The role of pramipexole functionalized MWCNTs to the fabrication of Pd nanoparticles modified GCE for electrochemical detection of dopamine

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Abstract

Background Interest in functionalized carbon nanotubes for many applications arises from a variety on the kind of modification atoms or molecules that are attached to it. Dopamine, the feel-good hormone, release by neurons and playing an important role in body systems. Abnormal dopamine levels cause nerve disorders such as Parkinson's disease and schizophrenia.

Objectives The aim of this study was the design and fabrication of electrochemical sensor based on MWCNTs and Pd nanoparticles for detection and determination of dopamine in biological samples.

Methods For this purpose, we report the synthesis of pramipexole-functionalized MWCNTs (pp-MWCNTs) for efficient capture of palladium nanoparticles and fabrication of Pd/pp-MWCNTs nanocomposite. Morphological and structural characteristics of the nanocomposites were characterized using various techniques including field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDX), and Fourier transform infrared spectroscopy (FT-IR).

Results This newly synthesized nanocomposite may have numerous applications in nanotechnology and sensing. We show that the synthesized nanocomposite reported here will be applicable for modifications of bare glassy carbon electrode (Pd/pp-MWCNTs/GCE) to sense of dopamine electrochemically. Two linear calibrations for dopamine are obtained over ranges of 0.01 to 10 μM and 10 to 200 μM with a detection limit of 1.4 nM. The Pd/pp-MWCNTs/GCE shows high stability and sensitivity, and an acceptable decrease of over-potential for the electrooxidation of dopamine that decreases interference in the analysis. The proposed Pd/pp-MWCNTs nanocomposite can be used as a voltammetric detector for dopamine monitoring in routine real sample analysis.

Conclusions The proposed sensor showed high sensitivity and selectivity in sensing dopamine in biological samples.

Keywords Electrochemical sensor · Pramipexole · Dopamine · Nobel metal nanoparticles

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Abbreviations

pp-MWCNTs	Pramipexole-functionalized MWCNTs
PdNPs	Palladium nanoparticles
FESEM	Field emission scanning electron microscopy
TEM	Transmission electron microscopy
XRD	X-ray diffraction
FT-IR	Fourier transform infrared spectroscopy
GCE	Glassy carbon electrode
EDX	Energy dispersive X-ray spectroscopy
AMT	2-amino-5-mercapto-1,3,4-thiadiazole
PEDOT	Poly(3,4-ethylenedioxythiophene)
PANI	Polyaniline

Introduction

Dopamine ($C_8H_{11}NO_2$) is a chemical substance released by nerve cells and functions as a neurotransmitter, to transmit signals to other nerve cells [1]. It is proved that dopamine is responsible for the regulation of hormonal balance, metabolism, as well as renal and cardiovascular systems. Abnormal level of dopamine indicates a neurological disorder such as Parkinson's and Schizophrenia disease [2]. The death of dopamine-secreting neurons causes a deficiency in dopamine production. This is the main reason for Parkinson's disease, which results in tremor and motor impairment. Early diagnosis of dopamine concentration levels is important to treat these disorders [3]. As the first problem, the concentration of dopamine is very low ($0.01\text{--}1\text{ }\mu\text{M}$) in the extracellular fluid of the central nervous system and many research groups have the interest to develop the highly sensitive and selective methods for determination of dopamine in biological systems [4]. Typically, the determination of dopamine is performed by using spectrophotometry [5], chromatography [6], capillary electrophoresis [7] and electrochemiluminescence [8]. Compared commonly used methods, development of electrochemical instrumentations, with a wide range of electrode modifiers, has provided the innovative methods for determination of dopamine. Furthermore, simple operation, high sensitive, cheap instruments and fast response in electrochemical methods make it attractive to researchers [9]. Li et al. reported the fabrication of nanohybrid containing a polymerized film of copper-2-amino-5-mercapto-1,3,4-thiadiazole ($Cu(II)$ -AMT) and reduced graphene oxide, as a proper mimetic enzyme for the ultrasensitive detection of dopamine [10]. Ye et al. constructed a photo-electrochemical sensor based on tremella-like $ZnIn_2S_4$ /graphene composite for dopamine detection [11]. Interferences from biochemical species such as ascorbic acid and urea that usually coexist in biological samples are the second main problem in the electrochemical measurement of dopamine. Many conventional electrodes suffer from moderate selectivity due to the overlapping of dopamine signals with urea and ascorbic acid [12]. Moreover, dopamine is an organic material that is easily oxidized, polymerized, and oxidation products accumulate at the electrode surface (fouling effect), which causes sensor performance degradation. Using nanostructured materials as modifier can improve sensitivity and selectivity at electrochemical sensing of dopamine.

In the last decade, carbon nanostructures-based electrodes have been widely used in the preparation of electrochemical sensors and biosensors [13]. Among them, carbon nanotubes (CNTs) have become more prominent due to their enormous benefits such as peerless structures, high electronic conductivity, loss of surface fouling and important mechanical strength [14]. Oh et al. used single-walled carbon nanotubes modified electrode for dopamine detection with limit of detection

$0.51\text{ }\mu\text{M}$ in the presence of ascorbic acid and uric acid [15]. Sangamithirai et al. prepared a nanocomposite containing poly(o-anisidine) and carbon nanotubes for modification of GCE that determine dopamine [16]. Furthermore, MWCNTs with other promising materials have been used as nanocomposite to enhance sensors performance in terms of sensitivity and selectivity [17]. In the last decades, special attention has been paid to use of noble metal nanoparticles so that increase the efficiency of electrochemical sensors [18]. High active sites on the surface area of CNTs provide an ideal platform for separate immobilization of metal nanoparticles [19]. Caetano et al. described the synthesis process of a nanocomposite containing carbon nanotubes and gold nanoparticles. The prepared nanocomposite was used to the fabrication of electrochemical sensor for dopamine detection [20]. Huang et al. fabricated a hybrid electrode based on 3D graphene foam with carbon nanotubes and gold nanoparticles [21]. Among different Nobel metal nanoparticle, Pd-based catalysts are more attractive to the researchers due to lower cost and good electro-catalytic ability [22]. Pd nanomaterials have also been used for making various types of dopamine electrochemical sensors. For example, carbon nanofiber covered with Pd nanoparticles, were used for simultaneous determination of dopamine, urea and ascorbic acid [23], PdNPs along with poly(3,4-ethylene dioxythiophene) film synthesized and used to simultaneous determination of dopamine and uric acid [24], a nanocomposite based on graphene oxide and PdNPs was fabricated for electrochemical determination of dopamine [25] and Pd–Pt nanoparticles immobilized on graphene oxide were used as an electrochemical sensor for simultaneous determination of ascorbic acid, dopamine and uric acid [26].

In this report, a simple structure developed as a voltammetric dopamine sensor using anchored PdNPs onto functionalized MWCNTs. Here, the MWCNTs have been functionalized by pramipexol that act as a support of the PdNPs. The Pd/pp-MWCNTs then uniformly immobilized onto the surface of the GCE. The experimental results showed that the Pd/pp-MWCNTs modified GCE exhibited excellent electrocatalytic activity towards the oxidation of dopamine. On the base of our knowledge, the present strategy for preparing an electrochemical sensor for determination of dopamine by immobilizing Pd nanoparticles onto the surface of pramipexol-functionalized MWCNTs has not been reported so far. The prepared Pd/pp-MWCNTs modified GCE is supposed to have very promising applications in electrochemical-based sensors.

Experimental

The materials, instrumentation and synthesis process of Pd/pp-MWCNTs nanocomposite are listed in the Supporting information.

Preparation of modified electrode

The surface of the GCE was carefully polished with alumina powder on polishing cloth until a smooth surface was obtained. Then, it was rinsed successively with ethanol and double distilled water in an ultrasonic bath for 2 min and dried in a stream of nitrogen gas. 1.0 mg of

Pd/pp-MWCNTs was dispersed in 1.0 mL of ethanol by 10 min ultrasonic agitation to obtain a homogeneous Pd/pp-MWCNTs suspension. 5.0 μL of the Pd/pp-MWCNTs suspension was dropped on the surface of GCE to obtain the Pd/pp-MWCNTs/GCE. For comparison, pp-MWCNTs modified GCE (pp-MWCNTs/GCE) was prepared using a similar procedure.

Fig. 1 **a** FT-IR spectra of MWCNT-COOH and MWCNT-CO-pramipexole. **b** XRD pattern of Pd/pp-MWCNTs nanocomposite. **c** FESEM image of Pd/pp-MWCNTs nanocomposite. **d** TEM images of Pd/pp-MWCNTs nanocomposite. **e** EDX pattern of Pd/pp-MWCNTs nanocomposite

Results and discussion

Characterization of Pd/pp-MWCNTs nanocomposite

To confirm the functionalization of MWCNTs by pramipexole, the control experiment carried out using FT-IR spectroscopy. Figure 1a demonstrates the FT-IR spectra of carboxylated MWCNTs (MWCNT-COOH), and pp-MWCNTs. As seen in the spectrum of MWCNT-COOH, the band at 1705 cm^{-1} is related to stretching vibrations of carbonyl in the carboxylic acid group. Moreover, the presence of a broad peak in $2400\text{--}3450\text{ cm}^{-1}$ is corresponding to the OH group, which represents the oxidation of MWCNTs and induce functional groups such as hydroxyl on the surface of MWCNTs. The spectrum of pp-MWCNTs displays the absorption band at 1642 cm^{-1} is related to the carbonyl stretching of the amide groups ($-\text{CONH}-$). Also, symmetric and asymmetric methylene stretching bands at 2868 and 2923 cm^{-1} was assign to the bending vibration of CH_2 . The indicator IR bands at 3411 and 3547 cm^{-1} were ascribed to the NH stretching vibrations. These results confirm that the pramipexole was bonded to the surface of MWCNTs through amidation reaction.

The crystal structure of the Pd/pp-MWCNTs nanocomposite was studied by XRD (Fig. 1b). Four major diffraction peaks situated at 38.2° , 44.38° , 64.55° , and 77.45° correspond to (111), (200), (220) and (311) crystal planes of the Pd nanoparticles (JCPDS FileNo. 05–0681) and prove the successful synthesis of Pd^0 . The XRD spectra of the functionalized MWCNTs exhibit plane of hexagonal graphite (002) at $2\theta = 26.3^\circ$, indicating that no structure change occurred during chemical treatment of MWCNTs [27].

The structure and morphology of Pd/pp-MWCNTs nanocomposite were described by FESEM and TEM. Figure 1c, d show that the nanocomposite has a stable structure consisted of well-distributed Pd nanoparticles on the surface of the MWCNTs and there is no serious agglomeration phenomenon. In actual, the CNT walls can be used as the support substrate of Pd nanoparticles. Here, direct covalent sidewall functionalization of MWCNTs has effectively prevented the agglomeration of Pd nanoparticles and the stacking of MWCNTs, as well as enhancing the electron conductivity of nanocomposite. EDX analysis specifies the elemental composition of the synthesized nanocomposite. According to EDX patterns of nanocomposite (see Fig. 1e), the presence of metallic Pd, C, O, and N were confirmed in the structure of Pd/pp-MWCNTs.

Electrochemical impedance spectroscopy analysis

Electrochemical impedance spectroscopy (EIS) is a powerful and valuable technique to determine the impedance change of

the electrode surface during different modification steps. The related experiments were done in $5\text{ mM } [\text{Fe}(\text{CN})_6]^{3-/4-}$ solution containing 0.1 M KCl at scanning frequencies from 0.01 to 50.0 Hz . Figure 2a shows the results of EIS on the bare GCE, pp-MWCNTs/GCE and Pd/pp-MWCNTs/GCE in the solution of $[\text{Fe}(\text{CN})_6]^{3-/4-}$. From the semicircle portion situated at the high-frequency range of Nyquist plot, the charge transfer resistance, R_{ct} , value for the GCE extracted to be $2558\ \Omega$. Nyquist plots obtained for the GCE after each modification step showed a significant decrease in R_{ct} that indicates the formation of the conductive layer on the electrode surface. Subsequent to the addition of Pd to the structure of nanocomposite, we observed a dramatical decrease in the charge-transfer resistance value in the Nyquist plot. The decrease in R_{ct} due to the addition of Pd nanoparticles to the surface is expected; because of two electron-conducting agents have synergic effect at the electron transfer process.

Fig. 2 a Nyquist plots of GCE (a), pp-MWCNTs/GCE (b) and Pd/pp-MWCNTs/GCE (c) and (b) cyclic voltammograms of the GCE (green line), pp-MWCNTs/GCE (blue line), and Pd/pp-MWCNTs/GCE (red line) in $5\text{ mM } [\text{Fe}(\text{CN})_6]^{3-/4-}$ (1:1) solution containing 0.1 M KCl

Cyclic voltammetry characterization of modified electrodes

The CV was used to examine the electrochemical propriety of Pd/pp-MWCNTs. Figure 2b shows the cyclic voltammogram for the bare and modified GCEs in 0.1 M KCl containing 5.0 mM $\text{Fe}(\text{CN})_6^{3-/4-}$ as the redox probe. As seen in Fig. 2b, the anodic and cathodic peak currents were increased after modification of GCE by pp-MWCNTs and Pd/pp-MWCNTs, respectively. Whereas the peak to peak separation was decreased compared to the GCE. These results can be explained with the electro-catalytic effect of Pd nanoparticles and MWCNT used in this work.

Electrochemical behavior of dopamine on the surface of bare and modified electrodes

Cyclic voltammetry was used to investigate the electroanalytical performance of bare and modified electrodes. Figure 3 demonstrates the electrochemical behaviors of bare GCE, pp-MWCNTs/GCE and Pd/pp-MWCNTs/GCE at the presence and absence of dopamine in 0.1 M PBS (pH 6.0). In the absence of dopamine, the background current of Pd/pp-MWCNTs/GCE shows very large amounts compare to bare

GCE (inset of Fig. 3) because of the great electroactive surface area and good conductivity of nanocomposite [28]. In the presence of dopamine, a relatively weak pair redox peaks with low currents and high separation at anodic and cathodic peak potentials ($\Delta E_p = 225$ mV) observes at the bare GCE, which can be attributed to slower electrochemical reaction of dopamine on the bare GCE. In the case of the MWCNTs modified GCE (Fig. 3b), the peak currents were higher than the bare GCE and the ΔE_p decreased to 100 mV, which can be related to the high conductivity and large surface area of MWCNTs. At the surface of pp-MWCNTs/GCE, the anodic and cathodic peak current of dopamine increases by a factor of 2, and the peak-to-peak separation is 50 mV lower than the bare GCE. This result can be attributed to two factors: (i) MWCNTs provided large surface area and good adsorption ability for adsorption amount of pramipexole and (ii) the positively charged amino group of dopamine at the experimental pH value of 6.0 which facilitates the adsorption of dopamine on the negatively charged pp-MWCNTs/GCE surface. The Pd/pp-MWCNTs/GCE displays the largest peak current (4 times more than the bare GCE) and the lowest over-potential. This dramatical enhancement of peak current can be attributed to the synergistic effect of pp-MWCNTs and Pd nanoparticles as follows: (i) the Pd nanoparticles act as main active sites and

Fig. 3 Cyclic voltammograms of GCE (a), MWCNTs/GCE (b) pp-MWCNTs/GCE (c) and Pd/pp-MWCNTs /GCE (d) in 100 μM dopamine and 0.1 M PBS at scan rate of 0.1 V s^{-1} . Inset: cyclic voltammograms of GCE (a) and Pd/pp-MWCNTs/GCE (b) in the absence of dopamine

catalytic centers, which upturn the conduction of electrons; (ii) the pp-MWCNTs platform provide effective matrix with large surface area for immobilization of Pd nanoparticles, which increase interaction of analyte with electrode surface. According to the above study, Pd/pp-MWCNTs nanocomposite can be a worthy choice for the electrochemical detection of dopamine.

Effect of solution pH

The pH effect of the buffer solution on the sensor response was studied over the pH range 5.0 to 10.0 in 0.1 M PBS containing 100 μM dopamine (Fig. 4). The higher anodic current was obtained at pH 6 and then decreased substantially from pH 6 to 10 (inset B in Fig. 4). This pH is close to the optimal pH for the operation of dopamine [29] and was selected as the optimum value for the electrochemical detection of dopamine in the subsequent experiments. The effect of the pH on the oxidation potential of dopamine was studied and a linear regression equation of $E_{\text{pa}}(\text{V}) = -0.0664 \text{ pH} + 0.73$ ($R^2 = 0.9910$) was recorded in the pH range 5.0 to 10.0 (inset C in Fig. 4). As expected, oxidation peak potential (E_{pa}) of dopamine shows the linear shift to more negative

amounts with the slope of -0.0664 V/pH unit which is close to the Nernstian value of 0.059 V at 25°C and proves that the number of protons and electrons participating in the electrochemical reaction are equal.

Effect of scan rate

In order to obtain information on the kinetic parameters and electro-oxidation mechanism of dopamine, cyclic voltammetry studies were done by Pd/pp-MWCNTs/GCE at different scan rates. Figure 5 illustrates cyclic voltammograms at the Pd/pp-MWCNTs/GCE in an unstirred 0.1 M PBS pH 6.0 with 100 μM dopamine. Experiments started at the scan rate of potential 0.01 Vs^{-1} . Upon addition of potential scan rate up to 0.3 Vs^{-1} , the redox peak currents of dopamine increased linearly as following equations: $I_{\text{pa}} (\mu\text{A}) = 0.0425 (\text{Vs}^{-1}) + 1.2905$; $R^2 = 0.9961$ and $I_{\text{pc}} (\mu\text{A}) = -0.0258 (\text{Vs}^{-1}) - 0.7125$; $R^2 = 0.9878$. These results reveal that the oxidation of dopamine is an adsorption controlled process [30]. The number of electrons for the electro-oxidation of dopamine was calculated using Laviron's equation [16].

$$i_p = nFQv/4RT \quad (1)$$

Fig. 4 **a** Cyclic voltammograms of Pd/pp-MWCNTs/GCE in 0.1 M PBS and 100 μM dopamine at different pH values (from a to f: 5.0, 6.0, 7.0, 8.0, 9.0, and 10.0), **(b)** variation of the peak currents versus pH and **(c)** variation of peak potentials versus pH

where F is the Faraday constant, n the number of electrons, T represents the temperature (298 K), R the gas constant and Q is the charge related to the oxidation peak of dopamine, the number of electrons involved in the oxidation reaction were found to be 2 for dopamine. Therefore, the redox reaction of dopamine is a two-electron and two-proton process. In addition, Tafel region was monitored at the scan rate of 0.025 V s^{-1} and a Tafel plot was depicted by the rising oxidation part of the i - E curve of dopamine on the modified electrode (Fig. 5c).

The obtained slope of Tafel was 0.038 V per decade and the electron transfer coefficient was calculated to be $\alpha = 0.38$.

Analytical performance

Differential pulse voltammetry (DPV) was utilized to ascertain the electroanalytical ability of Pd/pp-MWCNTs nano-composite at determination of dopamine. Figure 6 shows the DPVs of a Pd/pp-MWCNTs/GCE in 0.1 M PBS containing

Fig. 5 a Cyclic voltammograms of Pd/pp-MWCNTs/GCE in 0.1 M PBS and $100 \mu\text{M}$ dopamine at different scan rates: (a) 0.01 , (b) 0.025 , (c) 0.050 , (d) 0.075 , (e) 0.1 , (f) 0.15 , (g) 0.2 , (h) 0.25 and (i) 0.3 V s^{-1} ,

(b) variation of the peak currents, I_p , vs. the scan rate, and (c) Tafel plot recorded at scan rate 0.025 V s^{-1}

different concentrations of dopamine. As seen from Fig. 6, the anodic signal increased linearly with the increase of dopamine concentration in the two ranges of 0.01–10 μM and 10–200 μM . The calibration curves are presented in the inset of Fig. 6. In the range of 10–200 μM , the linear regression equation is $I_p(\mu\text{A}) = 0.244 C(\mu\text{M}) + 2.6783$ $R^2 = 0.9847$. In the meantime, the measurements in the range of 0.01–10 μM

presents a calibration curve with linear regression equation of $I_p(\mu\text{A}) = 0.0669 C(\mu\text{M}) + 4.1355$ $R^2 = 0.9938$. The detection limit was 1.4 nM ($3.3S_b/m = 3$). The electrochemical response in such a low concentration range was enough to show the rather high sensitivity of the sensor towards dopamine. Compared with the results of previous reports (Table 1), the proposed sensor in this work

Fig. 6 DPVs obtained at the Pd/pp-MWCNTs/GCE in 0.1 M PBS. The dopamine concentrations in μM are the following: (a) 0.01, (b) 0.1, (c) 5, (d) 10, (e) 30, (f) 50, (g) 100, (h) 130, (i) 160 and (k) 200. Inset: linear dependence of the peak currents with dopamine concentration

Table 1 The results obtained for dopamine detection in real sample ($n = 5$) using Pd/pp-MWCNTs/GCE

Sample	Added (μM)	Found (μM)	R.S.D	Recovery (%)
Serum	0	—	—	—
	30	29.0 ± 0.84	2.9	96.3
	60	69.4 ± 1.93	2.7	115.1
Urea	0	—	—	—
	30	30.40 ± 0.48	1.6	109.6
	60	65.77 ± 0.48	0.7	101.0

exhibited a higher sensitivity, wider dynamic response range, and low detection limit.

Interference test and stability evaluation

The influence of various coexistent interference substances on the detection of $100 \mu\text{M}$ of dopamine was investigated by DPV under the optimized conditions. The tolerance limit was taken as the amount of foreign species causing $\pm 10\%$ error in detection dopamine. For 250-fold concentration of Al^{3+} , K^+ , Na^+ , SO_4^{2-} , NO_3^- , Cl^- , NO_2^- and 100-fold concentration of Fe^{3+} , Ca^{2+} , Co^{2+} glucose, sucrose and uric acid changes of anodic currents were less than 10%. Furthermore, interference study was done on levodopa drug which has the same function and structure as dopamine and also ascorbic acid. No interferences were observed at similar concentrations for determination of dopamine. The reproducibility of the proposed sensor was studied by evaluating the oxidation current of $100 \mu\text{M}$ of dopamine with three independent electrodes. The RSD of the electrode response was only 2.8%, indicating a proper reproducibility. Since the presented sensor can be used at the monitoring of biological samples, evaluation of its long-term stability is the main factor. The stability of the sensor was investigated by DPV technique at the $100 \mu\text{M}$ dopamine solution. After 2 months' storage at room temperature, the

current response of the fabricated sensor to $100 \mu\text{M}$ dopamine decreased 3.2% of its initial oxidation current. The exceptional long-term stability can be attributed to the high stability of synthesized nanocomposite on the electrode surface in the studied solution.

Estimation of dopamine in serum and urine samples

The practical applicability of the modified electrode was evaluated by the determination of dopamine in human urea and serum samples. Two samples of human blood serum were procured from the local clinical laboratory (Dr. Ganati Lab, Sabzevar, Iran). 1.0 mL of human blood serum samples or human urea samples were added into the electrochemical cell containing 9.0 mL 0.1 M PBS (pH 6.0) and analyzed without any further pretreatment. Subsequently, the prepared samples were spiked with certain amounts of dopamine. The amounts of dopamine in the human blood serum and human spiked urine were determined by the calibration curve. The percentages of the recovery values were estimated by comparing the concentrations obtained from the samples with actually added concentrations. The results summarized in Table 2. The recoveries ranged from 96.3% to 115.1%, which shows good reliability and accuracy of this method in the practical sample analysis.

Conclusions

In summary, we reported the synthesis of the Pd/pp-MWCNTs nanocomposite by covalent bonds of pramipexole to MWCNTs and then immobilization of PdNPs on it. The Pd/pp-MWCNTs nanocomposite characterized and used as a new platform for dopamine detection. The Pd/pp-MWCNTs/GCE exhibited the great electro-catalytic ability, board linear range, low detection limit and stable response toward dopamine detection. From the DPV studies, a detection limit of 1.4 nM and linear range of 0.01–200 μM were obtained for dopamine. With excellent sensitivity and selectivity, the proposed sensor

Table 2 Comparison between various methods for determination of dopamine with the proposed method

Modifier	LOD (μM)	LDR (μM)	Method	Ref.
MWCNTs/CeO ₂ -PEDOT ^a	0.030	0.1–400	DPV	[31]
PEDOT-modified laser scribed graphene	0.330	1–150	DPV	[32]
CuO nanoparticles	0.055	0.4–40	DPV	[33]
^b PANI-NiO	0.015	2.4–20	DPV	[34]
PdNPs	0.025	0.05–130	DPV	[35]
β -MnO ₂	8.200	0.03–65	Amperometry	[36]
Pd/pp-MWCNTs	0.001	0.01–200	DPV	This work

^a Poly(3,4-ethylenedioxythiophene)

^b Polyaniline

can be feasibly used to determination of dopamine in practical real samples.

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Author's contributions MB designed this study, BM and HV synthesized and characterized the Pd/pp-MWCNTs nanocomposite, MN and MM performed the electrochemical experiments, MB and MN wrote the manuscript and MBT prepared drug material. All authors read and approved the final manuscript.

Compliance with ethical standards

Consent for publication All authors agree to publish the manuscript.

Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval Not applicable.

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