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Environmentally benign, bright luminescent carbon dots from IV bag waste and chitosan for antimicrobial and bioimaging applications

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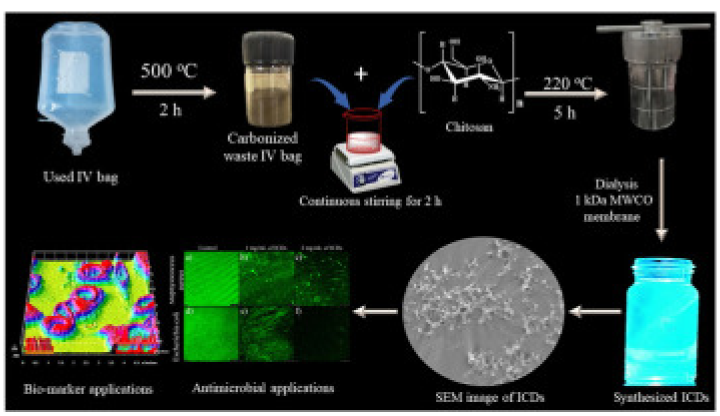
Highlights

- Luminescent carbon dots are prepared from waste IV bag by simple two-step strategy.
- Carbon dots exhibits better antibacterial and biofilm inhibition properties.
- Durable carbon dots supports for fluorescent HeLa cells cellular imaging.

Abstract

Luminescent carbon dots have gained significant attention in various fields due to their unique optical properties and potential applications. Here, the study was aimed to propose a novel and sustainable approach for the synthesis of luminescent carbon dots (ICDs) using IV (Intravenous) medical bag waste. The ICDs were synthesized through a facile and cost-effective method that involved the carbonization of IV bag waste followed by surface functionalization with chitosan. The synthesized ICDs were characterized using UV–Visible spectrum (UV–Vis), Fourier Transform Infrared Spectroscopy (FT-IR), X-Ray Diffraction analysis (XRD), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). The size of the ICDs is between 2 and 8 nm. The ICDs effectively inhibited the growth of both gram positive and gram negative bacterial strains with the inhibitory activity in the range of 11–14 mm and 12–18 mm, respectively. Results of antibiofilm activity of ICDs varying concentrations (50 and 100 μg/ml) showed that it effectively distorted the biofilm architecture and thereby validated its promising potentials. *In vitro* antioxidant activity showed remarkable DPPH radical scavenging potentials of ICDs (33.4%–70.1%). Results of MTT assay revealted that ICDs showed potent cytotoxic effect on HeLa cells in a dose dependant matter (25–400 μg/ml). Furthermore, when HeLa cells were excited at wavelengths of 380 nm, 440 nm and 540 nm, cell-imaging experiments using ICDs revealed the presence of blue, green, and red fluorescence. This innovative method not only addresses the issue of IV bag waste in a sustainable manner but also opens up exciting possibilities for the advancement of versatile carbon-based materials in the field of biomedicine.

Graphical abstract



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Introduction

Carbon dots (CDs), nano-sized materials with stable photoluminescence properties, have emerged as a competitive alternative to heavy-metal-containing quantum dots and rare-earth-doped nanocrystals (Liu et al., 2020). Their low toxicity (Chan et al., 2021), biocompatibility (Park et al., 2020), and favourable chemical properties have made them suitable for various applications, including drug delivery (Zeng et al., 2016), sensing (Raveendran and Kizhakayil, 2021), and optoelectronics (Stepanidenko et al., 2021). CDs are also promising for bioimaging (Kaur and Verma, 2022), and energy harvesting in luminescent solar concentrators (Zhou et al., 2018). While early CD synthesis methods involved harsh conditions, recent hydrothermal approaches offer greener and bottom-up fabrication at lower temperatures. However, the use of high-cost or toxic precursors in CD synthesis hampers scalability. To address this, researchers have explored renewable biological by-products like grass, plant leaves, apple juice, and waste paper. Nonetheless, the challenge remains to develop an industrial-scale fabrication approach for CDs due to their increasing demand (Long et al., 2021). The cost-effectiveness and environmental impact of conventional CD synthesis methods, which rely on expensive or hazardous chemicals, pose obstacles to their practical implementation and sustainability, despite their potential in bioimaging, sensing, and drug delivery.

Global demand for Poly(ethylene terephthalate) (PET) has risen due to population growth and increased needs (Oladele et al., 2023). Scientists are researching sustainable methods to repurpose PET waste into carbon dots (CDs) to lessen environmental impact. These efforts aim for a circular, eco-friendly economy. Various PET utilization strategies include its use in construction materials (Mohan et al., 2021), oil spill adsorbents (Saleem et al., 2018), and water purification hydrogels (Chan and Zinchenko, 2021). Research also focuses on turning PET waste into carbon nanomaterials like carbon nanotubes and graphene (Chen et al., 2022). For instance, Hu et al. (2019) developed a low cost and greener method of producing fluorescent CDs from PET and further proved its ability to detect Fe^{3+} and PPi in water and urine samples, offering potential as a sensing system. Kumari and Chaudhary (2020) utilized plastic waste-derived CDs to detect *E. coli*, exhibiting excellent optical properties and a 60–70% quantum yield. The CDs detected *E. coli* in water with a sensitivity of 108 CFU/ml, while being biocompatible and non-toxic. Perikala and Bhardwaj (2022) recycled non-biodegradable plastic wastes like masks, gloves and syringes into white-light CDs through pyrolysis and embedded them in a scalable polymer phosphor. The scalable sustainable phosphor exhibited broad emission, yielding high quality white LED with CRI ~70 and (0.25, 0.32) CIE coordinates for advanced lighting. Recently, PET waste is innovatively turned into nitrogen-doped Carbon Dots (NCDs), reducing landfilling and CO_2

emissions, serving as both LED materials (48.16%) and water sensors (Ma et al., 2023). Liang et al. (2023) synthesized CDs from PET wastes through an eco-friendly approach and further validated its application in sustainable agriculture through enhanced green pea seed germination, seedling growth, and metabolic pathways.

In healthcare facilities, there is a significant amount of waste generated from IV bags, which contain carbon-rich polymers like polyethylene and polypropylene (Kibria et al., 2023). However, this waste presents an opportunity to transform it into valuable nanomaterials and reduce its environmental impact. Researchers are increasingly interested in sustainable methods for synthesizing carbon dots (CDs) using waste materials such as PET (Atchudan et al., 2021; Manzoor et al., 2023). Furthermore, chitosan derived from chitin, is well known for its antimicrobial properties and biocompatibility. These qualities make it a promising agent to enhance the functionality of CDs (Villalba-Rodríguez et al., 2022). The development of a simple and low-cost recycling process for PET waste is essential to promote sustainability and conserve both energy and resources. In this context, combination of chitosan with carbon extracted from discarded IV bags emerged as a significant method to minimize PET wastes and further explore the biomedical applications of CDs. Thus, in the present investigation an innovative and environmentally-safe method was employed to synthesize luminescent carbon dots (ICDs) from discarded IV bag waste and chitosan by optimizing factors like reaction conditions, precursor concentrations and temperature. Subsequently, the resulting ICDs were assessed for their notable antimicrobial potentials, cell imaging proficiency and biocompatibility. This method not only provides a viable way for the judicious utilization of IV bag waste but also paves the way for versatile carbon-based materials. By adopting this sustainable method, we can mitigate the environmental effects of waste and foster the development of cost-effective, functional nanomaterials for biomedical applications. The successful preparation of glowing carbon dots using IV bag remnants and chitosan offers potential in areas such as cellular visualization, antimicrobial treatments, and biofilm control. This study aims to pave the way for the eco-friendly and effective use of waste in the fabrication of functional nanomaterials, promoting advancements in biomedicine and supporting a more sustainable future.

Section snippets

Materials and chemicals

The IV bags used in the present study were obtained from Saveetha Medical College and Hospital, Chennai, India. In order to prepare the sample, distilled water was employed as the dispersion solvent. For the antimicrobial experiments, the samples were dissolved in ethanol (Himedia, India). The test bacterial growth media Nutrient Broth and antibacterial assay medium Muller Hinton Agar was obtained from Himedia, India.…

Instrumentation

In this research, a Teflon-coated stainless-steel autoclave (50 ml) sourced…

Result and discussion

Through an eco-friendly two-step process, the widely known thermoplastic polyester, PET, known for its excellent heat resistance and durability against mineral acids, oxidizing agent and sunlight was effectively converted into fluorescent ICDs. This innovative technique involves combination of air thermal oxidation and a hydrothermal procedure. Briefly, the discarded IV bags were exposed to open air and heated to 500 °C for 2h. This step lead to a series of changes in polymer and resulted in a…

Conclusion

To summarize, this research presents an eco-friendly method for synthesizing ICDs from repurposed IV bags made of plastic waste. The process has piqued scientific interest for its potential environmental benefits. A comprehensive array of analytical techniques, including UV, FT-IR, and SEM, confirmed the ICDs' characteristics. These ICDs display strong fluorescence and feature –COOH and –OH groups, making them water-soluble. They have shown efficacy in inhibiting bacterial growth and biofilm…

Credit authors statement

Ramasamy Ramasubburayan: Methodology, Investigation. Nangan Senthilkumar: Writing – original draft. Kuppusamy Kanagaraj: Methodology. Sanjay Basumataray: Validation. Sellamuthu Kathiresan: Figure editions. Jagadeesan Manjunathan: Software. Meyyappan

Revathi: Formal analysis. Manickam Selvaraj: Reviewing. Santhiyagu Prakash: Supervision.…

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.…

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