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Review article

Carbon dots and their biomedical and biotechnological applications

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ABSTRACT

Carbon dots, a recently discovered nanoparticle, have attracted significant attention due to their impressive fluorescent, chemical, mechanical, photostability, and biocompatibility properties. Carbon quantum dots (CQDs) are a novel form of nano-carbon whose use has recently surpassed semiconductor quantum dots (QDs) in terms of their many desirable properties. This is because CQDs are made up of carbon atoms rather than carbon molecules. This study clarifies the process of synthesis and optical characteristics of CQDs, as well as current breakthroughs in CQDs' biological applications in bioimaging. This paper discusses the recent developments and achievements reached with CQDs, with a particular emphasis on their synthetic pathways, chemical and optical characteristics, and biological applications, as well as fresh perspectives on this fascinating and potentially fruitful topic of research.

Keywords: Carbon dots; biosensing; bioimaging; carbon quantum dot; optical properties.

INTRODUCTION

A unique kind of carbon nanoparticle, known as carbon dots (CDs), can be produced when single-walled carbon nanotubes are purified. CDs have been used in a variety of scientific disciplines, including biology and optoelectronics research (1). New research avenues have been opened in the domains of sensing, optoelectronics, catalysis, biotherapy, and medicine due to the fluorescent features CDs possess (2). Significant time and effort have been expended in recent years on developing methods for mass-producing biocompatible CDs with such a high quantum yield (QY), where a high QY is defined as a value greater than 20%. Using these CDs may lead to more accurate bioimaging and more sensitive sensing (3). Biocompatibility and high QY factors are not only hard to regulate independently but are also at odds with one another. Carbon nanotubes, graphene, and fullerene disunification form part of the top-down approach, while bottom-up synthesis requires the introduction of carbon hydrates as a carbon source for the reaction using solvents under specific synthesis settings. Both methods result in the formation of CDs. The most typical and uncomplicated preparation techniques include hydrothermal and solvothermal treatment, as well as irradiation with a microwave. These techniques require fewer or no extra chemicals than other approaches (4).

Fragmenting carbon allotropes, such as nanotubes, graphene, and fullerene are necessary for top-down CD synthesis, but bottom-up CD synthesis does not require them. In CD synthesis, a closed synthesis reactor and carbon hydrates are employed as a carbon source for reactions with solvents. Other unusual techniques with good results included chemical ablation, laser ablation, and electrochemical carbonization. Fig. 1 presents these methods with multiple routes that lead to varied applications, demonstrating the adaptability of CDs (5).

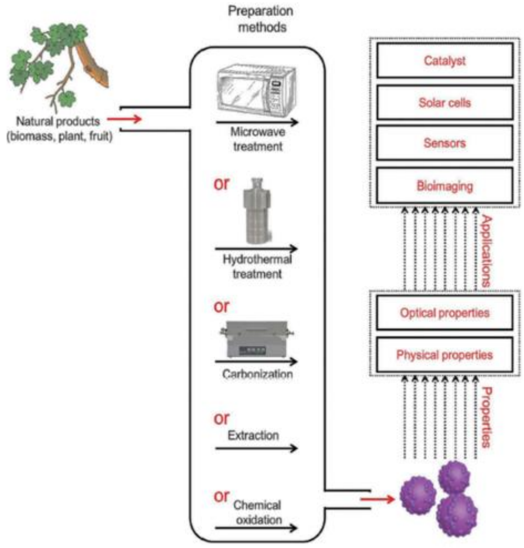

Fig. 1: Various methods for CDs preparation (7).

Doping with various types of heteroatoms may cause the emission spectra to shift either to red or blue, depending on the type of doping. CDs may display low cytotoxicity that is conditional on the kind of ligands used for the passivation process, making them suitable for *in vivo* research. This is perhaps the most essential aspect of the process (6).

Preparation of CDs

Over time, researchers have produced a wide number of distinct synthetic methods for the creation of CDs as can be seen in Table 1. Most of the synthesis efforts are directed toward developing low-effort, low-cost, and small-footprint techniques, or toward scalable approaches with the eventual objective of generating high-quality CDs. Strategies can be broken down into two broad categories: top-down and bottom-up which are employed when it comes to characterizing the many synthetic methods (7).

Top-down

Laser ablation, arc discharges, oxidative cracking, and electrochemical oxidation are all examples of top-down procedures that break down bigger carbon structures (8). Due to the presence of a combination of carbon nanostructures of varying sizes, this approach has the drawback that the CDs produced do not have a consistent size, making it difficult to separate and purify components. In addition, the quantity of CDs that can be produced using this method is relatively low. Both oxidative cracking and laser ablation require the surface of the CD to be passivated with a strong acid. Electrochemical methods have surpassed methods used previously because they do not involve the use of poisonous chemicals (9).

Bottom-up

CD manufacture can be accomplished via bottom-up approaches beginning with basic carbon precursors, such as organic molecules or polymers. A variety of chemical events, including dehydration and further carbonization procedures, are required to produce CDs. The precursors often include -OH, -COOH, and -NH_2 groups, which makes the production of CDs more likely to occur via dehydration and carbonization reactions that take place at higher temperatures. Bottom-up approaches are now used on a large scale to make CDs that have uniform morphologies, limited size distributions, and stable characteristics. This is possible because bottom-up procedures have a straightforward operation and well-specified carbon precursors. Approaches such as microwave syntheses and solvothermal or hydrothermal processes are examples of common bottom-up procedures (8,9).

Properties of carbon quantum dots

Optical properties

There are two possible origins for fluorescence that are produced by CQDs: fluorescence from surface defects and fluorescence emission from band gap changes of conjugated π -domains. If the infinite network is converted into a finite network, then a bandgap may be produced in the grapheme sheet (10).

Table 1: Different top-down and bottom-up approaches in synthesizing CDs

Methods	Carbon source	Advantage	Disadvantage
Laser ablation	SWCNTs	Easy to manipulate the size of CDs	High-cost and sophisticated process
Arc discharge	Graphite powder and cement	Large scale preparation	Low quantum yield and low purity
Chemical oxidation	Candle soot	High yield, high purity	Environmental pollution and low quantum yield
Electrochemical oxidation	MWCNTs	Easy to manipulate the size of CDs	Required longer time
Pyrolysis	Citrate	Easy operation, less time consuming	Broad size distribution
Template	F127	Easy to manipulate the size of CDs	Cumbersome steps
Microwave	PEG-200 and saccharide	Rapid and constant volumetric heating	High energy cost, uneven heating
Hydrothermal/solvothermal	L-ascorbic acid	Cheap, eco-friendly, controllable	Low yield, low purity
Organic approach	p-bromobenzoic acid	Easy to manipulate the size and functional group of CDs	A complex process, with harsh reaction conditions
Sonochemistry/ultrasonication	Glucose	Mild experimental conditions, green energy sources	Low yield, not easy to dope

The formation of sp2 islands inside of a graphene sheet, and other techniques are viable options for isolating conjugated p-domains. Sp2 domains on such a graphene sheet can be made by reducing exfoliated graphene oxide (GO). By surrounding the sp2 islands with a sp3 matrix composed of oxygen and carbon, an effect similar to that of embedding large aromatic molecules within non-conjugated polymers was achieved. It is possible to localize electron-hole couples in conjugated p-domains. The bandgap of the domains is size-dependent (11).

Surface flaws are another possible source of fluorescence. Surface flaws are locations where a sp2 domain is not quite complete. It is the surface energy that is trapped by these imperfect sp2 domains. Possible causes of this fluorescence include hybridized (sp2 and sp3) carbons or functionalized surface imperfections in a similar way to how aromatic molecules in a solid matrix could be thought of as surface flaws. Total emissions may be multi-colored as there are often many surface imperfections, each with its unique excitation and emission wavelengths. Fluorescence is caused by the recombination of electron-hole pairs at highly populated and levels on sp2 domains.

Photoluminescence

The most remarkable quality of CQDs is their ability to adjust their photoluminescence, allowing them to emit strongly in the ultraviolet, visible, and near-infrared parts of the spectrum. An excitation-dependent luminescence spectrum is another name for this important characteristic that might be used. Because of this, the emission color of the CQDs can be adjusted following the wavelength of the excitation light by utilizing the quantum confinement effect (QCE) in conjunction with the size of the nanoparticles. Fig.2 depicts the excitation-dependent luminescence spectra as well as the colors of a CQD sample (12). CQDs' PL properties originate from their surface passivation for high QY, which is induced by energy states that are related to surface imperfections. Tests supporting the luminescence model in Fig.3 have been shown in many publications. This explains why CQDs' luminescence is so closely linked to their surface condition (13).

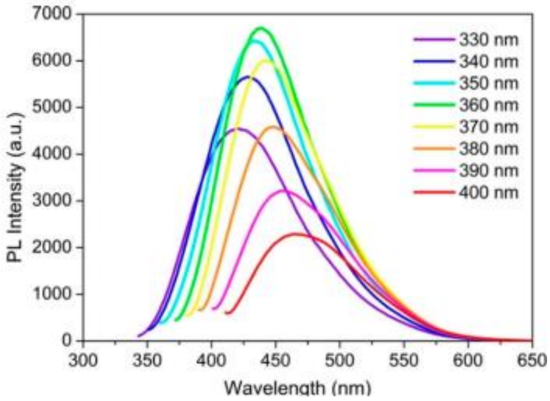

Fig. 2: Excitation-dependent luminescence spectra of CQDs (12).

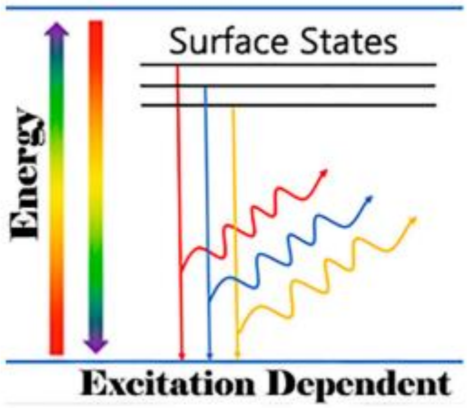

Fig. 3: Several surface energy levels contribute to CQDs' multi-colored photoluminescence (13).

Applications of carbon quantum dots

Table 2 lists examples of how CDs and CD-based compounds have been used in the biomedical and biological sciences. This study focused on the interplay between CDs' composite structure, characteristics, and applications, with an emphasis on the specialized design of CDs for certain tasks.

Table 2: Bio applications of CDs-based composites

Precursors	Composites material	Advantage	Application
Citric acid and urea	C_3N_4	Promotes water-splitting and enhances red light absorption	Bioimaging and PDT
CTAC and triethanolamine	MSN	Provide drug-loading sites	Cancer cell targeting and drug delivery
Pyrene and polyethyleneimine	Black phosphorus	Enhanced NIR absorption	Photothermal-chemo combination therapy
Citric acid and urea	ZIF	Carrier for ECL labels and enhancing the ECL signals	Biosensor
Pyrene and polyethyleneimine	MXenes	Marrow-band gap nano-sonosensitizer	Sonodynamic therapy
Di(Dopa-Se)	Hydrogels	Self-healing and adhesion properties	*In vivo* cancer detection

Carbon dots for bio-sensing

Because of their physical, electrical, and electrochemical qualities, CDs are sensitive in a variety of settings, which has led to their use as bio-sensing probes. The smaller a sample is, the greater its potential for sensitivity, and because of CDs' size, it is possible to utilize fewer of them, which brings the overall cost down. Over the last several years, it has been generally understood that the host is not an independent factor in the development of many degenerative disorders; rather, the two factors are connected. In today's world, the presence of metal ions in the body of a human being that serve as early warning indications for illnesses can be readily identified by using CDs as bio-sensing probes.

Carbon dots for biotherapy

Established methods of biotherapy still have room for advancement, as they are not always effective. For example, they can often extend patients' lives by a few days instead of years, and they frequently cause extremely severe adverse effects. Both invasive procedures and chemotherapy cause damage that is not repairable to the normal cells that are treated. QDs have been utilized as fluorescent agents in the bioimaging and biotherapy fields throughout the last decade due to their excellent water dispersibility and photostability (14). By contrast to their semiconductor ancestors, CDs are a novel family of nanoparticles that have improved fluorescence intensity, photostability, photobleaching, and cytotoxicity. Drug delivery is just one biotherapy application in which CDs have found widespread use, along with photodynamic and photothermal therapy and other specialized approaches. Chemotherapy is among the most well-established methods of treating cancer, and, because of their biocompatibility, CDs are of tremendous importance to the discipline of drug delivery (15).

Biomedical applications

Bioimaging

In vivo and *in vitro* bioimaging using quantum dots (QDs) have received extensive study over the past several decades. Due to their greater brightness, stability, and inability to biodegrade, conventional QDs can be more effective than organic dyes or fluorophores in some applications (16). Nitric acid has been used to coat carbon soot with PEG1500, resulting in carbon quantum dots (CQDs); these were used in cytotoxicity and bioimaging and were evaluated and compared to semiconductors CdSe/ZnS quantum dots (17). However, CQDs did not enter the nucleus of cells and instead labeled the cellular membranes and cytoplasm. CQDs have been fused to the TAT protein of the human immunodeficiency virus to aid in nuclear labeling. This buildup allows CQDs to cross the nuclear membrane and enter cells (18). Passivation of the CQD surface modifies their optical characteristics, making them useful for bioimaging. Passivated CQDs were created from maltose in a microwave for testing purposes. After 24-hour incubation with CQDs, cell viability was not affected, and the green fluorescence that they emitted indicated that they had entered the cells (19). CQDs offer significant potential in the fields of bioimaging and biolabeling because they are biocompatible and don't harm living things. They also can fluoresce in more than one color. CQDs have been found to have minimal toxicity, and antioxidant activity, with outstanding bioimaging performance in both *in vitro* as well as *in vivo* imaging investigations (16-18).

Biosensors

CQDs are employed as biosensors because they can dissolve in water, are not toxic, work well with cells, emit different colors depending on how excited they are, can pass through cells, have a high photostability, and are not toxic. CQD-based biosensors can be used to see glucose (20), phosphate (21), nucleic acid (22), cellular copper ions (23), potassium ion, and pH (24). ROS sensors have been made that use CQDs encased in ascorbic acid hydrogel to find reactive oxygen species (ROS). They can be used to measure ROS levels after chemotherapeutic compounds have been given to see how well the drug works (25). As a biomarker, β-glucuronidase (GLU) is very important because it can stop the growth of cancer cells by changing the fluorescence intensity of N-doped CQDs (26). That makes it a useful tool for detecting cancer and other physiological illnesses in their earliest stages. Real-time pH imaging and biosensing using two-photon microscopy has been achieved in lung cancer A549 cells and mouse LLC-MK2 cells in vitro and in tumor tissues in vivo by implanting tumor cells into nude mice (27). When metal attaches to CQDs, it turns off its light source, regardless of how much metal is present. Because of this, they are a reliable method for finding metal. N-(-aminoethyl)-aminopropyl methyl dimethoxy silane was used to create the CQDs (AEAPMS). Rhodamine B-doped silica nanoparticles with surface coatings of ethylenediamine and methoxy silane groups were used to detect Cu^{2+} ions (28).

Electrochemical biosensors

CQDs are very stable, can be modified on the surface, and conduct electricity well. Applications in biosensing, optical sensors, photovoltaic cells, chemical sensors, nanomedicine, and electrocatalysis could all benefit from their utilization (29). People have also said that CQDs with polymers can detect hemoglobin with high sensitivity and high selectivity (30). Only one instance of CQDs used as an electrode modifier in the creation of a DNA detector for identifying individual gene mutations (31) has been reported. These graphene-based CQDs are good candidates for electrochemical biosensors because of biocompatibility; enzyme uptake improvement at electrodes; hydrophobic carbon framework (32).

Food toxin detection

CQDs are utilized to detect harmful substances, heavy metals, and pathogens in food because of their exceptional optical characteristics (33). Apple juice CQDs have been utilized to identify *P. aeruginosa*, *M. tuberculosis*, and *M. oryzae* (34). Fluorescent probes made from honey, maize flour, spoiled milk, and China grass CQDs are used to visualize the trace metals Fe^{2+}, Cu^{2+}, and Cr6+, correspondingly (35). CQDs can be used in different ways because they have strong PL properties and oxygen and nitrogen functional groups on their surfaces. Chemosensors made from CQDs have been used to find Fe^{3+} and tartrazine (36).

Drug delivery

Cancer and other disorders are commonly treated with chemotherapy, but this method is usually not very precise and can lead to toxicity and resistance to multiple drugs (37). The targeted distribution of medication is preferable because it increases bioavailability, boosts efficacy, and decreases negative impacts (38). This medicine is allowed to escape before it reaches its intended target. Moreover, its fluorescence enabled imaging-guided drug distribution. Substances targeted for the nucleus or the mitochondria have also been delivered via CQDs (39). Many forms of cancer or metabolic disorders involve mitochondria in critical ways. When subjected to hydrothermal treatment, CQDs containing chitosan, ethylenediamine, or Mercaptosuccinic acid have been used to undergo temperature-dependent transit and receptor-mediated endocytosis in mitochondria, making them more stable for the detection of mitochondria than MitoTracker dye. Thus, accurate diagnosis and prognosis necessitate the imaging of tumor cells. In addition, CQDs combined with tumor-penetrating peptides have shown promising results against brain cancers. Conjugated CQDs with peptides that can penetrate the RGERPPR protein have been employed to enter the tumor's blood vessels. Hydrothermal treatment using maleimide-polyethylene glycol-amino succinimide succinate (Mal-PEG-NHS) and resorcinol guaiacol pyridine phosphorothioate (RGERPPR) have been used to functionalize citric acid quantum dots (CQDs). The manufactured nanoparticles showed specificity for glioma and *in vivo* bioimaging delivery.

Other applications

The following study expands on the previous use of carbon dots and their biotechnological applications, reporting the findings of several researchers.

Qie *et al.*, (40) noted that the wide variety of bacteria and of their capacity to develop antibiotic resistance presents a significant obstacle to the use of conventional antibacterial treatments. One approach for treating bacteria is photothermal therapy, which involves the transformation of light energy into localized physical heat to destroy the microorganisms that are the target of the given therapy target. However, many photothermal materials are unable to selectively target bacteria, which could result in thermal damage to normal tissue. This has a significant negative impact on the biological uses of photothermal materials. In this study, they developed and manufactured bacterium-affinitive photothermal carbon dots (BAPTCDs). MurD ligase, an enzyme present in bacteria and responsible for peptidoglycan (PG) synthesis, is the intended target of the CDs used. BAPTCDs demonstrated remarkable photothermal characteristics in addition to their identification capabilities. Because of their chiral structure, BAPTCDs can form extremely strong bonds with bacteria. Competition with D-glutamic acid on MurD ligase binding sites is another way that they can inhibit enzyme activity. This prevents the production of bacterial walls. In addition to this, it enhances the precision with which laser irradiation can kill bacteria. CD possesses exceptional antibacterial properties because of the interaction of its biochemical and physical effects. In addition, it has the potential to aid antibiotic stewardship and the prevention of the spread of antibiotic resistance.

Cui *et al.*, (41) examined the distinctive structure and interesting features of CDs that have garnered significant attention in a variety of sectors, including biological sensing, drug administration, and photodynamic therapy, making them the rising star of carbon-based nanomaterials. Interest in the biomedical and photocatalytic uses of CDs is increasing due to their low toxicity, outstanding photostability, and photo-induced electron transfer capacity. This paper summarizes new findings on the methods of synthesis, optical characteristics, biological applications, and photocatalytic uses of CDs. The future of CDs-based biosensors, biological dyes, biological vehicles, and photocatalysts are also discussed, along with the expectations for their development.

Khayal *et al.*, (42) found that miniaturized carbon dot engineering, scientific breakthroughs in their synthesis, and ground-breaking uses in allied disciplines all play a vital role in the astounding development of cutting-edge technologies in hitherto uncharted fields. CDs, their regulated characterization, and their application in speedier, cheaper, and more reliable products across many scientific areas are all the result of scientific progress and its conjugation with multidisciplinary sectors. As a result, CD technology represents a breakthrough in nanotechnology. Technology, the environment, and numerous kinds of CD nanomaterials have attracted major attention due to their remarkable potential in this crucial area of energy. This study emphasizes the function and significance of carbon dots, as well as the latest developments in their synthesis techniques, attributes, and potential applications.

Qu *et al.,* (43) found that CDs can be tuned for emissions by changing the wavelength at which they are excited. CDs come in a wide variety of forms, including carbon nanotubes, CQDs, and carbonized polymer dots. Their novel characteristics make them attractive candidates for use in a variety of biotechnological fields, such as imaging, sensing, catalytic, and illumination. When it comes to tailored nanomedicine and monitoring of surgical operations, they are seen as excellent alternatives to the present fluorescence biomarkers. Coverage includes the combination of imaging with targeting capabilities in dual-modal imaging agents for improved biomarker collection, as well as the incorporation of therapeutic and imaging agents for more precise tracking of drug distribution. To provide the reader an idea of where the area is headed, theragnostic agents with three functions (such as targeting, imaging, and treatment) were discussed.

Koutsogiannis *et al.,* (44) found that due to their unique fluorescence, chemical and mechanical characteristics, great photostability, and biocompatibility, CDs have attracted considerable attention. CDs have the potential to revolutionize several areas of electronics and biology, especially in the fields of biosensing, bioimaging, biotherapy, and drug administration, due to their exceptional mix of advantageous properties and the simplicity of their synthesis. In particular, this study demonstrates the utility of carbon dots as probes for imaging cells and bacteria and as cation-sensing probes, as well as how they may be manufactured in a variety of simple and inexpensive ways through either the bottom-up or the top-down path. We also detail how their remarkable adaptability has led to novel biotherapy approaches, particularly in cancer theragnostics.

Ding *et al.,* (45) found that CDs have the unique advantages of being simple to prepare, having excellent optical properties, being biocompatible, and being amenable to being modified in structure and function. Nevertheless, most reported CDs have insufficient excitation and emission inside the red/near-infrared (R/NIR) regions, severely limiting their usefulness in biological tests and treatment. Significant efforts have been made in recent years to create CDs with enhanced R/NIR emission and excitation via controlled reactions and accurate separations. Reviewing their synthetic pathways, precursors, and luminescence techniques, Ding et al. (56) summarize current developments in the design and manufacture of CDs with long-wavelength or multicolor emissions. Meanwhile, the use of CDs in photothermal/photodynamic treatment, medication delivery/release, bioimaging, and senses are often disregarded. New prospects for CDs in biological disciplines are highlighted, as well as the existing difficulties in exerting control over their optical qualities.

Wang *et al.,* (46) suggested that the hydrothermal process was used to produce CDs that emit near-infrared light. In an aqueous solution, as-prepared CDs had a comparatively high QY of 33.96%, and their peak in the near-infrared fluorescence reached 685 nm. Under very acidic circumstances, the CDs displayed pH-sensitive properties. As-prepared CDs showed outstanding resistance to acid, maintaining a high intensity even after the pH was reduced to zero. Notably, CDs could detect variations in Fe^{3+} concentration in living cells. It is also possible to use them to make emissive white and red LEDs. Due to this finding, the science of imaging and detecting live cells could entail greater use of aqueous-phase high QY CDs.

Molaei *et al.,* (47) reported that nano carbon quantum dots, also known as CQDs, have attracted growing interest due to their features, including their tiny size, emission of fluorescence, ease of production, and potential for functionalization. CQDs are nanostructures with dimensions less than 10 nm with a fluorescent emission from 0 D carbon. Fluorescence in CQDs originates from two different places: bandgap changes in conjugated domains and surface defects. Both of these sources contribute to the overall fluorescence. Because the CQDs are capable of fluorescence emission in the near-infrared (NIR) spectral range, they are suitable for use in applications related to the medical field. The fluorescence emitted by these structures is capable of being altered with reference to the wavelength of the excitation source. CQDs have been found to be useful in many different industries, such as biomedicine, photocatalysis, photodiodes, and solar energy conversion, light-emitting diodes (LEDs), and other fields. CQDs have several potential uses in biomedicine, including cancer treatment, bioimaging, and the transport of drugs and genes. In comparison to heavy metals semiconductor QDs, fluorescent CQDs have minimal toxicity, in addition to other excellent physicochemical features; this makes them prime candidates for implementation in biomedical settings. Their use in blood-brain barriers (BBB), drug distribution, and cancer therapy all benefit from CQDs' unique properties and gene delivery are also discussed, as are the most recent advances in these biomedical applications.

Chan *et al.,* (48) found that CDs have attracted a lot of attention in several sectors over the last decade due to their remarkable photoluminescence capabilities and the simplicity with which their optical properties may be adjusted by doping and functionalization. The photoluminescence processes of CDs are discussed after a brief overview of their production, structure, and optical characteristics. Various CD-based sensing processes are then described, along with a range of sensor configurations. Finally, most new studies on carbon dot-based detectors for the sensitive and precise measurement of a wide range of analytes is detailed in depth. Metals, cations, positive ions, biomolecules, biomarkers, polyaromatic explosives, contaminants, vitamins, and medications are just some of the analytes that can be measured. This study concluded by indicating where things stand, what is holding them back, and what the future may hold for practical sensing applications of carbon dots.

Chaudhary *et al*., (49) reported that scientists and technocrats have lately shown a significant amount of interest in carbon (C) dots due to their low toxicity as well as their outstanding fluorescence and optical qualities. In addition, C-dots are used in nanomedicines. C-dots form the subject of a significant amount of research due to the many fascinating features and versatile uses they exhibit. This concise study discusses the many methods of synthesis, characteristics, and, more particularly, nano medicinal uses of C-dots. Some examples of these applications include biological imaging, cancer medication delivery, regenerative therapies, and biosensing. The study provides more information on the basic concerns involving the transit of medications using C-dots, their absorption inside the body, and their elimination from the body. Additionally, the study sheds light on how further advancements in biomedical research may be made with the use of C-dots and where we believe the area would be heading in the not-too-away future.

From the first discovery of CQDs, various easy, cheap, and efficient synthetic methods for creating fluorescent CQDs have been developed that are photostable, biocompatible, non-blinking, and resistant to photobleaching. There is growing evidence that CQDs create fluorescence through two different processes. The first is due to a surface defect-induced fluorescence, and the second is associated with a band gap transition in sp2 conjugated carbon. Forming sp^2 domains in a graphene sheet in such a manner that conjugated domains are segregated results in the creation of a band gap in the graphene sheet. When CQDs are made smaller, the band gap that emits high energy may become much greater. CQDs are a natural match for the field of bioimaging and biosensing due to their high biocompatibility and environmentally acceptable structure. Some examples of biosensing research include electrochemical biosensing and the detection of harmful substances. CQDs require a high enough QY to compete with cheaper and more widely available alternatives, such as fluorophores and semiconductor QDs. The discipline of nanomedicine has been profoundly disrupted because of CQDs. Researchers have applied significant efforts toward the goal of using CQDs to deliver medicine to tumor-specific regions, making use of targeted receptors.

CONCLUSION

CDs are an intriguing category of nanomaterials and have garnered a lot of attention from scientists over the last decade. CDs are rapidly gaining prominence in the practice of the health and life sciences due to their high stability, minimal toxicity, and adaptable optical features. Meanwhile, new functionalities are being generated thanks to progress in the synthesis of CDs with unusual architectures. For CDs to reach their full potential in a variety of contexts, researchers require a better grasp of the structure-function links between their constituent parts. In this review, we discussed current developments in the synthesis of CDs for applications in bioimaging, biosensors, and drugs for the management of bacterial, neoplastic, and viral illnesses. In the future years, CDs may completely replace the more traditional semiconductor quantum dots, which have been shown to be effective in a variety of biological studies and fields of use. Studies of CDs' cytotoxicity, biocompatibility, and photostability have been conducted in both laboratory and animal settings, with impressive findings. In this review, we discussed CDs that have been manufactured in a wide range of ways, demonstrating a wide range of optical characteristics and uses, as well as a wide range of biocompatibilities. More effective detection and treatments using CD-based compounds for biological applications may be made by switching to a universal preparation technique that can be scaled up for commercial production. In addition to their promising theragnostic use, CDs will likely play a huge role in a wide variety of other fields.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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