**Quantum dots for drug delivery in cancer research**

**Anita Antil1, Sandeep Singh2\*, Rajwinder Kaur1, Satish Sardana2, Inderjeet Verma3**

**1Chitkara College of Pharmacy, Chitkara University, Punjab, India**

**2Amity Institute of Pharmacy, Amity University, Gurugram, Haryana, India**

**3MM College of Pharmacy, Maharishi Markandeshwar Deemed-to-be-University, Ambala, Haryana, India**

**Abstract**

The significant contribution to cancer nanomedicines is the result of successful advance in the fields of nanotechnology, bioimaging, formulation development, and molecular biology. Cancer is one of the main causes of death worldwide in the 21st century because it poses a significant danger to public health. Carcinogenesis, cancer invasion, and metastatic pathways are all unknown. As a result, developing a unique strategy to cancer diagnosis is critical, and real-time monitoring is critical in revealing the disease's underlying biological mechanisms. Although various ways have been established to reduce fatalities, chronic pain, and improve quality of life, there is still a gap in the adequacy of these cancer therapies. Quantum dots (QDs) are one of the most likely components in the nanomedicine toolbox. Nano diagnostics imaging, targeted medication delivery, and photodynamic therapy are just a few of the possible medical applications for these nanocrystal fluorophores. QD-based nanotechnology is useful in developing a biomedical imaging platform for cancer behavior analysis because of the optical and chemical benefits of quantum dots (QDs). Quantum dots (QDs) made of semiconductor nanocrystals have exceptional photophysical properties, and QDs-based probes have shown promising results in cellular and in vivo molecular imaging. A growing number of studies have revealed that QD-based technology could be a potential method in cancer. Specifically focuses the use of QD-based nanotechnology in cancer cell imaging and tumor microenvironment research in vivo and in vitro, as well as the remaining challenges and future prospects. The influence of QDs on tumor metastasis studies will become increasingly essential in the future as QD synthesis and modification progress.

**Keywords:** Quantum dots, cancer, nanotechnology, nanocarrier

1. **Introduction**

Cancer is the world's most serious health issue, the leading cause of mortality, and a worldwide health burden in every country. By 2018, it is expected that 18.1 million new cancer diagnoses, and 9.6 million cancer-related deaths would have occurred [1, 2]. Several studies have focused on the modulation of cell adhesion as a mechanism of cancer invasion and development in the last few years [3, 4]. However, rate-limiting mechanisms governing cancer invasion and progression, such as the dominant signaling pathway, receptor–ligand interactions, and protease substrate interactions, have yet to be identified. Cancer invasion is now recognized as a complex and adaptable process involving the tumor stromal microenvironment [5,6]. It's a broad group of diseases that affect several organs, but they're all defined by the uncontrolled proliferation of aberrant cells that can infect neighboring tissues and possibly spread. The tumor microenvironment, which consists of tumor stromal components, host cells, and nearby supportive tissues, is an essential component for tumor growth and progression because of its dynamic interactions with the tumor [7, 8]. Components such as fibroblasts, endothelial cells, and macrophages may be activated and release functional molecules that promote or prevent cancer invasion once the tumor microenvironment responds to the tumor cells [9-13]. These tumor cells have an impact on the microenvironment, encouraging cancer growth in a mutually beneficial way [14,15]. Thus, knowing the biological behavior during tumor advancement is required to fully explain the mechanism of cancer invasion and progression, and an adequate approach for understanding cancer biological behavior should be developed. Quantum dots (QDs), a heterogeneous class of manufactured nanoparticles with unique optical and chemical properties that make them essential nanoparticles with multiple potential uses spanning from medicine to energy [16], are one of the most intriguing advancements in nanotechnology. With great specificity and sensitivity, QD-based probes can be utilized to target cancer compounds. This strategy has been proven in several studies to be critical for understanding the molecular mechanisms of cancer invasion as well as valuable for studying the tumor microenvironment [17-19]. To concentrate on the recent use of QDs in cancer diagnostics, such as early detection of primary tumors including ovarian cancer, breast cancer, prostate cancer, and pancreatic cancer, as well as regional lymph nodes and distant metastases. The major advancements in the application of QD-based nanotechnology for cancer research, including the detection of primary tumors in vitro, tumor imaging in vivo, study of tumor microenvironment for invasion, progression, and multimodality biomedical molecular targeting imaging, as well as major remaining issues and future perspectives, are summarized here.

* 1. **What are quantum dots?**

Quantum dots are nanoscale semiconductor particles that exhibit unique electronic and optical properties due to quantum confinement effects. These properties make them valuable for a wide range of applications, including electronics, optoelectronics, bioimaging, and quantum computing [16]. When UV light strikes QDs (CdSe—ZnS core-shell nanoparticles), these semiconducting nanoparticles emit light of various colors at specified wavelengths (fig.1)



**Figure 1. Quantum Dots**

Alexey I. Ekimov, a Russian physicist, discovered semiconductor nanoparticles known as quantum dots in 1981 [20]. QDs range in size from 2 to 10 nm in diameter and contain 200 to 10,000 atoms [16]. When semiconductor particles are made small enough, quantum phenomena occur, limiting the energies. Because energy is proportional to wavelength (or colour), the particle's optical characteristics can be finely controlled based on its size (fig. 2) [20]. QDs have special optical features that make them good candidates for luminous nanoprobes and carriers in biological applications. Dissolving, dispersion, adsorption, and coupling, among other methods, can be used to load pharmaceuticals into QD nanocarriers for medications [21, 22]. The application of QD fluorescence imaging technology and therapy-based multifunctional nano-drugs to cancer detection and treatment is expected [23].



**Figure 2. Quantum dots have the ability to turn a spectrum of light into different colors. It produces a different hue depending on the size of the dot.**

* 1. **Properties of QDs**

**The size, shape, composition, and structure of a quantum dot define its attributes. Ideal QDs have a variety of properties:**

1. **Quantum dots, often known as "designer atoms," have a wide range of optical and electrical features that allow them to overcome the limitations of standard semiconductors.**
2. high drug loading capacity and encapsulation efficiency.
3. appropriate preparation and purification process (2) high drug loading capacity and encapsulation efficiency.
4. low toxicity and high biocompatibility
5. a specific level of mechanical strength and stability, as well as particle size and form that are appropriate
6. In vivo, a longer duration of residency.
7. No adverse medication reactions
8. Quantum dots are made up of thousands of microscopic metal particles the size of a human hair.
9. Quantum dots can be shaped into various shapes and coated with various biomaterials.
10. Quantum dots emit UV light and the size of the dots determines the colour e.g. 2nm Quantum dots luminescence bright green, 5 nm Quantum dots – luminescence red.
11. Fluorescent quantum dots are often composed of chemicals from groups II to VI and III to V, such as Ag, Cd, Hg, Ln, P, Pb, Se, Te, and Zn, among others.
12. As the size of quantum dots shrinks, the wavelength they emit shortens.
13. Quantum dots have a wide range of excitation.
14. Because quantum dots emit at a particular wavelength, the spectra of numerous fluorescent emissions do not overlap. (24, 25).
	1. **Advantages of QDs**

The advantages of ideal QDs are as follows:

1. QDs modified antibodies, aptamers, folic acid, and other biological molecules to target medicine delivery to specific organs.
2. QDs control and release medications in a rather unique way. The style of managing and releasing pharmaceuticals of QDs is usually an outbreak release at first, and then it exhibits a consistent release for a long time.
3. Drug QDs can dramatically increase drug efficacy at low concentrations, deliver at shorter intervals and lower doses, and lessen side effects.
4. QDs increase medication contact area and improve oral drug absorption and bioavailability.
5. In the process of imparting increased medication stability and use, QDs can avoid rapid drug breakdown by digestive enzymes in the body.
6. Drug-loaded nano-particle carriers can alter the mechanisms of membrane transport and enhance the permeability of drugs in bio-film, and then improve the absorption effects of the drugs in cells.
7. The original medicine can be modified using nanoparticles as carriers to increase water solubility or get a targeted and sustained release function, increasing the anticancer treatment's activity and lowering adverse drug reactions [26, 27].
8. **Formulation and Characterization of Quantum Dots**
	1. **Formulation of Quantum Dots**

Synthesising semiconductor materials at the nanoscale is necessary for the creation of quantum dots. Group II-VI (like CdSe, CdTe) and III-V (like InP, GaAs) compounds are the most popular semiconductor materials utilised for QD production. The optical and electrical qualities of the Quantum Dots that are needed will determine the material choice [28].

* 1. **Several methods for synthesizing Quantum Dots**
1. **Colloidal synthesis:** This method involves the chemical synthesis of quantum dots in a colloidal solution. It typically utilizes precursors containing semiconductor materials such as cadmium, lead, or indium. By carefully controlling the reaction conditions, including temperature, reaction time, and precursor concentrations, quantum dots of desired size and properties can be obtained. The colloidal synthesis method is widely used due to its simplicity and versatility [28].
2. **Sol-Gel Method**: The sol-gel method is another technique used for quantum dot formulation. In this approach, metal alkoxides or organometallic complexes are hydrolysed and condensed to form a gel. The gel is then calcined or annealed to yield the desired quantum dots. A relevant reference for sol-gel synthesis of quantum dots is the study [29].
3. **Electrochemical Synthesis:** Electrochemical methods offer a versatile approach for quantum dot synthesis. In electrochemical synthesis, an electrode is used to initiate and control the reaction between precursors, which allows for precise control over the quantum dot properties. Key references for electrochemical synthesis techniques include the works [30,31].
4. **Molecular Beam Epitaxy (MBE):** Molecular Beam Epitaxy is a vapour phase deposition technique used to grow atomically thin layers of various materials, including quantum dots. MBE allows for the precise control of growth parameters, resulting in high-quality quantum dots with tailored properties. Notable references for quantum dot synthesis using MBE include the studies [32,33].
5. **Plasma synthesis:** Plasma synthesis involves the generation of a plasma, which is a high-energy, ionized gas, to produce quantum dots. In this method, precursor gases containing the desired semiconductor materials are introduced into a plasma reactor, where they are broken down and condensed to form nanoparticles. The use of plasma allows for efficient and rapid synthesis of quantum dots, with control over size, shape, and composition [34].
	1. **Characterization of Quantum Dots**

Quantum dots (QDs) are nanoscale semiconductor crystals that exhibit unique optical and electrical properties. Due to their size-dependent properties and potential use in various applications, it is crucial to characterize QDs accurately. In this guide, we will explore the different techniques used for the characterization of quantum dots, providing proper references along the way.

* 1. **X-ray Diffraction (XRD):**

XRD is often employed to determine the crystal structure and size of quantum dots. It allows researchers to analyse the position and intensity of the X-ray diffraction peaks, providing information about the lattice parameters and crystal structure [35].

* 1. **Transmission Electron Microscopy (TEM):**

TEM offers detailed information about the size, shape, and morphology of quantum dots. The analyses of the sizes and morphologies of the as-prepared nanoparticles were studied using a high resolution JEOL 7550 scanning electron microscope equipped with a TEM detector. Samples were prepared after drop-coating 10 µL of the sample on carbon coated grids 200 mesh Cu (100). High-resolution TEM provides atomic scale imaging, facilitating the determination of nanocrystal structure [36].

* 1. **Scanning Electron Microscopy (SEM):**

SEM offers valuable information about the surface morphology and size distribution of Quantum Dots [36].

* 1. **Photoluminescence (PL) Spectroscopy:**

PL spectroscopy is widely used to study the light emission properties of quantum dots. It measures the intensity and wavelength of the emitted light, providing information about the bandgap, energy levels, and quantum efficiency. The photoluminescence measurements of the films were performed at room temperature using a spectrophotometer. The emission spectra of the films were measured before the storage test and after five days of storing the poultry meat under the films [37].

* 1. **Absorption Spectroscopy:**

UV-Vis absorption spectroscopy measures the absorption spectrum of Quantum Dots, revealing their bandgap energy. PL spectroscopy measures the emission spectrum, providing information about their luminescent properties [38].

* 1. **Energy-Dispersive X-ray Spectroscopy (EDS):**

EDS is used to analyze the elemental composition of Quantum Dots [39].

* 1. **Fourier Transform Infrared Spectroscopy (FTIR):**

FTIR helps identify the organic ligands or surface capping agents on the Quantum Dots [40].

* 1. **Dynamic Light Scattering (DLS):**

DLS provides information about the hydrodynamic size and size distribution of Quantum Dots in solution [41].

1. **Applications of QD-based Nanotechnology for Cancer Research**
2. **Ovarian cancer**

Ovarian cancer is the second most frequent genital tract cancer in women and the primary cause of death among gynecological cancers. CA 125 is an epithelial antigen that can be used as a tumor marker in the identification and treatment of ovarian cancer [42-44]. The capacity to visualize native processes in living organisms is crucial for clinical diagnostic applications, but it is difficult to achieve in practice due to constraints in conventional imaging and a lack of adequate fluorescent markers. QDs are attractive fluorophores for in vivo fluorescence imaging due to their unique photophysical properties, which can overcome many of the drawbacks of traditional dyes. Wang et al. [45] found CA125 in ovarian cancer specimens of various types (fixed cells, tissue slices, and xenograft tumor) with high specificity and sensitivity using QDs with a maximal emission wavelength of 605 nm (QD605). When QDs were compared to fluorescein isothiocyanate (FITC), the labelling signals from QDs were brighter, more specific, more stable. Nathwani [46] produced biocompatible QDs coated with the natural protein silk fibroin (SF) and used these QD conjugates as a fluorescent marker for successful bioimaging of HEYA8 ovarian cancer cells. In addition, QD signals have a better photostability than typical organic dyes [47]. pH-dependent photo luminescent CdSe/ZnSe/ZnS QDs were produced in SKOV-3 human ovarian cancer cells, implying applications for intracellular pH sensors. In human ovarian epidermal carcinoma cells, Kawashima et al. successfully targeted EGFR single molecules (A431) [48,49]. QDs' capabilities have opened up new avenues for enhanced molecular and cellular imaging, as well as ultrasensitive bioassays for ovarian cancer diagnoses.

**Table 1. Development of QDs-based nanotechnology for ovarian cancer research:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no.**  | **Type of QDs** | **Type of human ovarian cancer cell**  | **Outcomes**  | **Reference**  |
| 1. | QD605 | CA125 | Labeling signal more specific and stable | 45 |
| 2. | QDsSF(QDs conjugates) | HEYA8 | Better photostability | 46,47 |
| 3. | CdSe/ZnSe/ZnS | SKOV-3 | Enhanced molecular or cellular imaging for ovarian cancer diagnose | 48,49 |

1. **Breast Cancer**

Wu et al. [50] investigated a new technique for labelling HER2 (human epidermal growth factor receptor 2, HER2) on the breast cancer cell membrane, also known as c-erbB-2 or HER2/neu, which is overexpressed in 25–30% of invasive breast cancer [49,50] and plays a key role in breast cancer prognosis and treatment selection [50-53]. Following that, other trials using QDs to detect HER2 for breast cancer diagnosis were completed [54,55]. Using intact breast cancer cells and clinical specimens, Yezhelyev et al. [56] reported the use of multicolor QDs for quantitative and simultaneous profiling of multiple biomarkers, as well as a comparison of the new QDs-based molecular profiling technology with standard western blotting and fluorescence in situ hybridization (FISH). In breast cancer cells MCF-7 and BT474, the multicolor bioconjugates were employed to detect five clinically relevant tumor markers simultaneously, including HER2 (QD-HER2), ER (QD-ER), PR (QD-PR), EGFR (QD-EGFR), and mTOR (QD-mTOR). The use of QD-Abs profiling revealed a quantifiable link between HER2 gene amplification and HER2 protein expression. This research implies that conjugated QDs could be used to detect low levels of HER2 protein expression, but the clinical implications of this finding need to be explored further. We recently used QDs conjugated with antibody for assessment of HER2 status in breast cancer to address the limitations of the research in terms of clinical use [57]. Our research included 700 patients with aggressive breast cancer, 3 men and 697 women. Our QD immune histochemistry (QDs-IHC) analytical system was used to determine the expression of HER2 in breast cancer in an automated, quantitative, sensitive, and simple approach. The QDs-based methodology is more sensitive, accurate, and cost-effective than traditional IHC, particularly in cases of IHC (2+), indicating that this new method has clinical potential, particularly in developing countries [24].

**Table 2. Development of QDs-based nanotechnology for breast cancer research:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no.**  | **Type of QDs** | **Type of human breast cancer cell**  | **Outcomes**  | **Reference**  |
| 1. | HER2 (QD-HER2), ER (QD-ER), PR (QD-PR), EGFR (QD-EGFR) | MCF-7 | to detect low levels of HER2 protein expression | 56 |
| 2. | mTOR (QD-mTOR | BT474, | detect five clinically relevant tumor markers | 56,57 |
| 3. | QDs-IHC | HER-2 | automated, quantitative, sensitive, and simple approach. | 24 |

1. **Pancreatic Cancer**

Pancreatic cancer patients have a median survival time of about 6 months, and only about 5% of those diagnosed with the disease live longer than 5 years [58,59]. Due to the lack of distinct symptoms and diagnostic constraints, the majority of patients are diagnosed at an advanced stage. [56]. With the help of proteins/peptides directed against overexpressed surface receptors on cancer cells/tissues such as the transferring receptor, antigen claudin-4, and urokinase plasminogen activator receptor, QDs can target the purpose of early diagnosis of pancreatic cancer [61], even at an early stage of development (uPAR) [62]. Qian [63] used increased photoluminescence efficiency and stability CdSe/CdS/ZnS QDs as an optical agent for imaging pancreatic cancer cells using transferring and anti-Claudin-4. The monoclonal antibody anti-Claudin-4 is also used to demonstrate pancreatic cancer specific uptake. This targeted QDs platform will be further developed to develop a pancreatic cancer early detection imaging tool. Non-cadmium-based QDs were employed by Yong et al. [64] to image live pancreatic cancer cells in a very efficient and safe manner. Bioconjugation of functionalized InP/ZnS QDs with pancreatic cancer-specific monoclonal antibodies, such as anticlaudin 4, permitted in vitro targeting of pancreatic cancer cell lines. The bioconjugates' receptor-mediated transport was further validated in vitro by the discovery of poor targeting in nonpancreatic cancer cell lines lacking the claudin-4 receptor. These findings point to InP/ZnS QDs having enormous promise as noncadmium-based, safe, and effective optical imaging nanoprobes in diagnostic imaging.

**Table 3. Development of QDs-based nanotechnology for pancreatic cancer research:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no.**  | **Type of QDs** | **Type of human pancreatic cancer cell**  | **Outcomes**  | **Reference**  |
| 1. | CdSe/CdS/ZnS QDs | Claudin-4 | pancreatic cancer early detection imaging | 62 |
| 2. | InP/ZnS QDs | anticlaudin 4 | effective optical imaging nanoprobes in diagnostic imaging. | 63,64 |

1. **Prostate Cancer**

Prostate adenocarcinoma is the most frequent cancer among men in the West, with 192,280 new cases and 27,360 deaths in the United States alone in 2009 [65]. PSA-based screening has revolutionised prostate cancer detection and ushered in the PSA era, in which prostate cancer was discovered at an earlier stage and in greater numbers than ever before [66,67]. PSA is also a significant prognostic indicator for prostate cancer [68]. In vivo imaging of early prostate cancer with a fluorescent probe coupled to PSA is a selective and sensitive method. Gao et al. [69] have demonstrated sensitive and multicolor fluorescence imaging of cancer cells under in vivo settings using QDs probes attached to a PSMA monoclonal antibody (Ab), another marker for prostate cancer detection and therapy. Shi [70] demonstrated that QDs have a higher detection quality than IHC for androgen receptor (AR) and PSA detection in prostate cancer cells. Both of these studies [71] highlight why QDs are interesting nanoparticles for diagnostic applications by demonstrating their potential as a diagnosis tool. Antibodies attached to QDs are typically full-length antibodies, resulting in significantly lower binding activity [72]. Recently, a study found that using single chain antibody fragments (scFvs) coupled with QDs has a lot of benefits in terms of solubility, activity, ease of preparation, and ease of structure-based genetic engineering, all of which were validated by detecting prostate cancer cells [73].

**Table 4. Development of QDs-based nanotechnology for prostate cancer research:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.no.**  | **Type of QDs** | **Type of human prostate cancer cell**  | **Outcomes**  | **Reference**  |
| 1. | QDs | antibody fragments (scFvs) | detecting prostate cancer cells | 74 |

1. **Gastrointestinal cancer**

Bostick et al. [75] used QD-based multiplexed imaging to identify five biomarkers on the same tissue slide, from which more biomarkers could be assessed using numerous slides stained with the five separate biomarkers. They also advised creating a workflow for each biomarker's quantitative analysis. The technology was effective and convenient, taking only 7 hours to test six biomarkers, which was beneficial for clinical use.

1. **Patents of QDs**

Patents and related searches were conducted analytics on the official website of world intellectual property organization to assess and organize recent work in area of treatment for diseases.

**Table 5. Shows a list of Quantum Dots patents**

|  |  |  |  |
| --- | --- | --- | --- |
| **Patent No.**  | **Assignee Issue**  | **Date** | **Reference**  |
| US 4637988  | Eastman Kodak Company  | 1987 | 24 |
| US 6114038  | BioCrystal Ltd  | 2000 | 24 |
| US 6274323  | Quantum Dot Corporation  | 2001 | 24 |
| US 7181266  | Massachusetts Institute of Technology, Beth Israel Deaconess Medical Center  | 2007 | 24 |
| CN 200810041133  | Shen Bo Crane  | 2009 | 24 |
| CN 201010185953 | Mao Quan, Chu Hou Sen  | 2012 | 24 |
| CN 201410239033 | Im Kwon, Yang Xudong, Chen Jie, Chen Yang, Sun Yang,Xue Qing, Bai Yang,Dongfeng Xia  | 2014 | 24 |
| EP 3073728A1 | Nokia Technologies Oy | 2016 | 76 |
| EP2603935B1 | Samsung Electronics co Ltd. | 2018 | 77 |
| US10630927B2 | Nokia Technologies Oy | 2021 | 78 |

1. **Role of Quantum Dots for cancer diagnosis and therapy**

Quantum dots (QDs) are semiconductor nanocrystals that glow when stimulated by light. They offer outstanding optical features, including as high brightness, photobleaching resistance, and a wavelength that may be adjusted. QDs can now be used in cancer imaging thanks to recent advances in surface modification. Sentinel lymph-node mapping could be aided by QDs with near-infrared emission. In vivo tumor targeting could be accomplished by combining QDs with biomolecules such as peptides and antibodies. We address future opportunities for further refining QD technology to identify metastatic cancer cells, quantitatively assess the quantity of specific molecular targets, and advise targeted cancer therapy by providing biodynamic signals for target suppression [82].

1. **Challenges and Future Prospects**
	1. **Nanotoxicology**

Although QDs have significant potential for biomedical imaging and detection, toxicological and pharmacological concerns, mostly due to heavy metal and colloidal instability, have hampered progress in cancer diagnosis and treatment [79, 80]. These problems may not stymie application development in vitro, but they pose significant obstacles to in vivo cancer imaging in humans. To decrease toxicity and increase detection efficiency, efforts have been made to develop innovative QDs based on their components, sizes, surface coatings, and valences. However, issues such as QD modification-induced coating shell deterioration should be considered [81-83]. Nonspecific RES buildup, including the liver, spleen, and lymphatic system, should also be examined [79, 84]. There have also been reports of immunological response and genotoxic effects [85]. QDs smaller than 5 nm can be eliminated by the kidney, according to several studies [86]. Long-term toxicological and pharmacokinetic studies involving QD breakdown, excretion, persistence, and immune response should be rigorously assessed when considering biosafety for in vivo applications. Several low-toxicity QDs have been created as alternatives for Cd, Se, Zn, Te, Hg, and Pb, due to their toxicity [87, 88]. By replacing Cd with Zn, for example, reduced toxicity can be attained. Environmental changes, such as temperature, chemical, and photochemical disturbances, are also less sensitive to such QDs. These doped QDs exhibit good quantum efficiency and color tunability, making them interesting candidates for future efforts to reduce QD-based cytotoxicity. They can also cover most of the visible spectral window due to their narrow emission spectra (45 nm to 65 nm whole width at half maximum). Doped QDs that emit in the near-infrared range will be produced soon. Before QDs can be used in any medical process, they will need to undergo extensive scrutiny and research into their toxicity profiles.

* 1. **Biocompatible and biodegradable nanoparticles: design and fabrication**

The comparatively large size (15 nm to 30 nm) and short circulation half-life in the blood vascular system hinder QD-based in vivo imaging and targeting research. Various current groups are attempting to extend the circulation period of QDs by adding passivating molecules such as PEG to the particles and regulating the overall charge of the particles to avoid adsorption to plasma proteins [89-91]. Alternatively, any contrast agent must be cleared from the body before it may be used clinically. A new discovery reveals a size threshold of 5 to 6 nanometers in diameter below which QDs cannot escape the liver and be cleared through the kidneys [92,93].

* 1. **QDs' reproducibility, dependability, and comparability**

The current clinical applications of QDs are severely constrained by a scarcity of data on their repeatability and comparability, as well as their quantification capability. Due to varying materials and surface chemistries, distinct functionalized QDs from various sources will have different fluorescence quantum yields. As a result, the first step is to derive and set quality requirements for these materials of various functionalized QDs [94-96].

1. **Conclusion**

Over the years, nanotechnology has showed a lot of promise in cancer treatment. Nanomaterials (QDs) have enhanced cancer detection and treatment due to their better pharmacokinetic and pharmacodynamic properties. Due to their specificities, nanotechnology provides for targeted medicine delivery in damaged tissues with minimal systemic toxicity. QDs are technological wonders with properties that have the potential to transform cancer diagnosis and treatment. Currently, QDs are frequently employed in vitro for a variety of purposes, including identifying cancer biomarkers in molecular pathology, disclosing cancer invasion, focusing on the tumor environment, and giving a fresh approach to better understanding tumor heterogeneity understanding, diagnosis, classification, and treatment of cancer. Multifunctional nanoplatforms, which integrate therapeutic components with multimodality imaging, are the future of nanomedicine. The ultimate goal is for nanoplatform-based agents to provide efficient and selective in vivo targeted drug delivery without systemic toxicity, with the dose given as well as therapeutic efficacy evaluated noninvasively over time. Inefficient delivery, possible toxicity, and a lack of measurement are all important hurdles to QD clinical translation.

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