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Simultaneous electrochemical determination of dopamine and acetaminophen using multiwall carbon nanotubes modified glassy carbon electrode

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ABSTRACT

A highly sensitive method was investigated for the simultaneous determination of dopamine (DA) and acetaminophen (AP) using acid functionalized multi-wall carbon nanotubes (f-MWCNTs) modified glassy carbon electrodes (GCEs). Both DA and AP were accumulated at the surface of f-MWCNTs modified GCE (under open circuit condition for 30 s). In differential pulse voltammetry (DPV) technique both DA and AP give sensitive oxidation peaks at 125 mV and 307 mV, respectively. Under the optimized experimental conditions (such as supporting electrolyte pH, accumulation time and scanning rate, etc.) DA and AP give linear response over the range of 3–200 μmol L^{-1} (r = 0.992) and 3–300 μmol L^{-1} (r = 0.989), respectively. The lower detection limits were found to be 0.8 for DA and 0.6 μmol L^{-1} for AP. The interfering species such as ascorbic acid (AA), uric acid (UA) and reduced form of Nicotinamide adenine dinucleotide (NADH) showed no interference with the selective determination of DA and AP. The investigated method showed good stability, reproducibility (1.3% (DA) and 2.3% (AP)), repeatability (1.9%) and high recovery in pharmaceutical preparation (1.7% (DA) and 2.7% (AP)), and human serum (1.7% (DA) and 1.9% (AP)).

1. Introduction

Dopamine (4-(2-aminoethyl) benzene-1,2-diol (DA)) (Scheme 1a) is a naturally occurring biogenic catecholamine formed by the decarboxylation of 3,4-dihydroxyphenylalanine and is a precursor to epinephrine and nor-epinephrine in a biosynthetic pathway [1], which functions as a neurotransmitter in the central and peripheral nervous systems. Insufficient DA concentration due to the loss of DA-producing cells may lead to a disease called Parkinson's disease [2] in which a person loses the ability to execute smooth and controlled movements [3–5]. DA can be supplied as a medication, however its excess dosage may act on the sympathetic nervous system causing increased heart rate and blood pressure. Acetaminophen (*N*-acetyl-*p*-aminophenol or paracetamol (AP)) (Scheme 1b) has been used comprehensively all over the world as a pharmaceutical pain reliever for patients who are susceptible to aspirin and safe up to therapeutic doses [6]. AP relives pain in the central nervous system and the concentration of it is high. In contrary, the physiological levels of DA are below 200 μmol L^{-1} [7], thus the investigation of electrochemical response of DA at the low concentration with the existence of excess AP is necessary. Few methods based on the chemical modification of traditional electrode materials have been reported for the determination of DA (e.g., electrochemical determination of DA in the presence of ascorbic acid using sodium dodecyl sulfate micelles as masking agent [8], poly-chromotrope 2B modified GC electrode [9], Nafion/carbon-coated iron nanoparticles–chitosan composite film modified electrode [10] and PtAu hybrid film modified electrode [11]) and AP (e.g., L-cysteine film modified GC electrode [12], carbon-coated nickel magnetic nanoparticles modified GC electrodes [13], and 4-amino-2-mercaptopyrimidine self-assembled monolayer modified gold electrode, etc. [14]). However, most of these methods face oxidation of biomolecule at electrode, fouling of electrode (due to adsorption of the oxidation products), unstable analytical signal [15], require high over potential, high detection limit, slow response and most of all are complex. The recent use of carbon nanotubes (CNTs) modified electrodes has revolutionalized the electrochemical techniques for the determination of biomolecules due to their exceptional properties [16–19] e.g. small dimensions, high mechanical strength [20], electric [21,22] and thermal behavior [23,24], biocompatibility, high stability, modifiable sidewalls [25–28], high surface area (creating a large interfacial region, which can have properties different from bulk material [29]), and are therefore best suited for almost any aspect of nanotechnology, including electronic and optoelectronic devices, biomedical, pharmaceutical, cosmetic, automotive, aeronautic and aerospace industries, catalytic, and analytical chemistry [30,31]. The good conductivity, the capability to accelerate electrode reactions (electro-catalytic effect in

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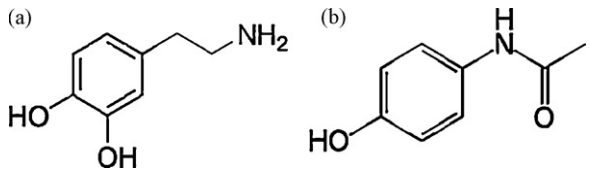

Scheme 1. (a) Dopamine (4-(2-aminoethyl) benzene-1, 2-diol) and (b) acetaminophen (*N*-acetyl-*p*-aminophenol).

redox processes) and modifiable sidewalls have made CNTs (both single wall (SWCNT) and multiwall (MWCNT) carbonanotubes) ideal candidates for constructing high-performance sensors [32,33]. Pristine MWCNTs (p-MWCNTs) has shown electron transfer kinetics due to the open ends of the MWCNTs, i.e. the so-called "edge-plane defects" [34–36] but poor dispersion in both organic and aqueous medium [29]. To overcome this limitation and bring about their purification, surface modification and electrochemical activation [37]. They are usually treated with oxidizing acids (e.g., nitric acid). However, over oxidation should be avoided as it will slow down the electron transfer at edge-plane defects [34]. In the present work, we report a highly sensitive electrochemical method for the simultaneous determination of DA and AP using f-MWCNTs modified GCE. The proposed method is simple, sensitive, easy to apply and economical for routine analysis. We believe that the proposed method would be a potential step forward in the simultaneous electrochemical determination of DA and AP in biological fluids.

2. Experimental

2.1. Materials

p-MWCNTs (10–50 nm in diameter) were obtained from CNT Co. Ltd., Incheon, Korea. Nitric acid (HNO_3), acetaminophen ($C_8H_9NO_2$), dopamine ($C_8H_{11}NO_2$), N,N-dimethylformamide (DMF) (C_3H_7NO), sodium hydroxide (NaOH), hydrochloric acid (HCl) and alumina powder (Al_2O_3) were purchased from Aldrich, sodium phosphate monobasic monohydrate ($NaH_2PO_4{\cdot}H_2O$) and sodium phosphate dibasic dihydrate ($Na_2HPO_4{\cdot}2H_2O$) used for the preparation of phosphate buffer solution (PBS) of pH 8.0 were obtained from Merck. All the reagents were of analytical grade. Double distilled water and 0.1 μmol L^{-1} PBS pH 8.0 (as supporting electrolyte) were used throughout the experimental work.

2.2. Functionalization of p-MWCNT

p-MWCNTs were rinsed with double-distilled water and dried prior to functionalization. 50 mg of the dried p-MWCNTs were refluxed in 4 mol L^{-1} HNO_3 for 24 h and filtered through polycarbonate membrane [38]. The residues were washed with double distilled water and dried at 60 °C for 12 h. The dried acid f-MWCNTs (MWCNTs-COOH) were then crushed in a mortar with pestle and dispersed homogeneously in DMF *via* ultrasonic agitation for 10 min. p-MWCNTs did not show dispersion in DMF and settled at the bottom of the vial soon after their sonication, whereas f-MWCNTs showed homogeneous and stable dispersion in DMF for several days (see Fig. 1a and b, Section 3.1).

2.3. Preparation of f-MWCNTs modified GCE

Prior to modification, the GCE was mechanically polished with alumina powder (0.05 μm) to mirror finish and ultrasonicated in double distilled water for 3 min. The freshly cleaned GCE was electrochemically activated in a 0.1 μmol L^{-1} H_2SO_4 solution at a scan rate of 100 mV/s using 20 times cyclic potential sweeps in the range of −0.5 to 2.0 V. 20 μL of the freshly prepared (5 mg/5 mL) dispersion of f-MWCNT in DMF was dropped onto the GCE surface and the solvent was evaporated with infrared (IR) lamp. The diameter and surface area of the f-MWCNT modified GCE were determined as 3.0 mm and 0.0314 cm^2, which were in agreement with the reported values [39].

2.4. Pharmaceutical sample solution preparation

15 tablets of the PACIN^{TM} 650 and Dopaminum Hydrochloricum (Roche South Korea) were finely powdered in a mortar with pestle. Calculated amounts of the tablets required for 300 μmol L^{-1} of AP and DA were separately transferred into 25 mL volumetric flask and were dissolved in PBS pH 8. The content of the flask were sonicated for 5 min to affect complete dissolution. Finally the solutions were filtered and suitable aliquot of the clear filtrate were collected and stored in the refrigerator for further use.

2.5. Serum sample preparation

Drug-free human blood, obtained from healthy volunteers (after obtaining their written consent), was centrifuged at 4000 rpm for 30 min at room temperature. A 1.2 mL of acetonitrile was added to a 2 mL serum sample to remove serum protein, followed by fortification with DA and AP dissolved in PBS to achieve the final concentrations of DA and AP as 300 μmol L^{-1} and 200 μmol L^{-1}, respectively. After vortexing for 45 s, the mixture was centrifuged for 10 min at 10,000 rpm to remove the serum protein residues. Supernatant was taken carefully and appropriate volumes of this supernatant were transferred into the electrochemical glass cell and diluted upto the volume with the PBS.

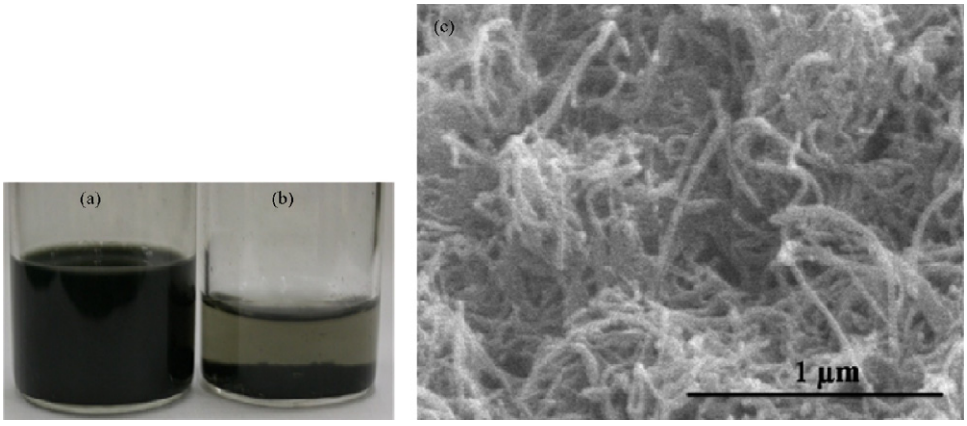

Fig. 1. Digital images of the MWCNTs dispersed in DMF (a) f-MWCNTs, (b) p-MWCNTs and (c) SEM micrograph of the surface of f-MWCNTs modified GCE.

2.6. Apparatus

All electrochemical measurements were carried out using computer-controlled portable Potentiostat (RS-PDA1, Palm Instruments, and Netherland). The voltammetric experiments were performed in an electrochemical cell that contains bare or f-MWCNTs modified GCE as a working electrode, platinum wire as an auxiliary electrode and Ag/AgCl as a reference electrode. All potentials mentioned in this paper were referred to the reference electrode. Magnetic stirrer was used for the convective transport of the analyte. A centrifuge instrument (Model Eppendorf-5417C) was used to separate the precipitated protein before analysis of the human serum. Ultrasonic bath (Bransonic 5210, USA) was used for the dissolution of sample and cleaning the electrode surface. pH meter (Mettler Toledo MP220, UK) was used for the pH measurement. Morphology of the f-MWCNTs modified GCE was studied using a Hitachi S-570 field emission-scanning electron microscope (FE-SEM).

2.7. Analytical procedure

The f-MWCNTs modified GCE was first activated in PBS by cyclic voltammetric sweeps between 0.0 and 0.6 V until stable cyclic voltammograms were obtained. After obtaining the stable cyclic voltammograms, the f-MWCNTs modified GCE was transferred into a new cell containing PBS and certain concentration of the analyte. Cyclic voltammograms were taken individually for DA and AP followed by their binary mixture to confirm the peak positions. The open-circuit accumulation time was 30 s. For the calibration of the analytes, differential pulse voltammogram from 0.0 to 0.6 V at a scan rate of 30 mV/s was recorded. Upon using the differential pulse voltammetric technique the oxidation peaks for DA and AP appeared at 125 and 307 mV, respectively. After every measurement, the f-MWCNTs modified GCE was dipped into 0.1 μmol L^{-1} NaOH solution for few seconds to remove the adsorbed substances. For the serum sample the electrode was dipped in 1 μmol L^{-1} HCl for 30 s followed by dipping in 0.1 μmol L^{-1} NaOH solutions. To check the reproducibility of f-MWCNTs modified GCE surface, 5 successive cyclic voltammetric sweeps were performed in pure PBS before each experiment. All sample solutions were deoxygenated by purging N_2 gas before each experiment.

3. Results and discussion

3.1. Characterization of f-MWCNT modified GCE

Fig. 1a and b shows the digital images of the p-MWCNTs and f-MWCNTs dispersed in DMF and the SEM micrograph of the f-MWCNTs modified GCE surface (Fig. 1c). It was observed from the digital images that f-MWCNTs dispersed well in DMF compared to p-MWCNTs, which settle down at the bottom of the vial soon after agitation. SEM micrograph showed densely packed f-MWCNTs onto the GCE surface. The micrograph also revealed that f-MWCNTs are efficiently entrapped onto the GCE surface.

3.2. Cyclic voltammetric behaviors of DA and AP on f-MWCNTs modified GCE

Fig. 2 illustrates the cyclic voltammograms of DA and AP on f-MWCNTs modified GCE in PBS within the potential window of 0.0–0.60 V and at scan rate of 50 mV/s. Both DA and AP showed well-behaved oxidations peaks at the f-MWCNTs modified GCE with their main oxidation steps at 150 and 335 mV, respectively, whereas no separate peaks were observed for DA and AP at bare GCE under the same conditions (the results for the bare electrode are not shown in Fig. 2). The current enhancement for DA and AP on

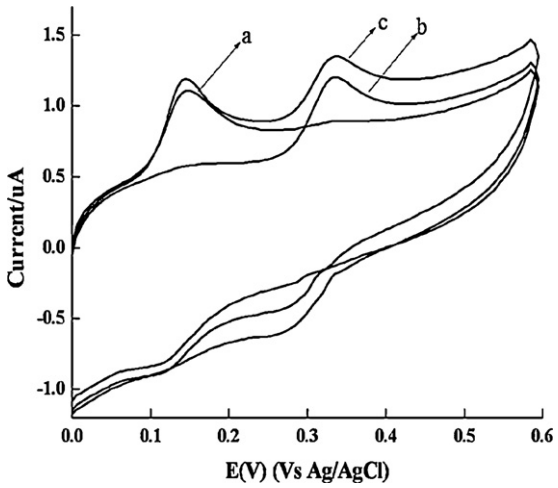

Fig. 2. Cyclic voltammograms of (a) DA, (b) AP and (c) DA and AP mixture in PBS at f-MWCNT-modified GCE. Concentration of each analyte = 50 μmol L^{-1}; E_{ads} = 0.0 V; t_{ads} = 30 s; scan rate: 50 mV/s.

f-MWCNTs modified GCE might be attributed to the large surface area, strong adsorptive ability, unique structure with unsaturated suspending bonds, pentagons carbon loops, pentagon–heptagon defect pairs of the f-MWCNTs [40].

3.3. Simultaneous determination of DA and AP

Fig. 3 exhibits the differential pulse voltammograms (DPVs) obtained for DA and AP mixture on f-MWCNT modified GCE in PBS by synchronously changing the concentrations of DA and AP. The current responses due to the oxidations of DA (at 125 mV) and AP (at 307 mV) with the peak difference of 182 mV were observed to increase linearly with a correlation coefficient of 0.992 and 0.989, respectively. Whereas no oxidation peaks for DA and AP were observed on bare electrodes under the same condition. The peak positions for DA and AP in mixture might be attributed to the different electrochemical activity of their function groups (Scheme 1) [40]. The oxidation mechanism of DA and AP at separated potentials on the f-MWCNTs modified GCE might involve the electrostatic interaction of the electrode surface and the analyte. f-MWCNTs

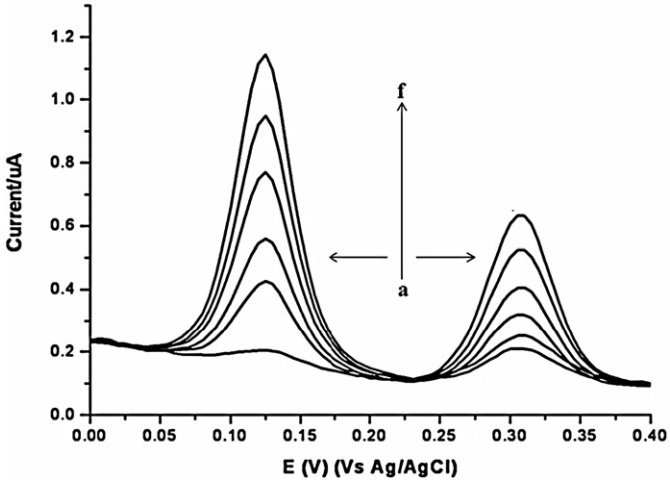

Fig. 3. DPVs for the mixture containing DA and AP with different concentrations at f-MWCNTs modified electrode, DA concentrations: (a) 2 μmol L^{-1}, (b) 10 μmol L^{-1}, (c) 50 μmol L^{-1}, (d) 120 μmol L^{-1}, (e) 150 μmol L^{-1}, (f) 200 μmol L^{-1}; AP concentrations: (a) 10 μmol L^{-1}, (b) 40 μmol L^{-1}, (c) 80 μmol L^{-1}, (d) 140 μmol L^{-1}, (e) 200 μmol L^{-1}, (f) 250 μmol L^{-1}; scan rate: 30 mV s^{-1}, pH 8.0.

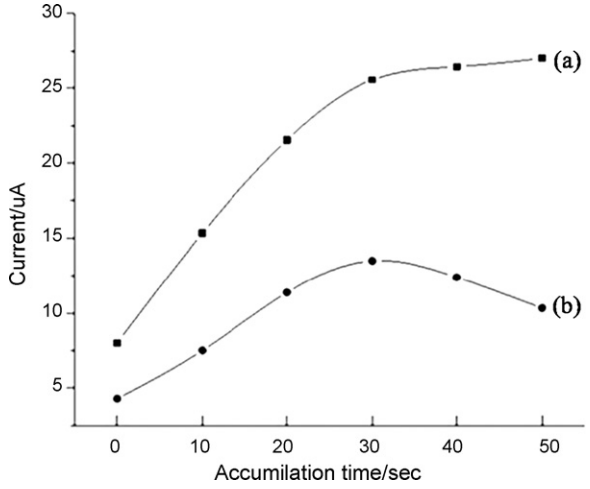

Fig. 4. Optimization of open circuit accumulation time (seconds) on f-MWCNTs modified GCE for (a) DA (50 μmol L^{-1}) and (b) AP (100 μmol L^{-1}) using CV technique in 0.1 μmol L^{-1} PBS (pH 8) and 50 mV/s scan rate.

modified GCE contains electron rich groups in its backbone, which acts both as electron source and multivalent nature reaction sites. These groups are capable to oxidize DA and AP with respect to their oxidation potentials and reduce their selves.

3.4. Preconcentration of DA and AP on f-MWCNTs modified GCE

Optimization of the experimental conditions such as accumulation time, scant rate, supporting electrolyte pH and scan rate have been carried out to get the maximum response for the investigated method. In case of individual DA and AP solutions, the accumulation time showed no obvious effect on the oxidation peak current of DA and AP. However, for the mixed solution of DA and AP after 2 min of the accumulation time, the response was poor therefore the accumulation time ranging from 0 to 50 s was optimized again for the mixed solution. As can be observed (Fig. 4) the current for DA and AP increases up to 30 s, however after 30 s a decrease in the current response was observed. The remarkable increase in peak current with an increase in the accumulation time (t_{ads}) is owing to the adsorption kinetics of DA and AP on f-MWCNTs modified GCE. The adsorption equilibrium was estimated to reach t_{ads} in 30 and 50 s for DA and AP, respectively. A little difference in the adsorption kinetic for these species is reasonable due to the little difference in molecular structure of DA and AP. In this study, an accumulation time of 30 s was chosen as optimum for the mixture of DA and AP to obtain stable peak with higher sensitivity and shorter analysis time. The influence of electrode potential E_{ads} plays an important role for preconcentration. Experimental results showed that peak currents decreased slightly when the accumulation potential shifted from 0.0 to 0.60 V. Hence the potential around 0 V was considered as favorable for obtaining the maximal peak currents for both the species in pH 8.0. The DPV measurements were also carried out by transferring f-MWCNTs modified GCE into a blank electrolyte solution after the surface accumulation. Similar DPV peaks with only a very small decrease in peak current was observed for the medium exchange, which proved that the interaction of DA and AP with f-MWCNTs modified GCE was strong, and the DPV peaks were mainly contributed by the species pre-accumulated at the electrode surface. The effect of scan rate for CV and DPV techniques on the anodic peak current of DA and AP was also studied. The optimum scan rate for CV and DPV was 50 and 30 mV/s respectively. The electrochemical oxidation behaviors of DA and AP on f-MWCNTs modified GCE in various pH media (e.g. phosphate buffer (pH 8), sodium citrate-buffer (pH 3.0–6.2), Britton–Robinson buffer (pH 2.0–7.0) were compared by CV and DPV. The maximum peak currents and peak resolutions for DA and AP oxidation were observed in the PBS (pH 8). This phenomenon could be attributed partly to the dissociation of carboxylic (COOH) group of f-MWCNTs in different pH environments. COOH group dissociated into negatively charged carboxylate (COO^-) group, when the solution pH was 8. Under this condition, the NH_2 group of DA molecules (pK_a 8.9) [41,42] and the NH group of AP molecules could obtain protons and form the positive ions of DA and AP. Thus the negatively charged (COO^-) group on the surface of f-MWCNTs modified GCE finds an affinity to the positively charged ions of DA and AP, which could catalyze and promote the oxidation of DA and AP efficiently, hence PBS pH 8 was chosen as the determining medium.

3.5. Effect of interferences

In biological samples, AA, UA and reduced form of NADH are the common important interferences. Furthermore, at bare electrodes these molecules oxidize at a potential close to that of DA and AP [43,44]. The voltammetric responses were recorded by using f-MWCNTs modified GCE in 0.1 μmol L^{-1} PBS (pH 8) before and after the successive addition of 10 mmol L^{-1} AA, 10 mmol L^{-1} UA and 10 mmol L^{-1} NADH. This was done to check the accuracy of the developed method in the presence of AA, UA and NADH. No change in the peak currents for DA and AP was observed under the potential range used. It was concluded that AA, UA and NADH are not interfering with DA and AP at f-MWCNTs modified GCE. This behavior could be explained on the basis of the dissociation ability of COOH group of f-MWCNTs in different pH environments. In PBS (pH 8.0) COO^- groups are negatively charged and might be responsible to repel the negatively charged species. AA, UA and NADH remains negatively charged (which are highly resonance stable due to their special chemical structure) as they could easily donate proton in the basic medium of pH 8, consequently they could not interfere to the detection procedure of DA and AP. From the above discussion we can conclude that f-MWCNTs modified GCE can be applied for the determination of DA and AP in the presences of AA, UA and NADH.

3.6. Stability, reproducibility and repeatability of the modified electrode

Stability of f-MWCNTs modified GCE was tested by keeping the electrode in PBS pH 8 for 30 days, after this time period the CVs were recorded and compared with CVs obtained before immersion. The results indicated that peak current decreased only slightly for f-MWCNTs modified GCE, which indicated that f-MWCNTs modified GCE has good stability. A relative standard deviation (R.S.D.) of 1.3% and 2.3% for 10 measurements of 100 μmol L^{-1} of DA and AP, respectively suggested that f-MWCNTs modified GCE has higher reproducibility. Four f-MWCNTs modified GCE fabricated independently, were used to determine 100 μmol L^{-1} AP and the R.S.D. was 3.5%, revealing an excellent repeatability of the electrode preparation procedure. To ascertain the repeatability of the electrode, 10 measurements of 100 μmol L^{-1} AP were carried out using f-MWCNTs modified GCE at the intervals of 1 h. The R.S.D. value was found to be 1.9%, which indicated that f-MWCNTs modified GCE has good repeatability.

3.7. Analytical application

3.7.1. Calibration curve

Fig. 5a exhibits the DPVs that were obtained in different concentrations (3–200 μmol L^{-1}) of DA in the presence of 20 μmol L^{-1} AP on f-MWCNTs modified GCE. The voltammetric peak corre-

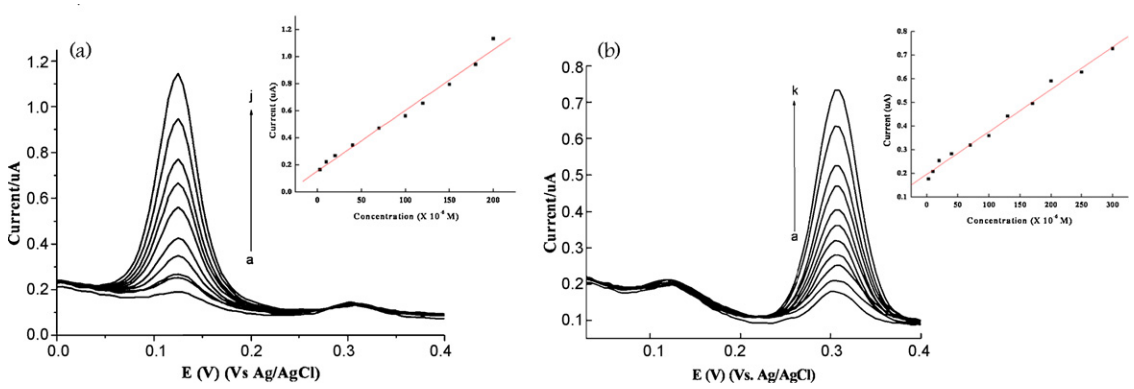

Fig. 5. (a) DPVs obtained for DA in the presence of 20 μmol L^{-1} of AP at f-MWCNTs modified GCE in 0.1 mol L^{-1} PBS (pH 8). Concentration of DA: (a) 3 μmol L^{-1}, (b) 10 μmol L^{-1}, (c) 20 μmol L^{-1}, (d) 40 μmol L^{-1}, (e) 70 μmol L^{-1}, (f) 100 μmol L^{-1}, (g) 120 μmol L^{-1}, (h) 150 μmol L^{-1}, (i) 180 μmol L^{-1} and (j) 200 μmol L^{-1} and (b) DPVs obtained for AP in the presence of 10 μmol L^{-1} of DA at f-MWCNTs modified GCE in 0.1 mol L^{-1} PBS (pH 8). Concentration of AP: (a) 3 μmol L^{-1}, (b) 10 μmol L^{-1}, (c) 20 μmol L^{-1}, (d) 40 μmol L^{-1}, (e) 70 μmol L^{-1}, (f) 100 μmol L^{-1}, (g) 130 μmol L^{-1}, (h) 170 μmol L^{-1}, (i) 200 μmol L^{-1}, (j) 250 μmol L^{-1} and (k) 300 μmol L^{-1}.

Table 1
Determination of DA an AP in pharmaceutical preparations.

Tablet	Sample	Labeled		Found (mg)		Recovery (%)		R.S.D. (%)	
		DA	AP	DA	AP	DA	AP	DA	AP
PACIN™ 650	1	–	650	–	653	–	100.5	–	2.70
	2	–	650	–	656	–	100.9	–	2.72
	3	–	650	–	655	–	100.8	–	2.71
Dopaminum hydrochloricum	1	200	–	201.7	–	100.85	–	1.70	–
	2	200	–	203.1	–	101.55	–	1.71	–
	3	200	–	201.9	–	100.95	–	1.74	–

Table 2
Determination of dopamine and acetaminophen in human serum samples.

Human serum	Added (μmol L^{-1})		Found (μmol L^{-1})		Recovery (%)		R.S.D. (%)	
	DA	AP	DA	AP	DA	AP	DA	AP
Sample 1	10	10	10.00	10.02	100	100.2	1.70	2.03
Sample 2	50	100	49.25	98.99	98.5	98.99	1.70	1.93

sponding to the oxidation of DA was found to increase linearly in consonance with the increase in bulk concentration of DA, whereas the peak current for oxidation of AP remain the same as the number of cycles increased. Fig. 5b exhibits the DPVs that were obtained in different concentrations (3–300 μmol L^{-1}) of AP in the presence of 10 μmol L^{-1} DA on f-MWCNTs modified GCE. The voltammetric peak corresponding to the oxidation of AP was found to increase linearly in consonance with the increase in the bulk concentration of AP, whereas the peak current for the oxidation of DA remain the same as the number of cycles increased. The inset figures (Fig. 5a and b) show the plots of the DPV peak currents versus the increasing concentrations of DA and AP, respectively. The peak currents corresponding to the oxidation of DA and AP increased linearly while increasing the concentrations with correlation coefficients of 0.994 and 0.995, respectively. A similar study is performed by Kachoosangi et al. using multiwalled carbon nanotube modified basal plane pyrolytic graphite electrodes (MWCNT-BPPGE) for the detection of paracetamol in pharmaceutical products. The detection limit (0.1–25 μmol L^{-1}) obtained by Kachoosangi et al. was 45 nM whereas for our method the detection limits was found to be 0.8 and 0.6 μmol L^{-1} for DA and AP, respectively but with improved linear range. These results indicated that the f-MWCNTs modified GCE is sensitive towards DA in the presence of high concentration (upto 100 μmol L^{-1}) of AP and towards AP in the presence of high concentration (upto 100 μmol L^{-1}) of DA.

3.7.2. Determination of DA and AP in pharmaceutical preparation and human serum

The investigated method was validated for the determination of DA and AP in pharmaceutical preparations (PACIN™ 650 and Dopaminum Hydrochloricum) and human serum samples. After sample preparation and adequate dilution steps as described earlier, the DPVs method was applied to the determination of DA and AP in pharmaceutical preparations and human serum samples. The summarized results for the analysis are given in Tables 1 and 2. The mean results of the five determinations for the pharmaceutical preparations of AP and DA were close to the values declared on the labels. To check the accuracy of the investigated method in pharmaceutical preparations and its applicability to the determination of AP and DA in the human serum, the recovery studied were carried out. The obtained recovery results in Tables 1 and 2 indicates that f-MWCNT modified GCE can be successfully used for the determination of DA and AP in both the pharmaceutical preparations and human serum.

4. Conclusion

An electrochemical method was developed and successfully applied for the simultaneous determination of DA and AP using f-MWCNTs modified GCE. A pre-concentration step was established for the accumulation of these species at the electrode obtaining well separated voltammetric peaks for sensitive and selective deter-

mination of DA and Ap. In the anodic sweep from 0.0 to 0.6 V, both DA and AP adsorbed at the surface f-MWCNTs modified GCE and oxidized at 125 and 307 mV, respectively upon using DPV. Experimental conditions such as supporting electrolyte pH, accumulation time and scanning rate, etc., were optimized for the investigated method. DA and AP give linear response over the range of 3–200 μmol L^{-1} (r = 0.992) and 3–300 μmol L^{-1} (r = 0.989), respectively. The lower detection limits were found to be 0.8 and 0.6 μmol L^{-1} for DA and AP, respectively. The interfering species such as AA, UA and reduced form of NADH showed no interference with the selective determination of DA and AP. The investigated method showed good stability, reproducibility (1.3% (DA) and 2.3% (AP)), repeatability (1.9%) and high recovery in pharmaceutical preparation (1.7% (DA) and 2.7% (AP)), and human serum (1.7% (DA) and 1.9% (AP)). The proposed method is simple, sensitive, easy to apply and economical for the routine analysis, which could be used not only in evaluating the quality of some medicines in marketplaces but also in investigating their contents in human bodies.

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