Full Paper

Simultaneous Determination of Dopamine and Paracetamol using a Gold Electrode Modified with MWCNTs/GO Nanocomposite Capped Au Nanoparticles

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Abstract- In this research project, a sensitive electrochemical sensor was developed for simultaneous voltammetric determination of dopamine (DA) and paracetamol (PA) based on a gold electrode modified with functionalized multi-wall carbon nanotubes/graphene oxide (f-MWCNTs/GO) nanocomposite capped with gold nanoparticles (AuNPs). The modified electrode showed excellent electrocatalytic activity for the oxidation of DA and PA molecules in aqueous solutions with well-separated oxidation peaks for each species. The fabrication process of the proposed sensor was evaluated by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Cyclic voltammetry (CV) and also electrochemical impedance spectroscopy (EIS) were used to investigate the electrochemical properties of f-MWCNTs/GO/AuNPs/AuE. Under the optimized experimental conditions, the calibration curves were linear over the concentration ranges of 1-400 µM with a detection limit of 0.5 and 0.3 µM for DA and PA, respectively. Finally, the constructed electrode was successfully applied for the quantitative measurement of dopamine and paracetamol in pharmaceutical and urine samples.

1. INTRODUCTION

Dopamine (2, (3, 4-dihydroxyphenyl) ethylamine, DA) is one of the main neurotransmitters which plays important functions in the control of central nervous, renal, cardiovascular and hormonal networks. It is also involved in some of the neurological diseases such as Parkinson, Alzheimer and Schizophrenia [1]. Thus, its quantification in human body fluids is necessary in diagnoses, prevention and treatments of these neurological diseases [2,3]. Paracetamol (N-acetyl-p-aminophenol, PA) is an efficient antipyretic and analgesic medicine which is widely used for the relief of pains [4]. At common remedial doses, paracetamol seems to be safe and it has no poisonous effects on human health [5,6]. However, the overdose of PA can lead to the accumulation of poisonous metabolites which may beget hepatotoxicity and nephrotoxicity [7]. Therefore, the development of a simple, quick and sensitive analytical method for the quantification of DA and PA in biological fluids and pharmaceutical samples is of great significance. Several papers have reported the determination of dopamine and paracetamol based on various analytical methods such as chromatography [8,9], electrophoresis [10], spectrofluorimetry [11], spectrophotometry [12], mass spectrometry [13] and also electrochemical methods [14]. Since the electrochemical activity of dopamine and paracetamol is high, the electrochemical techniques are appropriate for the determination of these drugs. However, the poor capability of the bare electrodes in the direct electrochemical activity of different electroactive materials has led to the use of modified electrodes [15]. Multi-walled carbon nanotubes (MWCNTs) with quasi-one- dimensional (1D) structures are being used as an ideal material for the fabrication of electrode due to their high surface area, high electrical conductivity, mechanical strength, chemical stability and moreover, the unique electronic and nano-structural properties [16].

Graphene oxide (GO), a two-dimensional carbon material, is a promising support material for the incorporation of the different nanostructures because of its astonishing electrochemical properties, ambipolarity, maximum surface area to volume ratio and also high conductivity [17]. However, the hydrophobic property and irreversible aggregation of GO in aqueous solutions, limit its application in biological analysis. In order to reducing the aggregation of graphene, a new strategy is the combination of GO with MWCNTs to form a conductive network that possesses the unique properties of the two carbon allotropes [18,19].

Gold nanoparticles (AuNPs), with interesting properties such as large surface area, good biocompatibility and high conductivity, have been used to increase the sensitivity and also the detection limit in electrochemical measurements [20].

In the present study, a new electrochemical sensor was developed for the simultaneous voltammetric determination the concentration of DA and PA in aqueous solutions, using functionalized multi-wall carbon nanotubes/graphene oxide (f-MWCNTs/GO) hybrid nanocomposite and gold nanoparticles (AuNPs). This electrode was fabricated through the electrochemical deposition of AuNPs to pre-casted f-MWCNTs/GO hybrid composite on the

surface of a gold electrode. The developed sensor revealed high selectivity for dopamine and paracetamol in the presence of some interfering species. Finally, it was successfully applied for the determination of dopamine and paracetamol in real samples.

2. EXPERIMENTAL

2.1. Chemicals

Dopamine and hydrogen tetrachloroaurate trihydrate ($HAuCl_4.3H_2O$) were purchased from Sigma-Aldrich (USA) and paracetamol was obtained from Borhan Darou (Iran). MWCNTs (>95%, outer diameter 5-15 nm) and graphene oxide (>99٪, particle size 3.4-7 nm) were purchased from US research nanomaterials, Houston, USA. All the solvents and the other salts which were used in this study were of analytical grade and were attained from Merck chemical company (Darmstadt, Germany). Deionized water was applied for the preparation of the solutions.

2.2. Instrumentation

Voltammetric measurements were carried out using a µ-Autolab III (Eco Chemie, The Netherlands) potentiostat/galvanostat equipped with NOVA software. The electrochemical impedance spectroscopy (EIS) measurements were carried out using Gill AC potentiostat (ACM). All electrochemical experiments were performed in a three-electrode cell containing; an Ag/AgCl/KCl (3.5 M) reference electrode, a platinum wire counter electrode and a 2.0 mm diameter gold disk as the working electrode. The three electrodes were purchased from Azar Electrode Company (Urmia, Iran). The pH adjustment of solutions was carried out with a Metrohm pH meter (model 827 pH, Swissmade). The scanning electron microscope (SEM) images of different modified electrodes, were taken using a LEO 1450VP SEM (Germany). Surface elemental analysis of f-MWCNTs/GO/AuNPs modified electrode was accomplished by the energy-dispersive X-ray (EDX) technique using Oxford-7353 EDX microanalyzer.

2.3. Preparation of the modified electrode

Prior to use, the gold electrode surface was polished on a kit containing alumina powder of $0.5\mu m$, and then washed with double-distilled water. It was sonicated for 5 min in a 1:1 mixture of water and ethanol in the next step. The modifier suspension was prepared by dispersing 2.5 mg of functionalized multi-wall carbon nanotubes and 2.5 mg of graphene oxide in 2.5 ml of dimethylformamide (DMF) with ultrasonic agitation for 20 minutes, which is abbreviated as f-MWCNTs/GO. 5 µl of the prepared suspension was casted directly onto the gold electrode surface by a microsyringe and then it was placed under the radiation of an IR lamp to dry completely. The modified electrode is introduced as f-MWCNTs/GO/AuE. At the next stage, the fabricated electrode was placed in an electrochemical cell containing 0.5 mM

HAuCl$_4$.3H$_2$O and 0.1 M KNO$_3$ solution and the chronoamperometry technique was used at a constant potential of -0.2 V for 360 s for deposition of the gold nanoparticles on the electrode surface. Then, the modified electrode was washed with double-distilled water and dried in air. Figure 1, shows the schematic illustration for the construction of the target electrode.
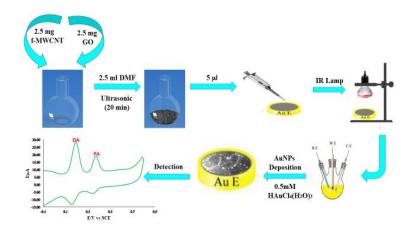
Figure 1. Schematic illustration for construction of f-MWCNTs/GO/AuNPs/AuE

2.4. Preparation of real samples

A paracetamol tablet (500 mg) from Obeidi Pharmaceuticals Company in Iran, was purchased from the local drug store. After weighing the tablet, it was crushed as a soft powder by a moss. Then it was dissolved in 100 ml of distilled water in the volumetric flask and placed in an ultrasonic bath for 20 minutes and then filtered. After proper dilution, the pharmaceutical sample was used for electrochemical measurements.
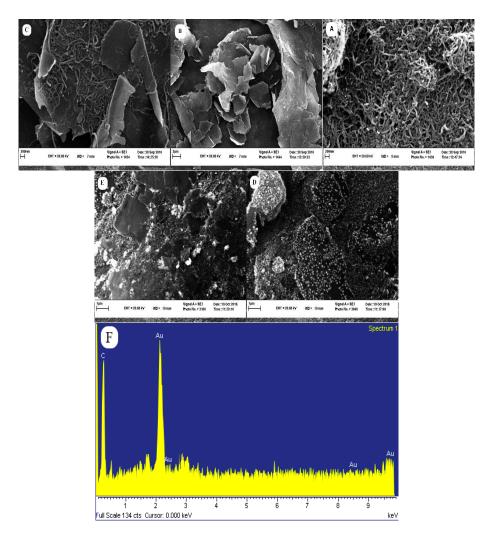
A dopamine ampoule (200 mg) was diluted according to the concentration range of the calibration plot and the resulting solutions were used for the real sample analysis. The urine sample was taken from a healthy person and, the sample was centrifuged for 10 min at 3500 rpm in order to remove the precipitated materials. It was diluted 50 times [21,22] with 0.1 M phosphate buffer (PBS) solution with pH 7 and, then the electrochemical measurements were carried out after addition certain amount of standard solution to the sample.

3. RESULTS AND DISCUSSION

3.1. Characterization of f-MWCNTs/GO/AuNPs nanocomposite

The surface morphology of the constructed sensor was investigated by scanning electron microscopy (SEM). The SEM image of f-MWCNTs (Figure 2A) depicts a tube-like structure which indicates that the f-MWCNTs well deposited on the surface of the bare electrode. As is shown in Figure 2B, the GO has a layered structure with ultra-thin flat graphene sheets [21]. After multiwall carbon nanotubes are added to GO, a nano-network is seen between the

graphene sheets and nanotube bundles which creates a particular three-dimensional structure (Figure 2C). This intricate structure, confirms the π-π interactions between the f-MWCNTs and the GO nanocomposite and developing a high surface area [23]. Figures 2D and 2E, show the SEM images of the f-MWCNTs/GO/AuNPs at two scales.
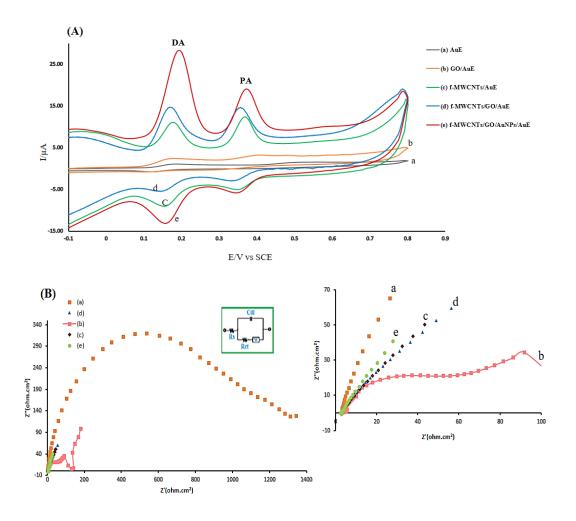

Figure 2. Scanning electron microscopy (SEM) images of (A) f-MWCNTs/AuE, (B) GO/AuE, (C) f-MWCNTs/GO/AuE, (D and E) f-MWCNTs/GO/AuNPs /AuE and (F) EDS spectrum of f-MWCNTs/GO/AuNPs /AuE

The SEM image of f-MWCNTs/GO/AuNPs shows the uniform distribution of the gold nanoparticles throughout the carbon layer structure. The gold nanoparticles along with f-MWCNTs and GO, provide effective and electroactive sites and easier mass transport. EDS can display the more precise elemental analysis of nanomaterials when combined with imaging equipment. Figure 2F, shows the EDS spectrum of the f-MWCNTs/GO/AuNPs Au electrode, which clearly indicates the deposition of AuNPs on the surface of the electrode.

3.2. Electrochemical characteristics

Cyclic voltammetry was used to investigate the electrochemical behavior of the analytes and validate the fabrication process of the sensor [24]. Figure 3A, shows the cyclic voltammograms of DA and PA at different modified electrodes in the potential ranges of -0.10 to 0.80 V and at a scan rate of 50 mV/s. As is obvious in this Figure, at the bare and GO modified electrodes, the oxidation peaks of DA and PA appear very weak and broad. Whereas, at f-MWCNTs/AuE, the oxidation peaks of DA and PA are observed at 0.178 V and 0.369 V and likewise, the oxidation peaks at f-MWCNTs/GO/AuE are appeared at 0.169 V and 0.358V, respectively. However, as shown in Figure 3A, the intensity of the oxidation peak currents of DA and PA molecules at f-MWCNTs/GO/AuE is low.

Figure 3. (A) Cyclic voltammograms for 0.1 mM dopamine and paracetamol solution with the scan rate of 0.05 V/s and (B) electrochemical impedance spectra in 5 mM [Fe (CN)6] -3/ -4 (1: 1) solution containing 0.1 M of KCl of (a) AuE, (b) GO/AuE, (c) f-MWCNTs/AuE (d) f-MWCNTs/GO/AuE, and (e) f-MWCNTs/GO/AuNPs/AuE

When the gold nanoparticles are added to the f-MWCNTs/GO composite on the Au electrode under the same conditions, the oxidation peak of DA and PA molecules are appeared

at 0.183 V and 0.371V with a peak-to-peak separation (ΔE_p) of 43 mV and 40 mV, respectively. As a result, the synergistic effect of f-MWCNTs, GO and AuNPs, accelerate the electron transfer rate of DA and PA molecules at the electrode surface and, therefore, the oxidation peaks current increases.
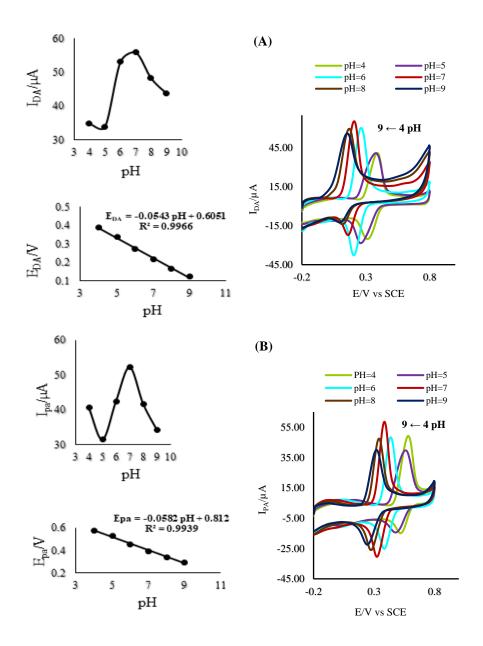
Electrochemical impedance spectroscopy (EIS) is a reliable and sensitive technique for investigation the electron transfer kinetics and probing the interfacial properties of the modified electrodes [25,26]. Therefore, the fabrication process of the fabricated sensor was characterized by EIS. Figure 3B, shows the Nyquist plots of the bare and modified gold electrodes which were obtained in a solution containing 0.1 M KCl and 5 mM $[Fe(CN)_6]^{3-/4-}$ at the formal potential of $[Fe(CN)_6]^{3-/4-}$. In the EIS technique, the events that occur in electrochemical systems, are stimulated by electrical circuits. The apparent resistance measured by the EIS method consists of a half-circle region and a nearly linear region. The half-circle region is measured at high frequencies and corresponds to the kinetic control of the charge transfer process. While the linear region is related to low frequencies and indicates the limitation of the redox process through diffusion.

The electrical equivalent circuit which was used for quantitative analysis of the EIS results is shown in the inset of Figure 3B. As is evident in this Figure, (according to the Nyquist plot), the bare electrode illustrates a big semicircle with a charge transfer resistance (R_{ct}) about 1200 Ω that exhibits the highest resistance to the electron transfer when compared with GO/AuE (70 Ω) and f-MWCNTs/AuE (1.8 Ω). Whereas, R_{ct} is 1.57 Ω for f-MWCNTs/GO/AuE which shows that the proposed electrode decreases the resistance of the redox reaction and hence, enhances the conductivity. In addition, the use of carbon nanotubes and GO accompanying with the gold metal nanoparticles can effectively increase the electron transfer and the edge density per unit area.

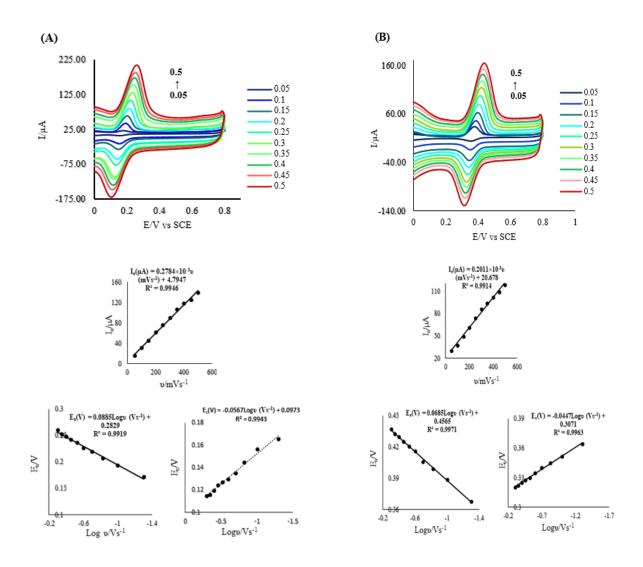## 3.3. Effective parameters

3.3.1. *Effect of pH*

The efficacy of pH on the electrochemical oxidation of DA and PA molecules was examined in 0.1 M PBS solution in the range of 4-9 (Figure 4). According to Figure 4, with increasing the pH of the solution, the anodic peak potential is shifted toward more negative values which indicate the role of protons in the rate-determining step of the redox reaction. The experimental results show that the peak current of the oxidation processes reaches a maximum at pH 7. Therefore, pH 7 was used as the optimum value in all measurements. Moreover, there is a linear relationship between the anodic peak current and the pH value in the pH range of 4 to 9, which shows that the equal number of protons and electrons are involved in the electrochemical oxidation reaction of DA and PA molecules.

Figure 4. The effect of pH on electrochemical oxidation of (A) dopamine and (B) paracetamol molecules at the surface of the f-MWCNTs/GO/AuNPS/AuE

3.3.2. Effect of scan rate

The influence of scan rate on the electrochemical behavior of DA and PA molecules at the f-MWCNTs/Go/AuNPs/AuE was investigated (Figure 5A & B). The experimental results denote linear relation between the peak currents and scan rate (v) in the range from 50 to 500 mV/s coinciding with the equations I_a (μA) $=0.2784 \times 10^3 v$ (mVs^{-1}) $+4.7947$ ($R^2=0.9946$) for DA and I_a(μA) $=0.2011 \times 10^{-3} v$ (mVs^{-1}) $+20.678$ ($R^2=0.9914$) for PA (Figure 5A & B). Therefore, it can be concluded that the electrochemical reactions of DA and PA molecules at the modified electrode are a surface-controlled adsorption kinetics process [27]. In addition, the peak potentials are shifted slightly towards the positive direction with increasing the scan rates which represents a quasi-reversible behavior for these electroactive systems [28].
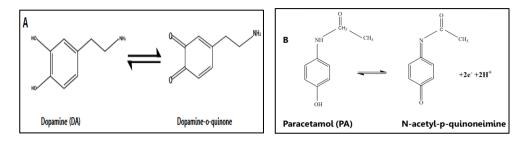
Figure 5. The effect of scan rate on the electrochemical response (the relationship between the anodic peak currents and scan rate and plots of anodic and cathodic peak potential changes versus the logarithm of scan rate) for (A) dopamine and (B) paracetamol molecules at the surface of f-MWCNTs/GO/AuNPs/ AuE

3.3.3. The redox mechanism of DA and PA molecules at f-MWCNTS/GO/AuNPs/AuE

The information about the electro-oxidation mechanism of DA and PA molecules at the surface of the fabricated electrode was acquired from the relationship between the values of potential and scan rate (υ). The number of electrons involved in the electrochemical process (n) and charge transfer coefficient (α) can be gained by using the variation of the anodic and cathodic peak potentials with the logarithm of scan rate, according to the Laviron equations [29]. The linear equations of the E_a and E_c vs. the logarithm of the scan rates, are expressed as $E_a = 0.2829 + 0.0885 \log \upsilon$ and $E_c = 0.0973 - 0.0567 \log \upsilon$ with $R^2 = 0.9919$ and 0.9943, for dopamine, respectively (Fig 5A). Likewise, the linear equations for paracetamol were obtained as: $E_a = 0.4565 + 0.0685 \log \upsilon$ with $R^2 = 0.9971$ and $E_c = 0.3071 - 0.0447 \log \upsilon$ with $R^2 = 0.9963$ (Figure 5B). According to the above equations, the values of the charge transfer coefficient (α)

and the electron transfer number (n) were calculated as 0.61 and 1.7 for DA, and 0.61 and 2.1 for PA, respectively. The experimental results show a quasi-reversible mechanism for electro-oxidation of dopamine and paracetamol molecules at the surface of the proposed electrode which can be explained via a two-proton and two-electron process (Figure 6A & B) which is in agreement with the results which are reported by the other research groups [30].

Figure 6. A schematic representation for electro-oxidation of (A) dopamine and (B) paracetamol at the f-MWCNTs/GO/AuNPs/AuE
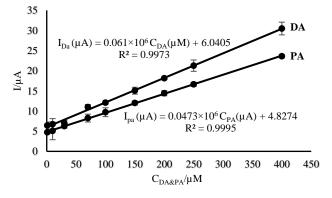
3.3.4. Effect of the amounts of f-MWCNTs and GO

The synergistic effect of f-MWCNTs and GO which have been employed as the modifier materials facilitates the electrochemical process and reduces the charge transfer resistance. Accordingly, optimizing the amount of modifying materials is of particular importance. The effect of the amounts of f-MWCNTs and GO coated on the electrode surface was examined by differential pulse voltammetry (DPV). For this purpose, the amounts of f-MWCNTs and GO were changed from 0-5 mg while the final amount of mixture was kept constant. With increasing the amounts of f-MWCNTs and GO from 0 to 2.5 mg, the anodic peak currents of DA and PA molecules increase and then decrease from 2.5 to 5, which indicates that the inordinate accumulation of each modifier material at the electrode surface, prevents the electrical conductivity of the electrode [31]. Therefore, the best synergistic effects are obtained with 2.5 mg of carbon nanotubes and 2.5 mg of graphene oxide which are selected as the optimal amounts.

3.4. Analytical performance of the electrode for quantitative measurement of DA and PA

In order to assess the analytical performance of the proposed electrode for determining the concentrations of DA and PA in aqueous solutions, differential pulse voltammetry (DPV) was applied under the optimal experimental conditions. As shown in Figure 7, the peak currents increase linearly with increasing the concentrations of DA and PA in solution within the range of 1 to 400 µM. The limits of detection (LOD) were calculated 5×10^{-7} M and 3×10^{-7} M for DA and PA, respectively.

The analytical parameters (detection limit and linear range) of the proposed electrode are compared with the other constructed electrochemical sensors for determining the concentration of DA and PA (Table 1). As is evident in this Table, the results obtained by the proposed

electrode, are better or in some cases compared with the results which are obtained by the other research groups.

$$I_{Da}(\mu A) = 0.061 \times 10^6\, C_{DA}(\mu M) + 6.0405$$
$$R^2 = 0.9973$$

$$I_{pa}(\mu A) = 0.0473 \times 10^6\, C_{PA}(\mu A) + 4.8274$$
$$R^2 = 0.9995$$

Figure 7. Calibration curves for DA and PA using f-MWCNTs/GO/AuNPs/AuE in phosphate buffer solutions (pH 7.0) which are obtained by DPV technique

Table 1. Comparison of detection limits and dynamic ranges of some electrochemical sensors for quantitative measurements of DA and PA in solutions

Modified electrode	LOD of DA (μM)	LOD of PA (μM)	Dynamic range of DA (μM)	Dynamic range of PA (μM)	References
f-MWCNTs/GCE	0.8	0.6	3-200	3-300	[33]
Pyrolytic carbon films	2.3	1.4	18-270	15-225	[34]
MWCNT-BPVCM	2.3	3.5	5-300 300-1000	5-150 150-1000	[35]
Poly (new coccine)	0.2	0.3	0.7-200	1.5-120	[36]
poly (Rhodamine B)/MWCNTs/GCE	0.05	0.65	0.5-20	3-70	[37]
[AgL]$_n$ (L= 4-nitro phenylcyanamide)/GCE	0.7	0.5	5-200	5-300	[38]
AgNPs/rGO	5.4	-	10-800	-	[39]
PtAu/l-Cysteine/GCE	24	-	24-384	-	[40]
f-MWCNTs/PNR/GCE	Not given	-	75-180	-	[41]
LDH/CILE	5	-	10-700 700-1100	-	[42]
DMSAa/Au	30	-	100-1000	-	[43]
C$_{60}$/GCE	-	50	-	50-1500	[44]
Electrochemically reduced graphene	-	1.2	-	5-800	[45]
Graphene/chitosan/GCE	-	0.3	-	1-100	[46]
Nevirapine MCPE	-	0.77	-	25-250	[47]
nano-TiO$_2$/polymer	-	2.0	-	12-120	[48]
N-(3,4-dihydroxyphenethyl)-3,5-dinitrobenzamide	-	10.0	-	15-270	[49]
SPE/PEDOT	-	1.39	-	4-400	[50]
Lt/fMWCNT/MGCE	-	0.78	-	0.9-80	[51]
5-amino-3′,4′-dimethoxy-biphenyl-2-ol /CNPE	-	0.9	-	220-850	[52]
f-MWCNTs-GO/AuNPs/AuE	0.5	1-400	0.3	1-400	This work

3.5. Repeatability, reproducibility, and stability of f-MWCNTs/GO/AuNPs/AuE

The repeatability of the modified electrode was investigated in 0.1mM concentration of the DA and PA molecules. The relative standard deviations for 5 successive measurements were obtained 4% for DA and 1% for PA.

The reproducibility of the f-MWCNTs/GO/AuNPs/AuE was assessed by fabricating 5 similar modified electrodes and measuring the current responses in 0.1 mM of DA and PA solutions. The relative standard deviations (RSDs) were found to be: 4% and 2% for DA and PA, respectively.

In order to evaluate the stability of the proposed electrode, we kept the sensor for 10 days in a refrigerator and then, we measured the electrochemical signal every day by DPV technique for 0.1 mM solutions of DA and PA. The experimental results, showed 96.52% and 93.30% of the initial response of the electrode for DA and PA, respectively.

The obtained results show that the proposed electrochemical sensor has good stability, repeatability and reproducibility.

3.6. Effect of interferences

One of the important characteristics for appraising the performance and selectivity of an electrochemical sensor is to provide a distinctive signal for a target analyte in the presence of various interfering compounds generally found in biological and pharmaceuticals environments [32]. In biological samples, the ascorbic acid (AA) and uric acid (UA) commonly interfere with dopamine and paracetamol. Therefore, the simultaneous determination of dopamine and paracetamol in the presence of these interfering species is important. For this purpose, the DPV technique was used for 0.1 mM solutions of DA and PA in the presence of these interfering species in which their concentrations were 10 and 100 times greater than the target analytes. The results which are summarized in Table 2, show that the presence of the interfering species in solutions does not have any significant interference with the determination of DA and PA using the proposed electrochemical sensor.

Table 2. The effect of interferences on the determination of dopamine and paracetamol in solutions

Interferent	%Recovery (10 times)	%Recovery (100 times)
Ascorbic acid (AA)	103	101
Uric acid (UA)	98	104

3.7. Analytical application

In order to evaluate the practical performance of the proposed electrode, pharmaceutical (dopamine ampule, paracetamol tablet) and human urine samples were examined by DPV technique and the corresponding results are summarized in Tables 3 and 4. The diluted sample solutions were spiked with applicable concentrations of each analyte. The standard addition method was used for the measurement of the prepared samples. The amount of DA in each ampoule and PA in each tablet were 200 mg and 500 mg, respectively. The amounts of these analytes which were determined by the modified electrode, were found to be: 197.2 mg per ampoule for DA and 501.4 mg per tablet for PA. In addition, satisfactory recoveries were obtained for all of the analytical samples. Therefore, the matrix of samples has no significant effect on the electrochemical response of the constructed sensor and, therefore, it can be used to measure the concentration of DA and PA molecules in real samples.

Table 3. The experimental results for determination of dopamine and paracetamol in pharmaceutical samples

Real samples	Initial concentration (μM)	Added (μM)	Found (μM)	Recovery (%)	RSD (%)
Dopamine ampule	5.00	4.00	9.01	100.28	0.34
	100.00	4.00	103.97	99.25	1.35
Paracetamol tablet	5.00	4.00	8.98	99.50	1.02
	100.00	4.00	104.02	100.52	1.15

Table 4. The experimental results for determination of dopamine and paracetamol in human urine samples

Real sample	Added (μM)		Founded (μM)		Recovery (%)		RSD (%)	
	DA	PA	DA	PA	DA	PA	DA	PA
Urine	20.00	20.00	20.03	19.96	100.15	99.80	0.26	1.89
	40.00	40.00	39.78	40.05	99.45	100.12	1.15	0.47

4. CONCLUSION

In the current research work, a suspension of f-MWCNTs/GO along with the electrochemical deposition of gold nanoparticles on the surface of a gold electrode was used to construct a sensitive and selective electrochemical sensor for simultaneous determination of

dopamine and paracetamol in aqueous solutions. Due to the unique properties of graphene oxide and multiwall carbon nanotubes with high surface area and electrical conductivity, they were used to modify the surface of a gold electrode. The gold nanoparticles with catalytic properties and electrical conductivity well distributed as a reinforcing phase on the carbon nanomaterials. Therefore, the sensitivity of the fabricated sensor for determining the concentrations of DA and PA in solutions is enhanced as a result of this good biocompatibility and the synergistic effect of the modifiers. The proposed sensor has a favorable linear response, acceptable stability, good repeatability and reproducibility for quantitative determination of the two target analytes in solutions. In addition, the results obtained for quantitative measurement of DA and PA in pharmaceutical formulations and urine samples were satisfactory, which suggests that f-MWCNTs/GO/AuNPs/AuE can be used as a proper sensor for the simultaneous determination the concentration of DA and PA in aqueous solutions.

Acknowledgment

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