Review Paper

An Overview on Quantum Dot-based Nanocomposites for Electrochemical Sensing on Pharmaceutical Assay

Leyla Karadurmus, Goksu Ozcelik, Sena Vural and Sibel A. Ozkan

Department of Analytical Chemistry, Faculty of Pharmacy, Ankara University, Ankara, Turkey. *Department of Analytical Chemistry, Faculty of Pharmacy, Adıyaman University, Adıyaman, Turkey.

Abstract

Quantum dots (QDs) are one of the first nanotechnological materials to be integrated with sensor technologies and have been widely anticipated to eventually find application chances in several commercial pharmaceutical and clinical products. They are one of the most important developments in the rapidly growing world of material science technology. The excellent properties of QDs may allow the design of simple, precise, and inexpensive electrochemical methods for the detection of pharmaceuticals. Electrochemical techniques offer accuracy, high sensitivity, low cost, simplicity, ease of preparation of the samples in a very short time, and speed of analysis. The most commonly used voltammetric techniques are differential pulse voltammetry, cyclic voltammetry, square wave voltammetry, and stripping voltammetry. The purpose of this review is to show and communicate the advantages and uses of QD applications used in drug analysis. Besides, the present application methods of QDs to the pharmaceutical analysis and their related parameters were summarized between 2012 and 2021 years and summarized as a table.

Keywords: Quantum dots; Electroanalytical methods; Voltammetry; Drug analysis.

Introduction

Nanotechnology is a very popular topic for the scientific world today. In recent years, QDs have received great attention in the detection of pharmaceuticals in different sample matrices, \textit{in-vitro} bio-imaging, and \textit{in-vivo} applications. QDs are widely applied to detect many analytes such as ions, pharmaceuticals, small molecules, and biological macromolecules (1, 2).

In the voltammetric technique, a quantity concerning an analyte is obtained by measuring the current produced by the change of potential. The particular chemical is related to the peak current and the concentration of the corresponding species is related to the density of the peak current. The voltammogram, which is a plot of potential versus current, shows the behavior of the chemical reaction. The main advantages of voltammetry are the ability to simultaneously detect multiple analytes with different peak potentials and the low noise of the measurements leading to very high sensitivity. Voltammetric methods include cyclic voltammetry, differential pulse voltammetry, square wave voltammetry, linear sweep voltammetry, and stripping voltammetry. Cyclic voltammetry is one of the most used methods to measure electrochemical reaction rates and redox potential (3–6).

This review presents the applications of various electrochemical modes on QDs modified electrodes, modification style, and their related parameters in the analysis of drugs and pharmaceutically active
compounds from their dosage forms and biological media. Examples of different types of applications have been reported and as with all other aforementioned techniques. Moreover, it should be kept in mind that the electrochemical techniques have not only advantages but also limitations. Also, in this review, detailed information about quantum point nanomaterials and new applications on pharmaceutical analysis using quantum point-based nanosensors, advantages and disadvantages of quantum point nanosensors, and future perspectives will be given.

Quantum dots

The detection of pharmaceuticals is an important aspect of therapy safety. A range of detection techniques and novel materials have been developed to achieve rapid, sensitive, and precise monitoring of certain analytes. Nanomaterials with unique electronic, optical, mechanical, and thermal properties have been accepted as one of the most up-and-coming materials for opening new gates in the development of new analytical methods for the analysis of drugs. Nanomaterials indicate novel properties that present great opportunities for the improvement of new analytical methods for the analysis of drugs. In recent years, researchers have shown a great interest in the production of nanoparticles such as quantum dots, nanowires, nanotubes, nanorods, or nanofilms. Statistics of the annual number of publications on quantum dot-based nanocomposites for electrochemical detection in the last eight years are given in Figure 1. The excellent electrical and optical features of nanomaterials, such as quantum dots, carbon nanotubes, gold nanoparticles, nanorods, graphenes, and nanopores, are closely related to their sizes (7–11). Quantum dots (QDs) are nanoscale semiconductor materials, such as cadmium selenide (CdSe). Today, the most frequently generated quantum dots due to their optical and electrical properties are CdSe, InAs, CdS, GaN, InGeAS, CdTe, PbS, PbSe, ZnS. In quantum dots, size is a controllable parameter, which, when combined with the effect of quantum restriction, creates quantum dots with extraordinary optical and electrical properties. Quantum dots (QDs), usually semiconductor nanocrystals of 2-6 nm, are one of several nanomaterials that significantly impact research in many areas, such as chemistry and biology (12–15).

Researchers have employed QDs as labeling materials for biosensors. An extensive review of the improvement of assays and nanosensors using QDs as components is presented. QDs are of great interest in the development of optical probes for cellular, tissue, or whole-body imaging and biological detection (16). As a unique nanomaterial, QD-based sensors offer high sensitivity and selectivity in detecting certain analytes in the chemical and biochemical sciences. Integrated with QDs, electrochemical sensors have

Figure 1. Statistics of the number of publications per year related to quantum dot-based nanocomposites for electrochemical sensing.
led to the improvement of highly selective and efficient analytical techniques. QDs can significantly increase the density of the electrochemical signal in the electrochemical detection system and supply sharp and well-resolved voltammetry signals. In sensor technology, QD-based sensors are very suitable for creating highly selective, rapid, and precise tools for the detection of specific analytes (6, 17–22).

**Electroanalytical Methods in Drug Analysis**

Stability testing, quality control, and analysis of the development of a new pharmaceutical product have led to the continuous development of analytical methods (23, 24). There are many suitable methods for determining the content of the drug substance or active ingredients in pharmaceutical formulations and biological samples (25). Various methods such as chromatography, ultraviolet spectrometry, nuclear magnetic relaxation spectroscopy, capillary electrophoresis, and high-performance liquid chromatography have been used. However, these methods require expensive instruments, complex procedures, and specific sample pre-treatments (26).

Electroanalytical methods can be divided into various sub-divisions based on applying either potential or current and/or measuring potential, current, impedance, etc. In electroanalytical techniques, voltammetry is the leading method. Voltammetric techniques are also divided into subgroups such as cyclic voltammetry (CV), differential pulse voltammetry (DPV), and stripping methods. Amperometry is the other electroanalytical technique in which mostly used for the current measurements after the application of a constant potential. Electrochemical impedance spectroscopy (EIS) is one of the most comprehensive methods for the characterization of electrochemical systems with measuring resistive and capacitive properties. Electrochemical methods have attracted great attention due to their advantages in the field of drug analysis. These advantages include a wide range of linear concentrations, inexpensive, fast analysis times, simultaneous determination of several analytes, and the ability to measure small currents. It allows measurements to be performed with very small sample volumes in the microliter range (2, 27 and 28). For these reasons, electrochemistry is an appropriate method of analysis for the analysis of drugs. Besides, electrochemical methods can be used for in-vivo analysis of drugs. Voltammetry is the most widely used electroanalytical method. Voltammetry has a growing field of application due to its advantages in drug analysis. The voltammetric methods take advantage of explaining the oxidation and reduction effects of drug substances and pharmacological action mechanisms (5, 29). Commonly used voltammetric techniques are differential pulse, cyclic, square wave, and stripping voltammetry. Cyclic voltammetry (CV) is used to provide significant information about the oxidation/reduction mechanism of the drug active compounds, and techniques such as different pulses, square wave, and stripping voltammetry are used to determine the small volume of the drug (30). The performance of voltammetric methods depends to a large extent on the material of the working electrode. The voltammetric method uses a wide variety of solid electrodes, such as various carbon electrodes, noble metal electrodes, and modified electrodes (31). To increase selectivity on the electrode surface, it is necessary to change the surface quality, briefly change the electrode surface. Furthermore, it is possible to create a surface with an elongated and stable chemical structure giving reproducible results, and as the sensitivity and selectivity increase, the working potential range expands.

To summarize the numerous recent applications of voltammetric methods for the analysis of drugs, we listed the information on the electrode, supporting electrolyte, voltammetric mode, and detection limit in Table 1.

**Recent applications on pharmaceutical analyses using quantum dots based nanosensors**

A sensor is a device that can transform the physical, biological, or chemical property of a system into an analytically measurable, processable, and useful signal by a transducer.
| Active Compound | Method | Transducer | Linear Range | LOD/LOQ | Application | Reference |
|-----------------|--------|------------|--------------|---------|-------------|-----------|
| Catecholamine   | CV     | GQD/Lac/GCE| 1–120 μM     | 83 nM/126 nM | Pharmaceutical samples | (38) |
| Curcumin        | DPV    | GQD/GCE    | 0.4–200 μM   | 0.1 μM  | Turmeric powder | (39) |
| Metanil yellow  | DPV    | MIP/Au NP@NCDS @Ag NP/GCE | 0.06–50 μM | 0.03 μM | Turmeric powder | (39) |
| Metobromuron    | DPV    | MIP/Au NP@NCDS @Ag NP/GCE | 1 pM–2 nM | 0.2 μM | Wastewater samples | (40) |
| Oxalic acid     | Amperometric | NH2-GQD/GO/GCE | 0.5–2 mM 2-55mM | 50 μM | Urine samples | (41) |
| Metronidazole   | DPV    | CoCo2O4/N-CNTs/MIP/GCE | 0.005–0.1 μM | 0.48 μM | Human urine sample | (42) |
| Caffeic acid    | DPV    | N-CQD/HP-Ca2O/MWCNT/GCE | 0.05–4 μM | 0.004 μM | Red wine samples | (43) |
| Quercetin       | DPV    | NH2-GQD/Au-β-CD/GCE | 1–210 μM | 2.85 μM | Honey Tea | Honeysuckle Human serum | (44) |
| Sodashevar      | DPV    | MIP/AuNP/NS@GQD/PGE | 1–400 μM | 0.36 μM | Human serum sample | Pharmaceutical samples | (45) |
| Vitamin B2      | DPV    | PGBHA-NH2-GQD/MnO2 NCs/GCE | 0.1 to 100 μM | 0.04 μM | Real sample | (46) |
| Dopamine        | DPV    | PGBHA-NH2-GQD/MnO2 NCs/GCE | 0.1 to 100 μM | 0.04 μM | Real sample | (46) |
| Flutamide       | DPV    | N-CQD@Co3O4/MWCNT/GCE | 0.05–590 μM | 0.0169 μM | Human urine sample | (47) |
| Nitrofurantoin  | DPV    | N-CQD@Co3O4/MWCNT/GCE | 0.05–1220 μM | 0.044 μM | Human urine sample | (48) |
| Oxalplatin      | DPV    | CQDs@BHNN9866-NH2/MIP/GCE | 1–250 μM | 0.37 μM | Human urine sample | 5 mM phosphate buffer | (49) |
| Daunorubicin    | DPV    | CQD/PGE | 0.1–0.5 μM | 37 μM | Human urine sample | 5 mM phosphate buffer | (49) |
| Dosemazine      | DPV    | MIP/Au-N-GQDs/NS2/BGCE | 0.05–40.0 μM | 0.0028 | Human urine sample | (50) |
| Chlorpromazine  | DPV    | MIP/Au-N-GQDs/NS2/BGCE | 0.05–2.0 μM | 0.00025 | Human urine sample | (50) |
| Dobutamine      | DPV    | N-GQDs@NMeO3/CPE | 0.08–40.0 μM | 0.02 μM | Human urine sample | (51) |
| p-Aminophenol   | CV     | GQD/CPE | 100–1400μM 100–1400μM | 2 μM/10 μM | Human urine sample | (33) |
| Acetaminophen   | CV     | GQD/CPE | 100–1400μM 100–1400μM | 2 μM/10 μM | Human urine sample | (33) |
| Cocaine         | DPV    | AgNP-AptCdTeQDs/GCE | 0.05–6000 μM | 0.005 nM | Human urine sample | (52) |
| Doxorubicin hydrochloride | DPV | GQD/GCE | 0.018–3.60 μM | 0.016 μM | Human serum sample | (53) |
| Hydroxyfluridated poly-chlorobiphenyls | SWV | Tyr-ZnO QDs/GO/GCE | 2.8–27.65 μM | 0.15 μM | Phosphate buffer solution | (54) |
| Methyl dopa     | DPV    | TGA-CaO@Ag2S@QDs/GCE | 0.09–60 μM | 0.04 μM | Human urine sample | (36) |
| Ofloxazepine    | CV     | BMPBHP/CaS-QDs/MWCNTs/Au electrode | 0.02–100 μM | 0.006 μM | Human serum sample | Pharmaceutical samples | (55) |
| Active Compound | Method | Transducer | Linear Range | LOD/LOQ | Application | Reference |
|----------------|--------|------------|--------------|---------|-------------|-----------|
| Clopidogrel     | AdSDPV | fMWCNT/CdSe QDs/GCE | 2–40 μM | 0.076 μM | phosphate buffer solution (pH 2.14) | (56) |
| Lamivudine      | DPV/   | Ni-CoO/ GQDs/GCE | - | 56.18 μg/mL / 56.13 μg/mL | Human serum sample | (57) |
| Tenoxicam       | EIS    | Ni-CoO/ GQDs/GCE | 0.1–1000 μM | 0.05 μM | Pharmaceutical samples | (58) |
| Tyrosine        | DPV    | GQD/SPE    | 1–9.0 μM | 0.5 μM | Human urine sample | (59) |
| Acetaminophen   | DPV    | GQD/GCE    | 5–80 μM | 0.05 μM | Pharmaceutical samples | (60) |
| L-DOPA          | DPV    | Fe3O4@GODs/FMWCNTxGCE | 3–400 μM | 14.3 nM | Pickled vegetable | (61) |
| Donoxubicin     | DPV    | GQD-GCE    | 0.018–3.6 μM | 0.016 μM | Human serum sample | (62) |
| Cholesterol     | DPV    | β-CD@N-GQD/GCE | 0.5–100 μM | 0.08 μM | Human serum sample | (63) |
| Vitamin C       | CV     | Fe3O4@GQDs/GCE | 0.1–9 μM | - | 0.1 M pH 7.4 PBS | (64) |
| Nitrite         | SWV    | MWCNT-Chit/CdTe QD-CTAB/GCE | 1–100 μM | 0.30 μM | Pickled vegetable | (65) |
| Levofloxacin    | DPV    | GQD/GCE    | 0.05 to 100 μM | 10 nM | Milk samples | (66) |
| Lidocaine       | DPV    | Cd1–xMgxTe/QD-GO/CPE | 5.08–14.4 μM | 1.1 μM | Human urine sample | (67) |
| Epinephrine     | DPV    | Cd1–xMgxTe/QD-GO/CPE | 2.55–14.4 μM | 95 nM | Human urine sample | (68) |
| Folic acid      | CV     | nSe@ZnS/ electrode | 12–96 nM | 0 nM | Pharmaceutical samples | (69) |
| Acetaminophen   | DPV    | CQD/MWCNT/AgNPs/GCE | 0.001–10 μM | 0.38 nM | Pharmaceutical samples | (70) |
| Chloropamine    | DPV/CV | NO/GQDs/GCE | 3.0–1000 nM | 0.55 nM | Human serum sample | (71) |
| Nevirapine      | DPV    | pA@gO/ MoS2 QDs GCE | 0.1–80 μM | 0.05 μM | Human serum sample | (72) |
| Donohumycin      | DPV    | GQDs/Poly (TAβ-CD)/As electrode | 0.086 μM to 3.45 μM | 0.012 μM | Human serum sample | (73) |
| Rilpivirine     | DPV    | GQD/MWCNT/AgNPx/GCE | 1–7 nM | 0.05 nM | Human urine sample | (74) |
| Irinotecan      | DPV    | NiC3O4/ GQDs/GCE | 0.1–25 μM | 0.011 μM | Human urine sample | (75) |
| 5-Fluorouracil  | DPV/CV | GQDs/PANI/ZnO/GCE | 0.1–50 μM | 0.023 μM | Human Serum samples | (76) |
| Donepezil HCl   | CV     | SBT/ N-CNDS/CoPcs/PGE | 1.5 nM–400 μM | 0.5 nM | Human Urine Sample | (77) |
| Zolpidem        | DPV    | GQDs/DMCCE | 0.1–1 μM | 0.061 μM | Pharmaceutical samples | (78) |
| Active Compound         | Method     | Transducer                          | Linear Range       | LOD/LOQ       | Application                | Reference |
|-------------------------|------------|-------------------------------------|--------------------|---------------|----------------------------|-----------|
| Norfloxacin             | SWAdASV    | CdTe QD, Cd/Cr, Chitosine/EPH/GCE   | 0.2-7.4 μM         | 6.6 nM        | Pharmaceutical samples     | (76)      |
| Sotalol                 | DPV        | MIP/AuNPs/GQDs/SPCE                 | 0.1-250 μM         | 0.035 μM      | Pharmaceutical samples     | (77)      |
| Chloroquine             | CV         | GQDs/WS2/GCE                        | 0.5 - 82 μM        | 0.04 μM       | Pharmaceutical samples     | (78)      |
| Uric acid               | DPV        | CdSe QDs/1H/PGE                     | 0.25-7.29 μM       | 0.083 μM      | Pharmaceutical samples     | (79)      |
| Creatinine              | DPV, CV    | CdSe QDs/1H/PGE                     | 0.442-8.840 mM     | 0.229 μM      | Pharmaceutical samples     | (80)      |
| 6-Mercaptopurine        | DPV        | MIP/sol-gel/ZnO@GQDs/PGE            | 0.01-50.0 μM       | 5.72 μM       | Human serum sample         | (81)      |
| Kaempferol              | SWV        | PVP/GS QDs/CPE                      | 0.06-2 μM          | 0.06 μM       | Pharmaceutical samples     | (82)      |
| Metronidazole           | DPV        | GQDs-MIPs@GNPs/GCE                  | 0.005-0.75 μM      | 0.52 μM       | Human serum sample         | (83)      |
| Vitamin C               | SWV        | GQDs/β-CD/GCE                       | 0.01-170 μM        | 0.49 μM       | Human serum sample         | (84)      |
| Dopamine                | SWV        | QDMCPE                              | 7.5 μM – 0.6 μM    | 21 nM         | Pharmaceutical samples     | (85)      |
| Uric Acid               | SWV        | QDMCPE                              | 7.5 μM – 1.4 μM    | 21 nM         | Human urine sample         | (86)      |
| Dextromethorphan        | DPV        | PDDA/MWCNT/CQD/PGE                  | 2.600 μM           | 0.19 μM       | Human serum sample         | (87)      |
| Malachite green         | DPV        | GQDs/AuNPs/GCE                      | 0.4 - 10 μM        | 0.1 μM        | Fish samples               | (88)      |
| L-tyrosine              | DPV        | β-CD/GQDs/GCE                       | 0.1 - 1.5 μM       | 100 nM        | -                          | (89)      |
| Acetaminophen           | DPV        | Fe3O4@SiO2-PDDA/CNT/GCE             | 10-10 μM           | 39 nM         | -                          | (80)      |
| Isoproterenol           | DPV        | GQDs/SPE                            | 1.0 - 900.0 μM     | 0.6 μM        | Human urine sample         | (81)      |
| Methyldopa              | SWV        | GQDs-IL/PCE                         | 0.04-750 μM        | 0.01 μM       | Pharmaceutical samples     | (82)      |
| Theophylline            | DPV        | GQDs/SPE                            | 1.0 - 700.0 μM     | 0.2 μM        | Theophylline oral solution | (83)      |
| Topotecan               | DPV        | ds-DNA/GQD/ILCPE                    | 0.35-100.0 μM      | 0.1 μM        | Human serum sample         | (84)      |
| Imidacloprid            | DPV        | GQDs/ILMCNT/PANI/GCE                | 0.03-12.0 μM       | 9 nM          | Vegetable samples          | (85)      |
| Dopamine                | DPV        | Au-GQDs@Nafion/GCE                  | 2 - 50 μM          | 0.84 μM       | Human urine sample         | (86)      |
| Tyrosinamide            | EB         | N-acetylcycteine-capped Ag-In-SQDs/GCE | 0.01 to 2.81 nM and 2.81-10.81 | 3.34 μM | Human serum sample | (87) |
| Bisphenol S             | DPV        | CQD/AgNP/MIP/GCE                    | 10 nM-0.05 nM      | 11.2 nM       | Plastic products           | (88)      |
| Active Compound     | Method   | Transducer                        | Linear Range      | LOD/LOQ     | Application                  | Reference |
|---------------------|----------|-----------------------------------|-------------------|-------------|------------------------------|-----------|
| Pimozide            | DPV      | NH2-MWCNT/ decorated with and ZnONPs/ GQD/GCE | 0.062-5.20 mM     | 0.0102 nM   | Pharmaceutical samples       | (97)      |
| Uric acid           | DC-AMP   | QD/ Fe3O4/GCE                      | 0.0-1.45 μM       | 6 nM        | Human urine sample            | (98)      |
| Diethylstilbestrol  | LSV      | QD/SPCE                           | 0.05-7.5 μM       | 8.8 nM      | Human urine sample            | (99)      |
| Pancreatinol        | DPV      | PS-PNIPAm-P5/ COOH/MWCNT-GQDs / GCE | 0.1-7.0 μM 7.0-103.0 μM | 66 nM      | Human urine sample            | (100)     |
| Hydroquinone        | DPV      | CuO-His-GQD/GCE                    | 0.001-40 μM       | 0.31 nM     | Natural water samples         | (101)     |
| Dopamine            | LSV      | QD/GCE                            | 0.21 - 13.39 μM   | 1.3 μM      |                              |           |
| Amoxicillin         | SWV      | QDs-P6LC-PEDOT-PSS/GCE             | 0.90-69.0 μM      | 0.05 μM     | Milk sample                  | (34)      |
| Bioprotein 1S       | DPV      | hNiS/GQDs/MIPs/GCE                 | 0.1-50 μM         | 0.03 μM     | Plastic samples               | (102)     |
| Epinephrine         | SWV      | GQD-CS/CPE                        | 0.36-380.0 μM     | 0.0003 μM   | Human serum sample            | (103)     |
| Arginine            | DPV      | /MWCNT/Cds/CF/HP-PGE              | 0.287-33670 μM    | 0.081 μM    | Real samples                 | (104)     |
| Methionine          | DPV      | N-CQD/Sn02/SPE                     | 0.05-306 μM       | 8 nM        | B complex tablet              | (105)     |
| Uric acid           | DPV      | GQDs-thio/BPQDs/GCE                | 0.2-110 μM        | 0.09 μM     | Human serum sample            | (106)     |
| Riboflavin          | DPV      | PPy-BPQDs-MIPs/PEDOTNRs/GCE        | 0.01-4 mM         | 0.0033 mM   | Nicotin acid                 | (107)     |
| Cisplatin           | DPASV    | GQDs-thio/BPQDs/GCE                | 0.05-306 μM       | 8 nM        | Caffeic acid                 |           |
| Calycosin           | DPV      | PAG/DGCE                           | 11 μM-0.32 mM     | 9.8 μM      | Astagali Radix               | (108)     |
| Dexamethasone       | DPV      | GQDs/GCE                           | 0.4-100 μM        | 0.05 μM     | Real Sample                  | (109)     |
| Hydroquinone        | DPV      | GQDs/GCE                           | 0.5-100 μM        | 0.08 μM     |                                 |           |
| Citric acid         | DPV      | GNP/GCE                            | 0.1-50 μM and 50-500 μM | 15 nM      |                                 |           |
| Ciprofloxacin       | DPV      | LDH/GeTe QD/CPE                    | 25 nM-12 μM       | 42 nM       |                                 | (112)     |
| Active Compound       | Method  | Transducer                      | Linear Range       | LOD/LOQ  | Application             | Reference |
|----------------------|---------|--------------------------------|--------------------|----------|-------------------------|-----------|
| Norepinephrine       | SWAdASV | GQD/AuNP/GCE                    | 0.5–7.5 μM         | 0.15 μM  | Pharmaceutical samples  | (113)     |
|                      |         |                                |                    |          | Rat brain tissue        |           |
| Dopamine             | DPV     | SnO2-N-GQD/PANI/GCE             | 0.5–200 μM         | 0.22 μM  | L-ascorbic acid         | (114)     |
| Hydrazine            | CV      | GSe@NiHCF NPv electrode         | 1.6–1000 μM        | 0.5 μM   | Tap water               | (115)     |
|                      |         |                                |                    |          | Seawater                |           |
| Ascorbic acid        | DPASV   | GO/CdTe QDs/GCE                 | 32.3–500.0 μM      | 6.1 μM   | Fruit juice             | (116)     |
| Acetaminophen        | DPV     | GA@O-CQD/GCE                    | 0.001–10 μM        | 0.38 nM  | Pharmaceutical samples  | (68)      |
| Carbendazim          | DPV     | ZnCdTe QD+rGO/CPE               | 99.8 nM–11.8 μM    | 91.6 nM  | Orange juice            | (117)     |
|                      |         |                                |                    |          |                         |           |
| L- Tryptophan        | DPV     | NH2-GQDs@β-CD/GCE               | 1.0–30.0 μM        | 0.65 μM  | 10 mM Phosphate buffer  | (118)     |
|                      |         |                                |                    |          | pH 7                    |           |
|                      |         |                                |                    |          |                         |           |
| D-Tryptophan         | DPV     | AgNPs/GQD/GCE                   | 0.2 mM–10 μM       | 10 nM    |                         | (119)     |
|                      |         |                                |                    |          | -                       |           |
| L-cysteine           | DPV     | MIP/C3N4NTi@GQD/Ru@AuNP/GCE     | 0.1 μM–1 nM        | 0.2 μM   | Human urine sample      | (120)     |
|                      |         |                                |                    |          |                         |           |
| Uric acid            | CV      | UOx/GQDs/GCE                    | 1–800 μM           | 0.3 μM   | Human serum sample      | (121)     |
| Ascorbic acid        | CV      | UOx/GQDs/GCE                    | 0.39–1.0 μM        | 66 μM    |                         |           |
|                      |         |                                |                    |          |                         |           |
| Dopamine             | DPV     | rGO/CdSeQD/GCE                  | 4.9–74 μM          | 0.11 μM  | Human urine sample      | (122)     |
|                      |         |                                |                    |          |                         |           |
| Uric acid            | DPV     | rGO/CdSeQD/GCE                  | 9.0 μM–0.12mM      | 0.12 μM  |                         |           |
|                      |         |                                |                    |          |                         |           |
| Estradiol            | DPV     | GQD@PSSA/GCE                    | 0.001–6.0 μM       | 0.23 nM  | Human serum sample      | (123)     |
|                      |         |                                |                    |          |                         |           |
| Progesterone         | DPV     | GQD@PSSA/GCE                    | 56–156              | 56       |                         |           |
|                      |         |                                |                    |          |                         |           |
| Alprazolam           | DPV     | AgN-GQD/Au electrode            | 54–142              | 54       |                         |           |
| Diazepam             |         |                                |                    |          |                         |           |
| Clonazepam           | DPV     | AgN-GQD/Au electrode            | 54–454              | 54       |                         |           |
| Oxazepam             |         |                                |                    |          |                         |           |
| Diazepam             |         |                                |                    |          |                         |           |
| Chlordiazepoxide     | DPV     | AgN-GQD/Au electrode            | 52–250              | 52       |                         |           |
If the sensor includes a nanoscaled interaction, it is described as a nanosensor. Quantum dots have attracted much interest from researchers because of their unique optical, electrical, thermal, and catalytic properties and have been used in the construction of various electrochemical sensors. This review describes a few examples to illustrate the administration of electrochemical techniques for pharmaceutical and drug analysis. Special attention has been shown to voltammetric analyzes using quantum dots modified electrodes. Several articles are published every year related to the voltammetric analysis with quantum dots modified electrodes of pharmaceuticals. The publications related to the modification of quantum dots can be shown as follows.

Tang et al. have constructed an electrochemical sensor using a glassy carbon electrode (GCE) modified with graphene quantum dots (GQDs) for the determination of hydroquinone and catechol in 2018 (32). This sensor was designed by the electrodeposition method and characterized by electrochemical impedance spectra. The proposed GQD’s sensor revealed a very good sensitivity, reproducibility, and reliability in the electrochemical measurement, obtaining the detection limit down to 0.08 μM in the range from 0.5 μM to 100 μM. Simultaneous detection of HQ and CC with GQD/GC electrode was performed in river water samples with good recovery. In this study, the advantages of the proposed sensor, such as excellent electrocatalytic and conductivity properties and high precision, reliability, and reproducibility in electrochemical measurement, were utilized for HQ and CC.

A novel, highly sensitive, and selective CdS quantum dots (QDs) modified glassy carbon paste electrode (CPE) was developed by Pasandideh-Nadamani and co-workers in 2016 (33). They synthesized quite stable CdS QDs, which are characterized by X-ray diffraction (XRD) and transmission electron microscopy (TEM) techniques. CdS QDs were obtained in an in-situ technique using a thiosulfate precursor. The electrochemical determination of p-aminophenol (PAP) and acetaminophen (Ac) was investigated without any separation steps in the mixture.

Algarra and co-workers have constructed carbon quantum dots (CQDs) modified glassy carbon electrode (GCE) electrochemical determination of dopamine and acid uric (34). CQDs were obtained from graphite by the Hummers method and were characterized with various methods such as TEM microscope, XPS, Raman, solid-state NMR, and FTIR-ATR spectroscopies. The electrochemical determination of both compounds showed a significant enhancement in the peak current in the CQDs-GCE as compared to the bare glassy carbon electrode. By Linear Sweep Voltammetry (LSV), the proposed sensor exhibited high sensitivity. The lower limits of detection were found to be 1.3 μM and 2.7 μM for uric acid and dopamine, respectively.

By Wong and co-workers, an electrochemical method employing a cadmium telluride quantum dots (CdTe) in Printex 6L Carbon (P6LC) and within a poly(3,4-ethylene dioxythiophene) polystyrene sulfonate (PEDOT:PSS) film modified glassy carbon electrode (QDs-P6LC-PEDOT:PSS/GCE) was developed for the detection of amoxicillin (35). The morphological structures of the nanostructured material were characterized using transmission electron microscopy, X-ray diffraction, and confocal microscopy. Square-wave voltammetry (SWV) was employed to investigate the electrochemical behavior of amoxicillin. Under the optimum conditions, the obtained sensor exhibited good sensitivity, high selectivity, and stability. No significant interference was noticed from drugs and potential biological interferences such as paracetamol, ascorbic acid, uric acid, and caffeine. The proposed sensor could be used for simultaneous determination of amoxicillin in tablets, urine, and milk samples.

An electrochemical sensor has been developed for the simultaneous detection of methyldopa (MET) in tablet, urine, and human serum samples using a molding of an aliquot of thioglycolic acid capped CdSe@Ag2Se on a glassy carbon electrode by Asadpour-Zeynali and Mollarasouli (36). CdSe@Ag2Se was characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), FT-IR spectroscopy, photoluminescence spectroscopy, cyclic voltammetry, and UV–vis techniques. Differential pulse
Voltammetry (DPV) was used to examine the electrochemical determination of MET. Under the optimum conditions (pH 2.0), the linear methyldopa range and limit of detection are 0.09 to 60 µmol L\(^{-1}\) and 0.04 µmol L\(^{-1}\), respectively.

**Advantages and disadvantages of Quantum dots nanosensors**

Nanomaterials are ideal materials for creating sensors. In quantum dots, size is a controllable parameter, and when this property is combined with the “quantum limitation” effect, quantum dots have extraordinary optical and electrical properties. Because the size of quantum dots changes with the effect of quantum restriction, the color of their luminescence also changes. Quantum dots can be used as fluorescent probes for medical diagnosis and imaging. However, heavy metals such as CdSe, CdTe, and CdS tend to degrade under physiological conditions, and ion release is toxic (12, 37). The disadvantages and advantages of quantum dots in an electrochemical sensor are given in Figure 2.

**Conclusion**

The field of electrochemistry and nanomaterials are areas in which researchers are increasingly interested in pharmaceutical and pharmaceutical analysis. In voltammetry, more sensitive and selective analyzes can be performed with the use of nanomaterials. Quantum dots are mostly used for enhancing electrochemical sensor performances. Carbon-based quantum dots and semiconductor quantum dots get much attention thanks to unique quantum properties and signal amplifying characteristics. Moreover, carbon quantum dots are known as zero-dimensional nanocarbon material and show unique electron-transfer abilities and an increment of large surface area and rich surface functional groups.

It is hoped that more attention will be paid to the development of modern electroanalysis with emphasis on simplicity and modification of electrodes for the quality of drug analysis. This review aims to discuss some examples of the use of electroanalytical applications in the analysis of drugs with quantum dots modified electrodes and to give detailed information about these applications. The pharmaceutically active compounds in the selected publications are reported in detail on the table in alphabetical order. The table presents the available information about the electrode type and modification agent, method, media, application sample, linear range, and detection limit. In this review, analytical applications of selected publications’ drugs using electrochemical methods are discussed.
This review provides an overview of the analysis of aliquots with selected quantum modified electrodes using the voltammetry method.

Future Prospects

The quantum dots-based electrochemical nanosensors are becoming quite a well-known sensor in recent years due to their outstanding features. The future perspective of electrochemical sensors in pharmaceutical and biomedical analysis. Over the last few years, electrochemical nanosensors incorporation of quantum dots such as carbon quantum dots, graphene quantum dots, and semiconductor quantum dots are widely utilized to fabricate sensing platforms exhibiting better redox properties. Aptamer and MIP-based biosensor is widely fabricated by modified the electrode surface with Quantum dots. Furthermore, fluorescent or colorimetric-based processes are being facilitated by the incorporation of quantum dots-based sensing for the rapid detection of pharmaceutical and biomedical analysis. Moreover, the fabrication of a miniaturized sensing platform has overcome the gap between detection in a diagnostic laboratory and point-of-care detection. The future objectives of quantum dots-based electrochemical nanosensors development should be designing on-spot measurements and commercialized them at minimum cost.

Acknowledgments

Declared none.

References

(1) Farshbaf M, Davaran S, Rahimi F, Annabi N, Salehi R and Akharzadeh A. Carbon quantum dots: recent progresses on synthesis, surface modification and applications. Vol. 46, Artificial Cells, Nanomedicine and Biotechnology. Taylor and Francis Ltd. (2018) 1331–48.
(2) Huang H and Zhu JJ. The electrochemical applications of quantum dots. Analyst (2013) 138: 5855–65.
(3) Di Pietrantonio F, Cannatà D and Benetti M. Biosensor technologies based on nanomaterials. In: Functional Nanostructured Interfaces for Environmental and Biomedical Applications Elsevier (2019) 181–242.
(4) Eda H, Kara Ş and Ertas N. Quantum Dots for Pharmaceutical and Biomedical Analysis. In: Spectroscopic Analyses - Developments and Applications (2017) 144–69.
(5) Xu Q, Yuan A, Zhang R, Bian X, Chen D and Hu X. Application of Electrochemical Methods for Pharmaceutical and Drug Analysis. Curr. Pharm. Anal. (2009) 5: 144–55.
(6) Campuzano S, Yañez-Sedeño P and Pingarrón JM. Carbon dots and graphene quantum dots in electrochemical biosensing. Nanomaterials (2019) 9: 1–18.
(7) Merkoçi A. Nanoparticles Based Electroanalysis in Diagnostics Applications. Electroanalysis (2013) 25: 15–27.
(8) Wang F and Hu S. Electrochemical sensors based on metal and semiconductor nanoparticles. Microchim. Acta (2009) 165: 1–22.
(9) Baig N, Sajid M and Saleh TA. Recent trends in nanomaterial-modified electrodes for electroanalytical applications. TrAC - Trends Anal. Chem. (2019) 111: 47–61.
(10) Chomoucka J, Drbohlavova J, Masarik M, Ryvolova M, Huska D, Prasek J, et al. Nanotechnologies for society. New designs and applications of nanosensors and nanobiosensors in medicine and environmental analysis. Int. J. Nanotechnol. (2012) 9: 746–83.
(11) Fenzl C, Hirsch T and Baeummer AJ. Nanomaterials as versatile tools for signal amplification in (bio) analytical applications. TrAC - Trends Anal. Chem. (2016) 79: 306–16.
(12) Xu J and Zheng J. Quantum Dots and Nanoclusters. Nano-Inspired Biosensors for Protein Assay with Clinical Applications. Elsevier Inc. (2019).
(13) Drbohlavova J, Adam V, Kizek R and Hubalek J. Quantum dots - characterization, preparation and usage in biological systems. Int. J. Mol. Sci. (2009) 10: 656–73.
(14) Downloaded from www.sciencemag.org on March 4, 2011
(15) Bertoncello P and Ugo P. Recent Advances in Electrochemiluminescence with Quantum Dots and Arrays of Nanoelectrodes. ChemElectroChem (2017) 4: 1663–76.
(16) Hart JP. Electroanalysis of biologically important compounds. E. Horwood (1990).
(17) Wang J. Nanoparticle-based electrochemical bioassays of proteins. Electroanalysis (2007) 19: 769–76.
(18) Sobrova P, Ryvolova M, Hubalek J, Adam V and Kizek R. Voltammetry as a tool for characterization
of CdTe quantum dots. Int. J. Mol. Sci. (2013) 14: 13497–510.
(19) Lisdat F, Schäfer D and Kapp A. Quantum dots on electrodes - New tools for bioelectroanalysis. Anal. Bioanal. Chem. (2013) 405: 3739–52.
(20) Lan L, Yao Y, Ping J and Ying Y. Recent advances in nanomaterial-based biosensors for antibiotics detection. Vol. 91, Biosensors and Bioelectronics. Elsevier Ltd (2017) 504–14.
(21) Frigerio C, Ribeiro DSM, Rodrigues SSM, Abreu VLRG, Barbosa JAC, Prior JAV, et al. Application of quantum dots as analytical tools in automated chemical analysis: A review. Anal. Chim. Acta (2012) 735: 9–22.
(22) Bera D, Qian L, Tseng TK and Holloway PH. Quantum dots and their multimodal applications: A review. Materials (Basel). (2010) 3: 2260–345.
(23) Chen A and Chatterjee S. Nanomaterials based electrochemical sensors for biomedical applications. Chem. Soc. Rev. (2013) 42: 5425–38.
(24) Brett CMA. Electrochemistry. Principles, Methods and Applications. Oxford University Press (1993).
(25) Chen A and Chatterjee S. Nanomaterials based electrochemical sensors for biomedical applications. Chem. Soc. Rev. (2013) 42: 5425–38.
(26) Frigerio C, Ribeiro DSM, Rodrigues SSM, Abreu VLRG, Barbosa JAC, Prior JAV, et al. Application of quantum dots as analytical tools in automated chemical analysis: A review. Anal. Chim. Acta (2012) 735: 9–22.
(27) Bera D, Qian L, Tseng TK and Holloway PH. Quantum dots and their multimodal applications: A review. Materials (Basel). (2010) 3: 2260–345.
(28) Ozkan SA. Electroanalytical Methods in Pharmaceutical Analysis and Their Validation. (2012) 350.
(29) Vire JC and Kauffmann J-M. Trends in Electrochemistry in Drug Analysis. Curr. Top. Electrochem. (1994).
(30) Wang L, Yao L, Liu X, Cheng J, Liu W, Liu T, et al. CuCo2O4/N-Doped CNTs loaded with molecularly imprinted polymer for electrochemical sensor: Preparation, characterization and detection of metronidazole. Biosens. Bioelectron. (2019) 142: 111483.
(31) Shereema RM, Rao TP, Sameer Kumar VB, Sruthi T V, Vishnu R, Prabhu GRD, et al. Individual and simultaneous electrochemical determination of metanil yellow and curcumin on carbon quantum dots based glassy carbon electrode. Mater. Sci. Eng. C (2018) 93: 21–7.
(32) Mishra P and Bhat BR. A study on the electroreductive cycle of amino-functionalized graphene quantum dots immobilized on graphene oxide for amperometric determination of oxalic acid. Microchim. Acta (2019) 186: 1–10.
The Applications of Quantum Dots in Electrochemical Sensor of Drug Samples

N. N-doped carbon quantum dots @ hexagonal porous copper oxide decorated multiwall carbon nanotubes: A hybrid composite material for an efficient ultra-sensitive determination of caffic acid. Compos. Part B Eng. (2019) 174: 106973.

(44) Zhou Z, Zhao P, Wang C, Yang P, Xie Y and Fei J. Ultra-sensitive amperometric determination of quercetin by using a glassy carbon electrode modified with a nanocomposite prepared from aminated graphene quantum dots, thiolated β-cyclodextrin and gold nanoparticles. Microchim. Acta (2020) 187: 1–9.

(45) Mahmoud AM, El-Wekil MM, Mahnashi MH, Ali MFB and Alkahtani SA. Modification of N,S co-doped graphene quantum dots with p-aminothiophenol-functionalized gold nanoparticles for molecular imprint-based voltammetric determination of the antiviral drug sofosbuvir. Microchim. Acta (2019) 186.

(46) Lu J, Kou Y, Jiang X, Wang M, Xue Y, Tian B, et al. One-step preparation of poly(glyoxal-bis(2-hydroxyanil))-amino-functionalized graphene quantum dots-MnO2 composite on electrode surface for simultaneous determination of vitamin B2 and dopamine. Colloids Surfaces A Physicochem. Eng. Asp. (2019) 580: 123652.

(47) Muthusankar G, Devi RK and Gopu G. Nitrogen-doped carbon quantum dots embedded Co3O4 with multiwall carbon nanotubes: An efficient probe for the simultaneous determination of anticancer and antibiotic drugs. Biosens. Bioelectron. (2020) 150: 111947.

(48) Hatamluyi B, Hashemzadeh A and Darroudi M. A novel molecularly imprinted polymer decorated by CQDs@HBNNS nanocomposite and UiO-66-NH2 for ultra-selective electrochemical sensing of Oxaliplatin in biological samples. Sensors Actuators B Chem. (2020) 307: 127614.

(49) Eksin E, Senturk H, Zor E, Bingol H and Erdem A. Carbon quantum dot modified electrodes developed for electrochemical monitoring of Daunorubicin-DNA interaction. J. Electroanal. Chem. (2020) 862: 114011.

(50) Lu Z, Li Y, Liu T, Wang G, Sun M, Jiang Y, He H, Wang Y, Zou P, Wang X, Zhao Q and Rao H. A dual-template imprinted polymer electrochemical sensor based on AuNPs and nitrogen-doped graphene oxide quantum dots coated on NiS2/biomass carbon for simultaneous determination of dopamine and chlorpromazine. Chem. Eng. J. (2020) 389: 124417.

(51) Hasanpour F, Nekoeinia M, Sennani A and Shojaei S. NiMnO3 nanoparticles anchored on graphene quantum dot: Application in sensitive electroanalysis of dobutamine. Microchem. J. (2018) 142: 17–23.

(52) Shahdost-Fard F and Roushani M. Conformation switching of an aptamer based on cocaine enhancement on a surface of modified GCE. Talanta (2016) 154: 7–14.

(53) Hasanzadeh M, Hashemzadeh N, Shadjou N, Eivazi-Ziaei J, Khoubnasabjafari M and Jouyban A. Sensing of doxorubicin hydrochloride using graphene quantum dot modified glassy carbon electrode. J. Mol. Liq. (2016) 221: 354–7.

(54) Rather JA, Pilehvar S and De Wael K. A graphene oxide amplification platform tagged with tyrosinase-zinc oxide quantum dot hybrids for the electrochemical sensing of hydroxylated polychlorobiphenyls. Sensors Actuators B Chem. (2014) 190: 612–20.

(55) Mohammadi-Behzad L, Gholivand MB, Shamsipur M, Gholivand K, Barati A and Gholami A. Highly sensitive voltammetric sensor based on immobilization of bisphosphoramidate-derivative and quantum dots onto multi-walled carbon nanotubes modified gold electrode for the electrocatalytic determination of olanzapine. Mater. Sci. Eng. C (2016) 60: 67–77.

(56) Ozcelikay G, Kurbanoğlu S, Bozal-Palabiyik B, Uslu B and Ozkan SA. MWCNT/CdSe quantum dot modified glassy carbon electrode for the determination of clopidogrel bisulfate in tablet dosage form and serum samples. J. Electroanal. Chem. (2018) 827: 51–7.

(57) Chihava R, Moyo M and Shumba M. Impedimetric Determination of Antiretroviral Drugs on a Modified Glassy Carbon Electrode.

(58) Beitolahi H, Dourandish Z, Ganjali MR and Shakeri S. Voltammetric determination of dopamine in the presence of tyrosine using graphite screen-printed electrode modified with graphene quantum dots. Ionics (Kiel). (2018) 24: 4023–31.

(59) Zhao C, Liu Z, Xu W, Chen M, Weng S, Xu L and Cai Q. A glassy carbon electrode based on graphene quantum dots (GQDs) for simultaneous detection of acetaminophen and ascorbic acid. Anal. Methods (2015) 7: 8877–81.

(60) Arvand M, Abbasnejad S and Ghods N. Graphene quantum dots decorated with Fe3O4 nanoparticles/functionallized multiwalled carbon nanotubes as a new sensing platform for electrochemical determination of L-DOPA in agricultural products. Anal. Methods (2016) 8: 5861–8.

(61) Hashemzadeh N, Hasanzadeh M, Shadjou N, Eivazi-Ziaei J, Khoubnasabjafari M and Jouyban A. Graphene quantum dot modified glassy carbon electrode for the determination of doxorubicin...
hydrochloride in human plasma. J. Pharm. Anal. (2016) 6: 235–41.

(62) Ganganboina AB and Doong R an. Functionalized N-doped graphene quantum dots for electrochemical determination of cholesterol through host-guest inclusion. Microchim. Acta (2018) 185: 1–11.

(63) Hasanzadeh M, Karimzadeh A, Sadeghi S, Mokhtarzadeh A, Shadjou N and Jouryban A. Graphene quantum dot as an electrically conductive material toward low potential detection: a new platform for interface science. J. Mater. Sci. Mater. Electron. (2016) 27: 6488–95.

(64) Hu J, Guo F and Wang L. Voltammetric determination of nitrite by using a glassy carbon electrode modified with a self-assembled nanocomposite prepared from CdTe quantum dots, cetyltrimethylammonium bromide, chitosan and multiwalled carbon nanotubes. Microchim. Acta (2017) 184: 4637–46.

(65) Huang JY, Bao T, Hu TX, Wen W, Zhang XH and Wang SF. Voltammetric determination of levofloxacin using a glassy carbon electrode modified with poly(o-aminophenol) and graphene quantum dots. Microchim. Acta (2017) 184: 127–35.

(66) Matos CRS, Souza HO, Santana TBS, Candido LPM, Cunha FGC, Sussuchi EM and Gimenez LF. Cd 1-x Mg x Te semiconductor nanocrystal LPM, Cunha FGC, Sussuchi EM and Gimenez LFM. Cd 1-x Mg x Te semiconductor nanocrystal quantum dots. Microchim. Acta (2017) 184: 1755–64.

(67) Mir IA, Rawat K, Solanki PR and Bohidar HB. ZnSe core and ZnSe@ZnS core-shell quantum dots as platform for folic acid sensing. J. Nanoparticle Res. (2017) 19.

(68) Ruiyi L, Haiyan Z, Zaijun L and Junkang L. Electrochemical determination of acetaminophen using a glassy carbon electrode modified with a hybrid material consisting of graphene aerogel and octadecylamine-functionalized carbon quantum dots. Microchim. Acta (2018) 185: 1–9.

(69) Shamsi A, Ahour F and Sehatnia B. Nickel oxide nanoparticles decorated graphene quantum dot as an effective electrode modifier for electrocatalytic oxidation and analysis of clozapine. J. Solid State Electrochem. (2018) 22: 2681–9.

(70) Tiwari P, Nirala NR and Prakash R. Determination of the Anti-HIV Drug Nevirapine Using Electroactive 2D Material Pd@rGO Decorated with MoS2 Quantum Dots. ChemistrySelect (2018) 3: 5341–7.

(71) Alizadeh PM, Hasanzadeh M, Soleymani J, Gharamaleki JY and Jouryban A. Application of bioactive cyclic oligosaccharide on the detection of doxorubicin hydrochloride in unprocessed human plasma sample: A new platform towards efficient chemotherapy. Microchem. J. (2019) 145: 450–5.

(72) Aftab S, Kurbanoglu S, Ozcelikay G, Bakirhan NKNK, Shah A and Ozkan SASA. Carbon quantum dots co-catalyzed with multiwalled carbon nanotubes and silver nanoparticles modified nanosensor for the electrochemical assay of anti-HIV drug Rilpivirine. Sensors Actuators, B Chem. (2019) 285: 571–83.

(73) Hatamluyi B, Es’haghi Z, Modarres Zahed F and Darroudi M. A novel electrochemical sensor based on GQDs-PANI/ZnO-NCs modified glassy carbon electrode for simultaneous determination of Irinotecan and 5-Fluorouracil in biological samples. Sensors Actuators, B Chem. (2019) 540–9.

(74) Mohamed FA, Khashaba PY, Shahin RY and El-Wekil MM. Tunable ternary nanocomposite prepared by electrodeposition for biosensing of centrally acting reversible acetyl cholinesterase inhibitor donepezil hydrochloride in real samples. Colloids Surfaces A Physicochem. Eng. Asp. (2019) 567: 76–85.

(75) Dehgan-Reyhan S and Najafi M. Defective mesoporous carbon ceramic electrode modified graphene quantum dots as a novel surface-renewable electrode: The application to determination of zolpidem. J. Electroanal. Chem. (2019) 832: 241–6.

(76) Santos AM, Wong A, Cincotto FH, Moraes FC and Fatibello-Filho O. Square-wave adsorptive anodic stripping voltammetric determination of norfloxacin using a glassy carbon electrode modified with carbon black and CdTe quantum dots in a chitosan film. Microchim. Acta (2019) 186: 1–10.

(77) Roushani M, Jalilian Z and Nezhadali A. Screen printed carbon electrode sensor with thiol graphene quantum dots and gold nanoparticles for voltammetric determination of solatol. Heliyon (2019) 5.

(78) Srivastava M, Tiwari P, Mall VK, Srivastava SK and Prakash R. Voltammetric determination of the antimalarial drug chloroquine using a glassy carbon electrode modified with reduced graphene oxide on a disposable nanosensor based on GQDs-PANI/ZnO-NCs modified glassy carbon electrode for simultaneous determination of doxorubicin and epinephrine. J. Mater. Sci.: Mater. Electron. (2019) 30: 20000–14.

(79) Hooshmand S and Es’haghi Z. Microfabricated disposable nanosensor based on CdSe quantum dot/ionic liquid-mediated hollow fiber-pencil graphite electrode for simultaneous electrochemical quantification of uric acid and creatinine in human samples. Anal. Chim. Acta (2017) 972: 28–37.
The Applications of Quantum Dots in Electrochemical Sensor of Drug Samples

(80) Hatamluyi B and Es’haghi Z. Electrochemical biosensing platform based on molecularly imprinted polymer reinforced by ZnO-graphene capped quantum dots for 6-mercaptopurine detection. *Electrochim. Acta* (2018) 283: 1170–7.

(81) Zhang K, Song G, Li Y, Wu X, Li K and Ye B. Voltammetric studies of kaempferol on polyvinyl pyrrolidone claddling quantum dots CdS doped carbon paste electrode and analytical application. *Sensors Actuators, B Chem.* (2014) 191: 673–80.

(82) Ensafi AA, Nasr-Esfahani P and Rezaei B. Metronidazole determination with an extremely sensitive and selective electrochemical sensor based on graphene nanoplatelets and molecularly imprinted polymers on graphene quantum dots. *Sensors Actuators, B Chem.* (2018) 270: 192–9.

(83) Shadjou N, Hasanzadeh M, Talebi F and Marjani AP. Integration of β-cyclodextrin into graphene quantum dot nano-structure and its application towards detection of Vitamin C at physiological pH: A new electrochemical approach. *Mater. Sci. Eng. C* (2016) 67: 666–74.

(84) Beitollahi H, Hamzavi M, Torkzadeh-Mahani M, Shanesaz M and Maleh HK. A Novel Strategy for Simultaneous Determination of Dopamine and Uric Acid Using a Carbon Paste Electrode Modified with CdTe Quantum Dots. *Electroanalysis* (2015) 27: 524–33.

(85) Rezaei B, Irannejad N, Ensafi AA and Dinari M. Application of modified carbon quantum dots/multiwall carbon nanotubes/pencil graphite electrode for electrochemical determination of dextromethorphan. *IEEE Sens. J.* (2016) 16: 2219–27.

(86) Hou J, Bei F, Wang M and Ai S. Electrochemical determination of malachite green at graphene quantum dots-gold nanoparticles multilayers-modified glassy carbon electrode. *J. Appl. Electrochem.* (2013) 43: 689–96.

(87) Shadjou N, Hasanzadeh M and Talebi F. Graphene Quantum Dots Incorporated into β-cyclodextrin: a Novel Polymeric Nanocomposite for Non-Enzymatic Sensing of L-Tyrosine at Physiological pH. *J. Anal. Chem.* (2018) 73: 602–12.

(88) Sofla SZ, Moradi M, Mohammadnejad S and Abbasi Z. Design of a Novel Nano-Sensor for Determination of Acetaminophen. *J. Appl. Environ. Biol. Sci.* (2014) 4: 51–6.

(89) Dourandish Z and Beitollahi H. Electrochemical Sensing of Isoproterenol using Graphite Screen-printed Electrode Modified with Graphene Quantum Dots. *Vol. 10, Anal. Bioanal. Electrochem.* (2018).

(90) Sanati AL and Faridbod F. Electrochemical determination of methylidopa by graphene quantum dot / 1-butyl-3-methylimidazolium hexafluorophosphate nanocomposite electrode. *Int. J. Electrochem. Sci.* (2017) 12: 7997–8005.

(91) Ganjali MR, Dourandish Z, Beitollahi H, Tajik S, Hajighahabaei L and Larjani B. Highly sensitive determination of theophylline based on graphene quantum dots modified electrode. *Int. J. Electrochem. Sci.* (2018) 13: 2448–61.

(92) Mahmoudi-Moghaddam H, Tajik S and Beitollahi H. A new electrochemical DNA biosensor based on modified carbon paste electrode using graphene quantum dots and ionic liquid for determination of topotecan. *Microchem. J.* (2019) 150: 104085.

(93) Nasr-Esfahani P, Ensafi AA and Rezaei B. Fabrication of a highly sensitive and selective modified electrode for imidacloprid determination based on designed nanocomposite graphene quantum dots/ionic/multiwall carbon nanotubes/polyaniline. *Sensors Actuators, B Chem.* (2019) 296: 1–8.

(94) Jang HS, Kim D, Lee C, Yan B, Qin X and Piao Y. Nafion coated Au nanoparticle-graphene quantum dot nanocomposite modified working electrode for voltammetric determination of dopamine. *Inorg. Chem. Commun.* (2019) 105: 174–81.

(95) Ghanbari K, Roushani M, Soheyli E and Sahraei R. An electrochemical tyrosinamide aptasensor using a glassy carbon electrode modified by N-acetyl-L-cysteine-capped Ag-In-S QDs. *Mater. Sci. Eng. C* (2019) 102: 653–60.

(96) Yao J, Chen M, Li N, Liu C and Yang M. Experimental and theoretical studies of a novel electrochemical sensor based on molecularly imprinted polymer and B, N, F-CQDs/AgNPs for enhanced specific identification and dual signal amplification in highly selective and ultra-trace bisphenol S determin. *Anal. Chim. Acta* (2019) 1066: 36–48.

(97) Aftab S, Kurbangulou S, Ozcelikay G, Shah A and Ozkan SA. NH2-Functionalized Multi Walled Carbon Nanotubes Decorated with ZnO Nanoparticles and Graphene Quantum Dots for Sensitive Assay of Pimozide. *Electroanalysis* (2019) 31: 1083–94.

(98) Abbas MW, Soomro RA, Kalwar NH, Zahoor M, Avci A, Pehlivan E, Hallam RK and Willander M. Carbon quantum dot coated Fe3 O4 hybrid composites for sensitive electrochemical detection of uric acid. *Microchem. J.* (2019) 146: 517–24.

(99) Gevaerd A, Banks CE, Bergamini MF and Marcolino-Junior LH. Graphene Quantum Dots Modified Screen-printed Electrodes as Electroanalytical Sensing Platform for Diethylstilbestrol. *Electroanalysis* (2019) 31: 838–
43.

(100) Zhao P, Ni M, Chen C, Zhou Z, Li X, Li C, Xie Y and Fei J. Stimuli-enabled switch-like paracetamol electrochemical sensor based on thermosensitive polymer and MWCNTs-GQDs composite nanomaterial. Nanoscale (2019) 11: 7394–403.

(101) Chen W, Li R, Li Z, Yang Y, Zhu H and Liu J. Promising copper oxide-histidine functionalized graphene quantum dots hybrid for electrochemical detection of hydroquinone. J. Alloys Compd. (2019) 1001–9.

(102) Rao H, Zhao X, Liu X, Zhong J, Zhang Z, Zou P, Jiang Y, Wang X and Wang Y. A novel molecularly imprinted electrochemical sensor based on graphene quantum dots coated on hollow nickel nanospheres with high sensitivity and selectivity for the rapid determination of bisphenol S. Biosens. Bioelectron. (2018) 100: 341–7.

(103) Tashkhourian J, Nami-Ana SF and Shamsipur M. Designing a modified electrode based on graphene quantum dot-chitosan application to electrochemical detection of epinephrine. J. Mol. Liq. (2018) 266: 548–56.

(104) Hooshmand S and Es’haghi Z. Simultaneous quantification of arginine, alanine, methionine and cysteine amino acids in supplements using a novel bioelectro-nanosensor based on CdSe quantum dot/modified carbon nanotube hollow fiber pencil graphite electrode via Taguchi method. J. Pharm. Biomed. Anal. (2017) 146: 226–35.

(105) Muthusankar G, Rajkumar C, Chen SM, Karkuzhali R, Gopu G, Sangili A, Sengottuvelan N and Sankar R. Sonochemical driven simple preparation of nitrogen-doped carbon quantum dots/SmO2 nanocomposite: A novel electrocatalyst for sensitive voltammetric determination of riboflavin. Sensors Actuators, B Chem. (2019) 281: 602–12.

(106) Ghovidivand MB, Ahmadi E and Mavaei M. A novel voltammetric sensor based on graphene quantum dots-thionine/nano-porous glassy carbon electrode for detection of cisplatin as an anti-cancer drug. Sensors Actuators, B Chem. (2019) 299: 126975.

(107) Zhang Z, Li Y, Xu J and Wen Y. Electropolymerized molecularly imprinted polypyrrole decorated with black phosphorene quantum dots onto poly(3,4-ethylenedioxythiophene) nanorods and its voltammetric sensing of vitamin C. J. Electroanal. Chem. (2018) 814: 153–60.

(108) Cai J, Sun B, Gou X, Gou Y, Li W and Hu F. A novel way for analysis of calycosin via polyaniline functionalized graphene quantum dots fabricated electrochemical sensor. J. Electroanal. Chem. (2018) 816: 123–31.

(109) Zheng S, Huang R, Ma X, Tang J, Li Z, Wang X, Wei J and Wang J. A highly sensitive dopamine sensor based on graphene quantum dots modified glassy carbon electrode. Int. J. Electrochem. Sci. (2018) 13: 5723–35.

(110) Alimohammadi S, Kiani MA, Imani M, Rafii-Tabar H and Sasanpour P. Electrochemical Determination of Dexamethasone by Graphene Modified Electrode: Experimental and Theoretical Investigations. Sci. Rep. (2019) 9: 1–10.

(111) Cincotto FH, Carvalho DAS, Canevari TC, Toma HE, Fatibello-Filho O and Moraes FC. A novel magnetic electrochemical sensor for the determination of mood disorder related substances. RSC Adv. (2018) 8: 14040–7.

(112) Carvalho S, Santana T, Matos C, Costa L, Sussuchi E and Gimenez I. Synthesis of Hydrotalcite-Supported CdTe Semiconductor Nanocrystals for Electrochemical Detection of Ciprofloxacin. J. Braz. Chem. Soc. (2019) 30: 1266–75.

(113) Fajardo A, Tapia D, Pizarro J, Segura R and Jara P. Determination of norepinephrine using a glassy carbon electrode modified with graphene quantum dots and gold nanoparticles by square wave stripping voltammetry. J. Appl. Electrochem. (2019) 49: 423–32.

(114) Hsu WF and Wu TM. Electrochemical sensor based on conductive polyaniline coated hollow tin oxide nanoparticles and nitrogen doped graphene quantum dots for sensitively detecting dopamine. J. Mater. Sci. Mater. Electron. (2019) 0: 0.

(115) Kalaivani A and Narayanan SS. Fabrication of CdSe quantum dots @ nickel hexacyanoferrate core–shell nanoparticles modified electrode for the electrocatalytic oxidation of hydrazine. J. Mater. Sci. Mater. Electron. (2018) 29: 20146–55.

(116) Kucukkolbası S, Erdoğan ZO, Baslak C, Sogut D and Kus M. A Highly Sensitive Ascorbic Acid Sensor Based on Graphene Oxide/CdTe Quantum Dots-Modified Glassy Carbon Electrode. Russ. J. Electrochem. (2019) 55: 107–14.

(117) Santana P, Lima J, Santana T, Santos L, Matos C, da Costa L, Gimenez LF and Sussuchi EM. Semiconductor Nanocrystals-Reduced Graphene Composites for the Electrochemical Detection of Carbendazim. J. Braz. Chem. Soc. (2019) 30: 1302–8.

(118) Xiao Q, Lu S, Huang C, Su W, Zhou S, Sheng J and Huang S. An electrochemical chiral sensor based on amino-functionalized graphene quantum dots/β-cyclodextrin modified glassy carbon electrode for enantioselective detection of tryptophan isomers. J. Iran. Chem. Soc. (2017) 14: 1957–70.

(119) Yao J, Liu C, Liu L, Chen M and Yang M. An
electrochemical sensor for sensitive determination of L-cysteine and its electrochemical kinetics on AgNPs/GQDs/GCE composite modified electrode. *J. Electrochem. Soc.* (2018) 165: B551–8.

(120) Yola ML and Atar N. Phenylethanolamine A (PEA) imprinted polymer on carbon nitride nanotubes/graphene quantum dots/core-shell nanoparticle composite for electrochemical PEA detection in Urine sample. *J. Electrochem. Soc.* (2018) 165: H1–9.

(121) Yu HW, Zhang Z, Shen T, Jiang JH, Chang D and Pan HZ. Sensitive determination of uric acid by using graphene quantum dots as a new substrate for immobilisation of uric oxidase. *IET Nanobiotechnology* (2018) 12: 191–5.

(122) Tavakolian E and Tashkhourian J. Sonication-assisted preparation of a nanocomposite consisting of reduced graphene oxide and CdSe quantum dots and its application to simultaneous voltammetric determination of ascorbic acid, dopamine and uric acid. *Microchim. Acta* (2018) 185.

(123) Arvand M and Hemmati S. Analytical methodology for the electro-catalytic determination of estradiol and progesterone based on graphene quantum dots and poly(sulfosalicylic acid) co-modified electrode. *Talanta* (2017) 174: 243–55.

(124) Ashrafi H, Hassanpour S, Saadati A, Hasanzadeh M, Ansarin K, Ozkan SA, Shadjou N and Jouyban A. Sensitive detection and determination of benzodiazepines using silver nanoparticles-N-GQDs ink modified electrode: A new platform for modern pharmaceutical analysis. *Microchem. J.* (2019) 145: 1050–7.

This article is available online at http://www.ijpr.ir