardiac procedures. Real-time imaging becomes critical in emergency situations where quick decisions and interventions are essential. Nanomaterial-enhanced imaging allows healthcare providers to rapidly assess and respond to dynamic changes in the patient's condition. The immediate feedback provided by real-time imaging can help streamline procedures, potentially reducing the overall time required for interventions. This is advantageous for both patients and healthcare providers. Real-time imaging assists healthcare providers in optimizing treatment strategies based on the observed dynamics. It enables them to adapt interventions in real-time, tailoring the approach to the specific needs and conditions of the patient.

Nanomaterials used in real-time imaging support continuous monitoring throughout the duration of a medical procedure. This continuous assessment is particularly valuable for detecting subtle changes or complications that may arise during the intervention. The combination of nanomaterials and real-time imaging enhances precision in medical procedures. Healthcare providers can visualize structures and navigate instruments with a level of accuracy that may not be achievable with conventional imaging techniques. Real-time imaging facilitated by nanomaterials is a transformative capability in medical procedures, providing immediate and dynamic visualization. This advancement is instrumental in improving the accuracy, efficiency, and outcomes of a wide range of medical interventions, from surgeries to interventional radiology procedures [98].

2.7. Site-specific imaging

Nanotechnology enables the development of stents with site-specific imaging capabilities. This means that the imaging properties are focused on the area surrounding the stent, providing targeted diagnostic information accurately captures one of the innovative

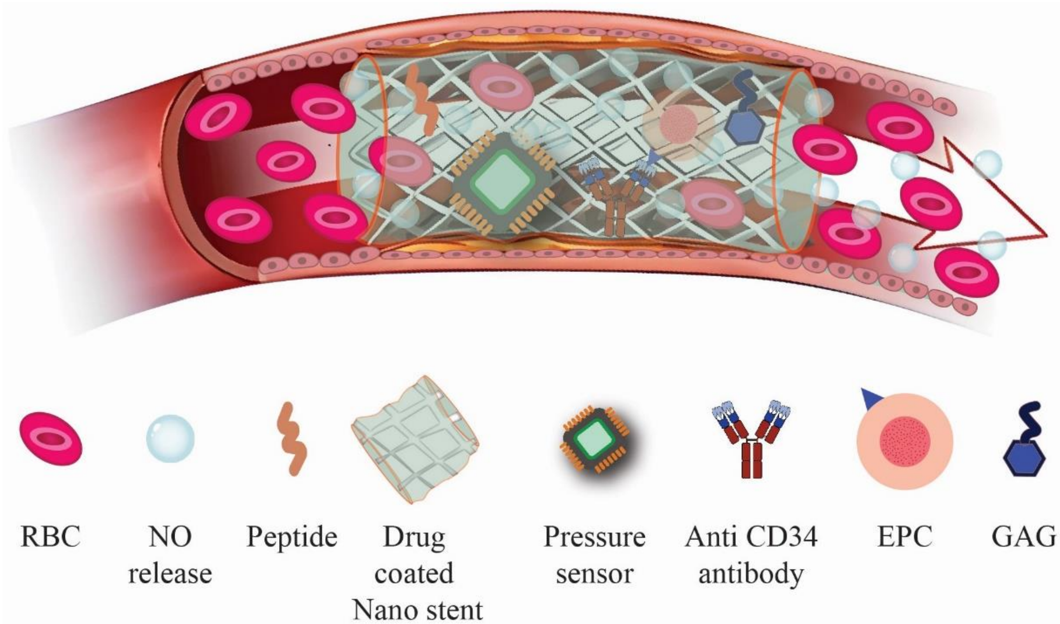

Figure 6. Drug eluting nano stents used in therapeutic interventions focuses on preventing blood clot formation via NO release, pressure sensor continuous monitoring, antibody tagging, addition of specific proteins, GAG, *etc*

applications of nanotechnology in the development of stents specifically, the integration of site-specific imaging capabilities. Nanotechnology allows for the incorporation of imaging agents directly into the stent material or coatings that results in localized imaging capabilities focused on the immediate vicinity of the stent. Imagining agents can be designed to target specific tissues, blood vessels, or cellular activities in the proximity of the stent. The site-specific imaging capabilities of nanotechnology-enhanced stents provide targeted diagnostic information about the region surrounding the stent. This is particularly advantageous for assessing the health and functionality of tissues adjacent to the stent, including identifying any potential complications or changes in the local environment [99] (Figure 6).

Nanomaterials integrated into the stent can serve as imaging probes to monitor the integration and healing of the stent within the surrounding tissues. This is crucial for assessing the long-term performance of the stent and detecting any issues, such as inflammation or tissue response. Site-specific imaging enables the early detection of issues or changes in the stented area. By providing focused diagnostic information, healthcare providers can identify potential problems at an early stage, allowing for timely intervention and management.

Nanotechnology allows for the customization of imaging agents based on the specific diagnostic needs of the stented area. This flexibility enables the development of stents with imaging capabilities tailored to different medical conditions, patient profiles, or procedural requirements. The integration of nanotechnology in stents facilitates real-time monitoring of the stented region. This dynamic imaging capability allows healthcare providers to observe changes, assess the effectiveness of the stent, and make informed decisions during and after the implantation procedure. Nanotechnology can support the integration of multiple imaging modalities within a single stent. This multimodal approach enhances the diagnostic capabilities, providing a comprehensive view of the stented area using different imaging techniques. The combination of diagnostic imaging and therapeutic functions, known as theragnostic, is achievable through nanotechnology. Stents with site-specific imaging capabilities can potentially deliver targeted therapies while simultaneously providing diagnostic information about the treatment response. Site-specific imaging can reduce the need for additional imaging procedures in cases where focused diagnostic information around the stent is sufficient. This contributes to more efficient patient care and resource utilization. Information obtained through site-specific imaging can inform the optimization of future stent designs.

By understanding the performance and interaction of stents with surrounding tissues, researchers and engineers can refine stent materials and structures for enhanced biocompatibility and efficacy. Nanotechnology-driven site-specific imaging capabilities in stents represent an exciting frontier in interventional cardiology. This technology has the potential to revolutionize the way healthcare providers monitor and assess the performance of stents, leading to more personalized and effective patient care [100].

2.8. Early detection

Improved visualization facilitated by nanotechnology can contribute to the early detection of abnormalities, allowing for timely interventions and potentially enhancing patient outcomes. Aptly captures a key benefit of improved visualization facilitated by nanotechnology in medical applications. Nanotechnology-driven enhancements in imaging contribute to the early detection of abnormalities, such as tumours, lesions, or structural anomalies. The improved clarity and resolution provided by nanomaterials aid healthcare professionals in identifying subtle changes at an early stage. Early detection, made possible by nanotechnology-enabled imaging, allows for prompt and timely interventions. Healthcare providers can initiate appropriate treatments or interventions at the earliest signs of abnormalities, potentially preventing the progression of diseases and complications. Early detection and timely interventions can lead to a reduction in the progression of diseases. By identifying and addressing health issues in their early stages, healthcare providers can implement strategies to halt or slow down the progression of conditions, improving overall patient outcomes. Detecting abnormalities at an early stage may result in less complex and more manageable treatment plans. Early interventions often require less aggressive treatments, leading to better tolerability by patients and potentially reducing the impact on their quality of life. Early detection is often associated with higher treatment success rates. When health conditions are identified in their early phases, there is a greater likelihood of successful outcomes, improved prognosis, and a higher chance of achieving positive responses to treatments. In many medical conditions, early detection is linked to improved survival rates. By identifying diseases at a stage when they are more treatable, patients have a better chance of responding positively to therapies, leading to increased survival rates.

Enhanced visualization allows healthcare providers to identify risk factors or preclinical signs of diseases. This knowledge enables the implementation of preventive measures, lifestyle changes, or early interventions to reduce the likelihood of disease development. Improved visualization through nanotechnology contributes to the development of personalized medicine approaches. Tailored treatments based on early diagnostic information and patient-specific factors can lead to more effective and targeted interventions. Early detection and intervention can positively impact a patient's overall quality of life. By addressing health issues before they become more severe, patients may experience less discomfort, fewer complications, and better overall well-being. Early detection and intervention may result in more cost-efficient healthcare. By addressing health issues at an early stage, the need for extensive and costly treatments, hospitalizations, and long-term care may be reduced. Nanotechnology-enhanced imaging can support the development of effective screening programs for various diseases. These programs aim to identify individuals at risk or in the early stages of specific conditions, allowing for proactive management. The improved visualization facilitated by nanotechnology in medical imaging holds tremendous potential for early detection of abnormalities. This early detection, in turn, can lead to timely interventions, improved patient outcomes, and a positive impact on overall healthcare efficiency and effectiveness [101].

2.9. Monitoring treatment response

In addition to diagnosis, nanotechnology-enhanced imaging can be valuable for monitoring how the body responds to treatment. This is particularly relevant in cases where stents are used as part of therapeutic interventions. Accurate monitoring the body's response to treatment is indeed a crucial application of nanotechnology-enhanced imaging. Nanotechnology-enhanced imaging allows for dynamic and real-time assessment of how the body responds to treatment. This is especially valuable in monitoring changes over time and assessing the effectiveness of therapeutic interventions. For stents used in therapeutic interventions, nanotechnology enables imaging that specifically focuses on the stented area (Figure 7).

This monitoring capability allows healthcare providers to observe the integration of the stent into the surrounding tissues, assess healing processes, and identify any potential complications. Nanotechnology facilitates the early detection of signs that might indicate complications or issues related to the stent or the treated area. This early identification is crucial for prompt intervention and management, potentially preventing the escalation of problems. Monitoring treatment responses with nanotechnology provides valuable data that can be used to optimize and tailor treatment plans. By understanding how the body is responding at a microscopic level, healthcare providers can adjust therapeutic strategies for better outcomes. The detailed information obtained through nanotechnology-enhanced imaging enables healthcare providers to customize follow-up care plans. This personalized approach ensures that patients receive the appropriate level of monitoring and intervention based on their responses to treatment. Nanotechnology allows for the assessment of tissue perfusion and viability in the treated area.

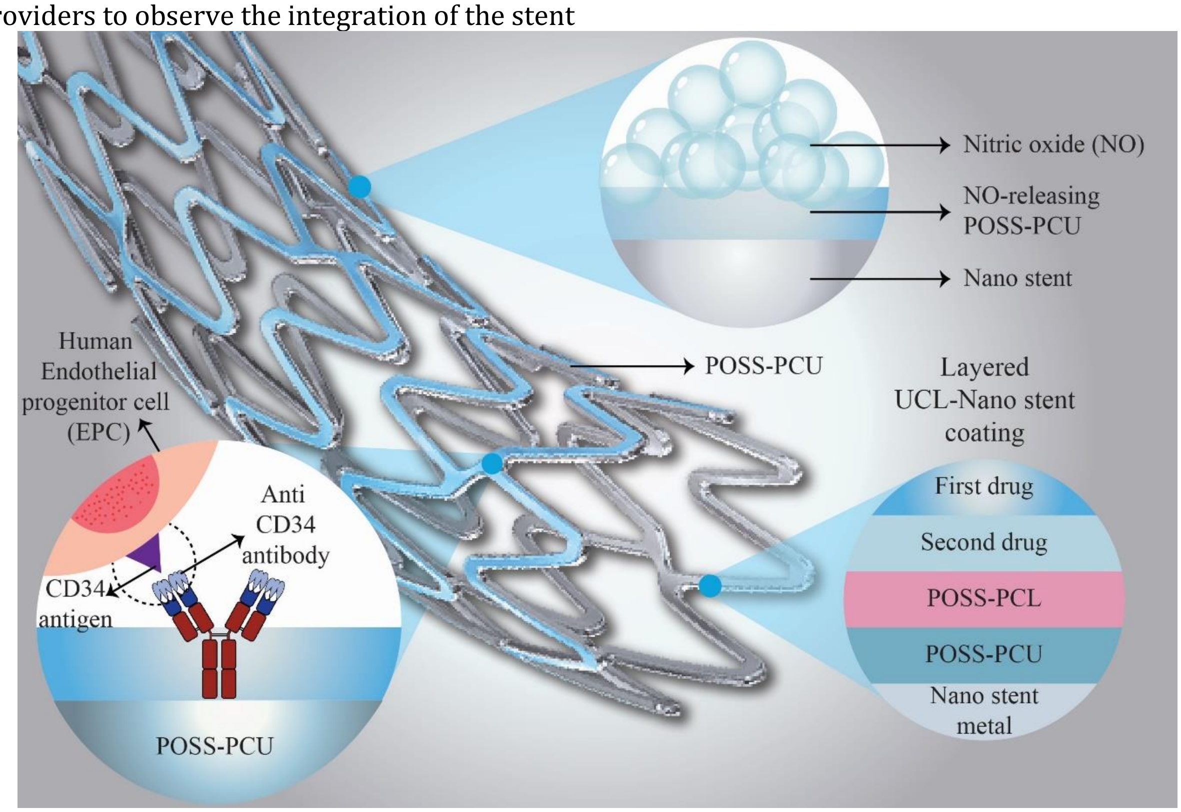

Figure 7. Stents used in therapeutic interventions; nano stent enables imaging that specifically focuses on the stented area using specifically coated antibodies

This is crucial for evaluating the health of tissues surrounding the stent, ensuring that they receive adequate blood supply and maintaining their functionality. Continuous monitoring with nanotechnology can reduce the need for invasive follow-up procedures. Non-invasive imaging techniques provide detailed information without subjecting patients to additional discomfort or risks associated with invasive interventions. In the context of stent-based interventions, nanotechnology-enhanced imaging can help in the early identification of restenosis-a potential complication where the treated blood vessel becomes narrowed again. Early detection allows for timely intervention to address restenosis and prevent further complications. Nanotechnology allows for the integration of therapeutic agents or responsive elements into stent material. This theragnostic approach combines diagnostic imaging with therapeutic functions, enabling simultaneous monitoring and treatment. By closely monitoring treatment responses, healthcare providers can make informed decisions to optimize care, potentially improving long-term outcomes for patients who have undergone stent-based interventions. The ability to monitor treatment responses through nanotechnology contributes to enhanced patient safety. Early detection of issues, coupled with timely interventions, reduces the risk of complications and improves overall patient well-being. Nanotechnology-enhanced imaging plays a pivotal role in monitoring treatment responses, especially in therapeutic interventions involving stents. The detailed insights provided by nanotechnology contribute to better-informed clinical decisions, personalized care, and improved patient outcomes [102].

2.10. Reducing invasiveness

Enhanced imaging capabilities can reduce the need for invasive procedures, as healthcare providers can gather more information non-invasively through advanced imaging techniques. Accurately highlights a significant advantage of enhanced imaging capabilities, particularly in the context of reducing the need for invasive procedures. Enhanced imaging capabilities allow healthcare providers to conduct comprehensive diagnostic assessments without the need for invasive procedures. This is particularly valuable in situations where the gathering of detailed information about internal structures or abnormalities is essential. On-invasive imaging procedures typically involve minimal or no discomfort for patients. This contrasts with invasive procedures that may cause pain, require anesthesia, or involve a longer recovery period.

Enhanced imaging techniques contribute to a more comfortable and patient-friendly diagnostic experience. Invasive procedures inherently carry a risk of complications, such as infections, bleeding, or adverse reactions to anesthesia. By relying on advanced imaging, healthcare providers can minimize these risks, enhancing patient safety and reducing the likelihood of procedural complications. Advanced imaging techniques often provide rapid and efficient diagnostic results. This can lead to quicker identification of medical conditions, allowing healthcare providers to initiate timely interventions without the delays associated with invasive procedures. Non-invasive imaging is generally more cost-effective compared to invasive procedures. Advanced imaging techniques can contribute to more efficient resource utilization, reducing overall healthcare costs and making diagnostic services more accessible. Enhanced imaging allows for serial monitoring of medical conditions over time without the need for repeated invasive procedures. This longitudinal approach facilitates the tracking of disease progression, treatment effectiveness, and the overall health status of the patient. Non-invasive imaging is often more readily accepted by patients, leading to higher compliance with diagnostic recommendations. Patients are more likely to undergo less invasive imaging procedures, contributing to better overall healthcare management. Advanced imaging techniques can be applied to a wide range of medical conditions and anatomical regions. This versatility makes non-invasive imaging a valuable tool in various specialties, providing detailed information without the need for specialized invasive procedures for each condition. Many non-invasive imaging procedures can be performed in outpatient settings, avoiding the need for hospitalization or prolonged stays.

This outpatient approach enhances convenience for patients and reduces the burden on healthcare facilities. Non-invasive imaging is integral to preventive medicine and screening programs. Techniques such as MRI, CT scans, and ultrasound enable the detection of abnormalities at early stages, allowing for preventive measures and interventions without resorting to invasive procedures. Continuous advancements in imaging technologies, including those enabled by nanotechnology, provide increasingly detailed and informative non-invasive images. This progress expands the scope of what can be achieved without resorting to invasive interventions. The use of advanced imaging techniques, characterized by their non-invasiveness, contributes significantly to patient-centric and cost-effective healthcare. By minimizing the need for invasive procedures, healthcare providers can prioritize patient comfort, safety, and efficient diagnostics, ultimately leading to improved overall healthcare outcomes [103].

2.11. Precision medicine

The integration of nanotechnology into stents aligns with the principles of precision medicine. By providing detailed and specific diagnostic information, healthcare providers can tailor treatments to individual patients' needs. It reflects the alignment of nanotechnology in stents with the principles of precision medicine. Nanotechnology-enhanced stents provide detailed diagnostic information about the stented area, allowing healthcare providers to tailor treatment approaches based on individual patient needs [104].

This personalized or customized approach is a core principle of precision medicine. Nanotechnology allows for the incorporation of imaging agents or sensors that can detect specific biomarkers relevant to an individual patient's condition. This information assists in understanding the unique characteristics of the patient's disease or response to treatment. In drug-eluting stents, nanotechnology enables precise control over drug release kinetics. This level of control allows for the customization of drug delivery based on the specific requirements of individual patients, optimizing therapeutic outcomes while minimizing side effects. Nanotechnology-enhanced imaging provides insights into how the body responds to stent implantation. This information can guide the development of tailored follow-up care plans, ensuring that patients receive the appropriate level of monitoring and intervention based on their unique responses. Nanotechnology allows for the early identification of individual risk factors or potential complications.

This early detection enables proactive measures to address specific risks, contributing to more effective and personalized care. Nanotechnology supports the integration of multiple diagnostic modalities into stents. This multimodal approach provides a comprehensive view of the stented area, allowing healthcare providers to consider various aspects of a patient's condition and tailor interventions accordingly. The integration of therapeutic and diagnostic functions, known as theragnostic, is achievable through nanotechnology. Stents with theragnostic capabilities can simultaneously diagnose and treat, aligning with the integrative and patient-focused principles of precision medicine. Detailed diagnostic information provided by nanotechnology can help reduce the need for trial-and-error approaches in treatment. By understanding the specific characteristics of a patient's condition, healthcare providers can make more informed decisions about the most effective interventions. Nanotechnology-driven data from stents can contribute to enhance predictive modelling. This allows healthcare providers to anticipate individual patient responses to treatments, optimizing decision-making for better outcomes. Precision medicine involves a careful assessment of the risks and benefits of treatment for each patient. Nanotechnology enables a more nuanced understanding of individual responses, facilitating a more accurate risk-benefit assessment for stent-based interventions.

Precision medicine often involves the integration of genomic and molecular data. Nanotechnology-enhanced stents can complement genomic information, providing a comprehensive understanding of both genetic and environmental factors influencing a patient's response to treatment. The integration of nanotechnology into stents aligns seamlessly with the principles of precision medicine, offering opportunities for personalized diagnostics and treatments tailored to individual patient needs. This approach has the potential to revolutionize the field of interventional cardiology, leading to more effective and patient-centric care [105].

2.12. Ongoing research and development

The field of nanotechnology in stent design is dynamic, with ongoing research aiming to optimize imaging properties and techniques. Continued advancements contribute to the evolution of diagnostic capabilities in interventional cardiology and other medical specialties. The incorporation of nanomaterials with imaging properties into stents represents a promising avenue for improving diagnostic capabilities. This approach has the potential to transform how medical professionals visualize and assess blood vessels and surrounding tissues, ultimately leading to more accurate diagnoses and better patient care.

The use of nanotechnology in stents aligns with the broader trend of employing nanomaterials for targeted drug delivery, imaging, and diagnostics in the field of medicine. The ability to manipulate materials at the nanoscale allows for precise engineering of properties to meet specific medical needs. As research progresses, different types of nanostents with various functionalities and applications will likely emerge. These innovations hold the potential to improve both the diagnostic and therapeutic aspects of cardiovascular interventions. Keeping an eye on scientific literature and developments in the field will provide insights into the specific types of nanostents and their potential impact on medical practice. The analysis provides a comprehensive overview of the broader trend of employing nanomaterials in medicine, specifically in the context of stents. The ability to leverage nanotechnology for targeted drug delivery, imaging, and diagnostics aligns with the increasing recognition of the benefits of manipulating materials at the nanoscale [106].

2.13. Broader trend in nanomedicine

The use of nanotechnology in stents is part of the broader trend of applying nanomaterials in various medical applications, encompassing targeted drug delivery, imaging, diagnostics, and therapeutic interventions. Accurately captures the broader trend of employing nanomaterials in diverse medical applications, showcasing the versatility and potential impact of nanotechnology across the medical field. Nanomaterials are inherently versatile and can be designed to serve multiple functions simultaneously. This multifunctionality is particularly valuable in medical applications where a single nanomaterial can be used for targeted drug delivery, imaging enhancement, and therapeutic interventions. Nanotechnology aligns with the principles of precision medicine by allowing for personalized and patient-specific approaches. From tailored drug release in stents to site-specific imaging, nanomaterials contribute to a more individualized and precise model of medical care.

The convergence of therapy and diagnostics, known as theragnostic, is a hallmark of nanotechnology applications. Nanomaterials can be engineered to combine diagnostic imaging capabilities with therapeutic functions, providing a holistic approach to patient care. Nanotechnology-enhanced imaging techniques go beyond traditional imaging modalities, offering improved resolution, sensitivity, and specificity. This advancement is crucial for early detection, accurate diagnosis, and monitoring of treatment responses. The ability of nanomaterials to deliver drugs in a targeted and controlled manner is a cornerstone of nanomedicine.

This targeted drug delivery minimizes side effects, maximizes therapeutic efficacy, and contributes to more efficient and patient-friendly treatments. Nanotechnology enables in vivo imaging, allowing healthcare providers to visualize and monitor biological processes within the body. This real-time imaging capability is instrumental in understanding disease mechanisms, tracking treatment responses, and guiding interventions. Nanomaterials can be customized based on specific medical needs. This customization extends to the size, shape, surface properties, and functionalities of nanoparticles, providing a tailored approach for different applications in medicine. Advances in nanotechnology prioritize the development of biocompatible materials, ensuring the safety and compatibility of nanomaterials within the human body.

This focus on biocompatibility is essential for minimizing adverse reactions and ensuring the overall well-being of patients. Nanotechnology plays a role in regenerative medicine by contributing to the development of nanomaterial-based scaffolds, drug delivery systems, and imaging techniques that support tissue regeneration and repair. Nanotechnology facilitates the creation of diagnostic nanosensors that can detect specific biomarkers or signals associated with diseases. These nanosensors offer rapid and sensitive diagnostic capabilities for a range of medical conditions. Nanotechnology enables remote sensing and monitoring of physiological parameters.

This capability is particularly relevant for continuous monitoring of health conditions, providing valuable data for both patients and healthcare providers. Ongoing research and advancements in nanomedicine continue to expand the applications of nanotechnology in medicine. This dynamic field holds the promise of innovative solutions for challenging medical issues. The use of nanotechnology in stents is part of a larger narrative where nanomaterials contribute significantly to diverse aspects of medical science and practice. This trend underscores the transformative potential of nanotechnology in shaping the future of healthcare [107].

2.14. Precise engineering at the nanoscale

The unique properties of nanomaterials and the ability to manipulate them at the nanoscale allow for precise engineering to meet specific medical needs. This level of precision is particularly advantageous in the development of medical devices like stents. The essence of the advantages offered by nanomaterials in the field of medicine, especially in the development of medical devices such as stents. Nanomaterials can be engineered with precise physical and chemical properties, including size, shape, surface charge, and composition. This tailoring enables the creation of materials with characteristics optimized for specific medical applications. The high surface-to-volume ratio of nanomaterials allows for intricate surface modifications. These modifications can be designed to enhance biocompatibility, reduce immune responses, and facilitate targeted interactions with biological tissues. Nanotechnology enables the customization of drug release kinetics in medical devices like stents. The controlled release of therapeutic agents from nanomaterials can be finely tuned to match the specific requirements of individual patients and medical conditions. Nanomaterials can be designed for enhanced biocompatibility, ensuring compatibility with biological systems. Additionally, bioactive properties can be incorporated into nanomaterials to promote beneficial interactions with cells and tissues. Despite their small size, nanomaterials can exhibit impressive mechanical strength. This property is advantageous for the development of robust and durable medical devices, such as stents, that can withstand physiological forces within the body. Nanomaterials allow for the creation of targeted drug delivery systems. In the context of stents, this enables the delivery of therapeutic agents precisely to the stented area, minimizing systemic exposure and reducing the risk of side effects. Some nanomaterials can be engineered to respond to specific stimuli, such as changes in pH, temperature, or the presence of certain biomolecules. This responsiveness can be harnessed to create smart and adaptive medical devices. Nanomaterials can serve multiple functions within a single device. For example, a nanomaterial-based stent may incorporate both imaging agents for diagnostics and drug delivery components for therapeutic purposes, showcasing the multifunctional capabilities of nanotechnology. At the nanoscale, materials exhibit unique interactions with biological molecules and structures. This enables precise and targeted interactions with cellular components, allowing for controlled responses in therapeutic applications. The precise engineering of nanomaterials allows for targeted drug delivery, reducing the risk of systemic side effects. This is particularly relevant in medical devices like drug-eluting stents, where minimizing side effects is crucial for patient safety. Nanomaterials can be incorporated into composite structures to combine the desirable properties of different materials. This flexibility allows for the creation of hybrid materials with optimized characteristics for specific medical device applications. Ongoing advancements in nanofabrication techniques contribute to the scalability and reproducibility of nanomaterial-based medical devices. This progress is essential for translating nanotechnology from research to practical clinical applications. The unique properties of nanomaterials, coupled with the ability to precisely engineer them at the nanoscale, offer a transformative platform for the development of highly customized and effective medical devices, including stents. This precision contributes to improved performance, reduced side effects, and enhanced therapeutic outcomes in various medical applications [108].

2.15. Multifunctional nanomaterials

Nanomaterials used in stents can serve multiple functions, such as drug delivery, imaging enhancement, and diagnostic capabilities. This multifunctionality contributes to the versatility of nano stents in addressing different aspects of cardiovascular interventions. Accurately highlights the multifunctional nature of nanomaterials in stents and how this versatility enhances their capabilities in cardiovascular interventions. Nanomaterials in stents can be designed to serve as carriers for therapeutic agents, allowing controlled and targeted drug delivery. This is particularly beneficial in preventing restenosis and promoting healing after stent placement. Incorporating nanomaterials with imaging properties into stents enhances their visibility under various imaging modalities. This contributes to improve monitoring of stent placement, tissue integration, and potential complications [109] (Figure 8).

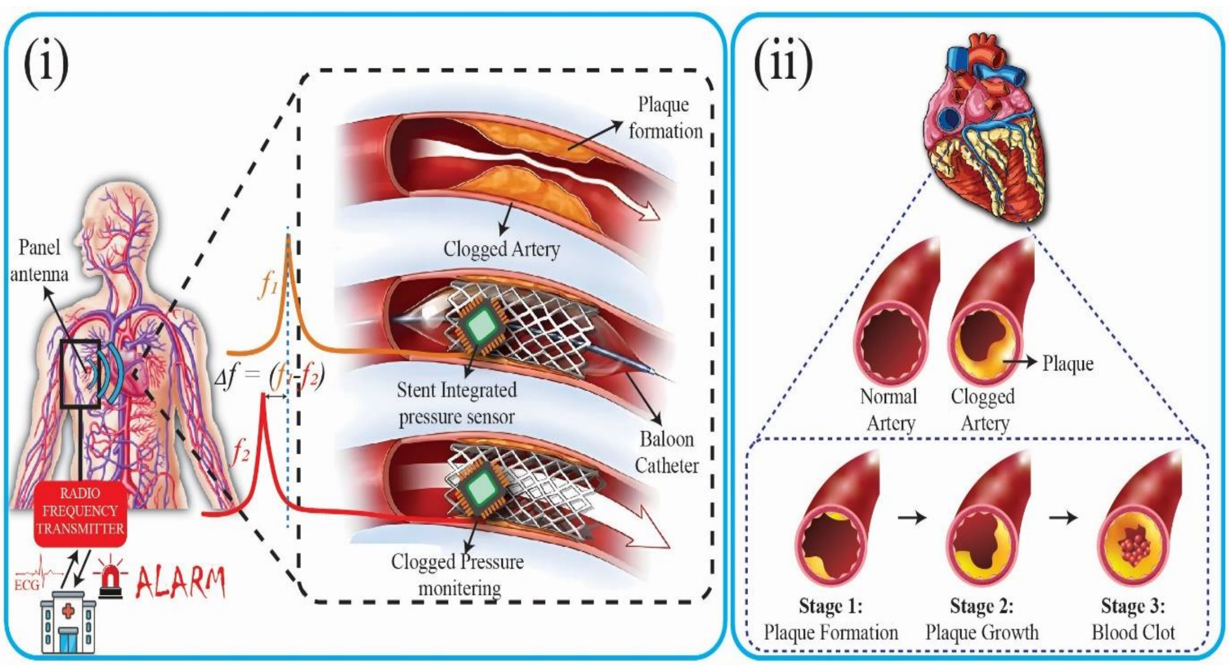

Figure 8. Nanomaterials used in stents can serve multiple functions, such as drug delivery, imaging enhancement, and diagnostic capabilities

Nanomaterials can be engineered to act as diagnostic sensors, detecting specific biomarkers or physiological changes. This diagnostic capability provides real-time information about the stented area, aiding in the early detection of issues or monitoring treatment responses. The combination of therapeutic and diagnostic functions, known as theragnostic, is achievable through nanotechnology. Nano stents can integrate both drug delivery systems and imaging agents, providing a comprehensive approach to cardiovascular interventions. Nanomaterials can be used to modify the surface of stents, improving biocompatibility and reducing the risk of adverse reactions.

This is essential for ensuring the compatibility of the stent with the surrounding biological environment. Some nanomaterials exhibit responsiveness to specific stimuli, allowing them to adapt to changes in the local environment. Responsive nanostents can, for example, release drugs in response to biochemical cues, enhancing the precision of therapeutic interventions. Nanomaterials can be engineered to have antimicrobial properties, helping to reduce the risk of infections associated with stent implantation. This is crucial for improving the overall safety of cardiovascular interventions. The mechanical properties of nanostents can be tailored to match the specific requirements of different arterial conditions. This customization ensures optimal performance and durability in diverse clinical scenarios. For bioresorbable nano stents, nanomaterials can be designed to degrade gradually over time. This aligns with the natural healing process of the body, eliminating the long-term presence of the stent and reducing the risk of complications. Nanomaterials enable precise interactions with cellular and molecular components at the nanoscale. This targeted interaction is valuable for influencing cellular responses, such as inhibiting smooth muscle cell proliferation to prevent restenosis. Surface modifications using nanotechnology can improve the interaction between the stent surface and blood components, reducing the risk of clot formation [thrombosis] and enhancing the hemocompatibility of the stent. In bioresorbable nano stents, nanomaterials allow for the customization of degradation kinetics. This flexibility ensures that the stent degrades at an appropriate rate, aligning with the healing process and minimizing potential complications. The multifunctionality of nanomaterials in stents contributes to the versatility of nanostents in addressing various aspects of cardiovascular interventions. This adaptability allows for a more comprehensive and tailored approach to patient care, leveraging the unique properties of nanotechnology for improved outcomes in cardiovascular medicine [110].

2.16. Tailoring properties for medical applications

The ability to tailor the properties of nanomaterials to meet the requirements of specific medical applications is a key advantage. This customization allows for the development of nanostents with properties optimized for both diagnostic and therapeutic purposes. Precisely captures a key advantage of nanomaterials in medical applications, particularly in the development of nanostents. Customizing the properties of nanomaterials allows for precise control over drug release kinetics in nanostents. This optimization is crucial for tailoring drug delivery to match the therapeutic requirements of individual patients and medical conditions. The mechanical properties of nanomaterials can be tailored to match the specific mechanical requirements of stents in different arterial locations. This ensures that nanostents provide the necessary structural support while maintaining flexibility and compatibility with various anatomical conditions. Nanomaterials offer the ability to modify stent surfaces to enhance biocompatibility. Tailoring surface properties helps reduce the risk of adverse reactions, inflammation, or immune responses, ensuring the compatibility of nanostents with the biological environment. In the case of bioresorbable nanostents, the degradation profiles of nanomaterials can be customized. This allows for the development of stents that degrade at a rate aligned with the natural healing process, minimizing the risk of

complications associated with prolonged presence in the body. Nanomaterials can be engineered in various sizes and shapes. This customization is advantageous for designing nanostents that fit specific anatomical features and accommodate variations in vessel size and geometry.
Customizing nanomaterials to be responsive to specific stimuli enhances the adaptability of nanostents. For instance, responsiveness to changes in the local environment can be harnessed to create smart stents that release therapeutic agents in a targeted and controlled manner. Tailoring nanomaterials allows for the integration of imaging agents into nanostents. This customization enhances the diagnostic capabilities of the stent, providing real-time imaging information for monitoring stent placement, tissue integration, and potential complications. Nanomaterials enable the creation of multifunctional nanostents that can simultaneously deliver drugs, enhance imaging, and provide structural support. This multifunctionality contributes to a comprehensive approach to cardiovascular interventions. The customization of nanomaterials facilitates the incorporation of various therapeutic agents, such as anti-proliferative drugs, anti-inflammatory agents, or antimicrobial substances. This allows for tailored treatment approaches based on the specific needs of patients. Tailoring the biodegradability of nanomaterials is essential for bioresorbable nano stents. This customization ensures that the stent degrades gradually, aligning with the healing process and minimizing potential long-term complications. Customizing nanomaterial properties can improve the hemocompatibility of stents by reducing the risk of blood clot formation [thrombosis]. This is crucial for preventing complications associated with blood vessel blockages. The ability to tailor nanomaterial properties allows for consideration of individual patient characteristics, ensuring that nanostents are optimized for specific clinical scenarios and patient needs. The ability to customize the properties of nanomaterials is a pivotal advantage that empowers the development of nanostents with properties optimized for both diagnostic and therapeutic purposes. This tailoring enhances the efficacy, safety, and patient-specific applicability of nanostents in cardiovascular interventions [111].

2.17. Emergence of different types of nanostents

As research progresses, different types of nanostents with diverse functionalities and applications will likely emerge. These innovations may range from stents designed for targeted drug delivery to those optimized for advanced imaging and diagnostics. Accurately anticipates the ongoing evolution and diversification of nanostent technologies as research progresses. Advances in nanostent technology may lead to the development of stents that incorporate multiple therapeutic agents. These could include combinations of anti-proliferative drugs, anti-inflammatory agents, and other medications tailored to address specific patient conditions. Future nanostents might be designed as personalized treatment platforms, allowing for the customization of drug release profiles based on individual patient characteristics, genetic factors, and response to therapy. Nanomaterials enable the creation of smart stents that respond to dynamic physiological conditions. These stents could release drugs in response to changes in the local environment or adapt their properties to optimize therapeutic outcomes. Bioresorbable nanostents could be enhanced with traceable markers for improved visibility during imaging. These markers might enable precise tracking of the stent degradation process and tissue healing over time. Future innovations may involve the integration of both therapeutic and diagnostic functionalities into a single device, aligning with the concept of theragnostic. These nanostents could provide real-time diagnostic information while delivering targeted therapies. Stents with advanced imaging capabilities, facilitated by nanomaterials, may emerge. These imaging stents could provide detailed information about vascular structures, tissue integration, and potential complications, enhancing the precision of diagnostics. Nanostents may encapsulate therapeutic nanoparticles, allowing for more efficient drug delivery. These nanoparticles could have specific properties, such as sustained release or targeted cellular interactions, optimizing their therapeutic impact. Future nanostents might integrate with external sensors or monitoring devices to provide real-time data on factors like blood flow, pressure, or temperature. This information could be valuable for adjusting treatment strategies and improving patient outcomes. Stents engineered with nanomaterials may have immunomodulatory properties to regulate the immune response at the implantation site.

This could contribute to minimizing inflammation and improving the long-term success of stent interventions. Stents made from nanocomposite materials may combine the advantages of different nanomaterials, such as enhanced mechanical strength, improved biocompatibility, and tailored drug release capabilities. Nano stents could be designed to offer dual-mode capabilities, simultaneously providing therapeutic benefits and serving as imaging agents. This integration could streamline treatment monitoring and enhance overall patient care. Advancements in nanotechnology may enable personalized surface modifications of nanostents, considering patient-specific factors to enhance biocompatibility, reduce the risk of complications, and promote successful integration with the vascular system. Nano stents could feature multifunctional coatings at the nanoscale, offering a combination of drug-eluting properties, enhanced biocompatibility, and imaging capabilities within a single device. The future landscape of nano stents is likely to be characterized by a diverse array of functionalities and applications. These innovations have the potential to revolutionize cardiovascular interventions by providing more personalized, effective, and patient-centric treatment options. Ongoing research and development efforts will play a crucial role in bringing these advancements from the laboratory to clinical practice [112].

2.18. Potential impact on cCardiovascular interventions

Nanostents hold the potential to significantly impact cardiovascular interventions by improving both diagnostic and therapeutic aspects. The integration of nanotechnology may lead to more effective treatments with reduced side effects and enhanced patient outcomes. The statement succinctly captures the transformative potential of nanostents in cardiovascular interventions. Nano stents align with the principles of precision medicine by offering personalized and targeted interventions. The ability to tailor properties, such as drug release kinetics and surface modifications, contributes to treatments that are finely tuned to individual patient needs. The controlled drug delivery facilitated by nanomaterials in stents can significantly reduce systemic exposure to therapeutic agents. This targeted approach minimizes the risk of side effects in healthy tissues, improving the overall safety profile of cardiovascular interventions. Nano stents enable a more controlled and sustained release of therapeutic agents, enhancing drug efficacy.

This precise drug delivery mechanism ensures that therapeutic concentrations are maintained at the target site, optimizing the treatment's impact on vascular health. By inhibiting smooth muscle cell proliferation, a common cause of restenosis, nanostents have the potential to significantly reduce the recurrence of narrowed blood vessels. This may lead to improved long-term outcomes for patients undergoing stent placements. Nanostents equipped with imaging enhancements provide clearer and more detailed information during diagnostic procedures. This improved visualization aids healthcare professionals in accurate stent placement, monitoring tissue integration, and detecting potential complications. The ability to engineer nanomaterials for enhanced biocompatibility reduces the likelihood of adverse reactions or immune responses. Customizable biocompatibility is crucial for ensuring the seamless integration of the stent within the biological environment. Nanotechnology allows for the development of smart stents that respond to changes in the local environment. These responsive devices can adapt to physiological conditions, providing dynamic and tailored therapeutic interventions. The versatility of nanostents enables more patient-centric approaches to cardiovascular care. Tailoring treatment strategies based on individual patient characteristics and needs contributes to personalized and effective medical interventions. Nanostents can serve multiple functions within a single device, combining drug delivery, imaging, and structural support. This multifunctionality enhances the efficiency and comprehensiveness of cardiovascular interventions. Bioresorbable nanostents, designed to gradually degrade, offer a temporary solution without the long-term presence of foreign materials. This can reduce the risk of late complications associated with permanent stents and promote natural vessel function. Nano stents, integrated with monitoring capabilities, allow for continuous assessment of physiological parameters. This real-time feedback can guide healthcare providers in adjusting treatment plans and optimizing patient care. The integration of nanotechnology contributes to the advancement of interventional cardiology, offering novel solutions to longstanding challenges and pushing the boundaries of what is possible in cardiovascular medicine. The integration of nanotechnology into stent design holds tremendous promise for transforming cardiovascular interventions. The potential improvements in diagnostic accuracy, treatment efficacy, and patient outcomes underscore the significance of ongoing research and development in this innovative field [114].

2.19. Dynamic nature of research

The field of nanomedicine is dynamic, and ongoing research is likely to unveil new possibilities and applications for nanostents. Monitoring scientific literature and staying informed about developments in the field will provide valuable insights into the evolving landscape of nanostent technology. Clinical Translation: While advancements in research are promising, the clinical translation of nanostents requires careful validation through preclinical studies and clinical trials. This process is crucial for ensuring the safety, efficacy, and regulatory approval of these innovative medical devices. The assessment accurately reflects the dynamic nature of nanomedicine, especially concerning nanostents. Ongoing research may lead to the discovery and exploration of new nanomaterials with unique properties and applications for nanostents. Keeping abreast of developments in nanomaterial science is essential to harness the full potential of these innovations. Continued research is likely to uncover innovative functionalities and capabilities for nanostents beyond the current applications. These could include advancements in targeted drug delivery, imaging enhancements, and the integration of novel technologies for improved patient outcomes. Nanomedicine research may reveal new therapeutic modalities that can be integrated into nanostents. This could include advancements in gene therapy, immunotherapy, or other cutting-edge approaches for addressing cardiovascular conditions at the molecular level. The interdisciplinary nature of nanomedicine encourages collaborations between researchers in fields such as materials science, biology, engineering, and medicine. These collaborations can foster novel ideas and accelerate the development of innovative nanostent technologies. Advances in nanofabrication techniques are fundamental to the development of nano stents. Monitoring progress in manufacturing methods at the nanoscale can contribute to more efficient and scalable production processes for these medical devices. As nanostents progress toward clinical translation, long-term safety and efficacy studies become increasingly critical. Continuous monitoring and evaluation of patients receiving nanostents in clinical settings provide valuable data for assessing their real-world performance. The development and deployment of nanostents in clinical practice necessitate adherence to regulatory standards. Staying informed about evolving regulatory guidelines and ensuring compliance with established standards are crucial for the successful translation of nanostents from the laboratory to the clinic. Research efforts should prioritize a patient-centric approach, considering not only the efficacy of nanostents but also factors such as patient comfort, quality of life, and long-term outcomes. Patient feedback and experiences contribute valuable insights to refine and optimize nanostent technologies. *Addressing Potential Challenges*:

Ongoing research and clinical studies should address potential challenges associated with nanostents, including biocompatibility, long-term durability, and the potential for unexpected interactions with biological systems.
Identifying and mitigating these challenges are integral to the success of nanostent technologies. The global nature of scientific research in nanomedicine emphasizes the importance of collaboration and knowledge sharing. Engaging with the broader scientific community facilitates the exchange of ideas, accelerates progress, and enhances the collective understanding of nanostent technologies. The dynamic and evolving nature of nanomedicine, particularly in the context of nanostents, underscores the need for continuous vigilance, collaboration, and adherence to rigorous scientific and regulatory standards. Staying informed about developments in the field and actively participating in the scientific discourse contribute to the advancement of nanostent technology and its successful translation into clinical practice [115-119].

2.20. Interdisciplinary collaboration

The development and optimization of nanostents often involve interdisciplinary collaboration, bringing together expertise from materials science, engineering, medicine, and other fields. This collaborative approach enhances the potential for breakthrough innovations. Interdisciplinary collaboration is a cornerstone in the development and optimization of nanostents, fostering a synergistic integration of knowledge and expertise from diverse fields. Experts in materials science play a crucial role in developing novel nanomaterials with specific properties suitable for nanostents. This includes considerations of biocompatibility, mechanical strength, and controlled drug release, among other material characteristics. Collaboration with biomedical engineers ensures that nanostents are designed with a deep understanding of physiological conditions and anatomical considerations. Biomedical engineers contribute to the optimization of stent design for effective integration with the human body. Involving medical practitioners and clinicians in the development process provides essential insights into the clinical needs and challenges associated with cardiovascular interventions. Their input helps align nanostent technologies with practical clinical requirements.
Collaboration with pharmacologists is crucial for optimizing drug delivery aspects of nanostents. Pharmacological expertise ensures the selection of appropriate therapeutic agents, consideration of drug interactions, and the development of formulations with optimal efficacy and safety profiles. Experts in biology contribute valuable insights into the biological responses to nanostents at the cellular and molecular levels. This interdisciplinary perspective aids in understanding how nanostents interact with living tissues and guides the development of biocompatible and effective devices. Collaborating with experts in nanofabrication techniques ensures that nanostents can be manufactured at the nanoscale with precision and consistency. Nanofabrication specialists contribute to the development of scalable and reproducible processes for mass production. Integration of advanced imaging technologies into nanostents requires collaboration with imaging experts. These professionals contribute to enhancing the diagnostic capabilities of nanostents, allowing for real-time monitoring and precise placement during interventions. Collaboration with regulatory affairs specialists ensures that nanostents comply with relevant regulations and standards. This interdisciplinary cooperation is crucial for navigating the complex landscape of regulatory approvals and bringing nanostents to market. Involving patient advocates in the development process ensures that nanostents are designed with a focus on patient-centered care. Patient feedback and perspectives contribute to the refinement of nanostent technologies to better meet the needs and preferences of those receiving the interventions. Collaboration with data scientists and statisticians is essential for analyzing complex datasets generated during preclinical and clinical studies. Their expertise helps in drawing meaningful conclusions, assessing the efficacy of nanostents, and

identifying trends or potential areas for improvement. Ethical considerations in the development and deployment of nanostents are paramount. Collaboration with ethicists ensures that ethical standards are upheld throughout the research and clinical translation process, safeguarding the well-being and rights of patients. Engaging in global collaboration expands the pool of expertise and diverse perspectives. Collaborating with researchers, institutions, and professionals from around the world contributes to a more comprehensive understanding of nanostent technologies and accelerates progress. The interdisciplinary collaboration is the driving force behind breakthrough innovations in nanostent development. By bringing together experts from various fields, researchers can leverage a collective understanding to address complex challenges, optimize device performance, and ultimately improve patient outcomes in cardiovascular interventions [120].

2.21. Potential for personalized medicine

The customization capabilities of nanotechnology align with the principles of personalized medicine. Nano stents have the potential to be tailored to individual patient needs, optimizing treatment outcomes and minimizing adverse effects (Table 4).

Table 4. The ability to be customized to each patient's needs, nanostents might maximize therapeutic results and reduce side effects

S. No.	Nanoparticles	Targets
AuNPs	AuNPs are used as fluorescence quenchers	Detection of SNP
	AuNP	Detect TP53 point mutations
	AuNP	Detection of SNPs in BRCA1
	AuNP	Detection of SNPs in CF genes
	AuNPs probes	Detect the expression of heparin in cancer cells.
	AuNPs electrochemical chip-based method	Detection of cancer cells with KRAS and BRAF mutations in lung cancer
	AuNPs fabricated as nanobeads with a fluorophore in a microarray system	For the detection of C677T polymorphism of the MTHFR gene
AgNPs	AgNP/Pt hybrid fabricated as nanocluster probe	Detect variant gene alleles in β-Thalassemia
	AgNP combined with carbon nanotubes	Detect the SNP related to mitochondrial DNA mutation
	AgNPs probes	Detection of single variation presence in the breast cancer BRCA1 gene
	DNA-AgNPs probes coating polystyrene microwells	Detection of the presence of the specific sequence DNA targets
QDs	QDs Qbead system	Multiplexed SNP genotyping systems of 200 SNP genotypes of the CYPP450 family
	QDs labelling in a microarray detection system	10,000 SNPs from the unamplified DNA in a single reaction
	QDs-mediated fluorescent method	Detection of hepatitis B M204I mutation, which is associated with drug resistance.
Polymer NPs	poly [α, l-glutamic acid] polymer/selumetinib and dabrafenib	BRAF, MEK-melanoma
	SMA/Crizotinib and dasatinib	Met, ROS1, KIT, and ABL-glioblastoma multiforme
	SMA/Sorafenib and nilotinib	VEGFR, PDGFR, FLT3, ALK, FGFR, c-KIT, JAK, CSF1R, RET, and Bcr-Abl-prostate cancer
	Chitosan-based polymeric nanoparticles/Imatinib	Bcr-Abl-colorectal cancer
	PLGA polymer/Tamoxifen	Estrogen receptor-positive breast cancer cells

Highlighting a key strength of nanotechnology in the context of personalized medicine, nanotechnology allows for precise control over drug release kinetics, enabling the customization of drug delivery profiles. This tailoring of drug release is crucial for matching the specific therapeutic needs of individual patients, considering factors such as the severity of the condition, patient response, and potential side effects. Nanostents can be designed with patient-specific formulations, considering variations in drug sensitivity, allergies, and other individual factors. This level of customization ensures that the therapeutic agents delivered by the stent are well-suited to the unique characteristics of each patient. The ability to engineer nanomaterials allows for the customization of stent designs to adapt to individual patient anatomies. This is particularly relevant in cardiovascular interventions where variations in vessel size, shape, and location may require personalized stent solutions for optimal efficacy. Nanotechnology facilitates the precise targeting of therapeutic agents to specific cellular or molecular sites.

This precision is advantageous in tailoring treatment approaches for individual patients, ensuring that the therapeutic impact is concentrated at the intended site of action. The targeted drug delivery enabled by nanostents minimizes systemic exposure to therapeutic agents. This is a critical aspect of personalized medicine, as it helps reduce the risk of systemic side effects, allowing for more focused and well-tolerated treatments. Personalized medicine emphasizes patient-centric approaches to healthcare. Nano stents, with their customization capabilities, enable the development of treatment strategies that prioritize individual patient needs, preferences, and overall well-being. The customization of nanomaterials used in nanostents extends to biocompatibility considerations. Stents can be engineered to enhance compatibility with the patient's biological environment, reducing the risk of adverse reactions and improving overall safety. Nanostents with integrated imaging functionalities can be tailored to provide personalized diagnostic information. This enables healthcare providers to monitor treatment responses on an individual level, allowing for timely adjustments and optimization of patient care. The adaptability of nanostents allows for flexible and dynamic treatment plans. If a patient's response to therapy changes over time, nanostents can be customized or adjusted accordingly to ensure continued effectiveness and address evolving medical needs.

Nanostents tailored to individual patient characteristics, there is the potential to enhance treatment efficacy. This personalized approach considers the specific factors influencing disease progression, optimizing the chances of successful outcomes. Personalized medicine involves considering patient feedback and preferences. Engaging patients in the customization process of nanostents can lead to more patient-centered solutions, promoting shared decision-making and improving treatment adherence. The customization capabilities of nanotechnology in the development of nanostents align seamlessly with the principles of personalized medicine. This alignment holds great promise for advancing cardiovascular interventions by providing treatments that are tailored to the unique characteristics and needs of individual patients [121].

2.22. Continuous monitoring of developments

Given the rapid pace of advancements in nanomedicine, continuous monitoring of scientific developments, clinical trials, and regulatory approvals is essential for healthcare professionals, researchers, and industry stakeholders. The use of nanotechnology in stents represents a significant advancement with the potential to reshape cardiovascular interventions. The precision and versatility offered by nanomaterials open new possibilities for improving both diagnostic and therapeutic aspects, contributing to the ongoing evolution of medical practice in the field of interventional cardiology. The assessment captures the dynamic nature of nanomedicine and underscores the importance of continuous monitoring for healthcare professionals, researchers, and industry stakeholders.

Continuous monitoring enables timely integration of groundbreaking innovations into clinical practice. Healthcare professionals can stay informed about emerging technologies and novel applications of nanomaterials in stents, ensuring that patients benefit from the latest advancements. Access to up-to-date information on nanomedicine allows healthcare professionals to make informed decisions in clinical practice. This includes selecting the most appropriate interventions, staying informed about potential risks and benefits, and tailoring treatments based on the latest evidence. Researchers and scientists benefit from continuous monitoring as it fosters collaboration and knowledge exchange. Staying informed about ongoing research initiatives and findings enables collaborative efforts that can accelerate the development of new nanostent technologies and treatment approaches. Continuous monitoring helps identify emerging trends and areas of focus in nanomedicine. This awareness enables healthcare professionals and researchers to anticipate future developments, align research priorities, and proactively address challenges in the evolving landscape of nanotechnology in stents. Access to the latest advancements in nanomedicine supports healthcare professionals in optimizing patient outcomes. Continuous monitoring ensures that patients receive state-of-the-art treatments, benefiting from the precision, versatility, and safety enhancements offered by nanotechnology in stents. Staying informed about the latest research findings and clinical outcomes aids in the ongoing assessment and management of potential risks associated with nanostents. This proactive approach enhances patient safety and contributes to the refinement of treatment strategies. Continuous monitoring provides opportunities for ongoing education and training. Healthcare professionals can engage in professional development activities to enhance their understanding of nanomedicine, ensuring competence in the application of cutting-edge technologies in clinical settings. Industry stakeholders, including manufacturers and regulatory bodies, benefit from continuous monitoring to inform strategic planning. Awareness of emerging trends and regulatory updates helps ensure compliance, guide research and development efforts, and promote the responsible introduction of new nanostent technologies to the market. Staying informed about advancements in nanomedicine empowers patients to actively participate in their healthcare decisions. Patients who are knowledgeable about the benefits and potential risks of nanostent technologies can engage in informed discussions with their healthcare providers, contributing to shared decision-making. Continuous monitoring is essential for ensuring regulatory compliance, particularly in the rapidly evolving field of nanomedicine. Regulatory bodies can stay informed about developments in nanostent technologies, update guidelines as needed, and facilitate the safe and responsible integration of these innovations into clinical practice. The use of nanotechnology in stents represents a transformative advancement in cardiovascular interventions. Continuous monitoring of scientific developments, clinical trials, and regulatory approvals is a cornerstone for unlocking the full potential of nanomedicine, fostering collaboration, and shaping the future of interventional cardiology [122].

3. Results and Discussion

Diagnostic nanostents and their applications in cardiovascular therapy would typically encompass findings from research studies, clinical trials, or theoretical analyses regarding the use of nanostents in diagnosing and treating cardiovascular diseases. Introduction of Nano-stents: Briefly introduce what nanostents are, emphasizing their unique properties such as size, surface characteristics, and potential for targeted delivery. *Imaging Modalities*: The discussion about how nanostents can be engineered to incorporate diagnostic agents such as contrast agents or nanoparticles for imaging purposes. This could include techniques like magnetic resonance imaging (MRI), computed tomography (CT), or ultrasound. *Bio-sensing Capabilities*: Highlight the ability of nanostents to detect biomarkers or changes in physiological parameters indicative of cardiovascular diseases. This may involve discussing the incorporation of biosensors or functionalized nanoparticles for real-time monitoring.

Drug Delivery: Describe how nanostents can serve as platforms for targeted drug delivery to treat cardiovascular conditions. Discuss the advantages of localized drug release, reduced systemic side effects, and improved therapeutic efficacy. Cellular Interaction: Explore how nanostents can interact with cells in the cardiovascular system, such as endothelial cells or smooth muscle cells, to promote tissue regeneration or inhibit pathological processes. Restenosis Prevention: Address the role of nanostents in preventing restenosis, a common complication of traditional stent placement, through mechanisms such as anti-proliferative coatings or bioactive surface modifications.

The findings of preclinical studies and clinical trials are summarized investigating the safety and efficacy of diagnostic nanostents in animal models or human patients.Highlight any notable outcomes, including improvements in diagnostic accuracy, therapeutic outcomes, or patient survival rates. The challenges and limitations associated with the use of diagnostic nanostents, such as biocompatibility issues, regulatory hurdles, or technical barriers are discussed. The future research directions aimed at addressing these challenges and advancing the field, such as the development of multifunctional nanostent platforms or the optimization of fabrication techniques. The key findings and implications of the research were summarized as discussed in the results and discussion section. Emphasize the potential of diagnostic nanostents to revolutionize cardiovascular therapy by enabling early disease detection, personalized treatment strategies, and improved patient outcomes. The specifics of the results and discussion section would depend on the particular research findings or clinical data available on diagnostic nanostents in cardiovascular therapy [123].

4. Conclusion

A revolutionary advancement in cardiovascular therapies, diagnostic nanostents combine real-time diagnostic capabilities with structural support. These novel gadgets have a lot of potential, and their multifunctionality and findings from intensive research and clinical investigations are highlighted in talks and outcomes. As we end, several important ideas surface that will influence how cardiovascular care is provided in the future. When performing diagnostic operations, professionals can view vivid, detailed images in real-time thanks to the unmatched capabilities of diagnostic nanostents. The successful integration of diagnostic nanostents within the physiological milieu is indicated by positive results from biocompatibility testing, which paves the way for their safe and efficient usage in clinical settings.

Diagnostic nanostents' mechanical robustness, which has been shown by in vitro testing and computational modeling, gives rise to confidence regarding their capacity to offer solid and long-lasting structural support. Combining therapeutic and diagnostic features into one device has great potential to simplify cardiovascular therapies and provide patients with a holistic approach to care. Clinical trials offer proof of the safety, viability, and possible advantages of diagnostic nanostents in practical situations. These trials range in size from early-phase research to large-scale trials. The therapeutic effect that has been observed, as evidenced by the controlled release of the drug, provides opportunities for additional optimization in terms of addressing cardiovascular conditions and customizing treatment plans for each patient. To monitor the function of diagnostic nanostents over extended periods and provide clinicians with information regarding their durability and sustained diagnostic efficacy, post-market surveillance and long-term follow-up studies are essential.

To help doctors select the best diagnostic strategy for various clinical circumstances, comparisons with conventional diagnostic techniques highlight the benefits and possible superiority of diagnostic nanostents. Challenges that are identified- whether they have to do with mechanical behaviour, biocompatibility, or long-term performance- become useful benchmarks for subsequent research endeavors, encouraging iterative improvements and breakthroughs. To sum up, diagnostic nanostents provide a revolutionary advancement in cardiovascular medicine by combining state-of-the-art diagnostics with structural support. The integration of nanotechnology with interventional cardiology has opened new avenues for targeted, accurate, and effective therapeutic and diagnostic approaches. Researchers, physicians, and regulatory agencies working together in the future will be crucial to realizing the full potential of diagnostic nanostents and guaranteeing a smooth transition into standard cardiovascular care. Diagnostic nanostents have the potential to redefine the standard of treatment and enhance patient outcomes in the field of cardiovascular therapies as they go from research to clinical implementation.

Authorship contribution statement

ARMS, HY, and MM conceptualized the idea and designed the draft. All the authors wrote the paper. NW made high-resolution images. KK performed the final check, analysis, and interpretation. All authors proofread and finally approved this version of the manuscript to be submitted for publication.

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