



Role of Carbon Quantum Dots in the Development of Herbal-Based Endodontic Irrigation Materials: A Literature Review

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Abstract

*Background: The irrigation process of root canals plays a significant role in cleaning the root system of microorganisms and dead tissue. However, chemical irrigation materials such as NaOCl often cause side effects such as tissue irritation and toxicity. Therefore, the use of safer and environmentally friendly natural materials has become the focus of recent research. Objective: This study aims to review the development of the use of Carbon Quantum Dots (CQDs) based on natural materials as an alternative for root canal irrigation. Method: The study was conducted by tracing literature from the last five years (2020–2025) through databases such as Google Scholar. Only experimental research that tests the efficacy and characterization of CQDs from herbal extracts was analyzed. Results: CQDs synthesized from plants such as betel leaf, green tea, ginger, and propolis have high antibacterial properties, fluorescence characteristics, and do not damage dentin tissue. These compounds are also effective against resistant bacteria such as *E. faecalis* and have the potential to be used in photodynamic therapy. Conclusion: Herbal-based CQDs are considered promising as a safe, efficient, and sustainable irrigation agent. However, more clinical trials are needed to prove its efficacy in endodontic practice.*

Keywords: Carbon Quantum Dots, Natural Materials, Endodontic Irrigation, Antibacterial.

INTRODUCTION

Root canal treatment (endodontics) is an important procedure for maintaining teeth that have pulp damage due to bacterial infection (Zhang et al., 2020). The root canal disinfection process can be carried out through irrigation, which is an important component of the success of endodontic treatment. Irrigation has three main functions, namely mechanical, chemical, and biological (Turky & Peters, 2025). Mechanically, irrigation serves to clean debris remnants and provide lubrication during the root canal instrumentation process (Dandie et al., 2020). Chemically, irrigation aims to soften and dissolve organic and inorganic tissues, prevent the formation of a smear layer during the preparation process, and help dissolve the smear layer that has already formed. Biologically, irrigation plays a role in providing an antiseptic effect and must be non-toxic, including the ability to destroy facultative anaerobic microorganisms (both in

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planktonic and biofilm forms), neutralize endotoxins, and not cause harmful effects on the surrounding tissues (Gulabivala & Ng, 2023).

Success of endodontic therapy greatly depends on the effectiveness of cleaning and disinfection of the root canal system, which is carried out through the use of irrigation materials (Haapasalo, Endal, Zandi, & Coil, 2005). Traditional irrigation materials such as sodium hypochlorite (NaOCl) and EDTA have been used for a long time due to their ability to dissolve tissue and eliminate microorganisms (Yu, Zhang, Yang, & Li, 2024). However, these materials have some drawbacks, such as potential cytotoxicity, causing periapical tissue irritation, and posing a risk to healthy tissue.

On the other hand, the increasing microbial resistance and the demand for more natural and biocompatible treatments have driven the development of safer, more effective, and environmentally friendly irrigation materials (Karojari et al., 2022; Sivakumar, Ravi, Prasad, & Sivakumar, 2018). In recent years, various herbal extracts such as *Azadirachta indica* (neem), *Curcuma longa* (turmeric), and *Moringa oleifera* have been studied due to their active phytochemicals that possess antibacterial and anti-inflammatory properties. However, the main limitations of herbal materials are their stability, penetration power, and effectiveness against bacterial biofilms within complex root channels (Chamseddine & Abiad, 2024).

Innovation in nanomaterial technology, particularly the use of Carbon Quantum Dots (CQDs), offers potential solutions (Salvi, Kharbanda, Thakur, Shandilya, & Thakur, 2024). CQDs are carbon nanoparticles with a very small size (<10 nm) that possess antibacterial, antioxidant, and photocatalytic properties, as well as high biocompatibility (Nie et al., 2020). When combined with herbal materials, CQDs can enhance the stability and antibacterial efficacy of herbal compounds, as well as penetrate the complex root canal structure (Khan, Mohammad, & Yoon, 2022). Moreover, CQDs also function as photosensitizers in photodynamic therapy, producing Reactive Oxygen Species (ROS) that are highly effective in killing resistant microorganisms such as *Enterococcus faecalis* (Pechnikova et al., 2025).

Therefore, the development of herbal-based endodontic irrigation material modified with Carbon Quantum Dots represents a new promising approach, in line with the increasing demand for more effective and safe therapies in modern endodontics

METHOD

The research method used is a literature review or bibliographic survey. A literature review study is a way to collect data or sources related to a specific topic that can be obtained from various sources such as journals, books, the internet, and other libraries. This research only uses literature sources from journal articles. The literature search was conducted for one month. The research literature search strategy uses the method of searching for articles that have passed the publication process on Google Scholar using the selected keywords: Indonesian language journals using "Carbon Quantum Dots", endodontic irrigation, herbal, and English language journals using "carbon quantum dots, endodontic irrigation, herbal". Appropriate articles or journals are selected for further use. This literature review uses published literature from 2020-2025 that can be accessed in full text format in pdf and scholar.

The selection phase of research articles is based on inclusion and exclusion criteria. The inclusion criteria used are: 1) articles relevant to the analysis of Carbon Quantum Dots from herbal materials; 2) full-text articles available in English and Indonesian; 3) articles published within the period of five years from the end of 2020 to 2025. Meanwhile, the exclusion criteria used are: 1) articles published before the year 2020; 2) non-article publications; 3) review articles.

The selection process of articles in this literature review uses the PRISMA model. The search results from six databases yielded a total of 120 articles. After screening, which involved eliminating qualitative and non-experimental articles, articles with duplicates, and articles that did not discuss the variables in this research at all, 20 articles were obtained. Subsequently, the eligibility process involved selecting articles that were accessible and the most relevant to the objectives of this literature review, which were related to the specified keywords, resulting in 10 articles being reviewed in this literature review. For more details, see Figure 1 below.

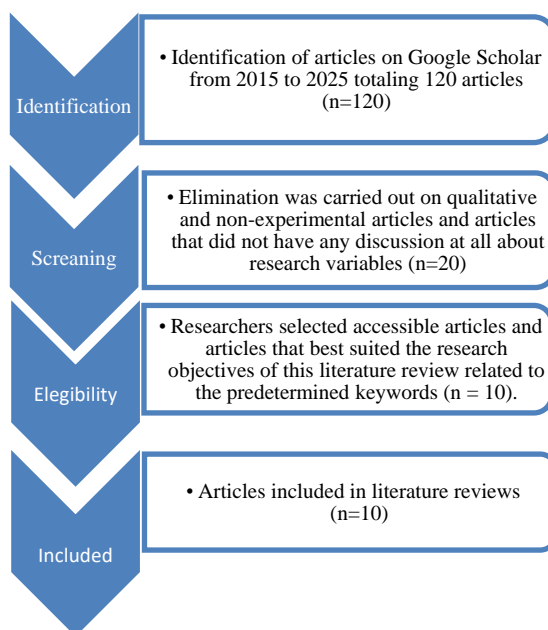


Figure 1. Steps of article selection based on the PRISMA model (Sulistiyawan, 2024)

RESULTS

Search results obtained a total of 10 articles that have met the inclusion criteria and the topic of study is Carbon Quantum Dots in the Development of Herbal-Based Endodontic Irrigation Materials.

No	Author	Title	Method	Results
1	de Carvalho et al. (2025)	Psidium guajava l. Hydroethanolic extract as endodontic irrigant: phytochemical analysis, antioxidant activity, antimicrobial action and biocompatibility	The hydroethanolic extract of <i>P. guajava</i> was produced using young guava leaves and extracted using absolute ethanol and ultra-pure water in a ratio of (30 g:100 mL). The solubility, total flavonoids, and total phenols were determined. The chemical composition was determined through high-performance liquid chromatography (HPLC), followed by the evaluation of free radical suppression activity by determining the IC50 value, which indicates the concentration	The solubility of the extract is 3.35%. Using the standard quercetin curve, the total flavonoid concentration is 0.130 ± 0.110 mg/mL. In addition, using the standard curve for phenolic acid, the total phenolic concentration is 1.770 ± 1.540 mg/mL. HPLC analysis revealed rutin, quercetin, and kaempferol as the main flavonoids in the

			<p>required to remove 50% of free radicals. Subsequently, the minimum inhibitory concentration (MIC) and minimum microbicidal concentration (MMC) of the extract were evaluated against strains using the Clinical and Laboratory Standards Institute (CLSI) guidelines (M27-S4 and M7-A9). Then, the antibiofilm activity was evaluated through the MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide) test. Finally, the cytotoxicity of the extract was evaluated through the Alamar Blue test, and genotoxicity through the micronucleus test on human keratinocyte culture (HaCaT cells). The data were analyzed using ANOVA and Tukey or Kruskal-Wallis and Dunn tests.</p>	<p><i>P. guajava</i> L. extract. The extract shows significant antioxidant activity, with an IC₅₀ value of 10.39 µg/mL. The MMC value ranges from 1.04–8.37 mg/mL. At a concentration of 8.37 mg/mL, the extract was effective in reducing the biofilm strain of standard and clinical <i>E. faecalis</i> and <i>C. albicans</i> after 10 minutes. Cytotoxicity analysis revealed that all tested concentrations showed relatively low toxicity to HaCaT cells. Genotoxicity assessment through micronucleus test showed minimal DNA damage at all tested concentrations. Overall, the hydroethanol extract of <i>P. guajava</i> L. at a concentration of 8.37 mg/mL is the most effective in reducing the biofilm strains of standard and clinical <i>E. faecalis</i> and <i>C. albicans</i>, while maintaining biocompatibility with HaCaT culture.</p>
2	Yanti, Batubara, Nurliza, and Hasim (2024)	The Antibacterial Effect of Lerak Fruit Decoction (<i>Sapindus rarak</i> DC) on the Growth of <i>Streptococcus mutans</i> as an Alternative Cavity Cleanser Material (In Vitro)	Laboratory experiment. It started with boiling 100 grams of lerak fruit with 100 ml of aquadest until it boils, then finding the KHM and KBM values of the material using the Dilution and Drop Miles Misra Method	The results of ANOVA and LSD tests showed that the lerak fruit decoction had an antibacterial effect with a KHM value of 12.5% and a KBM value of 25%
3	Wasiaturrahmah, Rayhan, Putri, Wardhana, and Apriasari (2023)	Effectiveness of Antibacterial Extract of Kecapi Leaves (<i>Sandoricum Merr</i>) Against the Growth of <i>Enterococcus faecalis</i>	A pure experimental research with only post-test and control group design. This research consists of 9 treatment groups, namely kecapi leaf extract (<i>Sandoricum koetjape Merr</i>) concentration of 10%, 20%, 30%, 40%, 50%, 60%, 70%, sodium	Based on the average value and data analysis, it was known that KHM was present at the concentration of kecapi leaf extract 10% and KBM at the concentration of 20%. Kecapi leaf extract (<i>Sandoricum koetjape</i>

			hypochlorite (NaOCl), and aquadest with 3 repetitions. KHM data was obtained from the measurement of delta Optical Density (OD) and KBM data was obtained based on the calculation of colony count	Merr) concentrations of 10%, 20%, 30%, 40%, 50%, 60%, and 70% had antibacterial effectiveness against the growth of <i>Enterococcus faecalis</i>
4	Kishan, Shah, Mamatha, Sreekumari, and Parikh (2025)	A randomized clinical comparative evaluation of interappointment flare-ups associated with the placement of <i>Azadirachta indica</i> , garlic, Triphala, and calcium hydroxide as intracanal medicaments in primary endodontic lesions	Dua ratus empat puluh patients indicated for root canal treatment were divided into two main groups, namely single-rooted teeth and double-rooted teeth. Each group was further divided into four subgroups, each consisting of 30 samples. After access was opened, instrumentation was performed according to the root canal configuration. Herbal medicine was prepared in the form of an aqueous extract. The placement of ICM in the subgroups was determined randomly through computerized randomization. Flare-up and pain between visits were assessed using VRS on days 1, 3, 7, and 14.	There was a statistically significant difference between the four groups, with $P = 0.02$ for double-rooted teeth and 0.03 for single-rooted teeth. The post hoc Tukey test showed a statistically significant comparison of flare-up incidence between the garlic and Triphala groups, supporting Triphala, with $P = 0.004$ for single-rooted teeth and 0.008 for double-rooted teeth.
5	Yanti, Nurliza, and Gani (2023)	Evaluating the Sapindusarak DC Chemical compounds for their ability to inhibit the growth of <i>Fusobacterium nucleatum</i> in vitro	Gas Chromatography-Mass Spectrometry (GC-MS) was used to identify compounds from Sapindusarak DC	After 48 hours, S. rarak DC at 12.5% and 6.25% concentrations showed better growth response to <i>F. nucleatum</i> compared to other concentrations. However, CHX was still higher, providing a growth response to <i>F. nucleatum</i> (98.42%)
6	Hassana, Zaazoua, Sadonya, and Mohamed (2024)	Investigating the effects of herbal nanoparticle endodontic irrigants on <i>Candida albicans</i> and <i>Enterococcus faecalis</i> : An in vitro study	Sixty single-rooted teeth were prepared mechanically. Thirty teeth were inoculated with <i>Enterococcus faecalis</i> , and 30 others with <i>Candida albicans</i> . These teeth were divided into three groups: Group 1 contained 20 teeth inoculated with <i>Enterococcus faecalis</i> , which were then divided into 10 teeth irrigated with	A significant reduction in postoperative CFU was shown for bacteria and fungi incubated in the nanoneem and nanocurcumin groups. However, NaOCl showed a much greater reduction in CFU compared to herbal nanoparticle

			<p>nanocurcumin and 10 teeth irrigated with nanoneem. Group 2 contained 20 teeth inoculated with <i>Candida albicans</i> and irrigated as in Group 1. Group 3 contained ten teeth inoculated with <i>Enterococcus faecalis</i> and ten teeth inoculated with <i>Candida albicans</i> irrigated with 2.5% NaOCl. Microbial extracts were collected from the teeth before and after irrigation and cultured. Preoperative and postoperative colony-forming units (CFU) were compared in each subgroup using the Mann-Whitney and Kruskal-Wallis tests to compare the differences between the groups.</p>	<p>irrigation. The use of nanoneem and nanocurcumin along with sodium hypochlorite as root canal irrigants is beneficial due to their antibacterial and antifungal effects.</p>
7	<p>Haripriya, Farzan, Baghkomeh, and Nuvvula (2024)</p>	<p>Comparative Evaluation of Antimicrobial and Smear Layer Removal Efficacy of <i>Mangifera indica</i> Kernel Extract as Root Canal Irrigant in Primary Molar: An In Vitro Study</p>	<p>Methanol extract <i>M. indica</i> was prepared using the standard method. The antimicrobial properties of the <i>M. indica</i> seed extract were determined using the agar diffusion method with 3% sodium hypochlorite and distilled water as controls, and the efficacy of smear layer removal was evaluated using SEM after processing the root samples with various concentrations of <i>M. indica</i> seed extract with 17% EDTA and distilled water as positive and negative controls.</p>	<p>The <i>M. indica</i> seed extract showed better antimicrobial efficacy, but its smear layer removal efficacy was less good if used as root canal irrigant.</p>
8	<p>Aly, Mostafa, and Mourad (2024)</p>	<p>Evaluation of Antimicrobial Efficacy of Propolis and Chamomile as Root Canal Irrigant on <i>Enterococcus Faecalis</i></p>	<p>45 anterior maxillary teeth that have been extracted were selected. Access to the quality and mechanical preparation of the root canal was carried out; the teeth were sterilized in an autoclave at 121°C for 20 minutes. These teeth were inoculated with <i>Enterococcus faecalis</i> with the strain reference ATCC 19433. Subsequently, they were divided into three groups, each irrigated with</p>	<p>Propolis and chamomile can be used as a natural alternative to chlorhexidine in root canal irrigation, although its concentration may need to be higher or applied for a longer period within the root canal</p>

			2% chlorhexidine, propolis, and German chamomile. The samples were cultured on ausklin empedu agar, then incubated at 37°C for 24 hours. Colony-forming unit counts were performed before and after irrigation.	
9	Mirza, Lestari, and Nugroho (2023)	The antibacterial activity of the essential oil extract of turmeric (<i>Curcuma xanthorrhiza</i> Roxb.) against the growth of <i>Streptococcus viridans</i>	Turmeric was extracted using the steam and air distillation method. The inhibition test was carried out using the diffusion disc method. The concentrations of the essential oil extract of <i>C. xanthorrhiza</i> Roxb used were 25%, 50%, 75%, and 100%	The average diameter of the inhibition zone at concentrations of 25%, 50%, 75%, and 100% were 0 mm, 8.22 mm, 12.16 mm, and 16.1 mm, respectively. The analysis of the data using Kruskal Wallis showed a significance value of 0.00 ($p < 0.05$).
10	Aslan, Mattulada, and Naja (2024)	Effectiveness of Aloe Vera Gel in Inhibiting <i>Streptococcus Viridans</i> in Root Canal Treatment	This study used a laboratory experimental method of Post Test Only Control Design. The true type of laboratory discovery experiment. This experiment was conducted with samples of gel containing aloe vera with concentrations of 25%, 50%, and 75% obtained from the under-gel. Decomposition of the caecilian's lid with aquades and 2.5% NaOCl, respectively. Positive control.	The average diameter of the inhibition zone at concentrations of 25%, 50%, 75%, and 100% were 0 mm, 8.22 mm, 12.16 mm, and 16.1 mm, respectively. The analysis of the data using Kruskal Wallis showed a significance value of 0.00 ($p < 0.05$).

DISCUSSION

Irrigation is a process carried out to facilitate mechanical preparation through smoothing by soaking the root canal using various types and concentrations of liquids, and ensuring the disinfection of the root canal by removing organic/inorganic debris, infected pulp tissue, microorganisms, and soft and hard tissue residues. A solution with optimal quality that can clean the root canal completely is not yet available, and although there have been new developments in the field of related research, a solution approaching ideal quality has not yet been developed (Mohammadi et al., 2021; Tekin & Demirkaya, 2020)

Root canal treatment aims to remove infection and prevent reinfection in the root canal system. Irrigation and medicamentous materials play a significant role in disinfecting the root canal system. With increasing concern about the side effects of chemical materials, natural materials are increasingly being studied and used due to their antimicrobial properties, biocompatibility, and minimal side effects (Ali et al., 2022)

It has been found that because of the complex structure of the root canal, mechanical instrumentation alone is not sufficient to remove microorganisms that settle in the pulp cavity and infected or non-infected pulp residues that can become nutrition for these bacteria (Abdelkafy et al., 2023). Therefore, it has been emphasized that the irrigation process carried out with an irrigation solution that allows disinfection of the root canal by removing microorganisms and tissue residues without damaging the surrounding tissue is very important (Esmail, Kamel, Nour El-dein, & El Sherif, 2020). Although various irrigation solutions used for this purpose can reduce the bacterial population significantly in infected root canals, in many clinical cases, some bacteria still remain and multiply, causing reinfection in the root canals and failure of root canal treatment. To improve the success rate of root canal treatment, research studies to find the ideal irrigation agent are still ongoing (Sarkees & Al-Maarrawi, 2020).

In recent years, there has been a significant increase in interest in the use of natural products. However, the conventional irrigation solutions currently used are defined as synthetic chemicals (Haapasalo, Udnæs, & Endal, 2003). Synthetic agents have some drawbacks, such as not having the specific properties of ideal irrigation materials, not producing adequate effects at high concentrations, having potential side effects, causing drug interactions if used concurrently, and not meeting safety requirements. In this context, this review aims to present the latest literature information about known and developing natural root canal irrigation agents, in addition to the known root canal irrigation agents (Chamseddine & Abiad, 2024)

Chlorhexidine gluconate (CHX) irrigation solution has been reported to show bactericidal effects by causing coagulation of intracellular components at high concentrations, while also showing bacteriostatic effects at low concentrations (Attavar, 2022). For bacteriostatic effects, a solution of 0.1 to 0.2% water is recommended in the oral cavity, while 2% is the concentration of irrigation solution commonly found in endodontic literature. Although CHX is widely used in root canal disinfection due to its high antimicrobial activity, its effectiveness in dissolving tissue is lower than that of NaOCl (Tekin & Demirkaya, 2020).

Herbal materials as root canal irrigation for dental root canals are considered superior due to their high biocompatibility, low toxicity, and additional properties such as antibacterial, anti-inflammatory, and antioxidant properties that help in periapical tissue healing. Some herbal extracts such as *Curcuma longa* (turmeric), *Azadirachta indica* (neem), lerak (*Sapindus rarak* DC), propolis, and green tea have been proven effective against *Enterococcus faecalis*, the main bacteria causing root canal infection, with minimal side effects compared to chemicals such as NaOCl, which are irritating and can damage tissue. In addition, herbal materials do not damage the dentin structure and are safe for the environment, making them a potential alternative in modern endodontic treatment (Das, Maity, Desai, Mazumdar, & Ghosh, 2024; Varshini, 2018)

Carbon Quantum Dots (CQDs) are carbon-based nanoparticles with very small sizes (usually <10 nanometers) that have fluorescence and high biocompatibility. CQDs belong to the family of Carbon Quantum Dots but are different because they do not contain heavy metals, making them safer for biomedical applications such as diagnostics, antimicrobial therapy, and drug delivery. CQDs usually consist of an amorphous or graphitic core and a surface covered with functional groups such as carboxyl (-COOH), hydroxyl (-OH), or amine (-NH₂) that allow them to dissolve in water and interact with biomolecules (Jiang et al., 2023)

CQDs have unique advantages in some of their clinical applications, such as their physical and chemical properties, their nano or small size, their large surface area to mass ratio, and increased reactivity (Gomes, Aveiro, & Kishen, 2023; Kishen &

Shrestha, 2022). Their customizable properties make them an attractive asset. Their size, usually varying less than 10 nm, will enhance the interaction of Carbon Quantum Dots with their surrounding environment and allow for the use of lower doses, thereby reducing the risk of unwanted side effects (Wagner, Knipe, Orive, & Peppas, 2019). CQDs can also act as an effective disinfectant, helping to eliminate residual microorganisms in root canals depending on the method of application. The long interaction duration of positive nanoparticles with negatively charged biofilms for 7 days will destroy the biofilm structure and result in significant bacterial death (Gomes et al., 2023; Kishen & Shrestha, 2022).

Carbon Quantum Dots can also be utilized to create new types of bonding resins with the potential for dental remineralization, as the zinc oxide Carbon Quantum Dots are biomimetic, meaning they can mimic the natural process of dental remineralization. CQDs with extremely small sizes can also be used to strengthen the bond between dental fillings and teeth (resin-dentin bonding). CQDs work by inhibiting collagenase activity, allowing them to penetrate deep into the collagen fibers of the tooth, which helps to enhance the bond between the filling material and the tooth. This can make dental fillings last longer (Subiksha et al., 2024).

Carbon Quantum Dots (CQDs) derived from natural materials represent a promising innovation in the field of dental medicine, particularly for root canal irrigation applications. Compared to chemically-based synthetic CQDs, those synthesized through green synthesis methods from herbal materials such as betel leaf, green tea, turmeric, and fruit peels show advantages in terms of biocompatibility, low toxicity, and environmental friendliness (Pete et al., 2023). The production process does not use harmful organic solvents, making it safe for humans and the environment (Ganesan & Nagaraaj, 2020). Moreover, many of these natural materials naturally contain antibacterial and anti-inflammatory compounds, so the CQDs produced inherit these bioactive properties, including the ability to inhibit pathogenic bacteria in the root canal, such as *Enterococcus faecalis* (Shenasa et al., 2025).

In the context of endodontics, natural CQDs are not only effective as antibacterial agents but can also function as drug carriers and agents in photodynamic therapy (PDT) (Lin, Wang, & Wu, 2022; Pechnikova et al., 2025; Xiang & Tan, 2022). For example, CQDs from betel leaf and propolis show high antimicrobial activity and do not cause a decrease in dentin microhardness, unlike hypochlorite solutions (NaOCl) which are irritating (Manikandan & Lee, 2022). The strong fluorescence of natural CQDs also allows for tracking biofilms and visualizing tissue during endodontic procedures (Humaera, Fahri, Armynah, & Tahir, 2021). Therefore, herbal-based CQDs are considered a future solution for safer, more effective, and sustainable irrigation materials in root canal treatment.

CONCLUSION AND RECOMMENDATION

Herbal-based Carbon Quantum Dots (CQDs) are considered a future solution in root canal irrigation due to their combination of high antimicrobial efficacy with biological safety and environmental sustainability. Compared to chemicals such as sodium hypochlorite (NaOCl), which are effective but toxic and can damage tissue, CQDs from natural materials like betel leaf, green tea, and propolis have been proven to cause no irritation, alter no dentin structure, and not contaminate the environment.

Herbal CQDs also have a unique ability: their extremely small size (nano) allows penetration into hard-to-reach areas of the root canal, such as lateral canals or isthmuses, while still maintaining their antibacterial effect. Additionally, their ability to produce light (fluorescence) opens up potential in diagnostics and photodynamic

therapy (PDT). All these advantages, combined with their environmentally friendly synthesis process and the use of easily obtainable natural resources, make herbal-based CQDs a modern irrigation option that is not only efficient but also in line with the principles of sustainable health.

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