International Journal of Research and Review
Volume 11; Issue: 7; July 2024
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Review Article

Quantum Dots in Dentistry - An Overview

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DOI: https://doi.org/10.52403/ijrr.20240759

ABSTRACT

Nanodentistry refers to cutting-edge research done to create novel devices, restorative materials, and medications with nanoscale dimensions, aiming to increase dentistry's functionality in a seamless manner. In this growing field of nanotechnology, a semiconductor nanocrystal has gained global attention. These artificial atoms are called 'Quantum Dots (QDs)', existing as a zero-dimensional nanocrystal containing bundles of infinite energy. Their fluorescence features, increased brightness than that of most organic dyes or proteins, have paved the way for their application into TV and monitors display, solar cells, photo detectors, waste water management, optical sensors. Their capacity to emit continuous and controllable narrow-emission spectra and precisely target particular biological structures is the reason behind their use in medical applications such as quorum sensing, lab on a chip technology, diagnosis like bio imaging, targeted medication delivery, lasers, cancer treatment, etc. This review highlights the types, structures, and the applications of these nano dots in dentistry.

Keywords: quantum dots, nanoparticles, nanodentistry, nanotechnology, nanodots

INTRODUCTION

In the growing field of nanotechnology, a semiconductor nanocrystal has gained global attention. These artificial atoms are called 'Quantum Dots (QDs)'S (2-10nm). In quantum mechanics, if an electron is closely confined with less movement in an infinitely thin layer, then the energy will also be infinite. The constructs generally present in mathematics are planes, lines and dots. In a quantum well, electron is confined in only one dimension and free movement is seen in the other two dimensions. A quantum wire is a 2D structure allowing propagation of electron in only one dimension. Considering electrons confinement in all three dimensions, a quantum dot exists as a zero-dimensional nanocrystal containing bundles of infinite energy. (1)

They are called artificial atoms because of their independent energy levels and meticulous modifiable band width according to their size. (2) If fitted within the width of the human thumb, every 10nm can consists approximately 300 million quantum dots. Being 10,000,000 times smaller than a tennis ball, quantum dots possess immense ability to convert light to any color in the visible spectrum easily with high efficiency.

QDs ≥5 nm are called larger QDs because of red or orange emission colour at the longer wavelength. Since they emit blue or green light at a shorter wavelength, QDs ≤3 nm are referred to as smaller QDs. Quantum dots of the same material, but with different sizes, can emit light of different colors due to an important property called size tunable emission. Thus, fluorescence is determined by the size of the quantum dot. [3] These manmade dots also possess unique properties making it desirable, like narrow emission spectra and photostability. QDs have symmetric and narrow bandwidth of ~30 nm full width at half maximal fluorescence, which enables emission of pure color. By contrast, the bandwidths of organic dyes like fluorescein vary between 50–100 nm. This behaviour enables multiplexed imaging with a single excitation source and thus prevents overheating of cells or tissue during multi-color imaging. [4]
QDs holds photostability by having longer emission lifetime than organic dyes. [5]
In 1980, A.I.Ekinmov et al initiated basic research on quantum confinement and suggested that the heating caused nano crystallites of the semiconductor to precipitate in the glass and that quantum confinement of electrons in these crystallites caused the unusual optical behaviour. [6]

STRUCTURE AND CLASSIFICATION:

Based on their electron confinement, three structural configurations are present namely, planar structure, vertical QDs and pyramidal or lens shaped. Among these, pyramidal QDs have been optimistic for laser applications.
According to the elements in the periodic table
According to the type (3 groups- core, core shell, alloy type)

TYPES OF QDs:

CORE QDs:

Single component QD uniformly made of the same material like selenides or sulfides. Their optical properties can be tuned by altering their size. [3]

CORE SHELL QDs (CSQDs):

This type of QDs consists of one material in the core with another material with different bandgap covering the core. The most common CSQDs is CdSe in the core and ZnS in the shell. The advantage is the high quantum yield provided by them, thus improving the brightness of semiconductors efficiently. [3]

ALLOYED QDs:

They are formed by two different nanocrystal semiconductors having their own bandgap energies exhibiting inherent properties from their parent semiconductor, also having homogeneous and gradient internal structures providing continuous tunable emission without having to change the size of the QD. [7] Example is cadmium selenium telluride.

SYNTHESIS:

Methods of QDs synthesis plays a major role in controlling their sizes. Colloidal synthesis is the most accessible technique for creating QDs, which chemically produces QDs suspended in solution. The easiest semiconductor to synthesize by colloidal process is Cadmium (e.g., CdS, CdSe, and CdTe) but it is a harmful heavy metal to the health and environment. Therefore, cadmium is in the legally restricted material list of the European Union. This method can be used in the lab to generate small amounts of QDs because they don't require any novel reagents, but producing large quantities of QDs is

challenging because their temperature needs to be precisely controlled. [8]
Two main categories of synthesis are present namely [3,9]

TOP-DOWN APPROACH:

- Wet chemical etching
- Reactive ion etching
- Focused ion beam
- Molecular beam epitaxy (MBE)
- Ion implantation
- E-beam lithography
- X-ray lithography

BOTTOM-UP APPROACHES:

A. WET CHEMICAL METHODS

- Microwaves
- Hot solution decomposition
- Hydrothermal
- Sol Gel
- Microemulsion

B. VAPOUR PHASE METHODS

- Physical vapour deposition
- Epitaxial growth
- Chemical vapour deposition

APPLICATIONS:

General applications include – tv and monitors display, solar cells, photo detectors, waste water management, computation, optical sensors and medical applications like Quorum Sensing, lab on chip technology, diagnosis like bio imaging, targeted drug delivery, lasers, Cancer treatment etc. More specific biomedical applications include studying transport mechanisms in cells, functional heterogeneity of cells, diffusion movements of membrane transport proteins, nonspecific labelling for imaging and detection, the contrast of blood and lymph vessels (including micro vessels), intracellular delivery, internalization of QDs by live cells, probes in other bioassays. [10,11]

Diagnosis of cancer:

Quantum dots are endowed with ability of glowing brightly when illuminated by ultraviolet light. This property is used by attaching the dots to specific molecules that will bind to the cancer cells. This greatly enhances the detection of oral cancers. [12,13]
Quantum dots are employed in both invitro and in vivo imaging.

Targeted drug delivery:

Properties like long blood dissemination, huge medication loading capacity, controlled discharge profile of drugs, and the inclusion of numerous focusing ligands on their surface are the benefits of quantum dot-based medicine delivery which is rising in popularity lately. Increased penetrability of medications, indifference to drug resistance, precise selectivity and enhanced solubility have made dots-based drug delivery a progressing option compared to conventional treatment methods. [11]

Lab on a chip:

Lab on a chip is a small microfluidic device ranging in size from few millimetres to few square centimetres where multiple biochemical operations and laboratory functions are integrated into this single circuit. Highly thorough screening output and diagnosis is obtained through complete automation when a single drop of patient’s blood is placed on this chip. [14] Quantum dots are integrated in the manufacturing process of these circuits, like Annexin V conjugated quantum dots for obtaining drug induced cell apoptosis quantitative assessment. [15]

Wound healing:

Quantum dots alone or in combination with polymers like carbon quantum dots with hybrid tannic acid and keratin (CQDs-TA/KA) hydrogel etc are widely researched as bio scaffold. [16] Their ability to enhance inflammation, antibacterial properties, mechanical strengthening of tissue scaffolds and enhancing angiogenesis in the wound area by improving expression of angiogenic proteins have made them the sought after research material for wound healing management. Literature also reveals invitro, in vivo and also in ova studies proving the efficiency of quantum dots in wound healing and regenerative field. [17]

APPLICATIONS IN RESTORATIVE DENTISTRY:

Fillers in resin composite:

The photopolymerizable resin composite may be able to "cure from within" if quantum dots are added. This is achieved by allowing the entire mass to release light internally. Fluorescence intensity of dental resin composites is dependent on Quantum dots (QDs) concentration and can be tailored by using a CdSe/ZnS core-shell quantum dots of appropriate core sizes. It can be considered as an alternative to incorporation of fillers in adhesive resins. [11] Recently, adhesive resin with nonagglomerated nanoparticles with potential of biomimetic remineralization has been considered as a breakthrough, Zinc oxide quantum dots were incorporated into Trimethylene glycol dimethacrylate (TEG-DMA) and glycerol dimethacrylate (G-DMA). [18]

Light cure units:

Quantum dots naturally produce monochromatic light, so they are incorporated into existing light emitting diodes for better efficiency. This limits the use of color filters in LED's. New LED designs are "Quantum Dot Light Emitting Diode" (QD-LED or QLED) and "Quantum Dot White Light Emitting Diode" (QD-WLED). QD-LEDs can be fabricated on a silicon substrate, which allows them to be integrated onto standard silicon-based integrated circuits. [19]

Luminophores:

Employing multiple core sizes of QDs in resin composite allows for fabrication of restorative materials with fluorescence properties that closely match natural teeth.

Dentin biomodification:

QDs possess strong inhibitory action on collagenase activity, and also due to their small dimension they are capable of completely penetrating into collagen fibres enhancing resin-dentin bonding interface durability thereby increasing the bond strength. Hence can used as a pre-treatment for biomodification of dentin.

LIMITATIONS OF QUANTUM DOTS:

Assessment of toxicity of QDs has been posed a big challenge. Many studies indicate that the cytotoxicity of CdTe QDs not only comes from the Cd2+ ions released but also from QDs intracellular distribution in cells and related nanoscale properties [18]. In a recent study case, the genotoxic response to CdTe QDs in human breast carcinoma cells was observed. [20] This toxicity of QDs can cause mutation in DNA, which will be passed onto generations also. Moreover, few other studies have revealed that QDs have poor solubility and stability.

FUTURE PROSPECTS:

Quantum dots play a significant role in drug delivery. In Endodontics, it can be used as a drug delivery system for intracanal medicaments and sealers. Also, when X ray radiation is given QDs rapidly fluoresce, this ability of QDs can be used to trace the root canals. Recently, a Chitosan Enhanced Radio-opaque Solution (CERS) has been researched and patented as an irrigating solution also used to trace the canal anatomy. [21] With further research, a QDs colloidal solution can be introduced for the same purpose. Further, immense research is required to produce non-toxic QDs.

CONCLUSION

Quantum dots being artificially made semiconductors give scientists more flexibility and control during synthesis and use of QDs for practical applications. This is an excellent and innovative area of research since Quantum dots has got immense potential to bring about optimistic changes in our day-to-day life. These designer atoms or mystical dots can be connected with perfection for all possible applications.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Subiksha K, Amit Jena, Saumyakanta Mohanty. Quantum dots in dentistry - an overview. *International Journal of Research and Review*. 2024; 11(7): 570-575. DOI: *https://doi.org/10.52403/ijrr.20240759*

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