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Significance and applications of carbon dots in anti cancerous nanodrug conjugate development: A review

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ABSTRACT

Carbon-based nanoparticles known as Carbon Dots (CDs) have attracted a lot of interest in the field of cancer therapy because of their special physicochemical characteristics and biocompatibility. They are attractive carriers for drug delivery systems due to their surface functional ability, superior water solubility, and size-dependent fluorescence. CDs are unique in that they have a large surface area, adjustable surface chemistry, and a remarkable ability to carry anticancer medications. Their lower systemic toxicity, regulated drug release, and capacity to get beyond biological barriers have completely changed the way that drugs are delivered. CDs have a variety of uses in the creation of anti-tumor nanodrug conjugates. CDs have been used in combination therapy, a multimodal strategy for cancer treatment that involves co-delivering various medications for synergistic benefits. The incorporation of CDs into anticancerous has-drug conjugates represents a noteworthy progression in the treatment of cancer medication delivery systems have been revolutionized by their capacity to improve medication stability, target specificity, and controlled release, which holds the promise of more effective and customized treatments. This review article deals with the synthesis of carbon dot-mediated nanodrug conjugate and their roles in cancer therapy.

Introduction

Nanotechnology, which implies the fabrication and alteration of materials at the nanometre scale, has created stirring new opportunities for a wide range of scientific fields including biomedicine [1], molecular diagnostic [2], pharmaceutic [3], optoelectronic, and environmental care [4]. Nanoparticles (NPs) are the most widely used type of nano system. These are structures with sizes ranging from 1 to 100 nm that result in unique physical-chemical characteristics that can be used for a variety of reasons. Nanoparticles (NPs) find extensive applications in the biomedical area, including bioimaging [5], drug delivery systems [6], therapeutic agents for photodynamic therapy (PDT) [7], photothermal therapy (PTT) [8], regenerative medicine [9,10], smart biomaterials [11], and sensing [12]. The most extensively researched materials are metal nanoparticles (MNPs), particularly noble metal NPs such as gold (AuNPs), silver (AgNPs) [4], platinum (PtNPs) [13], and palladium (PdNPs). Additional members of this broad family include liposomes [4], polymers, lipids, nanoparticles, and nanohybrids [4].

Carbon-based nanomaterials, commonly referred to as CDs, Carbon Quantum Dots (CQDs), or C-Dots (or CDs), recognized as the "rising star", have garnered significant attention recently in a variety of fields, including drug delivery, biological sensing, PDT, photocatalysis, and solar cells, due to their intriguing properties and distinctive structure. In particular, the exceptional electrical and optical characteristics of

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CDs—their low toxicity, biocompatibility, high photostability, tunable fluorescence, exceptional efficient up-converted photoluminescence (PL) behavior, and photo-induced electron transfer ability—have drawn more and more attention in biomedical and photocatalytic applications, usually range in size from 1 to 10 nanometers [4]. As illustrated in Fig. 1, CDs are commonly divided into three types: graphene quantum dots (GQDs), carbon nanodots (CNDs), and carbonized polymeric dots (CPDs). CDs are generally defined as small carbon nanoparticles (CNPs) in aqueous or other solutions. The sp2/sp3 hybridized carbon core with surface functional groups makes up most CDs. For example, GQDs are made up of mono- or multi-layer nano-sized graphite and surface/edge functional groups or interlayer defects [5]. These are anisotropic, with lateral dimensions greater than their height, and the size of π-conjugated domains and the surface/edge structures primarily determine their optical properties. CDs are used in the diagnosis of various diseases such as ocular diseases, infectious diseases, brain disorders, cancer, etc. [5]. In the continuous fight against cancer, CDs have emerged as a promising game-changer that offers hope. Their importance in cancer treatment can be seen from several important perspectives [5].

Cancer is one of the most serious health issues, with a high incidence and fatality rate affecting people worldwide. According to estimates, cancer killed 9.6 million people in 2017 and accounts for one in every six deaths globally, making it the second biggest cause of death behind cardiovascular disease [6]. A precise diagnosis is essential for an accurate and successful course of treatment, as every tumor requires a different combination of therapies, including surgery radiation, and chemotherapy. The primary challenges faced by oncologists are accurately determining the type of cancer and decisive the appropriate drug dosage that yields the greatest therapeutic benefit with the least amount of toxicity. Several cancers do not respond to the same treatment, and each one has benefits and drawbacks that frequently lower a patient's quality of life [7]. Many symptoms associated with chemotherapy patients, such as nausea, hair loss, pale complexion, etc., are brought on by most chemotherapy medications, which also harm healthy cells in addition to cancer cells [8]. In this regard, the new era of cancer research is nanotechnologies', such as CDs. The properties of CDs are governed by quantum confinement and surface state, and the synthesis strategy can modify them by employing various precursors or techniques. CDs can indeed be made to have amine, carboxyl, carbonyl, hydroxyl, ether, epoxy, and heteroatoms, which can function as chemical groups to graft other materials, such as organic, polymeric, and biological systems [9]. These systems could modify their chemical-physical properties, especially the PL, which shows a broad range of emission wavelengths as a function of both size (quantum effect), surface states, and groups, due to their varied design capability to obtain several size and surface functional groups [10]. With their diverse range of applications ranging from bioimaging to nano-carriers for drug delivery systems and potential agents for photodynamic (PDT) and photothermal treatment (PTT), CDs are a highly desirable material in the field of cancer application [4]. The review article seeks to explore the role and uses of CDs in the designing of nanodrug conjugates for cancer treatments. It will explain the method by which CDs can improve targeted therapy, personalized medicine, and drug delivery, and its importance in the advancement of cancer treatment.

Synthesis techniques

Various synthesis methods for CDs

A crucial factor in determining the characteristics and functions of CDs is their synthesis. These well-known CD synthesis techniques are typically divided into two categories: "top-down" and "bottom-up" depicted in Fig. 2 [11]. Graphite, carbon fibers, carbon nanotubes, and coal are among the carbon sources that are broken down and exfoliated in the top-down techniques. Small organic molecules like citric acid, glucose, fructose, and ascorbic acid can be pyrolyzed as part of bottom-up techniques [12]. These molecules can then be combined with other molecules to provide heteroatom doping atoms like nitrogen, boron, and sulphur. Here, we'll go over the key techniques for creating CDs, managing their size, and modifying their surface moieties through controlled pyrolysis [12].

Laser ablation

A novel technique in CDs synthesis that provides a unique way to

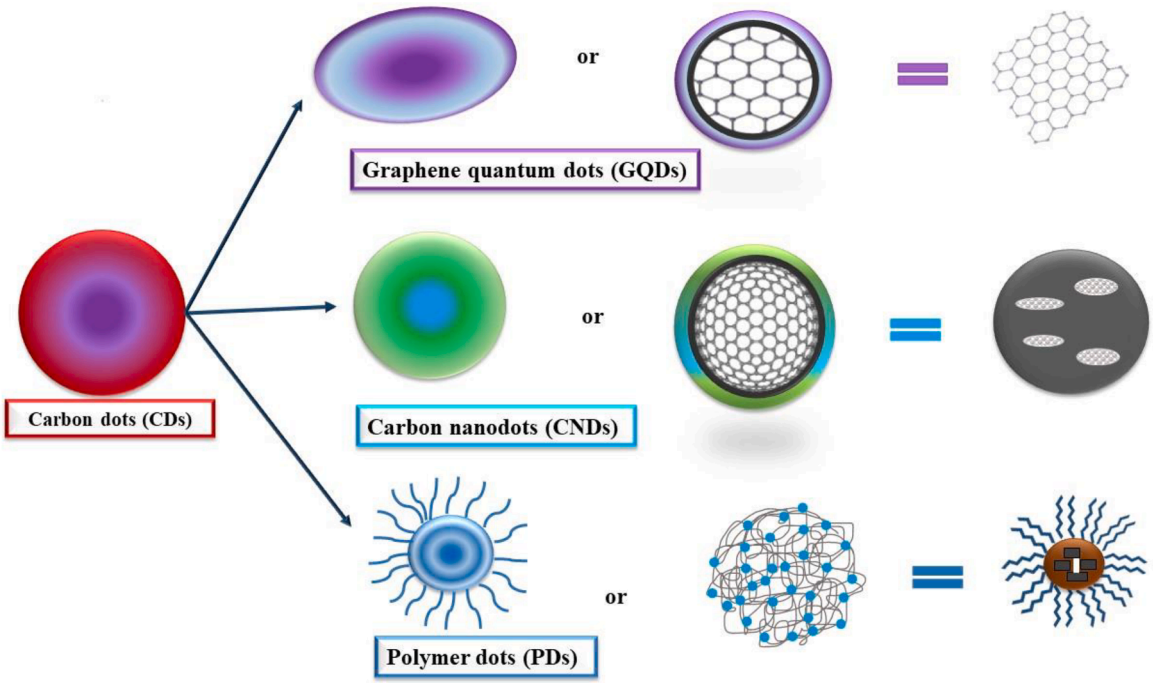

Fig. 1. Schematic representation of three classes of the CDs, a) Graphene quantum dots are made up of one or two graphene layers; b) Carbon nanodots have an amorphous or graphite-like structure and c) polymer dots are made up of aggregated linear polymers or polymer chains surrounding or inside a carbon core.

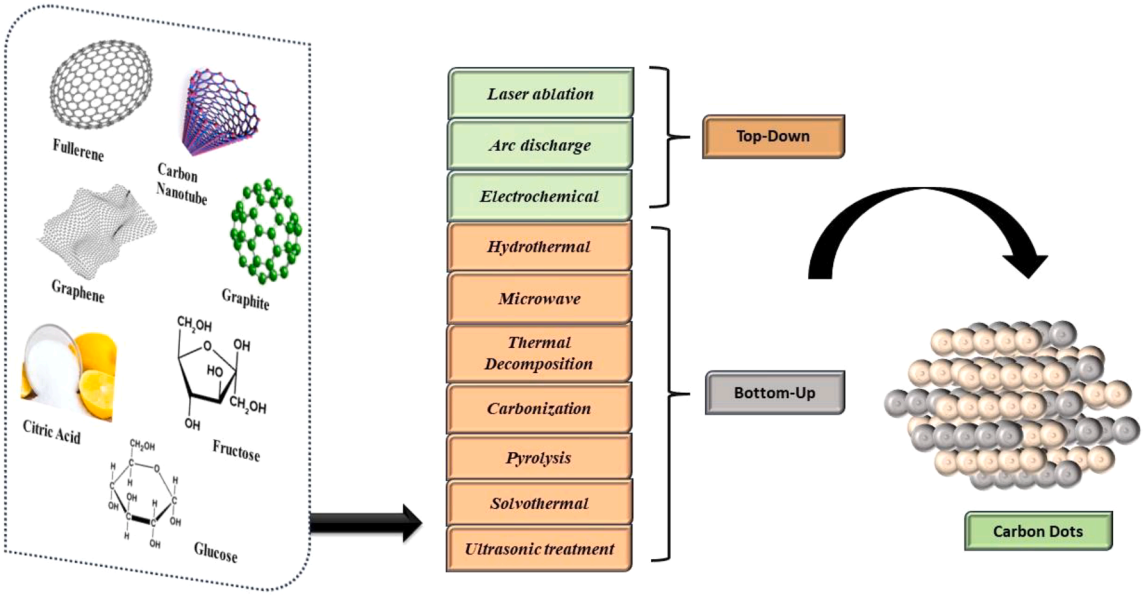

Fig. 2. Different Methods for the synthesis of Carbon Dots from both organic and inorganic sources.

fabricate them is laser ablation. This method starts the production of carbon particles by shining a laser beam at a target made of carbon that is submerged in a liquid. After that, these particles group together to produce CDs that have remarkable luminescence [12]. One notable feature of laser ablation is its capacity to generate precisely sized, highly photostable CDs. This approach shows the possibility of accurate and effective laser-based synthesis in the developing field of nanomaterials research and has applications in optical and imaging technology. Khyal et al. [11] created fluorescent C-dot by first combining cement and graphite powder, then heating the mixture to produce a carbon source. Moreover, carbon was extracted from the surface using a laser source and an argon gas vapor stream at 900 °C and 75 kPa to create CNPs [11]. These artificially created CNPs had varying diameters and no PL. Following a 12-hour reflux in aqueous nitric acid, the sample was treated with polyethylene glycol (PEG1500N) or poly (propionyl ethylene-imine-ethylene-imine) (PPEI EI). When excited at 400 nm, the fluorescence quantum yields of passivated C-dots with a diameter of around 5 nm showed a strong peak luminosity PL ranging from approximately 4 % to 10 % [13].

Hydrothermal approach

The hydrothermal approach is a well-known synthesis technique in which carbon precursors—typically organic chemicals like glucose or citric acid—go through a reaction in an aqueous solution at high pressures and temperatures. CDs with high water solubility and good crystallinity are typically produced by hydrothermal synthesis, which qualifies them for use in biological applications [11]. Using a hydrothermal method, Wang et al. [14] created nitrogen-doped CDs and a good fluorescence probe visible to the unaided eye for dopamine sensing. They were able to acquire a detection limit as low as 1.97 μg/mL and a linear range of 2–20 μg/mL [14].

Arc discharge process

An electric arc is formed between two carbon electrodes in an inert gas atmosphere using the arc discharge process, which is used to synthesize carbon nanotubes (CNTs). Carbon is vaporized and then condensed because of this high-energy process, creating CNTs with special structural characteristics [11]. PL nanoparticles from clean, carbon nanostructures that had been oxidized by nitric acid using the electrical flash method. The hydrophobic, luminous carbon nanotube nanoparticles with restricted dispersion seemed uncanny. Fluorescent nanoparticles might gather in water when oxidized carbon tubes were dispersed. CNPs were produced in very small quantities by arc discharge. AcD dust frequently contains a variety of intricate, challenging-to-extract elements [11,15].

Electrochemical synthesis

CDs are created precisely by carbonizing organic precursors at the electrode surface while an electric field is applied. This process is known as electrochemical synthesis. This process makes it possible to precisely fabricate CDs with specific sizes and morphologies, which makes it useful for a variety of applications, including electronic devices and sensors. Platinum (Pt) wire served as the anode and a counter electrode were placed 2 cm apart from a high-purity graphite rod that included intensely concentrated pyrolytic graphite [11,16]. They then submerged it in an ionic mixture of liquid and water and gave it persistent ability to promote the carbon content to peel off. To obtain 6 nm scale C-dots at 15,000 rpm at 20 °C from water poured over the exfoliation compounds, including ethanol, prior to pH neutralization, a variety of relationships between anionic fluid inserted and anodized water isolation, filter isolation, and ultracentrifugation were used in the peeling procedure; the fluorescent quantity yield was approximately 2.8–5.2 % [11].

Microwave-assisted synthesis

By exposing the reaction mixture of the precursor molecules to electromagnetic radiation with wavelengths ranging from 1 mm to 1 m, microwave-assisted synthesis is a straightforward and economical method for creating CDs [17]. Zhu et al. [18] created luminous CDs with a diameter of approximately 3.7 nm using first-time microwave irradiation. They cooked saccharides and an aqueous solution of polyethylene glycol for nearly three minutes in a (500 W) in domestic microwave oven. Glycerol was employed by Liu et al. [19] as the synthetic multicolor photoluminance CDs, with an average size of around 5 nm, and 4, 7, 10-trioxa-1,13-tridecanediamine (TTDDA) as the passivating agent [11,19].

Thermal decomposition

Researchers have also employed a different conventional bottom-up method for creating CDs: thermal degradation. In standard thermal decomposition, heat action causes a substance or complex to chemically break down. Generally, endothermic thermal processes occur during breakdown [20]. This kind of breakdown reaction can be either

irreversible (protein and starch breakdown) or reversible (calcium carbonate and ammonium chloride breakdown). Highly luminous CDs were reported by Wang et al. as the passivation agent through the thermal breakdown of organ silane, N-(β-aminoethyl)-γ-aminopropyl methyl dimethoxysilane (AEAPMS), and citric acid as the carbon source [21]. The reaction mixture was heated for a mere minute at 240 °C, and the observed diameter of the CD was approximately 0.9 nm. Wang et al. then used this technique to create the CDs from citric acid. They roasted the citric acid on a hot plate for thirty minutes at 200 degrees Celsius, neutralized it with a sodium hydroxide solution, and then solubilized it for purification. The CDs were found to be between 0.7 and 1 nm in size. These CDs show distinct QY based on varying synthesis circumstances in addition to independent PL and excitation-dependent characteristics. Wan et al. fabricated CD at 240 °C using the decomposition thermal technique with 1-butyl 3-methylbromide imidazolium and l-cysteine. The AFM study concluded that the height of the CDs was between 1.0 and 3.5 nm [11,21].

Carbonization synthesis

Since it is easy to carbonize a variety of precursor molecules, this is one of the most affordable, well-known, practical, and quick single-step methods for making CDs. Carbonization is a chemical process that creates solid compounds with a greater carbon content from organic sources by continuously pyrolyzing them in an inert atmosphere [11]. This ultrafast carbonization method was employed by Wei et al. [22] to create N-doped CDs. They employed a technique that is significantly faster (2 min only) than using ethylene-diamine and glucose as sources of nitrogen and carbon, respectively [22]. Together with 48 % of QY, the produced carbon dot's scale was found to be between 1 and 7 nm. Wang et al. conducted an incredible amount of work to produce blue-luminescence-producing CDs that were thermally reduced along with a 4.8–9 nm range in size by using carbonization in the presence of citric acid in the medium. A thermogravimetric analyzer was used to evaluate the thermal decrease phenomenon of CDs, which resulted in a five-fold increase in QY compared to non-reduced CDs. Dolai et al. prepared nanoparticles in the~2.4 ± 0.5 nm range by using 6-O-(O-dilauroyl-tartaryl)-D-glucose as the carbon source in the synthesis medium [11,22].

Pyrolysis synthesis method

The pyrolysis method is still preferred by certain researchers for creating CDs from precursor chemicals. Another kind of thermal deposition technique is pyrolysis, which involves subjecting different samples or organic materials to a process that is nearly irreversible in nature. Organic sample materials undergo physical and chemical changes in this inert atmosphere that result in solid remains that include carbon. As a result, pyrolysis typically involves extremely high temperatures and regulated pressure [11]. Feng et al. [23] produced citric acid CDs by thermal pyrolysis. During this procedure, they employed diethyl-ene--tri-amine, and they produced CDs with a size of 5–8 nm for transmission electron microscopy (TEM) analysis [23,24].

Solvothermal method

Numerous studies about the synthesis of CDs using tiny organic molecules as a carbon source abound in the literature. For example, the solvothermal approach to create N-doped CDs with NaNH2 as a source of nitrogen using carbon tetra chloride as the carbon source. Consequently, a spectacular 3.3 nm-sized and 0.5–5 nm-high CDs was created [12]. The solvothermal approach was used by the authors to prepare a highly crystalline product with a structure like graphite. SiCl4 and hydroquinone were utilized by Qian et al. in a different solvothermal synthesis approach to create Si-doped CDs. The authors prepared a mixture of SiCl4 and hydroquinone in a standard stainless-steel autoclave using acetone as a solvent, then heated it to 200 °C for 120 minutes. They thus created a Si-doped CDs product that measured 7 ± 2 nm [11].

Ultrasonic treatment

The synthesis of CDs has been extensively documented in literature due to the effectiveness of ultrasonic treatment. This method involves keeping carbon precursors, acid, alkali, and other oxidants under high ultrasound waves, which breaks down carbon particles into very small nanoparticles and causes continuous cavitation of the molecules. The use of high energy ultrasonic waves avoids the complex post-treatment process, making it possible to synthesize CQDs with a small size [11]. Li et al. [25] prepared a fluorescent CDs along with the ability of water solubility using activated carbon, employing the ultrasonic treatment approach, assisted by one-step H_2O_2 in the same year. The TEM findings demonstrated that the surface of prepared CDs was rich in hydroxyl groups, along with a magnitude of 5–10 nm [11,25].

Green synthesis approaches

As a sustainable and eco-friendly substitute for conventional techniques, green synthesis procedures for CDs have surfaced, solving issues with waste production and resource depletion [11]. These techniques create CDs with a variety of uses by using eco-friendly procedures and renewable resources.

One common method for green synthesis is to use precursors produced from biomass. Carbon sources include things like leaves, fruit peels, and other plant biomass. To produce CDs, the procedure frequently uses hydrothermal or pyrolysis techniques, in which the biomass is heated under regulated conditions. There are numerous benefits to this method [26]. By repurposing agricultural waste and lowering dependency on non-renewable resources, it encourages sustainability. Biomass is a cost-effective method that is appealing for producing CDs on a wide scale [11].

Another noteworthy green technique is fruit juice-based synthesis, which makes use of the natural sugars found in fruit extracts like grapefruit, orange, or lemon juice. Usually, the juice is heated or treated with simple chemicals during the procedure. The organic molecules included in the fruit juice are utilized in this green synthesis technique, which also adheres to green chemistry principles [27]. The resultant CDs capitalize on the biocompatibility provided by the natural source and find uses in biological imaging and sensing. Green tea, being high in polyphenols and bioactive chemicals, is used as the carbon precursor in a new method called green tea extract synthesis. The synthesis utilized either hydrothermal or microwave-assisted techniques to capitalize on the antioxidant characteristics of green tea, therefore endowing the resultant CDs with extra functions. For biomedical applications, where the antioxidant properties of the CDs can be useful in therapeutic delivery systems, the green tea extract synthesis holds great promise [11]. Waste-derived CDs use food waste or agricultural leftovers as carbon precursors, expanding on the idea of green synthesis. CDs are produced from these waste materials by pyrolysis or hydrothermal processes. This strategy improves the overall sustainability of the synthesis process in addition to addressing the waste management issue [28]. The resultant CDs demonstrate the adaptability of waste-derived green synthesis with applications in biosensing and environmental remediation [11,28]. A clean and renewable energy source is added to the green synthesis landscape via solar synthesis. CDs are created by using solar energy as the driving force in procedures like photocatalysis or solar-assisted techniques. This technique, which uses abundant and sustainable solar energy, is in line with the concepts of green chemistry [29]. Benefiting from the synthesis's environmental friendliness, applications for solar-generated CDs include photovoltaics, solar cells, and energy storage devices. Using water as a solvent and natural substances like glucose or starch as carbon precursors is the main goal of aqueous synthesis with natural precursors [30]. This approach's hydrothermal or microwave-assisted procedures help make the synthesis process more environmentally friendly. These techniques not only lessen the negative effects of nanotechnology on the environment, but they also pave the way for the creation of CDs with improved biocompatibility and

versatility. Green synthesis techniques for CDs are at the forefront of inventive and sustainable nanomaterial research as the need for environmentally friendly materials grows [31]. Fig. 3. Explains general mechanism of green synthesis for production of Carbon Dots for various applications.

Role of CDs in cancer therapy

In the field of cancer therapy, CDs are showing great promise as adaptable tools. Their functions include medication delivery, therapy techniques, and diagnostics. CDs are exceptional at PDT because of their capacity to produce reactive oxygen species in response to light wavelengths, which causes apoptosis in cancer cells. They function as drug transporters, improving the solubility of the drug and permitting tailored distribution, thus reducing systemic side effects [23]. CDs are also responsible for imaging agents that help visualize and detect cancer. Their versatility in biosensing and gene therapy presents opportunities for targeted gene modulation and early detection [32]. CDs have the potential to enhance the effectiveness of radiation therapy, hinder angiogenesis, and prevent metastasis [32]. Application of CDs are shown in Fig. 4. Hence, this section will discuss various mechanisms of CDs in Anti-Cancer therapy.

CD-based drug delivery systems

CDs are particularly attractive for drug delivery because of their luminescence, adaptable surface chemistry, ease of cellular ingestion, and high biocompatibility. Drug half-life, bioavailability, and solubility may all be improved by nano formulations. some CD nanocarriers were created to circumvent the shortcomings of some chemotherapeutic medications, which include poor water solubility, lack of biocompatibility, and a host of adverse effects [33]. The ability of CD-based drug delivery systems to encapsulate and solubilize anti-cancer medications is one of their main processes in cancer therapy. Since many chemotherapy drugs are hydrophobic, it can be difficult to make them soluble [34]. With certain medications, CDs can create stable inclusion complexes that increase their solubility. This increases the drug's bioavailability and guarantees that it will stay in a stable state. When a medication is taken, CD-drug complexes efficiently transport the medication to the tumor site, where it can start to work against cancer. Systems based on CDs can be modified to deliver drugs to cancer cells specifically [35]. Ligands or antibodies that selectively target receptors or antigens on the surface of cancer cells must be added to the CD carriers to functionalize them [35]. These CD carriers can bind to cancer cells only after being altered, avoiding healthy tissues in the process. By improving medication delivery to the tumor, this tailored strategy lowers systemic exposure and its related side effects. In precision medicine, where therapies can be customized for specific patients depending on the features of their cancer, targeted medication delivery is especially helpful [36]. Combination therapy—the simultaneous delivery of several medications or therapeutic agents—is made easier by CD-based drug delivery systems. To effectively combat the complexities of cancer, a diverse approach is often necessary [37]. Different medications with complimentary modes of action can be encapsulated in CD carriers to have a synergistic effect. For instance, a medicine may hinder angiogenesis or encourage death, while another may target a particular signalling pathway within cancer cells. The overall effectiveness of the treatment can be improved by combining various therapies [36].

As a novel treatment for metastatic colorectal cancer, Zheng et al. [38] developed a system based on fluorescent CDs in conjunction with Oxa (IV)-COOH (Oxa-CDs), an oxaliplatin derivative. According to their theory, Oxa-CDs enter cells via endocytosis because of CDs, and once inside, Oxa (IV)-COOH is converted to oxaliplatin (II), which lessens its toxicity to normal cells. Despite being a commonly used cancer treatment, doxorubicin (DOX) has several drawbacks, such as limited cell internalization, low penetration, and retention (EPR) impact, and cytotoxicity to normal cells. Using multifunctional nanocarriers, which have the advantage of accumulating at the tumor location due to the increased EPR effect, is one way to get around these issues with tumor-targeted drug delivery [38]. To enhance its anticancer efficacy,

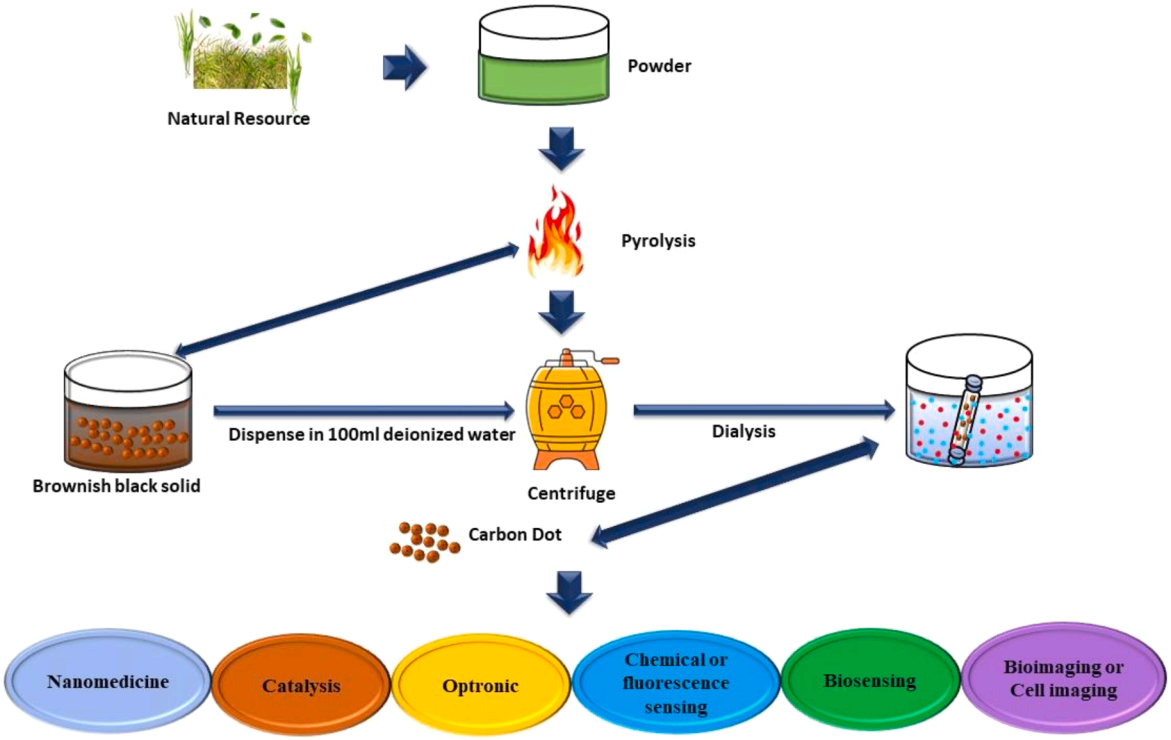

Fig. 3. A variety of plant-based organic resources can be used to create green CDs using chemical oxidation, carbonization, solvothermal and hydrothermal processes, microwave irradiation, and ultrasonic approach.

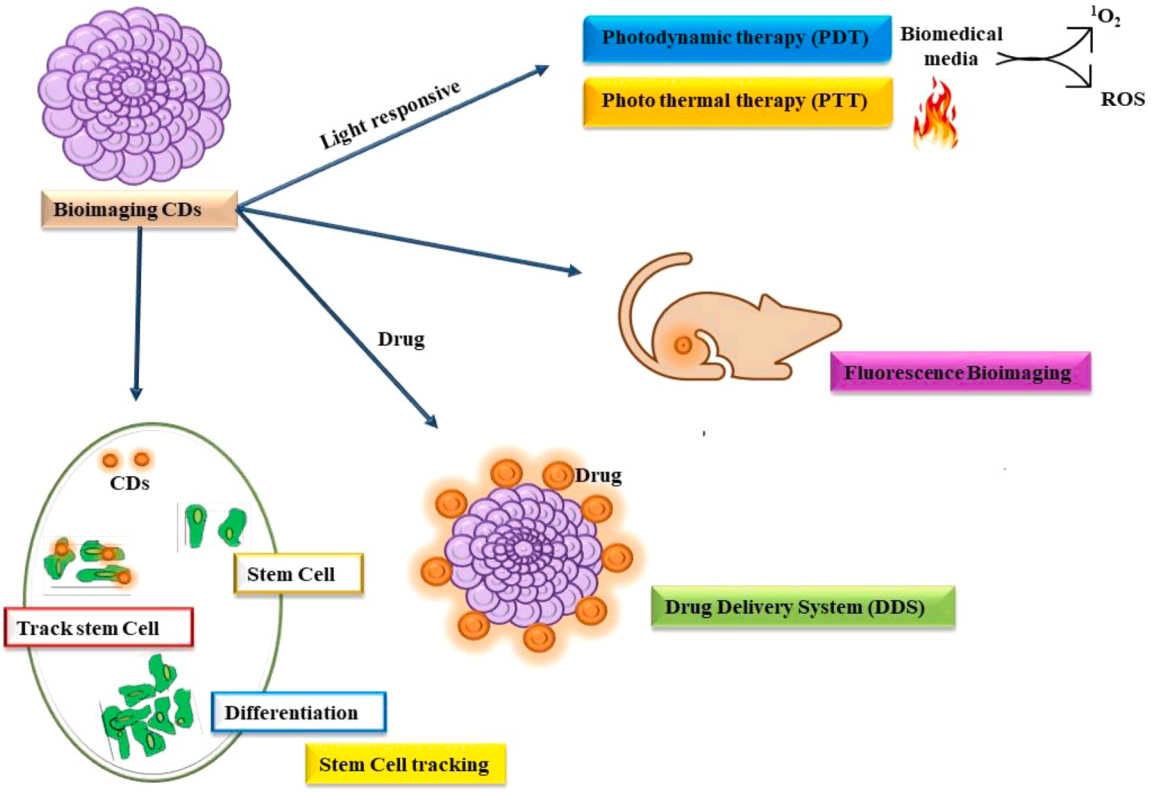

Fig. 4. Various Applications of CDs in cancer therapy.

developed a nucleus-targeted drug delivery method based on the covalent coupling of DOX and CDs functionalized with nuclear localization signal peptide (NLS-CDs) [39]. They demonstrated how the delivery method for DOX-CDs can aggregate specifically in the tumor location to cause A549 cells (human lung cancer cells) to undergo apoptosis and lessen free DOX-induced necrosis. They demonstrated that in vivo therapeutic tests, the DOX-CDs system demonstrates a greater capacity to prevent tumor growth than does free DOX. A multifunctional hybrid nanocarrier comprising fluorescent CDs, paclitaxel (PTX) coated on a mesoporous silica shell, and a Fe_3O_4 magnetic core was created by [40]. The research, both in vitro and in vivo, showed that CDs are capable of NIR-responsive drug release, as evidenced by their ability to absorb and convert NIR light into heat that breaks the PTX-mSiO_2 bonds and releases PTX. This suggests that combined photothermal/chemotherapy can be a beneficial therapeutic approach. It has also been demonstrated that CDs can carry genes within cells in addition to acting as drug delivery nanocarriers. A hybrid nanocarrier that is fluorescent and water-soluble, using CDs functionalized with polyethyleneimine (PEI) [41]. Comparing CD-PEI to control PEI25k, the in vitro tests demonstrate that CD-PEI could promote gene transfection in COS-7 and HepG2 cells with less cytotoxicity and either higher or comparable efficiency. They also show that internalized CD-PEIs show fluorescence emission, suggesting that these could be used for bioimaging and gene delivery [4, 41]. Chemotherapy side effects can be reduced significantly with the use of CD-based drug delivery devices. With CDs, systemic exposure of healthy tissues to powerful anti-cancer medications can be considerably reduced by enhancing drug solubility and facilitating tailored delivery. This results in a decreased frequency of side effects, which are frequently connected to conventional chemotherapy and include nausea, hair loss, and immunosuppression. Improving medication delivery to the tumor location while protecting healthy tissues is very important for raising cancer patients' quality of life [36,42].

CDs as imaging agents in cancer diagnosis

With multiple benefits that enhance patient outcomes, CDs have become a valuable imaging tool in the diagnosis of cancer. There are a desirable option for a variety of imaging modalities, such as computed tomography (CT) scans, magnetic resonance imaging (MRI), and fluorescence imaging, because to their distinct qualities. Due to their novel photophysical properties, CDs have been employed as contrast agents for in vivo optical imaging [43]. Direct PL imaging with light irradiation is the most used technique for optical imaging. The emitted photon of an imaging agent in down-conversion or multiphoton excited-up conversion fluorescence can be used to replicate the structure of cells or tissues. However, standard fluorescence microscopy cannot be used for common PL imaging due to the Abbe criterion's light diffraction limit [43]. Two main strategies are employed to overcome the diffraction limit: (i) single molecule localization-based imaging, comprising photo activated localization microscopy and stochastic optical reconstruction microscopy (STORM); and (ii) patterned illumination-based imaging, comprising structured illumination microscopy (SIM) and stimulated emission depletion microscopy (STED) [44].

For single molecule localization-based imaging, closely grouped fluorescent particles are resolved by stochastically turning on and off each particle's signal. Each imaging frame's centroid of the on-state particle is then calculated analytically. In some cases, it is possible to replicate the super-resolution PL image by combining multiple rounds. Together with direct PL imaging, afterglow imaging is considered a fantastic technique for bioimaging [45]. Due to the distinct delay luminescence, background photo-excited auto-fluorescence noise can frequently be reduced in afterglow imaging by utilizing phosphorescence and thermally activated delayed fluorescence (TADF). Comparable to that, contrast imaging methods also employ cathodoluminescence (CL). Because the CL emission is the product of a chemical reaction without photoexcitation, the CL imaging can be used as a unique biomolecular sensor with ultrahigh sensitivity and give distinctive

bio-imaging without photo-excited auto fluorescence from the background. [46] Subsequently, further strategies have been developed to further target cancer cells through bioimaging. Early in the tumor's development, researchers identified the impact of CD accumulation and improved uptake accumulation targeted imaging. With the introduction of nanotechnologies, CDs were further developed to allow for logical design tumor targeting imaging. Examples include in vivo biomarker imaging via interactions between CDs and different biomolecules, as well as stimulus-responsive imaging triggered by the unique charge and pH in the tumor microenvironment [45,46].

Several investigations have discovered and authorized specifically targeted CDs, which are cancer cell markers for a range of distinct malignancies. This permits their exclusive application in self-targeted bio-imaging as well as possible techniques for cancer diagnostics [4]. It has been shown that CDs, a potent new class of nanoprobes, can be used as a contrast agent in a variety of bio-imaging models. High PL quantum yield (QY), long-wavelength PL emission, low toxicity or nontoxicity, and renal cleavability are characteristics of the perfect CDs for bio-imaging. This would permit the appropriate application of intrinsic CDs for biological system observation in both in vitro and in vivo settings [47]. Early on, CDs uniformly penetrate and disperse across all cell types, providing equal uptake accumulation to malignant and normal cells. On the other hand, the distinct accumulation of CDs in tumor tissues has been shown by several investigations due to the enhanced permeability and retention (EPR) effect. For example, Su et al. found that CDs were efficiently removed by the kidneys and accumulated preferentially at the tumor site [48]. They found that a novel class of CDs, called hafnium-doped CDs (Hf-CDs), exhibited the ability to accumulate tumors preferentially. These CDs have several noteworthy properties, including strong stability, good biocompatibility, excellent water solubility, and exceptional CT contrast performance. These properties allow the CDs to be used, especially in CT/fluorescence imaging, for orthotropic liver cancer. During testing, the researchers found that the Hf-CDs may collect at the tumor site, allowing for rapid bio-imaging and suggesting a straightforward and adaptable multimodal imaging method [48]. Researchers created a biocompatible nanoplatform for long-term mitochondria-targeting cellular imaging using CDs. To strengthen the distinct accumulation, they enhanced the cellular uptake functions enhanced by magnetic fields [49].

Using a magnetic mesoporous silica nanoparticle ($Fe_3O_4mSiO_2$) conjugation of fluorescent CDs with triphenylphosphine (TPP), this study exploited surface modification to build a biocompatible nanoplatform. Furthermore, research revealed that the cellular absorption efficiency of human foreskin fibroblast (HFF) and mouse lung cancer cell (A549) cell lines may be rapidly increased under a static magnetic field. These distinct CD accumulations inside tumor regions paved the door for targeted absorption [50]. These stimulus-responsive methods have also been researched to achieve customized CD uptake based on the distinct microenvironment in tumor regions, in addition to direct uptake accumulation. For example, the interaction between the biomolecules and their carboxylic moieties allows the zwitterionic CDs to form bio conjugates with a wide range of biomolecules with ease. When they interact with the microenvironment of cancer cells, they lose their anionic component and leave a positive charge on their surface, which improves their targeted uptake in cancer cells enabling a range of customized bio-imaging approaches. This led to develop a particular class of zwitterionic CDs and to report on their targeted bio-imaging for pharyngeal and tongue cancer cell lines in humans [4,48].

Beyond conventional imaging modalities, CDs have a wide range of applications as imaging agents for cancer diagnosis. Their versatility in surface functionalization enables the creation of imaging agents with specific targeting capabilities. These imaging agents can selectively bind to particular receptors or antigens on the surface of cancer cells by affixing ligands or antibodies to CDs [48]. By limiting needless intrusive procedures and lowering the possibility of false positives, this focused strategy increases the specificity of cancer detection. By acting as theranostic agents, CDs can have a dual function in the diagnosis of cancer. This idea integrates therapy and diagnosis into a unified system. Theranostic drugs based on CDs provide therapeutic payloads directly to cancer cells in addition to providing imaging information [51].

Integration of CDs in nanodrug conjugate systems

Drug delivery and therapeutic uses have advanced significantly with the incorporation of CDs into nanodrug conjugate systems. Table 1. Explains few drug conjugates with their applications and advantages. CDs' exceptional biocompatibility makes them useful for medication delivery. There has been a lot of research in recent years demonstrating CDs' remarkable biocompatibility. Because of their high level of biocompatibility, these nanoparticles have few negative consequences and are readily absorbed by living things. Since CDs do not cause appreciable toxicity when utilized as carriers for medicinal medicines, they are a desirable choice for the creation of innovative drug delivery systems [5]. The cytocompatibility of CDs made from urea (CD-Urea) was established using dermal fibroblasts, demonstrating that treatment with CD-Urea at concentrations of 80–200 μg/mL significantly increased cell proliferation after 48 h. The pro-angiogenic effect in human umbilical vein endothelial cells (HUVECs) and the hemocompatibility of CD-Urea (100–1000 μg/mL) in red blood cells isolated from goat blood were demonstrated [11].

Due to their high-water solubility, CDs are ideal for use in watery environments like the human body. Their water-soluble nature guarantees their easy integration into drug delivery systems and their stability under physiological settings. This solubility is an important property that makes it possible for medicinal medicines to be transported to the desired locations within the body effectively. The incorporation of CDs into nanodrug conjugate systems is critically dependent on their surface functionalization. To accomplish tailored drug delivery, researchers can alter the surface of CDs by affixing molecules or ligands [62]. Huang and colleagues [63] discovered that while the precursor curcumin had negligible inhibitory activity against EV71 infection in RD cells, Cur-CPDs, which are derived from curcumin—a natural compound with antimicrobial, anticancer, anti-inflammatory, and antioxidant characteristics—were effective antiviral agents against enterovirus 71 (EV71). This is because the CPDs' unique pyrolytic curcumin polymers enhanced Cur-CQDs' exceptional aqueous solubility, antiviral efficacy against EV71, and biocompatibility. To precisely pinpoint the molecular mechanism underlying these drug-CPDs' antibacterial, anticancer, and antiviral properties, more research is still necessary [63]. Imaging agents like fluorophores can be used to functionalize the surface of CDs. This characteristic makes theranostics—the study of medication release and biodistribution—possible in real-time. Theranostic medication delivery systems integrate therapy with diagnostics, enabling medical practitioners to track the effectiveness of their treatment and make necessary modifications [64]. Real-time tracking of the drug's travel through the body helps to optimize the treatment strategy and offers important information into how successful it is. Depending on the various nanostructures of CDs and cell types, they can enter cells rapidly through clathrin, caveolae, energy-/temperature-dependent macropinocytosis, and/or lipid raft-mediated endocytosis [65]. Once inside the cell, they are distributed into mitochondria, lysosomes [66], endoplasmic reticulum, Golgi apparatus, and/or nucleoli [67]. It is advantageous to comprehend and research organelle-related disorders like cancer, Alzheimer's, Parkinson's, diabetes, and heart dysfunction by imaging organelles (e.g., imaging mitochondria and/or nucleolus) [68]. discovered that nucleus-targeted imaging in both fixed cells and living cells is possible with CPDs made from mPD and L-cysteine.

Another significant benefit in medication distribution is the small size of CDs, which are usually less than 10 nanometers. Compared to bigger drug carriers, their nanoscale size facilitate improved cellular uptake because they can penetrate cells more readily. This characteristic guarantees that a larger percentage of the therapeutic agent reaches its

Table 1
List of few Nanodrug conjugates with their application and advantages.

CDs (CDs)	Specific Drug	Nanodrug Conjugate	Application	Advantages	Reference
CD-Nano1	Doxorubicin	CD-Nano1-Doxorubicin	Cancer chemotherapy	Enhanced drug solubility, Targeted drug delivery to tumor cells, Reduced systemic toxicity	[52]
CD-Nano2	Paclitaxel	CD-Nano2-Paclitaxel	Anti-cancer drug delivery	Improved drug bioavailability, Sustained drug release, Enhanced cancer cell-specific delivery	[53]
CD-Nano3	Methotrexate	CD-Nano3-Methotrexate	Rheumatoid arthritis treatment	Increased drug stability, Reduced drug side effects, Precise targeting of inflamed joints	[54]
CD-Nano4	Gemcitabine	CD-Nano4-Gemcitabine	Pancreatic cancer therapy	Improved drug pharmacokinetics, Enhanced tumor penetration, Targeted delivery to pancreatic cancer cells	[55]
CD-Nano5	Curcumin	CD-Nano5-Curcumin	Anti-inflammatory and anti-cancer therapy	Enhanced curcumin bioavailability, Controlled drug release	[56]
CD-Nano6	5-Fluorouracil	CD-Nano6-5-Fluorouracil	Colorectal cancer treatment	Increased drug stability, Improved drug solubility,	[57]
CD-Nano7	siRNA	CD-Nano7-siRNA	Gene therapy and targeted RNA interference	Efficient delivery of siRNA, Reduced siRNA degradation, Gene-specific silencing for therapeutic purposes	[58]
CD-Nano8	Insulin	CD-Nano8-Insulin	Diabetes management	Enhanced insulin stability, Controlled release of insulin, Improved glycemic control for diabetes patients	[59]
CD-Nano9	Amoxicillin	CD-Nano9-Amoxicillin	Targeted antibiotic delivery	Site-specific antibiotic delivery, Reduced microbial resistance, Enhanced antibiotic stability	[60]
CD-Nano10	Methotrexate	CD-Nano10-Methotrexate	Treatment of autoimmune diseases	Increased drug bioavailability, Targeted therapy for autoimmune conditions, Reduced side effects in non-target tissues	[61]

designated target and improves drug delivery efficiency [69]. Better cellular absorption not only increases the effectiveness of treatment but also permits the use of lower quantities of medication, thereby lowering the possibility of adverse effects. The use of CDs in medication delivery systems that react to stimuli or triggers is a topic of active research. These can include variations in temperature, pH, or the presence of chemicals [70]. Carbon dot-based drug delivery systems can release the therapeutic agent in a controlled way in response to these stimuli. This exact control over drug release offers a new degree of therapy personalization and precision by guaranteeing that the drug is given precisely when and where it is needed [5]. Green room temperature phosphorescence (RTP) and blue fluorescence emission were displayed by the C-dots. C-dots' RTP and fluorescence both showed signs of pH sensitivity. While the RTP was more sensitive to pH across a larger linear range from 2.29 to 13.55, the fluorescence decreased as pH climbed from 9.15 to 13.55 [71]. Sonsin [72] reported the method by which thermal treatment alters the photoluminescent characteristics of CDs in the solid state. They discovered that its PL emission shows a persistent red shift with increasing temperature. Since the size of the CDs does not change in the AFM images, it is evident that quantum confinement is not the primary mechanism of PL emission, as indicated by the low Huang factor, which indicates a weak electron-phonon coupling [72]. Changes in its surface state, which were also validated by absorption tests, imply the electron-electron dispersion, as demonstrated by the non-dependence of the CDs' bandwidth in the solid state upon thermal treatment [11,72]. Another crucial factor in the creation of medication delivery systems based on CDs is scalability. The synthesis of CDs and their incorporation into drug delivery systems must be scalable to fulfil the demands of large-scale drug production to have a major influence on healthcare [73]. Researchers are hard at work creating efficient and economical synthesis methods that may be used in large-scale pharmaceutical production. These multipurpose devices could react to stimuli, transport medications, and act as imaging agents all at once [62]. By combining these features into one platform, personalized medicine and medication administration might be completely transformed and therapy and diagnostics could be approached from all angles [42].

Applications of CDs in anti-cancerous nanodrug development

CDs have become key players in the development of anti-cancer nanodrugs, providing a multimodal strategy to fight cancer. These minuscule carbon-based nanoparticles are used in theranostic ("theranostics" is a combination of the words "therapy" and "diagnostics." By customizing treatment to each patient's unique traits, this novel technique is revolutionizing the way of diseases, especially cancer, are managed and resulting in more accurate and efficient interventions), medication delivery, and diagnosis in cancer treatment [74]. Because of their fluorescence and biocompatibility, they are useful imaging agents in diagnostics that help spot cancer early. Utilizing surface-attached ligands, CDs are also utilized as medication carriers, precisely delivering chemotherapeutic medicines to cancer cells. Their theranostic properties allow for dynamic treatment monitoring by fusing real-time imaging with therapy [64,74]. This section of the article describes about various application of CDs in Anti-cancerous Nanodrug development

Targeted drug delivery using CD conjugates

Modern cancer therapy places a strong emphasis on targeted drug delivery, which aims to optimize the therapeutic effects of anti-cancer medications while avoiding damage to healthy tissues. Cancer is a complicated and diverse illness that varies from patient to patient in terms of its genetic composition, cellular function, and reaction to therapy. Precision medicine aims to reduce side effects and increase treatment efficacy by customizing medical procedures to each patient's unique traits [75]. Targeted medication administration becomes a crucial tactic in this situation. Although traditional chemotherapy is

successful in eliminating cancer cells, it also damages healthy tissues, which can result in severe side effects and systemic toxicity. The creation of medication carriers that can deliver anti-cancer medications to tumour areas specifically is a solution to these restrictions [5,75].The attachment of certain ligands or antibodies on the surface of cancer cells allows CDs to be actively targeted towards these cells. These ligands enable targeted and effective drug administration by recognizing and binding to receptors that are overexpressed on the surface of cancer cells. While reducing harm to healthy tissues, active targeting improves medication delivery's efficiency and specificity even more [74]. One of the most important components of targeted drug delivery is the precise and effective release of anti-cancer medications at tumour locations. Drug payloads can be included into CDs using a variety of engineering techniques, including as, covalent binding, physical encapsulation, or electrostatic interactions. These medication-loaded CD conjugates can be engineered to release their payload in response to stimuli, such variations in temperature, pH, or the presence of enzymes in the microenvironment surrounding the tumor [76]. To address different components of the disease, such as preventing angiogenesis, suppressing tumor development, and enhancing the immune system, cancer treatment frequently involves combining different medications. Combination therapy is a good fit for CDs since they can transport several drug payloads at once. The anti-cancer benefits of this strategy can be synergistically enhanced, making it more difficult for cancer cells to become resistant to a single therapy [37]. Co-administration of medications with various modes of action can enhance the effectiveness of treatment. CD combination may contain an immunomodulatory medication to boost the body's defences against the tumor and a chemotherapeutic agent to target cancer cells that divide quickly. This combined technique provides a more thorough approach to cancer treatment while also improving the overall therapeutic benefit [37].

Carbon dot's mediated photodynamic therapy (PDT)

PDT is one of the most promising non-invasive cancer treatment methods. It can be employed to eradicate malignant cells that have not yet been discovered at the resection margins, either by itself or in conjunction with surgery, chemotherapy, or ionizing radiation [4]. PDT uses photosensitizing medications that are pharmacologically inert until they are exposed to a specific light wavelength and oxygen, which produces reactive oxygen species and causes tissue necrosis and cell death [77]. Fig. 5. reports a schematic diagram of PDT approach

Certain photosensitizing medications, such as derivatives of phthalocyanine and porphyrin, have been approved for clinical use and could both image and treat cancer [78]. Due to their low selectivity, prolonged cutaneous photosensitivity, photostability, and reduced water solubility, their use is frequently restricted. PDT is especially useful in the treatment of different types of cancer. Its ability to target malignant cells specifically while preserving healthy tissues is one of its primary benefits. This accuracy is made possible by the light source's selective activation of the photosensitizer, which limits the cytotoxic effects to the area that is illuminated [4]. Several methods, including liposomes, polymer nanoparticles, gold nanoparticles, carbon nanotubes, graphene, and CNPs, have been explored for combining photosensitizing medications with other carriers in this region [4,11]. A novel theranostic system based on chlorin e6-conjugated C-dots (C-dots-Ce6) was recently produced by Huang et al. [64]. According to the in vitro data, C-dots-Ce6 have a remarkable photodynamic efficacy when compared to Ce6 alone, as well as good stability and solubility, minimal cytotoxicity, good biocompatibility, and increased photosensitizer fluorescence detection (PFD) upon radiation. In vivo studies indicated that the newly synthesized system is useful for simultaneous PFD and PDT of cancer in vivo and has superior imaging and tumor-homing capabilities without sacrificing photodynamic efficacy. A transdermal carbon dot-chlorine e6-hyaluronate (Cdot-Ce6-HA) compound was assessed in vitro and in

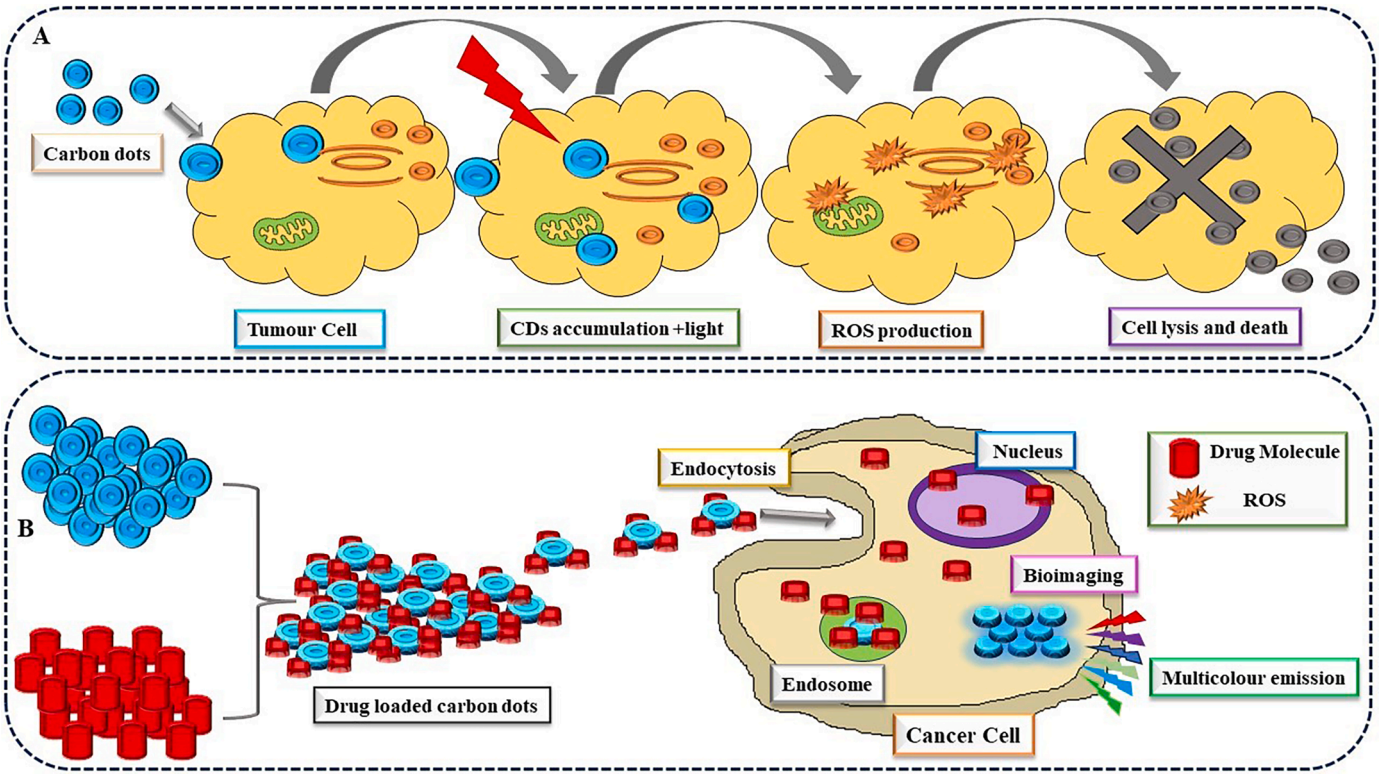

Fig. 5. (A) Photodynamic Therapy (PDT). CDs enter cells through their membranes and gather in the cytoplasm. Reactive oxygen species (ROS) are produced when light irradiation activates CDs, which causes cell lysis and death. (B) CDs loaded with medication enter cells and transport the drug to the nucleus, which is the general mechanism of image-guided drug delivery. Additionally, CDs' inherent multicolour fluorescence aids in cellular imaging and drug delivery pathway tracking.

vivo in 2015 by a different group for the PDT of melanoma skin cancer. They demonstrated that melanoma skin cancer is totally suppressed by laser irradiation following topical treatment, and that Cdot-Ce6-HA conjugates have a far more substantial photodynamic effect on cancer cells than Ce6 and Cdot-Ce6 [79]. Porphyrin-containing CDs (TPP-CDs) were synthesized by Li et al. [80] and their efficacious photodynamic activity in the treatment of hepatoma was demonstrated. Their findings demonstrated that TPP-CDs can decrease the tumor mass in vivo and have strong cytotoxicity, good photostability, biocompatibility, and cellular uptake during radiation exposure in vitro [80]. More recently, novel platinum-porphyrin conjugates were synthesized, photophysically characterized, and there in vitro light-induced anticancer activities. According to their findings, when exposed to laser radiation, the platinum-porphyrin conjugates exhibit strong cytotoxicity, indicating that this porphyrin complex holds great potential as an anticancer agent [81].

Carbon dot facilitated cancer imaging and diagnosis

The diagnosis and imaging of cancer are essential components of contemporary oncology that have transformed the way we identify and treat cancer. By determining the existence, location, stage, and features of cancer, these techniques are essential in enabling medical personnel to make well-informed decisions about patient care and treatment [4]. Medical imaging, which includes CT scans, MRI, ultrasound, and X-rays, is one of the most popular and effective imaging methods used in the detection of cancer. X-rays and CT scans are useful diagnostic instruments for identifying tumors and assessing their size and location because they use ionizing radiation to provide precise images of the interior components of the body. MRI produces incredibly detailed images using radio waves and strong magnets, which is especially helpful when evaluating soft tissues [82].

Ultrasound is a non-invasive, radiation-free technique that produces images by using high-frequency sound waves. It is frequently used for exams of the breast and abdomen. Positron emission tomography (PET) and single-photon emission computed tomography (SPECT) are two types of nuclear medicine imaging that use radioactive tracers that build up body parts. Gamma rays are released by these tracers, and specialized cameras pick them up [83]. Because they can provide functional information on tissue metabolism and help distinguish between benign and malignant tumors, PET and SPECT are especially useful for cancer diagnosis [42]. Fluorescence-guided surgery, which uses fluorescent dyes to highlight malignant areas during surgery and increase the accuracy of tumor excision, is a prominent example of molecular imaging already discussed in heading 3.2 [83,84]. Optical coherence tomography (OCT) is another cutting-edge method that produces high-resolution, real-time pictures of tissue microstructure using low-coherence light. OCT has demonstrated potential in the early detection of cancer, especially in the respiratory and gastrointestinal systems. The advent of non-invasive cancer monitoring, and diagnosis has been made possible by the invention of liquid biopsies [85]. In liquid biopsies, body fluids like blood or urine are analyzed to find cancer-specific biomarkers such exosomes, cell-free DNA (cfDNA), and circulating tumor cells (CTCs). These biomarkers can shed light on the existence of cancer, its genetic alterations, and how the disease reacts to therapy. Liquid biopsies are a less intrusive substitute for conventional tissue biopsies and are especially useful for monitoring the course of a disease and assessing the effectiveness of treatment [86]. The use of genomic and molecular profiling methods in cancer detection has become essential. Healthcare professionals can now recognize genetic changes in cancer cells because to developments in genomic sequencing and biomarker analysis. In addition to helping to establish the existence of cancer, this data is used to guide treatment choices, enabling the selection of targeted medicines that exactly match the genetic makeup of the tumor [65]. The diagnosis of cancer is being greatly aided by machine learning and artificial intelligence. Large volumes of medical data, such as genomic data, patient records, and medical imaging, can be processed by these technologies to find patterns and abnormalities that might not be noticeable to human observers. AI-driven diagnostic techniques are making cancer detection faster and more accurate, allowing for earlier intervention and better treatment outcomes [82].

CD-mediated intracellular drug release

The capacity of CDs to mediate intracellular drug release is one of their main advantages in drug delivery. This ability is essential for guaranteeing the therapeutic efficiency of the medications supplied. To get to the site of action, the medication must pass through several biological barriers, such as the circulation, cellular membranes, and subcellular compartments. Due to their ability to encapsulate medications and facilitate their effective distribution to the target cells, CDs are essential to this procedure [87]. Different medicinal agents, such as proteins, nucleic acids, peptides, and tiny compounds, can be placed onto CDs. The exact control of drug administration is made possible by this encapsulation, which also shields the medication from deterioration and premature release [88]. The medication can be delivered exactly when and where it is needed by programming CDs to release their payload in reaction to stimuli or triggers. Using pH-responsive CDs is a popular method of influencing intracellular drug release. The purpose of these CDs is to exploit the pH gradients seen in various cellular compartments. The medicine has a higher probability of reaching its target within the cell because of its pH-responsive nature, which guarantees that the drug is released following cellular absorption [66]. Furthermore, the regulation of intracellular drug release is significantly influenced by the surface chemistry of CDs. To help molecules that are sensitive to stimuli bind, functional groups can be added to the CD surface. Drugs or medical conditions cannot be excluded from the use of CD-mediated intracellular drug release [89]. Numerous therapeutic agents and medical illnesses, such as cancer, infectious diseases, and neurological disorders, can be treated with it [89]. Researchers and doctors can produce optimal drug release profiles by customizing the CD-drug conjugates to the unique requirements of the disease and the physiological properties of the target cells in question.

Advantages of carbon dots over traditional drug carrier

As pioneering drug carriers, CDs have drawn a lot of attention because they have several benefits over conventional drug carriers. These benefits are because of CDs' distinct qualities, adaptable surface chemistry, and biocompatibility, which make them a viable choice for drug administration in a range of therapeutic application 2. The selection between CDs and conventional drug carriers is contingent upon the unique prerequisites of the drug delivery system, the features of the therapeutic agent, and the intended drug delivery outcomes for a given application. Table 2 mentioned below is small insight of advantages of CDs over traditional drug carrier.

Challenges and future perspectives

Future developments and trends in drug delivery are expected with Carbon Dots (CDs)-based nanodrug conjugates. Using CDs, which are nanoscale carbon particles with distinctive optical and surface properties, researchers are investigating new approaches to improve the therapeutic efficacy and specificity of medications. One of the upcoming trends is the creation of CD-based targeted drug delivery systems, which enable exact drug release at particular body locations. Drug delivery to specific sites is made possible by functionalizing CDs with ligands that can identify and bind to cellular receptors. This reduces off-target effects and improves therapeutic outcomes. Improvements in CD surface engineering will probably lead to better drug loading capabilities and regulated release kinetics. Scientists are investigating the possibility of incorporating imaging features into CDs to allow for real-time tracking

Table 2
Comparative analysis of Carbon Dots as a drug carrier over Traditional Drug Carriers.

Characteristic	Carbon Dots	Traditional Drug Carriers	Reference
Composition	Composed of carbon-based materials	Composed of various materials	[90]
Biocompatibility	Generally biocompatible and low cytotoxicity	Varies based on carrier materials	
Particle Size	Typically, in the nanometer range	Varies depending on carrier type	[91]
Surface Functionalization	Highly versatile for surface modifications	Limited options for surface functionalization	[92]
Water Solubility	High water solubility	May require modifications for water solubility	[90]
Drug Versatility	Can accommodate various types of drugs	Limited by carrier material and structure	
Controlled Drug Release	Can be engineered for precise drug release	May offer limited control over drug release	[91]
Immune Response	Often induces a reduced immune response	May trigger immune reactions or responses	[23]
Environmental Impact	Can be synthesized using green methods	May involve less eco-friendly materials and processes	[93]
Stability	Relatively stable under certain conditions	May require specific storage and handling	[90]
Production Scalability	Challenges in large-scale production	Established production processes for scalability	[91]
Imaging Capabilities	Intrinsic imaging properties for diagnostics	May require the addition of imaging agents	[94]
Safety Profile	Limited long-term safety data	Safety profile can vary by carrier type and material	[95]
Research Stage	Active area of research with ongoing advancements	Well-established traditional drug carriers	[93]
Therapeutic Applications	Suitable for various applications	Established applications, but may be less versatile	[91]
Customization	Highly customizable for specific needs	Limited by carrier type and material	[96]

of medication administration and therapeutic outcomes. Future developments in targeted drug delivery, enhanced drug loading, and multifunctionality of CDs-based nanodrug conjugates are expected to open new avenues for more efficient and individualised medical treatments.

Conclusion

The literature review emphasises how CDs can reduce systemic toxicity while optimising the effectiveness of anti-cancer medications. Precision medicine in oncology has new opportunities thanks to CDs' ability to conjugate or encapsulate therapeutic chemicals and deliver them specifically to cancer cells. Beyond just delivering drugs, CDs are used in anti-cancer nanodrug conjugates. Theranostic techniques for more successful cancer management are made possible by the simultaneous diagnosis and therapy made possible by the incorporation of imaging capabilities into CDs. CDs' biodegradability helps to lower long-term toxicity, which addresses a crucial issue in the treatment of cancer. The ongoing investigation of CDs' potential in anti-cancer nanodrug conjugates, as this field of study progresses, shows promise for tailored and targeted therapeutics that could completely transform the way cancer is treated. CDs have a variety of roles in the development of next-generation anti-cancer treatments with increased efficacy and fewer side effects, including those of drug carriers and imaging agents.

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Vinay Kumar Pandey: Writing – original draft. **Anjali Tripathi:** Writing – original draft. **Anam Taufeeq:** Formal analysis. **Aamir Hussain Dar:** Project administration. **Antony V Samrot:** Writing – review & editing. **Sarvesh Rustagi:** Investigation. **Sumir Malik:** Methodology. **Tanima Bhattacharya:** Visualization. **Ayaz Mukarram Shaikh:** Writing – review & editing. **Béla Kovács:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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