REVIEW ARTICLE

Quantum Dots: An Emerging Approach for Lung Cancer Management

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ABSTRACT

Nanotechnology is an empirical approach that promises hope and novel treatment possibilities for cancer. This state-of-the-art technology offers innovative methods for diagnosing and treating a variety of illnesses. Though there have been some positive advances since the discovery of quantum dots (QD) nano-transporters, these advances are still in their development, even though they have been shown to be beneficial to society. QD has shown to be incredibly suitable for bio-imaging, targeted gene delivery, pharmacological research, biosensing, photodynamic therapy, and diagnosis through its usage in natural imaging and photography. The overview's main goal was to emphasize how important QD is for both cancer detection and therapy. The goal is to provide readers with a basic understanding of QD, including its benefits and applications in lung cancer management. Furthermore, we have discussed the many studies pertaining to cytotoxic analysis in order to demonstrate the safety of QDs. The current study provides a concise summary of the current research, fabrication methods, and applications of QD in lung cancer treatment.

Keywords: Quantum Dots, Lung cancer, diagnosis, Treatment, Imaging, Nanotechnology.

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INTRODUCTION

The uttermost prevailing and malignant type of carcinoma universally is pulmonary neoplasms. Lung tumor is the type of neoplasm that is most intermittently diagnosed, accounting for 11.6% of all occurrences of carcinoma globally. In the United States, 130,180 humans are approximately demised from pulmonary carcinoma in 2022, with 236,740 new cases[1]. Smoking is to blame for almost 80% of pulmonary carcinoma fatalities. A private or family lung neoplasm diagnosis as well as continuous exposure to air pollution, are additional risk factors for the disease [2]. Previously, only 22 cases of lung cancer that had been reported in the late 1840s could be found by the British author Hasse. In 1912, Adler could only locate 374 documented cases[3]. The WHO database revealed the expected death rate and new cases in 2023. Among men, the expected death rate and new cases were 117,55011 and 67.160 and in females, 120,790 and 59,910, respectively. Based on WHO guidelines, lung cancer is categorized into two categories: Non-small cell lung cancer (NSCLC) and small cell lung cancer (SCLC)[4]. SCLC is a highly aggressive form of lung cancer. It is spreading swiftly and growing at a rapid pace. Responds favourably to radiation therapy and chemotherapy. SCLC can affect anyone, although it primarily affects persons who have a lengthy history of tobacco use, particularly cigarette smoking[5]. All epithelial lung cancers that are not small-cell lung cancers are collectively known as NSCLCs. It accounts for 85% of lung cancers. In comparison to small-cell carcinoma, (NSCLCs) are classified as being relatively resistant to chemotherapy. They are usually treated with surgical removal with a curative aim, but preoperative and postoperative chemotherapy is becoming more common [6].

Conventional Methods of Diagnosis for Lung cancer

Radiographic diagnosis

A Japanese study found that annual screening for lung cancers with a clinic-based chest X-ray reduced death by 25%. Computed tomography (CT) is superior to plain radiography and conventional whole-lung tomography in identifying abnormalities of the peripheral lung. Spiral CT scans are more accurate at diagnosing conditions because they can continuously collect data, which lowers radiation exposure and scanning time when compared to plain radiography. Modern spiral CT scanning can detect nodules as small as 1 to 5 mm. Spiral CT scans have improved the ability to identify peripherally small tumors[7].

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Sputum examination

Sputum cytology can identify central tumours from larger bronchi like squamous and small-cell carcinomas. In the sputum samples, there were no microscopic adenocarcinomas (diameter 2 cm) that originated from small bronchi, bronchioles, and alveoli. Since cigarette exposure adjustments have enhanced the adenocarcinoma risk and declined the squamous carcinoma risk, respectively, this has become more and more significant. Sputum cytology is not precise or sensitive enough, according to studies.

Bronchoscopy

For some histological lung cancer diagnoses, the most common diagnostic method is white light bronchoscopy (WLB). When it comes to diagnosing pre-malignant lesions, bronchoscopy has considerable limits. These lesions consist of distinct layers of cells that are a few millimeters in diameter and 0.2 to 1 mm thick, making them difficult to see visually. To circumvent this constraint, fluorescent bronchoscopy was developed[8]. To get around this, a new type of laser photodynamic diagnostic device was created that uses 630 nm tumor-specific medication fluorescence. The usual endogenous fluorescence of the combination of cells, i.e., 500 to 580 nm, is different from this wavelength. According to morphological analysis, bronchial pre-neoplastic and early malignant lesions frequently exhibit angiodysplasia alterations. Smokers have been shown to develop pre-neoplasia. Thus, there is an interest in carrying out additional research to ascertain whether ASD can be utilized as a biomarker for early lesions and whether it is relevant for long-term follow-up.

Lung Tissue Biopsy

The standard for determining whether a malignancy is still present is a tissue biopsy. Samples of lung tissue biopsies must have sufficient tissue for the subtype of lung cancer to be identified using histopathological methods. The biopsy may confirm an early screening to minimize the need for repeat surgery, raise the complications, and postpone the initialization of treatment. Pleural fluid analysis, endobronchial ultrasound, thoracoscopy, mediastinoscopy, and surgical techniques are among the numerous approaches frequently employed to identify lung cancer. These processes are expensive, prone to errors, and could require more samples.[9]

Conventional Methods of Treatment for Lung Cancer

Conventional approaches for the cure of pulmonary carcinoma are categorized into categories such as chemotherapy, radiotherapy, and surgical treatment, immunotherapy and molecular targeted therapy.

Surgery

It is commonly known that a lobectomy, is the best line of treatment for NSCLC that is in its early stages. The majority of the evidence favors lobectomy over sub-lobar resection, notwithstanding the inconsistent nature of the data. The Lung Cancer Research Group's research 801, which was carried out, provides the strongest evidence. It showed that the likelihood of a local recurrence was three times higher for patients who received sub-lobar resections. Additionally, it appears from retrospective research that lobectomy often has a higher survival rate than limited resection[10].

Neoadjuvant chemotherapy

Neoadjuvant chemotherapy may be more advantageous than adjuvant therapy in that it can cure micrometastases early, slow the growth of tumors, which may result in complete resection, and be more tolerable. Neoadjuvant therapy was not shown to be beneficial in a noteworthy French study that compared before-operation chemotherapy with mitomycin, cisplatin, and ifosfamide in combination with surgery to surgery alone. Due to limited recruitment, an alternate randomized trial that contrasted surgery alone with induction chemotherapy with gemcitabine and cisplatin after surgery for stage IB/IIIA was prematurely halted. However, induction chemotherapy was found to boost stage IIB/IIIA survival in a statistically meaningful way by the researchers.[11]

Adjuvant chemotherapy

Sufferers at an early stage are recommended to get adjuvant chemotherapy because distant metastases frequently experience failure following surgery. Following surgical resection, adjuvant therapy—combination regimens based on cisplatin—is advised for individuals at stages II and III-A. This approach was found to provide a 5.4% five-year survival enhancement based on analysis of the five trials. Adjuvant therapy has also been shown in other studies to improve survival following total resection. Treatment for early-stage NSCLC with immunotherapy and molecules-targeted drugs is becoming more and more common[12].

Immunotherapy

Stage III NSCLC is extremely difficult to manage. Concurrent chemoradiation is the most accepted standard for unresectable stage III NSCLC for the past ten years. Treatment for both distant and locoregional micrometastatic illness is the goal of this strategy. Unfortunately, only 15% of sufferers with stage III NSCLC still have a dismal prognosis after five years[13-15].

Nanotechnology in lung cancer

Nanotechnology is presently used in various sectors in the medical field, from diagnosis to therapy, and its application has increased[16-20]. An innovative approach with significant potential for early identification and precise, successful cure has been made feasible by nanotechnology and its application in medicine. As Table 1 shows, the use of various nanomaterials as well as a wide range of intricate concepts, methods, processes, and instruments created at the nanoscale, are all included in nanotechnology. Researchers have developed or discovered a wide range of multifunctional nanomaterials over the last few decades to enhance our quality of life.[21-23]

Quantum Dots

The first biomedical imaging application of quantum dots (QDs), i.e., nanoscale semiconductor crystals, was published in 1998. Ekimov and Onushenko first disclosed QDs in a

Table 1: Nanotechnology in lung cancer diagnosis and treatment

Technology	*Nanomaterials*	*Application*	*References*
Fluorescence—in situ examination	Non-fluorescent and fluorescent NPs	Fluorescent agents	[24]
Computer tomography	Gold NPs	targeted contrast agent	[25]
Magnetic resonance imaging	SPIONs, manganese oxide NPs, and gadolinium oxide-based NPs	Improved contrast agents	[26]
Positron emission tomography	Gold/mesoporous silica hybrid nanoparticles, Gd2O3-doped carbon-11-choline (GdCho), and manganese oxide NPs.	Improved contrast agents	[27,28]
Photodynamic therapy	Hypocrellin B nanoparticles, quantum dots	Photosensitizer	[29]
Radiation therapy	Platinum and gold-based nanoparticles	Sensitizer	[30]
Gene therapy	Liposomal nucleic acid delivery technique, also known as lipofectamine, solid lipid, and polymer-based gene delivery vectors are all examples at hand.	Delivery of Nucleic acid	[31]
Chemotherapy	Polymers, dendrimers, and liposome-based drug delivery systems (a variety of chemotherapeutic agents)	Carriers, targeted carriers	[32,33]

glass matrix back in 1981. Since then, this field has been constantly expanding, and it now encompasses uses in sectors such as computers, biomedical imaging, light-emitting diode (LED) production, solar cells, and so on. QDs are fluorescent semiconductor nanocrystals that are smaller than the radius of the material's Bohr's exciton and made of atoms from Mendeleev periodic table's II-IV or III-V groups. Due to the impact of dimensional quantization, they have the characteristics of controlled photoluminescence. The science of QDs started to progress after Lus Brus found in 1984 a correlation between breadth & size of the energy gap band for semiconductor NPs. The purpose of encapsulating these nanocrystals was to produce core-shell nanocrystals, which would improve their stability, biocompatibility, and quantum yield of fluorescence[34]. By preventing metal ions from leaking from a core due to passivation on the semiconductor's QD surface with a high energy gap band, this structure greatly boosted luminescence efficiency. Initially, the QDs that generated the greatest interest were CdSe/ZnS and CdSe/CdS. The main element is cadmium. Nonetheless, it is generally acknowledged that cadmium ion leakage is the main reason behind cytotoxicity based on cadmium, which makes using QDs in vivo or in vitro challenging. The goal moved to producing cadmium-free QDs in order to facilitate their use in biology as the need for more biocompatible QDs grew. To be employed as bright probes for biosensors and bioimaging, Ag2Se, Ag2S, InP, CuInS2/ZnS, graphene quantum dots (GQDs), QDs comprising silicon (Si-QDs), QDs containing carbon (C-QDs), and C-QDs were produced[35].

Applications of Quantum Dots

In-vivo- In-vitro imaging

Despite its application in animal models, fluorescence imaging is constrained by the low visible light transmission within the living system. This has motivated scientists to employ QDs for deep-tissue optical imaging in NIR optical windows. There are many QDs bio-imaging formulations accessible presently in the literature. Large animals undergoing major cancer surgery can have real-time confirmation of total resection by using polydentate phosphine-coated QDs as direct visual aids. Research studies revealed that cellular imaging with capped InP@ZnS QDs showed five distinct lymphatic circulations draining at one time[35].

Drug delivery agent

QDs are appealing options for theranostic platforms because, in a more complicated design, they can serve as both the fluorescent labels and the principal nanocarrier. CdTe@CdS@ ZnS with paclitaxel (PTX), a well-liked drug substitute for the correction of many malignancies. QDs were co-loaded in NLCs to give therapeutic and diagnostic approaches. The percentages of instances with encapsulation efficacy (80%), drug loading (4.68%), and tumor growth suppression (77.85%) were attained. The anticancer medication PTX and the ZnSe:Mn/ZnS core-shell would be put into the nanocapsules. The system was composed of hydrophilic silica on the outside with amino groups acting as targets for the targeting molecules, ZnSe:Mn@ZnS QDs and PTX molecules loaded in the hydrophobic inner. The findings showed that PTX's solubility shows an increment of 630 times and that it might be administered sustainably for nearly 12 hours[35].

Sensors

Chan and Nie published publications on QDs (ZnS@CdSe) for extremely sensitive nonisotopic determination. The theory being proposed an impedimetric immunosensor including an anti-CA-125 monoclonal antibody, CdSe QDs, and loaded gold electrode. mercaptopropionic acid. The immunosensor was intended to detect the CA-125 serum biomarker in individuals suffering from ovarian cancer. In this setup, the desired biomarker could be present as low as 0.0016 U/Ml[36].

QDs in Lung Cancer Management

It is believed that the likelihood of a patient surviving increases with early detection. However, even though over 200 different types of cancer are becoming a real threat globally, current

Table 2: QDs in diagnosis and treatment therapy of lung cancer

Formulation	*Diagnostic and therapeutic agent*	*Key findings*	*Reference*
Ethylene-diamine-doped Carbon Quantum dots	N-CQDs and FA-NCQDs	Ethylene-diamine-doped CQDs showed high cytotoxicity compared to CQDs alone.	39
Indium phosphide (InP)/ZnS Quantum Dots	hydroxylated, amino, and carboxylic QDs	ICP-MS and cryosection fluorescence microscopy determined the biodistribution of three QDs.	40
QDs Based Nano-Biosensor	Reporter probe that is labeled with Cy5.	DNA-functionalized QDs are effective lung cancer bioimaging fluorescent nanomaterials.	41
Hybridization of quantum dots	AgInS2@ZnS nanocrystals induced by ctDNA.	Results show quantum dot growth and strong fluorescence signal changes.	42
Graphene quantum dots (GQDs)	Graphene quantum dots biofunctionalized with gold nanoparticles (AuNPs)	demonstrated extremely sensitive lung small cell detection.	43
Peptide-coated CdSe/ZnS QDs	Peptide-coated CdSe/ ZnS QDs	Findings indicate QDs showed cytotoxicity against tumor cells.	44
Wrinkled metal-based quantum sensor	Aluminium-based 3D QDs.	The chemical sensing limit of Rhodamine 6G and Crystal Violet was increased to single molecule sensing.	45
NIR-emitting Ag2S quantum dots	PEGylated Ag2S QDs loaded with 5-fluorouracil (5FU), cetuximab (Cet) antibodies	Highly selective and effective 5FU delivery of theranostic nanoparticles to EGFR-overexpressing lung cancer cells.	46
Molybdenum oxide quantum dots (MoOx QDs)	MoOxQDs	Showed robust and stable cathodic green emission. Successful determination of CYFRA21-1 with favourable analytical results was accomplished.	47
Quantum Dots-β-cyclodextrin nanocarrier for foliate-targeting	β-cyclodextrin (β-CD)	FA is an effective self-navigating molecule for cancer cell drug administration using QDs.	48
Trastuzumab	Trastuzumab	The genes HER1 and HER2 are overexpressed in cancer cells that originate from the breast, non-small cell lung, head and neck, and colon.	49
BP/DTX@PLGA	Poly(lactic-co-glycolic acid and docetaxel (DTX),	The distribution results in vivo suggest that BP/DTX@ PLGA exhibits remarkable tropism for targeting lung metastatic cancers as well as original tumors.	50
Core and multiple-layered shell ZnS/CdSe/CdS QDs	Folic acid (FA) was coupled with CdSe/ CdS/ZnS QDs in the core and multilayer shell.	The ability of FA conjugated QDs to effectively target tumor spheroids, hence validating the critical function of the FRα receptor as a target.	51
BPs/G-Rg3@PLGA	Poly lactic-co-glycolic acid and Ginsenoside Rg3 (G-Rg3).	Exhibits better controlled CPT therapy in conjunction with near-light irradiation, boosting photothermal tumor ablation.	52
2DG-grafted GQDs	2-deoxy-d-glucose (2DG) on graphene quantum dots (GQD).	When 2DG-grafted GQDs (2DG-g-GQD) were used in conjunction with radiotherapy (RT).	53

cancer diagnosis and cure modalities frequently fall short of providing significant progress. To achieve this, new, effective, and unique methods are required. Oncologists and other scientists working in the field of cancer are indispensable in this regard, as innovations must be implemented to advance the early screening and treatment of cancer. Tan revealed a crucial difference between the intracellular transport of glycosylated and nonglycosylated peptides in lung cancer cells and normal cells. Researchers[37] discovered that only glycosylated peptides were allowed to localize in the Golgi apparatus, while nonglycosylated peptides were restricted from entering the Golgi. This allowed normal lung tissue to distinguish between naked and glycosylated peptides. Researchers were unable to locate a comparable lung carcinomic cell that has allowed both glycosylated & naked peptides to pass through the Golgi apparatus.[37] Various research studies have explored the application of QDs for lung cancer diagnosis and treatment therapies.[38] Table 2 enlisted some of the use of QDs in the diagnosis and treatment therapy of lung cancer, respectively.

Future Prospectives

Although QDs are primarily known for their use as luminescent labels, their analytical relevance is expanding into new areas. These include the development of sensitive and selective chemosensors as well as the use of their high reactivity for the implementation of various online reactional schemes and their ability to be immobilized and/or encapsulated in solid supports. Combined with automated analytical techniques. QDs can potentially accelerate redox reactions or produce metastable or short-lived species for rapid measurement.

However, in terms of more ecologically favorable chemistry, automated techniques reduce waste production and reagent use, which could be a useful advantage when using heavy metal-containing semiconductor materials are worried, but they might also stop operators from entering interaction with hazardous substances. Furthermore, complicated reactional schemes or multiparametric calculations can be implemented very well with automated flow-based approaches; these ideas are also closely related to quantum dots nanotechnology. Quantum dots are also being used in the treatment of neoplasm and will be considered as a potential way to cure neoplasm.[50-55]

CONCLUSION

Globally, lung cancer is the primary cause of mortality from cancer. The lack of selectivity and access to typical cells in conventional lung cancer treatment causes cytotoxicity, rapid cellular uptake, and drug clearance. The introduction of quantum dots as a revolutionary drug-delivery mechanism has transformed the medical management of lung cancer. QDs offer biomedical applications such as bioimaging, medication administration, and pulmonary diagnostics. Challenges, including pulmonary toxicity and immune system reactions induced by QDs must be resolved for QDs to be practically transferred into clinical applications. In this study, we summarised the recent advancements in the literature regarding the application of QDs for lung cancer treatment.

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AUTHOR CONTRIBUTION

All the authors contributed equally to this manuscript.

REFERENCES

1. Siegel RL, Miller KD, Fuchs HE, Jemal A. Cancer statistics 2022. CA Cancer J Clin. 2022;72(1):7–33. Available from: https://doi.org/10.3322/caac.21708.
2. Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2018;68(6):394–424. Available from: https://doi.org/10.3322/caac.21492
3. Kanwal M, Ding XJ, Cao Y. Familial risk for lung cancer. Oncol Lett. 2017;13(2):535-42. Available from: https://doi.org/10.3892%2Fol.2016.5518
4. Lahiri A, Maji A, Potdar PD, Singh N, Parikh P, Bisht B, Mukherjee A, Paul MK.. Lung cancer immunotherapy: progress, pitfalls, and promises. Mol Cancer. 2023;22(1):40. Available from: https://doi.org/10.1186/s12943-023-01740-y
5. Groot PM, Wu CC, Carter BW, Munden RF. The epidemiology of lung cancer. Transl Lung Cancer Res. 2018;7(3):220-233. Available from: https://doi.org/10.21037/tlcr.2018.05.06
6. Chen JW, Dhahbhi J. Lung adenocarcinoma and lung squamous cell carcinoma cancer classification, biomarker identification, and gene expression analysis using overlapping feature selection methods. Nature.2021;11:13323. https://doi.org/10.1038/s41598-021-92725-8
7. Nooreldeen R, Bach H. Current and Future Development in Lung Cancer Diagnosis. Int J Mol Sci. 202;22(16):8661. Available from: https://doi.org/10.3390/ijms22168661
8. Andolfi M, Potenza R, Capozzi R, Liparulo V, Puma F, Yasufuku K. The role of bronchoscopy in the diagnosis of early lung cancer: a review. J Thorac Dis 2016;8(11):3329-3337. Available from: https://doi.org/10.21037/jtd.2016.11.81
9. Begum M, Narasimha K. Studies on Smilax perfoliata and Breynia retusa against Experimentally Induced Cancer in Swiss Albino Mice. International Journal of Pharmaceutical Quality Assurance. 2024;15(1):11-19. Available from: https://doi.org/10.25258/ijpqa.15.1.02
10. Khullar OV, Liu Y, Gillespie T, Higgins KA, Ramalingam S, Lipscomb J, Fernandez FG. Survival after sublobar resection versus lobectomy for clinical stage IA lung cancer: an analysis from the National Cancer Data Base. J Thorac Oncol. 2015; 10: 1625-1633. Available from: https://doi.org/10.1097/jto.0000000000000664 \
11. Dawood MN, Jamel HO. Synthesis, Characterization of New Ligand Derived from 4-aminoantipyrine and its Complexes with Few Metallic Ions and Evaluation of their Activity as Anticancer. International Journal of Drug Delivery Technology 12(04):1669-1681. Available from: http://dx.doi.org/10.25258/ijddt.12.4.32
12. Kelly K, Altorki NK, Eberhardt WEE, O'Brien MER, Spigel DR, Crino L, Tsai CM, Kim JH, Cho EK, Hoffman PC, Orlov SV, Serwatowski, Wang J, Foley M, Horan JD, Sheperd FA**.** Adjuvant erlotinib versus placebo in patients with stage IB-IIIA non-small-cell lung cancer (RADIANT): a randomized, double-blind, phase III trial. J Clin Oncol. 2015; **33**: 4007-4014. Available from: https://doi.org/10.1200/jco.2015.61.8918
13. Yoon S.M. Shaikh T. Hallman M**.** Therapeutic management options for stage III non-small cell lung cancer. World J Clin Oncol. 2017; **8**: 1-20. Available from: https://doi.org/10.5306/wjco.v8.i1.1
14. Antonia SJ, Villegas A, Daniel D, Vicente D, Murakami S, Hui R, Yokoi T, ChiappoA, Lee KH, Wit MD, Cho BC, Bourhaba M, Quantin X, Tokito T, Mekhail T. Durvalumab after chemoradiotherapy in stage III non–small-cell lung cancer. N Engl J Med. 2017; **377**: 1919-1929. Available from: https://doi.org/10.1056/nejmoa1709937
15. Antonia SJ, Villegas A, Daniel D, Vicente D, Murakami S, Hui R, Yokoi T, ChiappoA, Lee KH, Wit MD, Cho BC, Bourhaba M, Quantin X, Tokito T, Mekhail T. Overall survival with durvalumab after chemoradiotherapy in stage III NSCLC. N Engl J Med. 2018; **379**: 2342-2350. Available from: https://doi.org/10.1056/nejmoa1809697
16. Herbst R, Morgenstern D, Boshoff C. The biology and management of non small cell lung cancer. Nature. 2018;553(7689):446-454. Available from: https://doi.org/10.1038/nature25183
17. Koutu V, Gupta M, Das S, Rawar DK, Kharade V, Pasricha RK. Nanotechnology in Lung Cancer Therapeutics: A Narrative Review. Cureus. 2023; 15(1): e34245. Available from: https://doi.org/10.7759/cureus.34245
18. Duan Y, Shen C, Zhang Y, Luo Y. Advanced diagnostic and therapeutic strategies in nanotechnology for lung cancer. Front. Oncol. 2022;12:1031000. Available from: https://doi.org/10.3389/

fonc.2022.1031000
19. Wakale V, Kachave R, Gholap P, Mahajan K, Tare H. Design and Discovery of Genistein-based Drugs as a Potential Tyrosine Kinase Inhibitor for Lung Adenocarcinoma through Hybrid In-silico Methods. International Journal of Drug Delivery Technology. 2023;13(4):1422-1427. Available from: https://doi.org/10.25258/ijddt.13.4.47
20. Nakhaei, P, Margiana, R, Bokov DO, Abdelbasset, WK, Jadidi Kouhbanani, M.A, Varma RS, Marofi F, Jarahian M, Beheshtkhoo N. Liposomes: Structure, Biomedical Applications, and Stability Parameters with Emphasis on Cholesterol. Front. Bioeng. Biotechnol. **2021**;9: 705886. Available from: https://doi.org/10.3389/fbioe.2021.705886
21. Zangabad PS, Mirkiani S, Shahsavari S, Masoudi B, Masroor M, Hamed H, Jafari Z, Taghipour YD, Hashemi H, Karimi M, Hamblin MR. Stimulus-Responsive Liposomes as Smart Nanoplatforms for Drug Delivery Applications. Nanotechnol. Rev. **2018**;7: 95–122. Available from: https://doi.org/10.1515/ntrev-2017-0154
22. Scioli Montoto S, Muraca G, Ruiz ME. Solid Lipid Nanoparticles for Drug Delivery: Pharmacological and Biopharmaceutical Aspects. Front. Mol. Biosci. **2020**;7: 587997. Available from: http://dx.doi.org/10.3389/fmolb.2020.587997
23. Paliwal R, Paliwal SR, Kenwat R, Kurmi BD, Sahu MK. Solid Lipid Nanoparticles: A Review on Recent Perspectives and Patents. Expert Opin. Ther. Pat. **2020**; 30: 179–194. Available from: https://doi.org/10.1080/13543776.2020.1720649
24. Wolfbeis OS. An Overview of Nanoparticles Commonly Used in Fluorescent Bioimaging. Chem. Soc. Rev. 2015; 444743–4768. Available from: http://dx.doi.org/10.1039/c4cs00392f
25. Cole LE, Ross RD, Tilley JM, Vargo-Gogola T, Roeder RK. Gold Nanoparticles as Contrast Agents in X-ray Imaging and Computed Tomography. Nanomedicine 2015;10:321–341. Available from: https://doi.org/10.1002%2Fwnan.1642
26. Mortezazadeh, T. Glucosamine Conjugated Gadolinium (III) Oxide Nanoparticles as a Novel Targeted Contrast Agent for Cancer Diagnosis in MRI. J. Biomed. Phys. Eng. 2020;10:25. Available from: https://doi.org/10.31661/jbpe.v0i0.1018
27. Zhou T, Hang D, Li Y, Zhang J, Wu H, Wang H, Tian E, Yan J. Role of Gd2O3-doped Carbon-11-choline-lenvatinib Nanoparticles Contrast Agent PET/CT in the Diagnosis of Patients with Lung Cancer. Oncol. Lett. 2019; 19:1117–1124. Available from: https://doi.org/10.3892%2Fol.2019.11243
28. Fang D, Jin H, Huang X, Shi Y, Liu Z, Ben S. PPy@Fe_3O_4 Nanoparticles Inhibit Tumor Growth and Metastasis Through Chemodynamic and Photothermal Therapy in Non-Small Cell Lung Cancer. Front. Chem. 2021;9:789934. Available from : https://doi.org/10.3389%2Ffchem.2021.789934
29. Uprety B, Abrahamse H. Semiconductor Quantum Dots for Photodynamic Therapy: Recent Advances. Front. Chem. 2022;10, 946574. Available from: https://doi.org/10.3389%2Ffchem.2022.946574
30. Haume K, Rosa S, Grellet S, Śmiałek MA, Butterworth KT, et al. Gold Nanoparticles for Cancer Radiotherapy: A Review. Cancer Nanotechnol. 2016;7:8. Available from: https://doi.org/10.1186/s12645-016-0021-x
31. Nimesh S. Polyethylenimine as a Promising Vector for Targeted SiRNA Delivery. Curr. Clin. Pharmacol. 2012; 7:121–130. Available from: https://doi.org/10.2174/157488412800228857
32. Shi M, Gu A, Tu H, Huang C, et al. Comparing Nanoparticle Polymeric Micellar Paclitaxel and Solvent-Based Paclitaxel as First-Line Treatment of Advanced Non-Small-Cell Lung Cancer: An Open-Label, Randomized, Multicenter, Phase III Trial. Ann. Oncol. 2021: 32:85–96. Available from: https://doi.org/10.1016/j.annonc.2020.10.479
33. Zuo Y, Shen W, Wang L, Wang C, Pu J. Study on the Mechanism of Action of Paclitaxel-Loaded Polylactic-Co-Glycolic Acid Nanoparticles in Non-Small-Cell Lung Carcinoma Cells. Comput. Math. Methods Med. 2022; 2022:1–7. Available from: https://doi.org/10.1155%2F2022%2F8524951
34. Agrawal S, Gurjur P, Nagendran S. Carbon Quantum Dots: Properties, Synthetic Methods, Applications in Pharmaceutical and Pollutant Analysis. International Journal of Pharmaceutical Quality Assurance 14(04):1221-1230. Available from: http://dx.doi.org/10.25258/ijpqa.14.4.62
35. Le N, Zhang M, Kim K. Quantum Dots and Their Interaction with Biological Systems. *Int. J. Mol. Sci.* 2022;23: 10763. Available from https://doi.org/10.3390/ijms231810763
36. Matea CT, Mocan T, Tabaran F, Pop T, Mosteanu O, Puia C, Iancu C, Mocan L. Quantum dots in imaging, drug delivery and sensor applications. Int J Nanomedicine. 2017;12: 5421-543. Available from: https://doi.org/10.2147/ijn.s138624
37. Klepárník K, Modlitbová P. Preparation and Analysis of Quantum Dots: Applications of Capillary Electrophoresis. Methods Mol Biol. 2020;2135: 55-83. Available from: https://doi.org/10.1007/978-1-0716-0463-2_3
38. Jhangir M, Gilani S, et al. Quantum Dots: Next Generation of Smart Nano-systems. Pharmaceutical Nanotechnology. 2019;7: 234-245. Available from: https://doi.org/10.2174/2211738507666190429113906
39. El-brolsy HMEM, Hanafy NAN, El-Kemary MA. Fighting Non-Small Lung Cancer Cells Using Optimal Functionalization of Targeted Carbon Quantum Dots Derived from Natural Sources Might Provide Potential Therapeutic and Cancer Bio Image Strategies. *Int. J. Mol. Sci.* 2022;*23*: 13283. Available from: https://doi.org/10.3390/ijms232113283
40. Li L, Chen Y, Xu G, Liu D, Yang Z, Chen T, Wang X, Jiang W, Xue D, Lin G. In vivo Comparison of the Biodistribution and Toxicity of InP/ZnS Quantum Dots with Different Surface Modifications. Int J Nanomedicine. 2020;15: 1951-1965. Available from: https://doi.org/10.2147%2FIJN.S241332
41. Singh RD, Shandilya R, Bhargava A, Kumar R, Tiwari R, Chaudhury K, Srivastava RK, Goryacheva IY, Mishra PK. Quantum Dot Based Nano-Biosensors for Detection of Circulating Cell Free miRNAs in Lung Carcinogenesis: From Biology to Clinical Translation. Front. Genet. 2018; 9: 616. Available from: https://doi.org/10.3389/fgene.2018.00616
42. Yang L, Lin J, et al. High-sensitivity Flouroscence detection for lung cancer CYFRA21-1 DNA based on accumulative hybridization of quantum dots. Journal of Material Chemistry B. 2022. Available from: http://dx.doi.org/10.1039/D1TB02557K
43. Kalkat A, Pradhan R, et al. Biofunctionalized Graphene quantum dots based fluorescent biosensor towards efficient detection of small cell lung cancer. ACS Apllied Biomaterials. 2020. Available from: https://doi.org/10.1021/acsabm.0c00427
44. Woodman C, George A, et al. Applications and strategies in nanodiagnosis and nanotherapy in lung cancer. Seminars in cancer biology. 2021;69. Available from: https://doi.org/10.1016/j.semcancer.2020.02.009
45. Ganesan S, Tan B, et al. Wrinkled metal based quantum sensor for

In vitro cancer diagnosis. Biosensors and Bioelectronics. 2020;151. Available from: https://doi.org/10.1016/j.bios.2019.111967

46. Bavili N. Kiraz A. et al. Bypassing pro-survival and resistance mechanisms of autophagy in EGFR-positive lung cancer cells by targeted delivery of 5FU using theranostic Ag2S quantum dots. J. Mater. Chem. B. 2019;7: 7363. Available from: http://dx.doi.org/10.1039/C9TB01602C
47. Meng X, Chen X, Wu W, Zheng W, Deng H, Xu L, Chen W, Li Z, Peng H. Electrochemiluminescent immunoassay for the lung cancer biomarker CYFRA21-1 using MoO_x quantum dots. Mikrochim Acta. 2019;186(12):855. Available from: https://doi.org/10.1007/s00604-019-3917-4
48. Pilch J, Kowalik P, Kowalczyk A, Bujak P, Kasprzak A, Paluszkiewicz E, Augustin E, Nowicka AM. Foliate-Targeting Quantum Dots-*β*-Cyclodextrin Nanocarrier for Efficient Delivery of Unsymmetrical Bisacridines to Lung and Prostate Cancer Cells. *Int. J. Mol. Sci.* 2022;*23*:1261. Available from: https://doi.org/10.3390/ijms23031261
49. Leung K. Quantum dot-trastuzumab. In: Molecular Imaging and Contrast Agent Database (MICAD) [Internet]. Bethesda (MD): National Center for Biotechnology Information (US); 2004. 75.
50. Wang S, Shao J, Li Z, Ren Q, Yu XF, Liu S. Black Phosphorus-Based Multimodal Nanoagent: Showing Targeted Combinatory Therapeutics against Cancer Metastasis. Nano Lett. 2019;19(8):5587-5594. Available from: https://doi.org/10.1021/acs.nanolett.9b02127
51. Mangeolle T, Yakavets I, Lequeux N, Pons T, Bezdetnaya L, Marchal F. The targeting ability of fluorescent quantum dots to the folate receptor rich tumors. Photodiagnosis Photodyn Ther. 2019;26: 150-156. Available from: https://doi.org/10.1016/j.pdpdt.2019.03.010
52. Xiong J, Yuan H, Wu H, Cheng J, Yang S, Hu T. Black phosphorus conjugation of chemotherapeutic ginsenoside Rg3: enhancing targeted multimodal nanotheranostics against lung cancer metastasis. Drug Deliv. 2021;28(1):1748-1758. Available from: https://doi.org/10.1080/10717544.2021.1966129
53. Tung FI , Zheng LJ , Hou KT , Chiang CS , Chen MH , Liu TY . One-stop radiotherapeutic targeting of primary and distant osteosarcoma to inhibit cancer progression and metastasis using 2DG-grafted graphene quantum dots. Nanoscale. 2020;12(16):8809-8818. Available from:http://dx.doi.org/10.1039/C9NR10823H
54. Sharma V, Kumar V, Kumar P. Heterocyclic chalcone analogues as potential anticancer agents. Anticancers agents in medicinal chemistry. 2013;13(3):422-432. Available from: https://doi.org/10.2174/187152013804910424
55. Barani M, Bilal M, Rahdar A, Arshad R, Kumar A, Hamishekar H, Kyzas GZ. Nanodiagnosis and nanotreatmnet of colorectal cancer: overview. Journal of Nanoaprticle Research. 2021(23): 1-25. Available from: https://doi.org/10.1007/s11051-020-05129-6