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Application of Hematoxylin Multi-wall Carbon Nanotube Modified Carbon Paste Electrode as a Chemical Sensor for Simultaneous Determination of Dopamine and Acetaminophen

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A hematoxylin multi-wall carbon nanotube modified carbon paste electrode (HMWCNT-CPE) was fabricated and the electrochemical behavior of dopamine (DA) was investigated on it, using cyclic voltammetry, chronoamperometry and differential pulse voltammetry as diagnostic techniques. A comparison of the data obtained from the electrocatalytic oxidation of DA at HMWCNT-CPE, MWCNT-CPE, and hematoxylin modified CPE (HMCPE) clearly shows that a combination of MWCNT and hematoxylin definitely improves the characteristics of DA electrocatalytic oxidation. The kinetic parameters such as the electron transfer coefficient, α, and the heterogeneous electron transfer rate constant, k', for the oxidation of DA at the HMWCNT-CPE surface were determined using cyclic voltammetry. Differential pulse voltammetry (DPV) exhibits two linear dynamic ranges (2.0×10^{-1} µM to 8.0 µM and 8.0 µM to 1000.0 µM) and a detection limit of 6.0×10^{-2} µM for DA. In DPV, HMWCNT-CPE could separate the oxidation peak potentials of DA and acetaminophen (AC) present in the same solution though, at the unmodified CPE, the peak potentials were indistinguishable. The sensitivity of the modified electrode for DA determination in the absence and presence of AC is the same. It indicates the fact that simultaneous or individual measurement of DA and AC is possible without any interference. Low cost and simplicity, wide linear range, good reproducibility, and stability are the important advantages of this modified electrode. Finally, the modified electrode was successfully applied to the determination of DA and AC in pharmaceutical preparations.

Keywords: Dopamine; Acetaminophen; Hematoxylin; Biosensor, Simultaneous determination

1. INTRODUCTION

It has been shown that carbon tends to be more compatible with biological tissues than other commonly used electrode materials [1]. Among carbon electrodes, carbon paste electrode (CPE) is of

particular importance. The ease and speed of preparation and of obtaining a new reproducible surface, low residual current, porous surface, and low cost of carbon paste are some advantages of CPE over all other carbon electrodes. Therefore, CPE can provide a suitable electrode substrate for preparation of modified electrodes. It is essential to use different nano materials such as gold nanoparticles [2, 3], nano-nickel oxide [4], carbon nanoparticles [5], single walled carbon nanotubes [6, 7], double-wall carbon nanotubes [8], and multi-wall carbon nanotubes [9, 10] for improving the characteristics of CPEs. Carbon nanotubes, as a new kind of porous nanostructure material which are 10,000 times thinner than human hair and 100 times stronger than steel [11], exhibit several unique electrical, geometrical, and mechanical properties. Thus, they can promote electron transfer reactions when used as an electrode material in electrochemistry devices. The direct electrocatalytic activity of important chemical and biochemical compounds such as hydrazine [12], epinephrine [13], cholesterol [14], NADH and hydrogen peroxide [15], ascorbic acid [16], uric acid [17], proteins [18], nitric oxide [19], hydrogen sulfide [20], and glucose [21] have been investigated on the surface of different electrodes modified with carbon nanotubes. Also, the preparation of a carbon nanotube powder microelectrode and its usage in the electrocatalytic of dopamine oxidation has been reported by Zhao et al. [22].

Dopamine (DA) is an important neurotransmitter that belongs to catecholamines group and plays a very significant role in the central nervous, renal, hormonal and cardiovascular systems [23]. Many diseases are related to changes in DA concentration, and the determination of DA concentration in biological systems provides crucial information regarding DA physiological functions [24]. High performance liquid chromatography (HPLC) was used as a sensitive method with a high resolution for the determination of DA and other neurotransmitters [25,26]. However, this method is complicated and usually time-consuming. To be employed, it also needs well-trained personnel. Therefore, the development of simple, fast, and reliable alternative methods for the determination of DA is necessary. Due to the electroactive nature of DA, a lot of efforts have been made to devising electrochemical methods for its determination over the past few decades [23, 27-34].

Acetaminophen, AC (4'-hydroxyacetanilide) is a popular analgesic and antipyretic agent. Its action is similar to aspirin and is an appropriate alternative for patients who are sensitive to acetylsalicylic acid [35]. So far many methods have been used for the determination of AC in pharmaceutical formulations and biological fluids including titrimetry [36], UV–Vis spectrophotometry [37-39], near infrared transmittance spectroscopy [40], chromatography [41,42], and electrochemical methods [43–46]. The determination of DA at bare electrodes is complicated due to the presence of possible interferences such as AC which is oxidized at the same potential.

AC electrophysiological [47] effects support the idea that this potent analgesic drug can act in the central nervous system (CNS). Animal model studies have shown that AC might protect neurons from degeneration. For example, AC can protect primary rat embryonic DA neurons from glutamate toxicity [48]. Also, AC administration at antinociceptive doses affects serotonin (5-HT) and dopamine levels in various brain areas and the spinal cord in rats [49]. Additionally, important drugs such as AC will interfere with DA measurements in biological samples [50]. Thus, it is necessary to develop low-cost, simple, reproducible and reliable methods for simultaneous determination of DA and AC, which is a major goal of electroanalytical research [28]. Our research group has previously published something about biosensors which can be used for the simultaneous determination of various important

biological molecules [33,51-53] usually co-exiting in biological systems such as the extra cellular fluid of the central nervous system, serum, and urine. The above published results have their advantages and limitations. Consequently, it is necessary to have further efforts to fabricate simple, selective and sensitive biosensors that can improve the simultaneous determination of some biological molecules. Also, there are a few papers regarding the electrochemical properties of hematoxylin [54-56]. Based on this context, for the first time, we have employed hematoxylin multi-wall carbon nanotube modified carbon paste electrode (HMWCNT-CPE) for DA electrocatalytic oxidation and simultaneous determination of DA and AC that exit in synthetic and pharmaceutical preparations at the physiological pH (pH 7.0). Interestingly, HMWCNT-CPE successfully separates the electro-oxidation of these species into two well-defined peaks. The results show that the modified electrode has several definite advantages such as low cost and simplicity, wide linear range, good reproducibility and stability.

2. EXPERIMENTAL PART

2.1. Chemicals and apparatus

Hematoxylin, DA, AC, and other reagents were of analytical grade from Merck and used as received. Multi-wall carbon nanotubes (10-20 nm in diameter, length of 5-20 μm, purity of 95%) were purchased from NanoLab Inc. (Brighton, MA). A DA injection solution (from Caspian Tamin Pharmaceutical Co., Rasht-Iran), an AC oral solution and AC tablets of AC (from Pharma Chemi Darou Co., Tehran-Iran) were bought from a local drugstore. All the solutions were prepared with doubly distilled water. DA and AC solutions were prepared just prior to use. The buffer solution (0.5 M) was made up from H_3PO_4+NaH_2PO_4, and the pH was adjusted to 0.5 M H_3PO_4 and 2.0 M NaOH. All the electrochemical experiments were carried out using an Autolab potentiostat PGSTAT 30 (Ecochemie, Netherlands) equipped with a GPES 4.9 software. The cell used was equipped with a hematoxylin multi-wall carbon nanotubes modified carbon paste disk electrode (HMWCNT-CPE) as the working electrode, a platinum electrode as the auxiliary electrode, and a saturated calomel electrode (SCE) as the reference electrode. All the potentials in the text are mentioned versus this reference electrode. A personal computer was used for data storage and processing: The pH was measured with a Metrohm model 691 pH/mV meter.

2.2. Fabrication of HMWCNT-CPE

A mixture of hematoxylin (3.0 mg), graphite powder (100.0 mg), MWCNT (1.0 mg) and paraffin oil (80 mg) was blended by hand in a mortar with a pestle to prepare the hematoxylin MWCNT modified carbon paste (HMWCNT-CP). The body of the carbon paste working electrode was a Teflon rod with a hole (2 mm in diameter and 5 mm deep) bored at one end for paste filling. The electrical connection was made with a copper wire through the center of the rod which was screwed to the RDE device. To fabricate HMWCNT-CPE, the prepared HMWCNT-CP was tightly inserted into

the hole of the electrode body. A fresh electrode surface was generated rapidly by smoothing the resulting surface on white paper until a smooth shiny surface was observed. To fabricate hematoxylin CPE (HMCPE) and MWCNT-CPE, the use was made of the mixture of HMWCNT-CP that was free from MWCNT and hematoxylin respectively. The preparation of the electrodes was performed as well as the procedure that was discussed for HMWCNT-CPE.

3. RESULTS AND DISCUSSION

3.1. Electrocatalytic oxidation of DA at HMWCNT-CPE

Fig. 1 shows the cyclic voltammograms of HMWCNT-CPE (curve a) and HMCPE (curve c) in a 0.5 M phosphate buffer solution (pH 7.0) at a scan rate of 20 mV s^{-1}. As it can be seen, there was a pair of well defined redox couple of hematoxylin at HMWCNT-CPE with a high anodic peak current (2.4 μA), and relatively high background currents. However, for HMCPE, a cyclic voltammogram with a low anodic peak current (1.3 μA), and low background currents were observed. The higher background voltammetric responses and the higher sensitivity of HMWCNT-CPE than HMCPE are due to the increase of the surface area of HMWCNT as compared with HMCPE.

The cyclic voltammetric responses of the electrochemical oxidation of 0.80 mM DA at HMWCNT-CPE (curve b), HMCPE (curve d), MWCNT-CPE (curve e), and unmodified CPE (curve f) show that the anodic peak potential for the oxidation of DA at the different electrodes are about 210, 280, 300 and 540 mV respectively. The result regarding the oxidation of DA at MWCNT-CPE was reported in the literature [57]. Table 1 shows the electrochemical characteristics of DA oxidation at various electrode surfaces at pH 7.0. From Table 1, it is concluded that the best electrocatalytic effect on DA oxidation is observed at HMWCNT-CPE. For example, the results show that the peak potential of DA oxidation at HMWCNT-CPE (curve b) shifts about 70, 90, and 330 mV toward the negative values compared with those at HMCPE (curve d), MWCNT-CPE (curve e), and unmodified CPE (curve f) respectively. Similarly, there is a dramatic enhancement in the anodic peak current at HMWCNT-CPE as compared to the values obtained at HMCPE, MWCNT-CPE, and unmodified CPE. In other words, as the data obtained clearly show, the combination of MWCNT and hematoxylin (as a mediator) definitely improves the characteristics of DA oxidation.

Fig. 2A shows the cyclic voltammograms of a 0.80 mM DA solution (C_b=0.80 mM) at different sweep rates. As indicated by this Fig., the catalytic oxidation peak potential gradually shifts towards more positivity with the increase of the scan rate. It suggests a kinetic limitation in the reaction between the redox site of the hematoxylin and DA. However, the oxidation currents increase linearly with the square root of the scan rate (Fig. 2B), suggesting that at a sufficient overpotential, the reaction is mass transport controlled. From the slope of the I_P versus $v^{1/2}$ plot (Fig. 2B), one can obtain the number of electrons in the overall reaction. According to the following equation for a totally irreversible diffusion controlled processes [58]:

$$I_p = 3.01\times10^5\ n[(1-\alpha)n_\alpha]^{1/2}AC_bD^{1/2}v^{1/2} \quad (1)$$

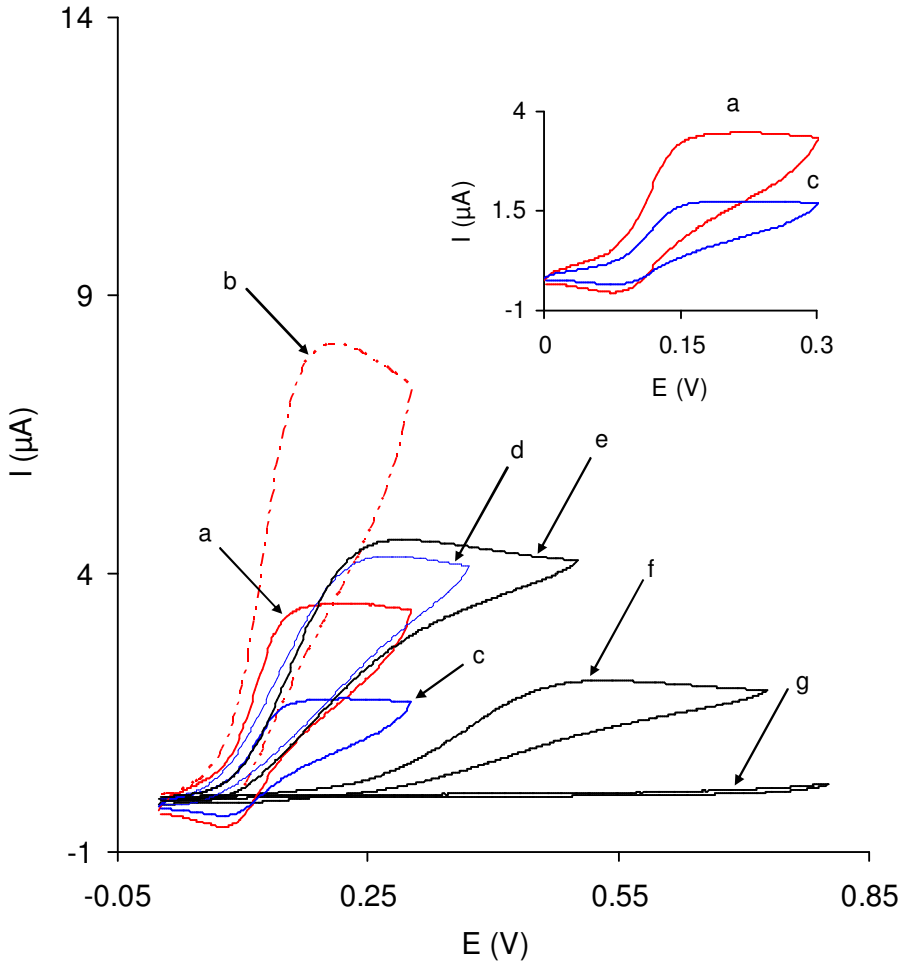

Figure 1. Cyclic voltammograms of HMWCNT-CPE in 0.5 M phosphate buffer (pH 7.0) solution in (a) the absence and (b) the presence of 0.80 mM DA, (c) as (a) and (d) as (b) for a HMCPE. (e) as (b) for MWCNT-CPE, (f) as (b) and (g) as (a) for an unmodified CPE. Scan rate: 20 mV s^{-1}.

Table 1. Comparison of electrocatalytic oxidation of DA on various electrode surfaces at pH 7.0.

Name of electrode[a]	Oxidation potential (mV)	Oxidation peak current (μA)
UCPE	540	1.50
HMCPE	280	4.05
MWCNT-CPE	300	4.14
HMWCNT-CPE	210	7.15

[a]UCPE: unmodified carbon paste electrode; HMCPE: hematoxylin modified carbon paste electrode; MWCNT-CPE: multi-wall carbon nanotubes modified carbon paste electrode; HMWCNT-CPE: hematoxylin multi-wall carbon nanotubes modified carbon paste electrode

and considering $(1 - \alpha)n_\alpha = 0.78$ (see below), $D = 9.8 \times 10^{-6}$ cm^2 s^{-1} (obtained by chronoamperometry below), and $A = 0.0314$ cm^2, it is estimated that the total number of electrons involved in the anodic oxidation of DA is $n = 1.84 \cong 2.0$.

In the case of slow potential scans, *v*, and large catalytic rate constant, k′, Andrieux and Saveant [59] developed a theoretical model for a heterogeneous catalytic reaction:

$$I_{cat} = 0.496nFADC_b v^{1/2}(nF/RT)^{1/2} \quad (3)$$

Low values of k′ result in coefficient values lower than 0.496. For low scan rates (2–14 mV s^{-1}), we found the average value of this constant to be 0.31 for HMWCNT-CPE in the presence of 0.80 mM DA. According to the approach of Andrieux and Saveant and using Fig. 1 in their theoretical paper [59], we calculated an average value of $k' = (3.0 \pm 0.1) \times 10^{-3}$ cm s^{-1}.

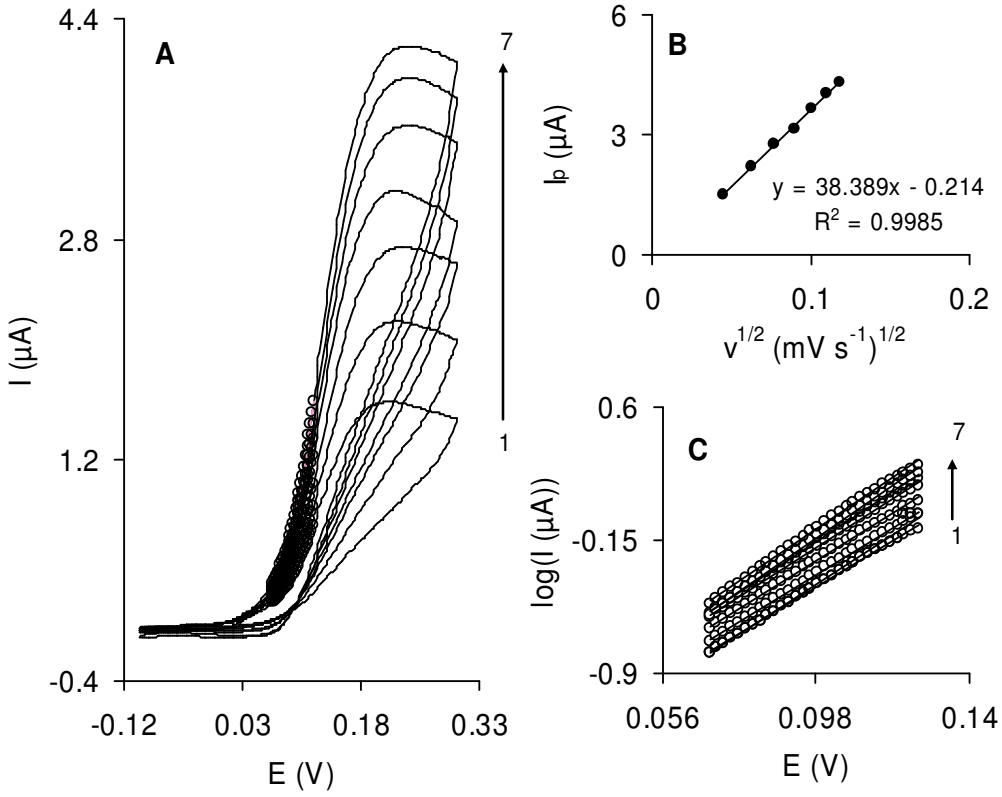

Figure 2. (A) Cyclic voltammograms of HMWCNT-CPE in 0.5 M phosphate buffer (pH 7.0) containing 0.80 mM DA at different scan rates. The numbers of 1-7 correspond to 2, 4, 6, 8, 10, 12 and 14 mV s^{-1} respectively. The points are the data used in the Tafel plots of (C). (B) Variation of the electrocatalytic peak current (I_p) with the square root of sweep rate. (C) Tafel plots derived from the rising part of the voltammograms shown in (A).

Fig. 2C shows Tafel plots that were drawn from the data on the rising part of the current voltage curve recorded for the scan rates (2 to 14 mV s^{-1}). This part of the voltammogram, known as

Tafel region, is affected by electron transfer kinetics between DA and hematoxylin, assuming the deprotonation of DA as a sufficiently fast step. In this condition, the number of electrons involved in the rate-determining step can be estimated from the slope of Tafel plot. A slope of 13.2 V decade^{-1} is obtained indicating a one electron transfer to be rate-limiting assuming a transfer coefficient of α = 0.22. Also, the value j_0 was found to be 1.0 μA cm^{-2} from Tafel plots [60].

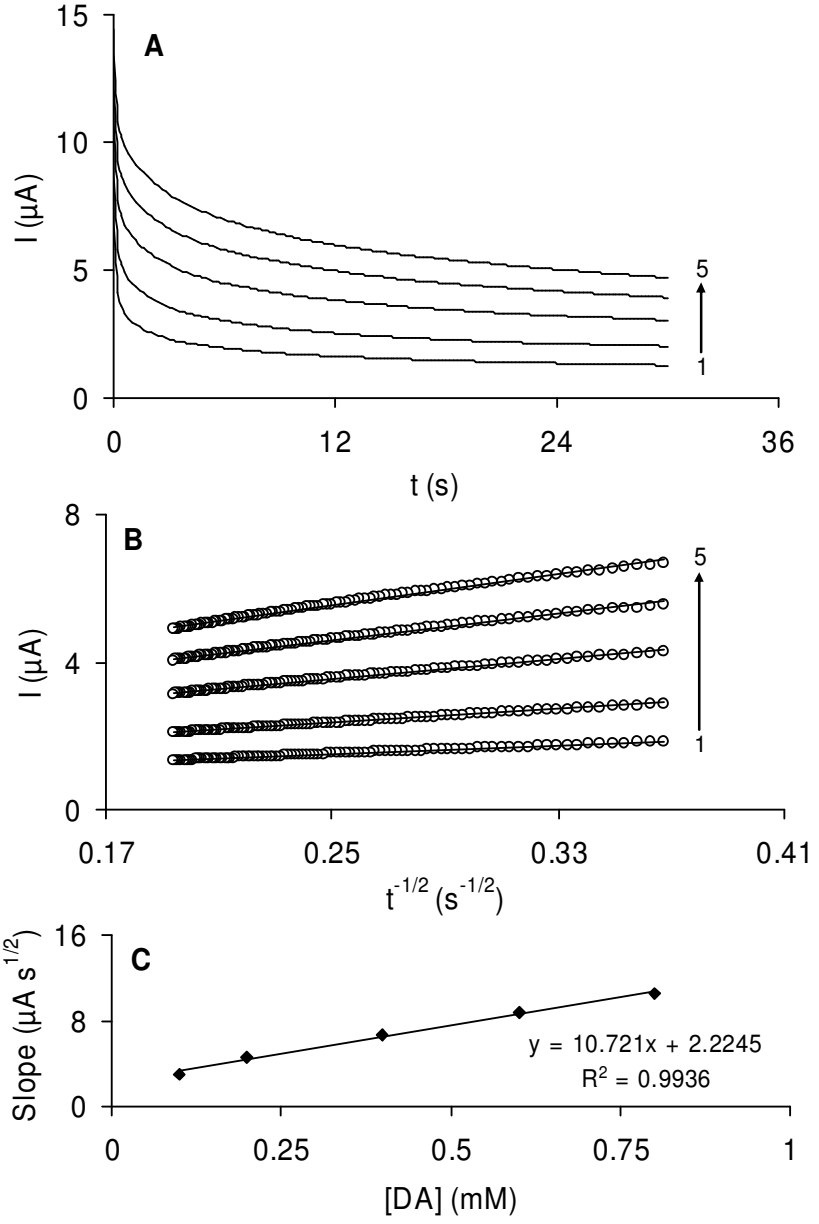

Figure 3. (A) Chronoamperometric response at HMWCNT-CPE in 0.5 M phosphate buffer (pH 7.0) at a potential step 280 mV for different concentrations of DA. The numbers of 1-5 correspond to 0.10, 0.20, 0.40, 0.60 and 0.80 mM DA. (B) Plots of I versus $t^{-1/2}$ obtained from the chronoamperograms. (C) Plot of the slope of straight lines of (B) against the DA concentration.

The catalytic oxidation of DA by HMWCNT-CPE was also studied by chronoamperometry. Chronoamperometric measurements are depicted in Fig. 3A. In chronoamperometric studies, we have determined the diffusion coefficient (D) of DA at HMWCNT-CPE surface. Based on Cottrell equation [60], the plot of I versus $t^{-1/2}$ will be linear and the value of D can be obtained from the slope. We have carried out such studies for various DA concentrations at HMWCNT-CPE (Fig. 3B). The slopes of the resulting straight line were then plotted versus the DA concentration (Fig. 3C), from whose slope we calculated a diffusion coefficient of 9.8×10^{-6} cm^2 s^{-1} for DA. However, the calculated value of the diffusion coefficient is in good agreement with previously reported ones [33,61,62].

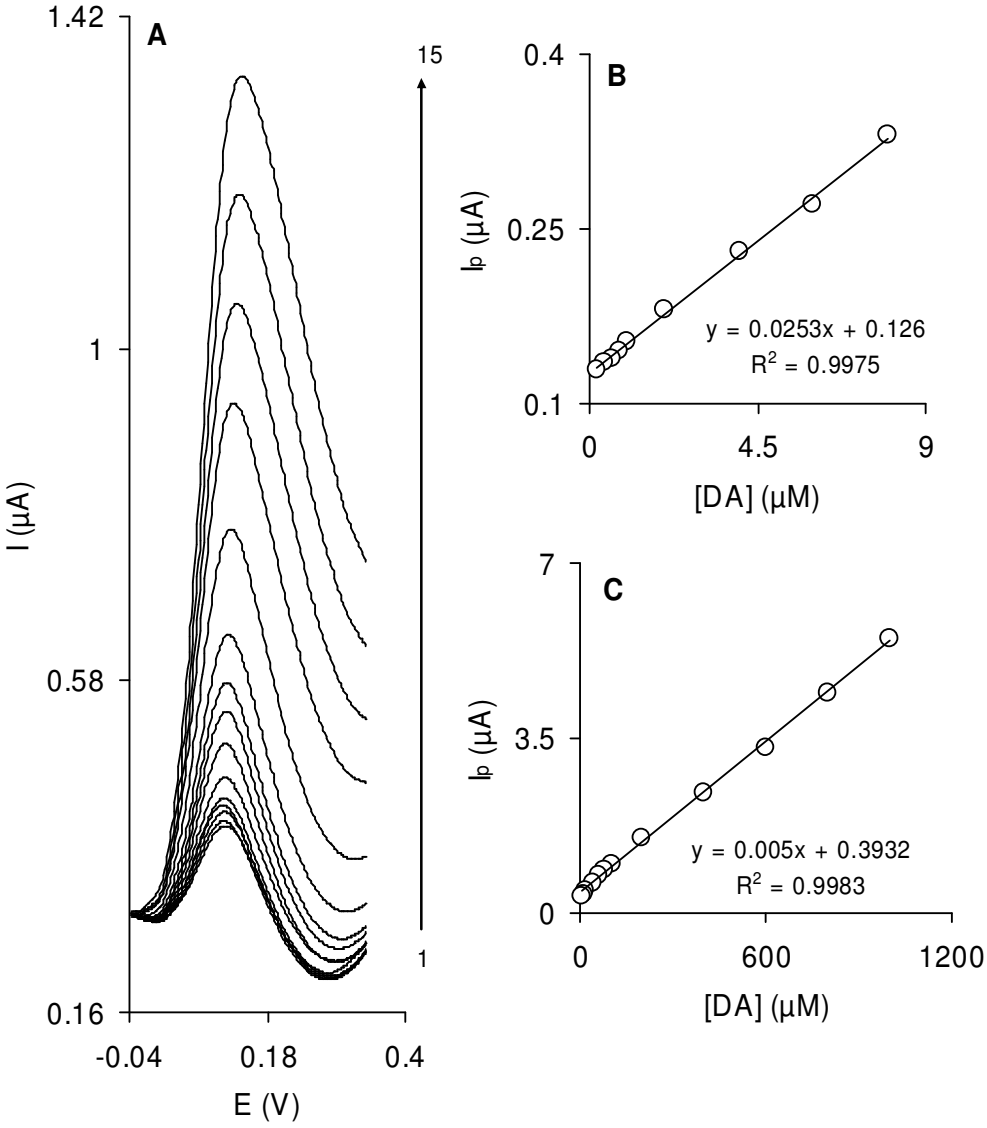

Figure 4. (A) Differential pulse voltammograms of HMWCNT-CPE in 0.5 M phosphate buffer solution (pH 7.0) containing different concentrations of DA. The numbers of 1-15 correspond to concentrations of 0.2-100.0 μM DA. (A) and (B) show the plots of the electrocatalytic peak current as a function of DA concentration in the range of 0.2-8.0 μM and 8.0-1000.0 μM DA respectively.

3.2. Calibration and limit of DA detection

The charging current contribution to the background current, which is a limiting factor in the analytical determination, is lower in DPV mode. In addition, the differential pulse voltammetry (DPV) has a much higher current sensitivity than cyclic voltammetry; it was used to estimate the lower limit of detection and the linear range of DA. The effects of increasing the concentration of DA in the range of 0.2 μM to 1000.0 μM on the voltammograms are presented in Fig. 4A. Also, Figs. 4A and 4B clearly show that the plot of peak current versus DA concentration is constituted of two linear segments of 0.2 μM to 8.0 μM (Fig. 4B) and 8.0 μM to 1000.0 μM (Fig. 4C) with different slopes. The plot of the average peak current of three replicates of DPVs versus DA concentration in the range of 0.2 μM to 0.8 μM (not shown) was used to estimate the lower limit of DA detection at HMWCNT-CPE. For these low concentrations, a linear least square calibration curve with a slope of 0.026 μA μM^{-1} and a correlation coefficient of 0.9941 are observed. From the analysis of these data, we estimate that the lower limit of detection ($X_{l.o.d.}$) of DA is 0.06 μM according to the definition $X_{l.o.d.}=(Y_{l.o.d}-Y_{bl.})/m$ [63]. The lower detection limit of DA obtained at the HMWCNT-CPE is lower than those previously reported for other modified electrodes [28,64-66].

Table 2. Comparison of analytical parameters of several modified electrodes for DA determination[a].

Modifier	pH	Peak potential Shift (mV)	Linear range (μM)	Detection limit (μM)	Concomitant compounds	Reference
$PNTIO_2$	7.0	-	12.0-120.0	2.0	AC	28
OB	8.0	215	0.06-0.80 0.80-8.0	0.02	AA, UA	33
PNCN	7.0	159	0.5-160	0.2	AA, UA	64
PEB	4.5	97	1.0-30	0.25	AA, UA	65
PASNT	7.4	-	0.2-10	0.08	AA, UA	66
CN	4.5	91	0.04-5.6	0.04	AA, UA	67
CPBC	4.7	-	40-5000	-	AA	68
HMWCNT	7.0	333	0.2-8.0 8.0-1000.0	0.06	AC	This work

[a]$PNTIO_2$: poly(acid yellow 9)/nano-TiO_2; OB: oracet blue; PNCN: palladium nanoparticle-carbon nanofibers; PEB: poly(evans blue); PASNT: phytic acid SWCNT; CN: carbon nanofiber; CPBC: cetylpyridine bromide-chitosan; HMWCNT: hematoxylin multi-wall carbon nanotubes; DA: dopamine; AC: acetaminophen; AA: ascorbic acid; UA: uric acid

The average voltammetric peak current and the precision estimated in terms of the coefficient of variation for 15 repeated measurements (n = 15) of 2.0 μM DA at HMWCNT-CPE were 0.181 ± 0.005 μA and 2.93 %, respectively. The coefficient of variation value indicates that the modified electrode is stable and does not undergo surface fouling during the voltammetric measurements. This also demonstrates the fact that the results obtained at the HMWCNT-CPE are reproducible in analytical applications. In Table 2, some of the response characteristics obtained in this work are compared with those previously reported by others [28,33,64-68]. The data in Table 2 show that the

responses of the proposed modified electrode are in most cases, superior, especially the peak potential shift and the linear dynamic range, as compared with the previously modified electrodes.

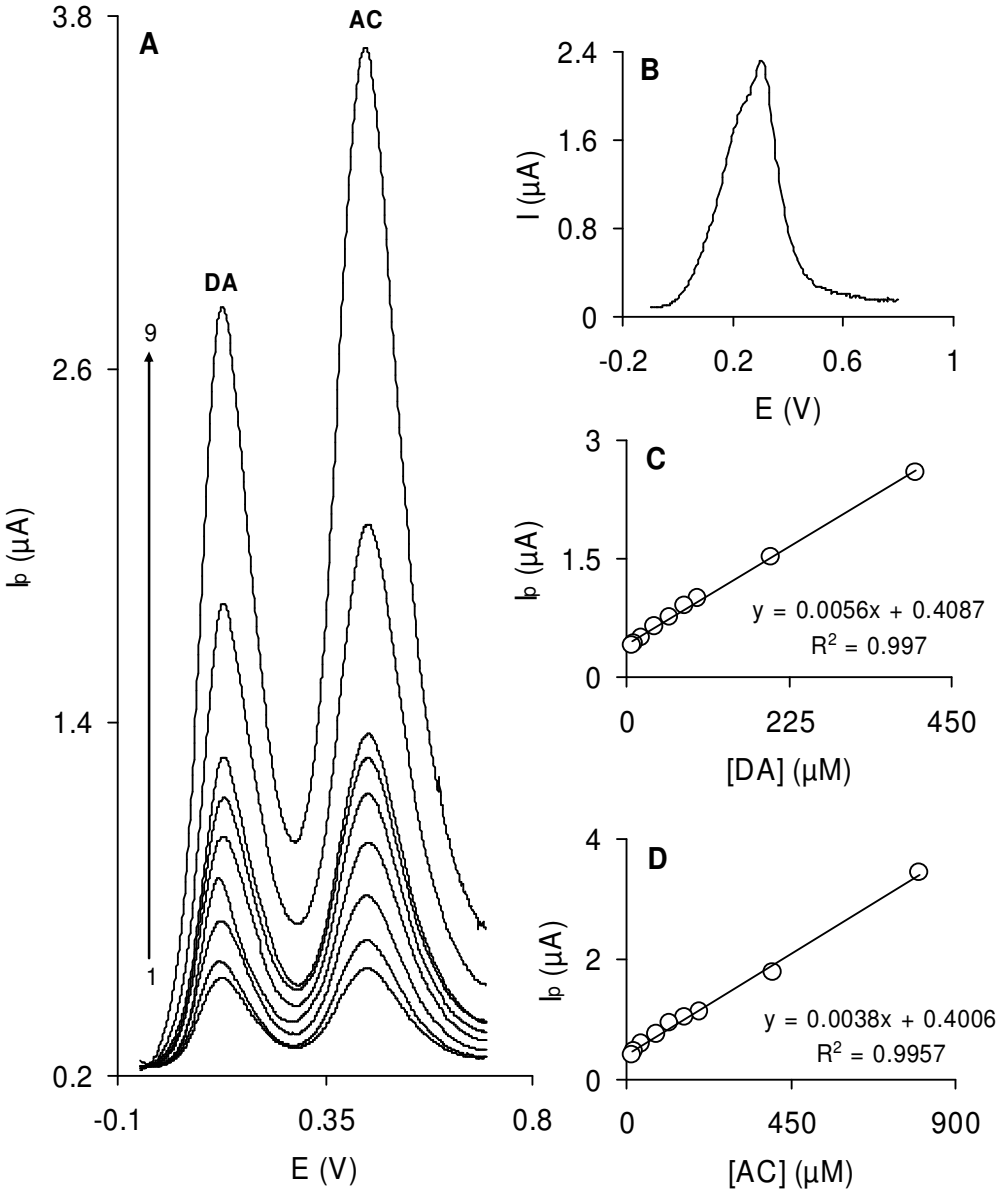

Figure 5. (A) Differential pulse voltammograms of HMWCNT-CPE in 0.5 M phosphate buffer solution (pH 7.0) containing different concentrations of DA and AC. The numbers of 1-9 correspond to mixed solutions of 8.0+16.0, 10.0+20.0, 20.0+40.0, 40.0+80.0, 60.0+120.0, 80.0+160.0, 100.0+200.0, 200.0+400.0 and 400.0+800.0 μM of DA+AC respectively. (B) The response of the mixed solution of 400.0 μM DA and 800.0 μM AC at the unmodified CPE. Plots of the peak current as a function of concentration of (B) DA in the range of 8.0-400.0 μM and (C) AC in the range of 16.0-800.0 μM.

3.3. Simultaneous determination of DA and AC

Figure 5A shows DPVs obtained through increasing concentrations of DA and AC. Figure 5B shows DPV of a mixture of 400.0 μM DA and 800.0 μM AC at an unmodified CPE. As shown, the unmodified CPE could not separate the voltammetric signals of DA and AC. On the other hand, in the case of HMWCNT-CPE, one could observe two well distinguished anodic peaks at potentials of 130 and 440 mV, corresponding to the oxidation of DA and AC respectively. The separation between the two peak potentials is sufficient for the simultaneous determination of DA and AC. Also, this potential separation is significantly greater than 188 mV previously reported for the determination of AC in the presence of DA at a poly(acid yellow 9)/nano-TiO_2 modified electrode [28]. Furthermore, substantial increases in peak currents were observed due to the increase of DA and AC concentration. It can be seen in Figs. 5C and 5D, in the whole investigated concentration range of 8.0 μM to 400.0 μM for DA and 16.0 μM to 800.0 μM for AC, the responses obtained increased linearly with the increase of the analyte concentrations. The linear least square calibration curves over the above ranges had slopes of 0.0056 μA μM^{-1} and 0.0038 μA μM^{-1} for DA and AC respectively. The sensitivity of HMWCNT-CPE to DA oxidation in a similar concentration range and in the absence of AC was found to be 0.005 μA μM^{-1}. It is very interesting to note that the sensitivities of the modified electrode to DA in the absence and presence of AC are virtually the same, which indicates the fact that the oxidation processes of DA and AC at HMWCNT-CPE are independent of each other. Thus, simultaneous or individual measurements of DA and AC are possible without any interference. If DA response was affected by AC concentration, the sensitivities of DA calibration curves in the absence and presence of AC would be different.

3.4. Determination of DA and AC in pharmaceutical preparations

In order to demonstrate the electrocatalytic oxidation of DA and AC in pharmaceutical preparations, we examined this ability in differential pulse voltammetric determination of DA concentration in an injection solution and AC concentration in an oral solution and a tablet sample. The injection solution of DA and the oral solution of AC were diluted 5000 and 4000 times respectively. Also, one AC tablet (0.435 g), after dissolving in 1.0 L doubly distilled water was diluted 40 times with a phosphate buffer (pH 7.0) before the measurements. Based on the repeated differential pulse voltammetric responses (n=3) of the diluted analytes and the samples that were spiked with specified concentration of DA and AC (not shown) and using the calibration plots which are shown in Figs. 5C, and 5D, measurements were made of DA and AC concentrations in the pharmaceutical preparations and of the recovery rate of the spiked samples. The results are listed in Table 3.

The reliability of the proposed modified electrode was also evaluated by comparing the obtained results with those declared in the label of the pharmaceutical preparations (Table 4). The results in Table 3 show the relative standard derivations (RSD%) and the recovery rates of the spiked samples are acceptable. Also, the data in Table 4 indicate that the results obtained by utilizing HMWCNT-CPE are in good agreement with those declared in the label of the preparations. Thus, the

modified electrode can be efficiency used for individual or simultaneous determination of DA and AC in pharmaceutical preparations.

Table 3. Determination of DA and AC in pharmaceutical preparations and recovery data for the three analytes were spiked with specified concentrations of DA and AC at HMWCNT-CPE[a].

Samples	Added (μM)		Found[a] (μM)		RSD (%)		Recovery (%)	
	DA	AC	DA	AC	DA	AC	DA	AC
Injection solution of DA	–	–	43.1	–	2.5	–	–	–
	20.0	140.0	62.8	141.5	2.1	2.3	99.5	101
	40.0	180.0	83.9	178.8	2.0	2.9	101	99.3
Oral solution of AC	–	–	–	39.2	–	2.7	–	–
	20.0	40.0	19.4	77.9	2.8	2.0	97.0	98.3
	30.0	60.0	30.4	101.2	3.0	1.9	101	102
Tablet of AC	–	–	–	51.2	–	2.6	–	–
	30.0	30.0	30.9	82.0	2.1	1.6	103	101
	45.0	60.0	45.9	109.4	2.6	1.7	102	98.4

[a]Three replicate measurements were made on the same samples

Table 4. Comparison of the total values of DA and AC of various pharmaceutical preparations obtained using HMWCNT-CPE with those declared in the label of the samples.

Samples	Declared value	Found value	RSD (%)
Injection solution of DA (mg mL^{-1})	40.0	40.8	2.7
Oral solution of AC (mg mL^{-1})	24.0	23.7	0.7
Tablet of AC (mg g^{-1})	725.3	711.7	2.7

[a]Results based on three replicate determinations per samples and the found values were obtained by multiplying the measured values by the appropriate dilution factor

4. CONCLUSIONS

Hematoxylin as a mediator of electron transfer can have a strong electrocatalytic effect on DA oxidation at the surface of HMWCNT-CPE. The peak potential of DA oxidation at HMWCNT-CPE shifts about 70, 90 and 330 mV to less positive potentials as compared with those at HMCPE,

MWCNT-CPE, and unmodified CPE respectively. The data obtained clearly show that a combination of MWCNT and hematoxylin can definitely improve the characteristics of DA electro-oxidation. The value diffusion coefficient (D) of DA is measured as 9.8×10^{-6} cm^2 s^{-1}. HMWCNT-CPE exhibits two wide linear ranges of 0.2 μM to 8.0 μM and 8.0 μM to 1000.0 μM for DA determination. The lower detection limit of DA at the modified electrode is 0.06 μM. Finally, the biosensor is used for the simultaneous determination of DA and AC in a DA injection solution, an AC oral solution, and an AC tablet with satisfactory results.

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