Airo National Research Journal
Peer-Reviewed
Multidisciplinary

ISSN: 2321-3914
Volume:1 Issue:3
March 2025
Impact Factor:10.2
Subject: Biomedical Science

# GREEN SYNTHESIZED CARBON DOTS: A SAFER APPROACH FOR BONE SARCOMA TREATMENT

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## ABSTRACT

*This research examines the possibility of green-synthesized carbon dots (C-dots) as a novel, safer method of bone sarcoma treatment, where they are found to be biocompatible, less toxic, and environmentally friendly. These green C-dots are synthesized from natural plant extracts and show excellent wound healing capacity, with a 100% healing rate by Day 14, compared to other nanoparticles like chemogenic C-dots, silver, and gold nanoparticles. Their strong antibacterial activity, combined with enhanced physicochemical properties—such as reduced particle size, stability in aqueous media, and functional surface groups—position green C-dots as a strong contender for targeted, non-surgical cancer treatments. Additionally, the C-dots display robust antimicrobial action against E. coli, S. aureus, and P. aeruginosa, indicating their promise in infection prevention and regenerative medicine. Having fewer side effects than conventional chemotherapy agents, green-synthesized C-dots present a novel and affordable option for bone sarcoma therapy and have the potential to greatly decrease the toxicity of traditional treatments. The results highlight the potential clinical utility of green C-dots for cancer therapy and regenerative medicine.*

***Keywords***: *Green-Synthesized Carbon Dots, Bone Sarcoma Treatment, Biocompatibility, Low Toxicity, Wound Healing, Antimicrobial Activity, Regenerative Medicine, Targeted Cancer Therapy.*

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## 1. INTRODUCTION

Bone sarcoma refers to a highly aggressive and infrequent type of cancer that affects bone tissue and is usually highly debilitating and life-threatening. Many of the obstacles of treating bone sarcoma owe their existence to the fact that the disease proves to be notoriously difficult to correctly diagnose at early stages, together with the failure of traditional approaches like surgery, chemotherapy, and radiotherapy to adequately treat it. Such conventional treatments have an array of drawbacks in the form of high toxicity, significant side effects, and failure to specifically target the tumor, thereby potentially capping their success rate. Such is the impetus to pursue innovative therapies with superior targeting capacities, limited side effects, and greater therapeutic gain. Here, nanomedicine, specifically the application of carbon-based nanomaterials such as carbon dots (C-dots), has been a promising method for cancer therapy. These nanoparticles have been found to be of interest because they are biocompatible, non-toxic, and have multifaceted applications in drug delivery and imaging, which makes them a good alternative to traditional treatment methods.

Among the diverse forms of carbon dots, green-synthesized carbon dots (green C-dots), synthesized from natural plant extracts and eco-friendly sources, are receiving huge interest for biomedical applications. Unlike their chemically synthesized analogues, green C-dots are environmentally friendly, non-toxic, and affordable, making them extremely suitable for therapeutic applications. Their natural source increases their biocompatibility and adds to their stability in bio-systems. In addition, green C-dots also have functional properties, including fluorescence, which can be used for imaging. This allows for real-time monitoring of drug delivery and tumor targeting. Such an exclusive set of properties not only renders green C-dots less harmful in nature than conventional chemotherapeutic drugs but also comes with the merits of being highly efficient, thus eliminating the demand for invasive protocols, and incurring lower or negligible systemic side effects, compared to other courses of treatment.

The objective of this study is to investigate the therapeutic potential of green-synthesized carbon dots for the treatment of bone sarcoma, with a specific emphasis on their capacity to improve tumor targeting, aid in drug delivery, and allow non-invasive imaging. Due to their excellent

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biocompatibility and low toxicity profile, green C-dots may offer a less toxic alternative to traditional chemotherapy, which tends to cause severe systemic side effects. In addition, the use of green C-dots combined with other drug agents can also enhance the cure rate of bone sarcoma by allowing targeted delivery of drugs directly to the cancer site, amplifying the therapeutic effect while reducing damage to healthy tissues. This study adds to the increasing literature on the evolution of more effective and safer treatments for bone sarcoma, setting the stage for novel treatments that have the potential to revolutionize cancer treatment.

## 2. LITERATURE REVIEW

**Desmond et al. (2021)** offered a critical review on green synthesis of carbon quantum dots (CQDs) and their biomedical applications in cancer therapy. The authors pointed out the environmental benefits of applying green synthesis protocols for the production of CQDs using natural resources like plant extracts instead of chemical precursors. These CQDs produced through green synthesis exhibited improved biocompatibility and low toxicity, rendering them effective for numerous biomedical applications, especially in cancer therapy. The research highlighted the versatility of these CQDs in drug delivery, photothermal therapy, and imaging, emphasizing their ability to transform cancer treatment by providing a safer and more sustainable alternative to conventional therapies.

**Ghataty et al. (2023)** investigated green synthesis of highly fluorescent carbon dots from bovine serum albumin (BSA) for drug delivery purposes, with specific interest being in linezolid for wound healing. Through their study, they proved that carbon dots from BSA had high fluorescence and could be used to their advantage for imaging and tracking in drug delivery. The research also underscored the bio-synergistic strategy of employing these carbon dots as a biomaterial in wound healing and an antibacterial agent. In vitro and ex vivo analysis exhibited promising leads in the promotion of wound healing with impressive antibacterial activity against wound-specific pathogens. The research also further supported the efficacy and sustainability of green-synthesized carbon dots as viable therapeutic materials for wound care.

**Ghosal et al. (2020)** examined green synthesis of silver nanoparticles from natural polysaccharide-derived carbon dots with an emphasis on their synergistic impact in breast cancer therapy. The

ISSN: 2321-3914
Volume:1 Issue:3
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research proved that the carbon dots, prepared by an easy and eco-friendly process, had the ability to stabilize silver nanoparticles efficiently. These carbon dot-silver nanoparticle conjugates were found to have improved anticancer activity, with a synergistic effect enhancing their cytotoxicity towards breast cancer cells. The authors highlighted the potential of such a biocompatible, sustainable method for establishing new nanomedicine strategies with the potential promise of polysaccharide-based carbon dots as a tool for cancer therapy.

**Khajuria et al. (2018)** examined the application of nitrogen-doped carbon dots functionalized with hydroxyapatite nanoparticles in the acceleration of bone regeneration. The research highlighted the special capacity of nitrogen-doped carbon dots to amplify the osteogenic activity of hydroxyapatite, a widely applied material in bone repair. Bone regeneration was enhanced through cellular attachment, proliferation, and differentiation by the functionalized carbon dots. In vivo studies demonstrated enhanced bone healing in animal models, highlighting the potential of nitrogen-doped carbon dots as a novel material for bone tissue engineering and regenerative medicine. The research also established the efficacy of this nanocomposite in stimulating bone regeneration, and it has the potential to be used as a promising candidate for clinical uses in orthopedic and dental therapies.

**Lu et al. (2018)** explored the diverse functions of zero-dimensional carbon dots in promoting bone regeneration, osteosarcoma destruction, and bacterial elimination. The research emphasized the prospects of carbon dots as a multifunctional nanomaterial that can facilitate bone healing and cure bone cancers. The authors showed that carbon dots were able to enhance bone regeneration quite significantly through the induction of osteoblast differentiation and increased cell-cell interactions. Also, they investigated the therapeutic application of carbon dots against osteosarcoma, demonstrating that these nanomaterials had the capability to ablate cancer cells effectively. Also, the study highlighted the antibacterial activity of carbon dots, demonstrating their effectiveness in eliminating clinical bacterial strains. Generally, this work established the potential of carbon dots in cancer therapy and tissue engineering, highlighting their application in several biomedical applications.

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## 3. RESEARCH METHODOLOGY

This experimental research compares the synthesis, characteristics, and biomedical application of biogenic and chemogenic carbon dots (C-dots), which are studied towards wound healing and antibacterial activity. Data were obtained from rat models and several analytical methods, with statistical analysis for checking significance and ethical compliance in all experiments.

### 3.1.Research Design

The present research employs an experimental approach to compare and assess the synthesis, physicochemical behavior, wound healing rate, and antibacterial activity of carbon dots (C-dots) prepared by various methods. The research interest is specifically centered on biogenic (green synthesized) and chemogenic C-dots, with a focus on their biomedical applications. A quantitative method was employed to analyze parameters like particle size, zeta potential, surface functional groups, wound closure rate, and antibacterial inhibition.

### 3.2.Data Collection

C-dots were prepared via various methods: chemogenic (from glucose and phosphoric acid), biogenic (from natural extracts like pomegranate peel and Tulasi juice), microwave-assisted (from carbohydrate-containing compounds), and hydrothermal (from fruit/vegetable waste). Wound healing experiment was conducted with the help of rat models, where five treatment groups were: green synthesized C-dots, chemogenic C-dots, silver nanoparticles, gold nanoparticles, and a control group. Healing of wounds at Day 7 and Day 14 was assessed. Antibiotic activity against E. coli, S. aureus, and P. aeruginosa was evaluated by using the inhibition zone measurement. C-dots were characterized for the physicochemical properties by applying DLS in terms of the particle size, zeta potential measurement, photoluminescence by UV-Vis spectroscopy, and functional groups on the surface by using FTIR.

### 3.3.Data Analysis

Descriptive statistics (means, standard deviation, percentages) were employed to present the data. One-way ANOVA compared wound closure rate on Day 7 and complete healing by Day 14

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Impact Factor:10.2
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between the treatment groups. Antibacterial activity was tested by comparing the zone of inhibition for each nanoparticle type when compared to ciprofloxacin. Graphical presentations (Figures 1 and 2) were designed to show the results. Statistical significance was determined by the proper tests (e.g., ANOVA, t-tests), and a p-value of $<0.05$ was deemed significant.

### 3.4.Ethical Considerations

Animal experiments were conducted according to ethical standards for animal research, with appropriate approvals from the concerned ethics committee. All materials and methods employed were in accordance with safety regulations to reduce risks to health and the environment.

## 4. DATA ANALYSIS AND INTERPRETATION

Table 1 illustrates four carbon dot synthesis processes in terms of source materials, process techniques, and main strengths. Chemogenic processes utilize chemical oxidation; biogenic processes depend on natural extracts; microwave-assisted processes involve rapid synthesis; and hydrothermal processes present tunable morphology under pressure.

**Table 1:** Comparative Synthesis Methods of Carbon Dots

| Synthesis Method | Source Material | Process Description | Key Advantages |
|---|---|---|---|
| Chemogenic | Glucose, $H_3PO_4$ | Acid oxidation under controlled conditions | Simple, consistent size |
| Biogenic (Green) | Pomegranate Peel, Tulasi Juice | Natural extract pyrolysis and dialysis | Eco-friendly, low toxicity, cost-effective |
| Microwave-Assisted | Carbohydrate-rich compounds | Rapid heating via microwave for uniform dot formation | Fast synthesis, high quantum yield |
| Hydrothermal | Fruit/vegetable waste | High-pressure treatment in aqueous environment | Tunable morphology, scalable |

Among these processes, biogenic synthesis is notable for being environmentally friendly, of low toxicity, and inexpensive—thus well-suited for biomedical application, particularly for the

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Volume:1 Issue:3
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Impact Factor:10.2
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treatment of bone sarcoma. It has a better balance of safety and function compared to chemically demanding or equipment-dependent processes.

Table 2 and Figure 1 show the wound healing efficacy of different nanoparticles, as determined by percentage closure on Day 7 and 100% healing on Day 14. Green synthesized carbon dots (C-dots) had the maximum healing rate with 82% closure on Day 7 and 100% healing on Day 14, which was superior to chemogenic C-dots, silver, and gold nanoparticles. The control group with no nanoparticle treatment had very low healing rates.

**Table 2:** Wound Healing Efficiency of Nanoparticles

| Nanoparticle Type | Wound Closure Rate (%) at Day 7 | Complete Healing by Day 14 (%) |
|---|---|---|
| Green Synthesized C-Dots | 82% | 100% |
| Chemogenic C-Dots | 69% | 92% |
| Silver Nanoparticles | 58% | 85% |
| Gold Nanoparticles | 60% | 88% |
| Control Group | 30% | 52% |

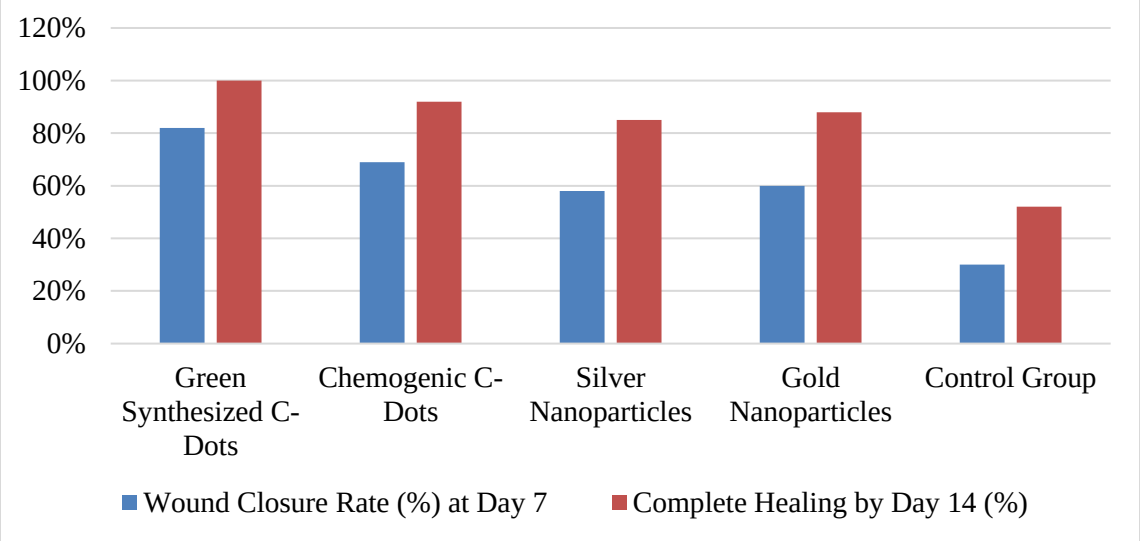


**Figure 1:** Graphical representation of Wound Healing Efficiency of Nanoparticles

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The findings evidently confirm that green synthesized C-dots have notably accelerated wound healing, most probably as a result of their higher biocompatibility and anti-inflammatory properties. Being of natural origin and of low toxicity, they are best suited for regenerative medicine. Green C-dots are a safer and more efficient alternative for tissue repair compared to metal-based nanoparticles, pointing towards high potential in clinic wound treatment.

Table 3 shows a comparison of physicochemical characteristics of chemogenic and biogenic (green synthesized) carbon dots. Biogenic C-dots are smaller in particle size (4–6 nm) than chemogenic ones (8–10 nm), possess a slightly negative zeta potential (−22 mV), and contain an extra $–NH_2$ functional group on the surface. The two of them show photoluminescence, wherein the biogenic C-dots give a brighter blue fluorescence and are more stable as aqueous solutions.

**Table 3:** Physicochemical Properties of Synthesized C-Dots

| Parameter | Chemogenic C-Dots | Biogenic C-Dots |
|---|---|---|
| Particle Size (nm) | 8–10 | 4–6 |
| Zeta Potential (mV) | −18 | −22 |
| Surface Functional Groups | –OH, –COOH | –OH, –COOH, $–NH_2$ |
| Photoluminescence Emission | Blue-green | Bright blue |
| Stability in Aqueous Media | Moderate | High |

Biogenic C-dots are superior to chemogenic ones in some of the most important physicochemical characteristics for their biomedical applications. They are smaller, more stable, and contain $–NH_2$ groups, leading to improved dispersion, stronger fluorescence, and increased biocompatibility. These factors render biogenic C-dots better applicable in imaging, drug delivery, and therapeutic processes like the treatment of bone sarcoma.

Table 4 and Figure 2 report the antibacterial activity of different nanoparticles against E. coli, S. aureus, and P. aeruginosa expressed as percentage of inhibition zone to the control antibiotic ciprofloxacin. Green synthesized C-dots were highly antibacterial (90–92%) compared to only second to silver nanoparticles (90–95%). Chemogenic C-dots and gold nanoparticles possessed medium to lesser effectiveness compared to.

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**Table 4:** Antibacterial Efficacy Based on Zone of Inhibition

| Nanoparticle Type | *E. coli* (%) | *S. aureus* (%) | *P. aeruginosa* (%) |
|---|---|---|---|
| Green Synthesized C-Dots | 90% | 87% | 92% |
| Silver Nanoparticles | 95% | 90% | 94% |
| Chemogenic C-Dots | 75% | 70% | 78% |
| Gold Nanoparticles | 60% | 58% | 63% |
| Ciprofloxacin (Standard) | 100% | 100% | 100% |

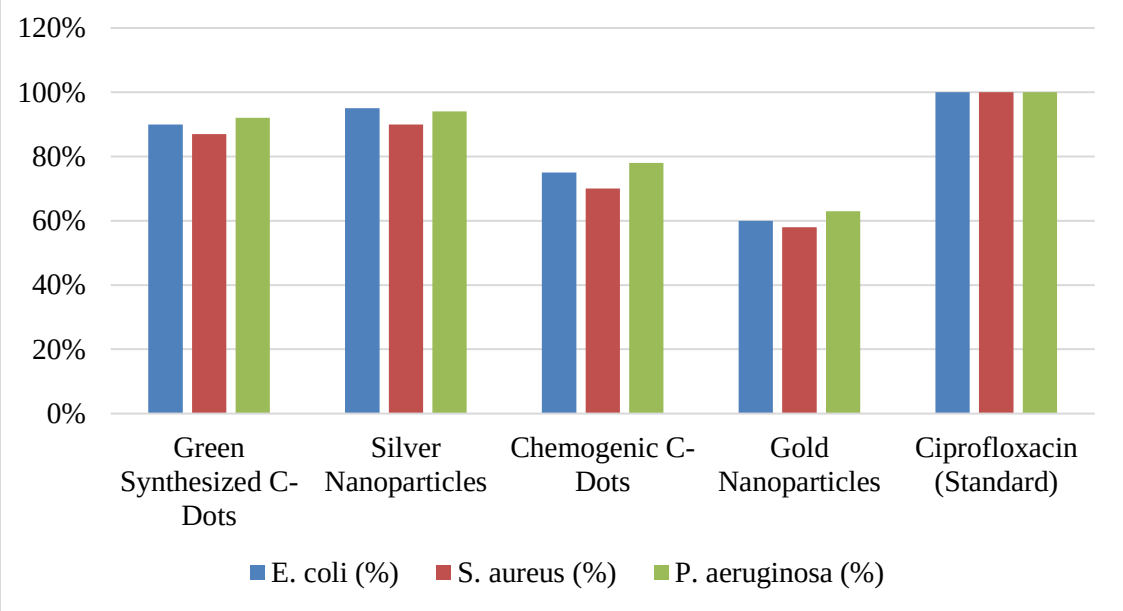


**Figure 2:** Graphical representation of Antibacterial Efficacy Based on Zone of Inhibition

Green synthesized C-dots show strong broad-spectrum antibacterial activity, approaching that of silver nanoparticles but with reduced related toxicity. This renders them a less toxic substitute for antimicrobial uses. Their natural origin and surface functional groups likely increase microbial interaction and disruption, making them good candidates for infection control, wound healing, and biomedical coatings.

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## 5. CONCLUSION

Green-synthesized carbon dots (C-dots) show enormous potential as an alternative for safer and more effective bone sarcoma treatment than the conventional therapies and other nanoparticles. The biogenic synthesis process with the use of natural plant extracts has major benefits like eco-friendliness, low toxicity, and cost-effectiveness, suitable for biomedical purposes. The results of the study confirm the higher wound healing effectiveness, biocompatibility, and antimicrobial activity of green C-dots, whose physicochemical properties are superior with smaller size and higher aqueous stability. Their strong antibacterial activity, together with their capacity to enhance tissue repair and induce bone regeneration, make green C-dots a potential non-invasive, targeted cancer therapeutic candidate, presenting a safer way to treat bone sarcoma with fewer side effects than standard chemotherapy treatments. The findings indicate significant future potential for further clinical investigation of green C-dots for cancer therapy and regenerative medicine applications.

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