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ORIGINAL PAPER

Electrooxidation of dextromethorphan on a carbon nanotube–carbon microparticle–ionic liquid composite: applied to determination in pharmaceutical forms

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Abstract The electrooxidation of dextromethorphan on a composite constructed with carbon nanotube–ionic liquid–carbon microparticles was investigated by cyclic voltammetry in a 100 mM phosphate buffer solution, pH 7.40. In the voltammograms, an irreversible diffusion-controlled anodic peak appeared. The diffusion coefficient of dextromethorphan, the electron-transfer coefficient, and the standard rate constant of the electrooxidation process were found to be 3.45×10^{-6} cm^2 s^{-1}, 0.65, and 1.67×10^{-3} cm s^{-1}, respectively. A sensitive and timesaving determination procedure was developed for the analysis of dextromethorphan, and the corresponding analytical parameters were reported. Using this method, dextromethorphan was determined with an LOD and LOQ of 8.81 and 29.36 μM in a linear range of 2.5×10^{-4} to 3.3×10^{-3} M, respectively. The proposed amperometric method was successfully applied to the analysis of commercial pharmaceutical products (syrup and oral drop), and the results were in good agreement with the declared values.

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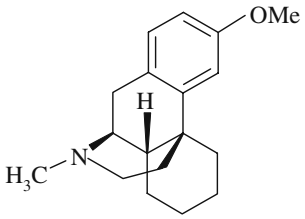
Introduction

Dextromethorphan [(+)-3-methoxy-17-methyl-(9α, 13α, 14α)-morphinan, Scheme 1], is an over-the-counter cough suppressant commonly found in cold medications. It is a safe, perorally administered antitussive agent which has a central action on cough center in the medulla. It is an innocuous non-narcotic cough suppressant, used for the relief of nonproductive cough [1] and is used in the treatment of respiratory disorder [2]. Other medical uses of dextromethorphan include the temporary relief of sinus congestion, runny nose, cough, sneezing, itching of the nose and throat, and watery eyes caused by hay fever, allergies, cold, or flu (influenza).

Different methods have recently been reported for the determination of dextromethorphan in pharmaceutical and biological samples. Among them, high performance liquid chromatography [3–5], the first and second-derivative technique UV spectrophotometry [6, 7], capillary electrophoresis [8], gas chromatography [9], and thin-layer chromatography [10] have been used. However, gas chromatography requires a tedious derivatization step, and the principal drawback of capillary electrophoresis-UV method consists of its poor sensitivity due to low loading capacity and short optical path length because of the small capillary dimensions. Dextromethorphan is prepared in combination with pseudoephedrine in cough cold syrups and biological samples. Syrups belong to a class of complex samples with intrinsic variability. Some techniques for determination of dextromethorphan in syrup samples were also reported [11].



Scheme 1 The chemical structure of dextromethorphan

Electrochemistry is most suitable for investigating the redox properties of drugs that can give insight into its metabolic fate [12]. Data obtained from electrochemical techniques are often correlated with molecular structures and pharmacological activities of drugs. Moreover, electrochemical techniques can be considered as convenient alternatives to routinely employed analytical methods, in that they present the great advantage of permitting a direct, simple, and rapid determination requiring a minimum volume of sample. Electrochemical techniques have also been used for the determination of a wide range of drug compounds. They have the advantage of not requiring, in most instances, derivatization, and they are less sensitive to matrix effects than other analytical techniques [13–16]. Additionally, electrochemical techniques allow the study of the redox mechanism of the drugs. Redox properties of drugs can provide insight into their metabolic fate, their in vivo redox processes, and their pharmacological activity [12, 17].

Carbon paste electrodes (CPEs) are greatly used due to their vast advantages such as low cost, easy preparation, miniaturization, surface renewability, compatibility toward different compounds as modifiers, wide potential window, low-charging current, and long life. In addition, the carbon paste electrodes can be modified by addition of various compounds [13, 14, 18–20].

Ionic liquids (ILs) have a number of valuable physical and chemical properties such as high ionic conductivity, electrochemical and thermal stability, ion-exchange properties, extraction and catalytic activity, negligible vapor pressure, wide electrochemical potential window, the ability to facilitate direct electron-transfer reactions, good biocompatibility, etc. ILs have the great potential applications in the field of electrochemistry and electroanalysis [21, 22] and had been used as the modifier for the fabrication of different kinds of chemically modified electrode for the detection of low molecular substances [23]. Recently, ILs have been proposed to be very interesting and efficient pasting binders in place of non-conductive organic binders for the preparation of carbon composite electrodes [24]. These types of electrodes show some advantages over traditional carbon paste electrodes CPEs such as high conductivity, provision of fast electron transfer, and antifouling properties [25, 26]. However, one major concern was the high background current which limits the analytical utility of these IL-based pastes. One approach to minimize the background current and to increase the analytical signal-to-background ratio is made via decreasing the electrode active surface area and increasing mass transport rate [27].

There has been a great deal of interest in the research of carbon nanotubes (CNTs) since their discovery by Iijima in 1991 [28]. CNT possesses subtle electronic properties, huge surface area, efficient catalytic activity, and excellent biocompatibility and electron-transfer ability. These subtle properties of CNTs reveal that they are fascinating electrode materials and able to promote electron-transfer reactions when use in electrochemistry. CNTs represented high electrocatalytic reactivity toward oxidation [29, 30] and reduction [31] reactions. CNTs can enhance the selectivity [26] and sensitivity [29, 30] and show antifouling effect [29]. CNTs have also been used in the electrochemical studies of biomacromolecules [23, 32] and biosensor design [23].

Electrochemistry and electrochemical determination of dextromethorphan have not, to the best of our knowledge, been reported in the literature. In the present work, we have studied the electrochemical behavior of dextromethorphan at a carbon nanotube–carbon microparticle–ionic liquid composite with the aim of developing an electroanalytical procedure for quantification of dextromethorphan in both bulk form and pharmaceutical formulation.

Experimental section

Chemicals and reagents

Butyl-3-methylimidazolium hexafluorophosphate was purchased from Flucka. Multi-wall CNTs were received from PlasmaChem GmbH, Germany. Carbon microparticles (graphite fine powder, extra pure) were purchased from Merck. Dextromethorphan was received as a gift from Alhavi Pharmaceutical Chemicals, Tehran, Iran. The pharmaceutical samples of dextromethorphan (syrup, oral drops, and tablet) were purchased from local drugstores. All other chemicals used in this work were of analytical reagent grade from Merck.

Procedures

The standard solution of authentic dextromethorphan was prepared in 100 mM phosphate buffer solution, pH 7.40 (which was also used as the supporting electrolyte), and then stored in the dark at 4 °C. Additional diluted solutions were prepared daily by accurate dilution just before use. Dextromethorphan solutions were stable and their concentrations did not change with time.

Prior to use, the CNTs were refluxed in a 2 M nitric acid solution for 12 h, washed with redistilled water several times, then dried and stored until use. Then CNTs were sonicated in a 3:1 sulfuric/nitric acid solution for 6 h in an ultrasonic bath at room temperature and then washed with distilled water until neutralization by vacuum filtration. The obtained sample was taken and dried overnight at 50 °C. This procedure is necessary for removing the probable amorphous carbons and catalytic impurities and causes scission and carboxylation of CNTs.

The calibration curve for the drug in PBS was measured with an amperometric technique. Working potential of 900 mV was used in amperometric measurements, in which the transient currents were allowed to decay to steady-state values.

All studies were carried out at room temperature

Apparatus

Surface morphological studies were carried out using scanning electron microscopy, using a Philips instrument, Model X-30.

Electrochemical measurements were carried out in a conventional three-electrode cell, powered by an electrochemical system comprising an μ-Autolab, Type III system (Eco Chemie, Utrecht, The Netherlands). The system was run on a PC using GPES software. An Ag/AgCl-Sat'd KCl and a platinum disk (from Azar Electrode, Iran) were used as reference and counter electrodes, respectively. The working electrode was a modified carbon paste electrode (vide infra).

Preparation of the working electrode

Traditional CPE was prepared by hand-mixing carbon microparticles and mineral oil with an 80/20% (*w*/*w*) ratio. CPE-modified with CNTs (NCPE) was prepared by mixing CNTs and carbon microparticles with a 10:90 mass ratio in dichloromethane. After the evaporation of the solvent under an IR lamp, the carbonaceous mixture and mineral oil with an 80/20% (*w*/*w*) ratio were mixed. IL-based carbon paste electrode (ICPE) and carbon nanotube–carbon microparticle–ionic liquid nanocomposite (INCPE) were prepared in the same ways, otherwise, the ionic liquid was employed instead of mineral oil. In all cases, the pastes were carefully mixed and homogenized in an agate mortar for 20 min and kept at room temperature in a desiccator before use. The paste was packed firmly into a cavity (4.05 mm diameter, geometric surface are of 0.128 cm^2 and 0.5 mm depth) at the end of a Teflon tube. Electrical contact was established via a copper wire connected to the paste in the inner hole of the tube. The electrode surface was gently smoothed by rubbing on a piece of weighing paper just prior to use. This procedure was also used to regenerate the surface of the electrodes.

Analysis of pharmaceutical preparations

For dextromethorphan determination in pharmaceutical preparations, the following procedures were employed. For tablet, an average mass of five tablets from the same batch was determined, then finely ground and homogenized in a mortar. The weighted amount of this powdered sample was used to prepare the sample solution, which was filtered and transferred to a volumetric flask. The volume was completed with the buffered electrolyte solution. For syrup and oral drop samples, the volume amount of samples transferred to a volumetric flask and the volume was completely by electrolyte solution.

Recovery tests

Recovery studies can show the possible interferences from common excipients used in the pharmaceutical forms. To study the reproducibility and accuracy of the proposed analysis method, recovery experiments were carried out using the standard addition method. In order to find out whether the excipients show any interference with the analysis, known amounts of pure drug were added to the pre-analyzed pharmaceutical formulations and the mixtures were analyzed by the proposed methods. The recoveries of the drugs were calculated using the corresponding regression equations of previously plotted calibration plots. The recovery results were determined based on five parallel analyses.

Results and discussion

Surface morphology studies

Figure 1a shows the scanning electron micrographs of the surface of CPE (A), NCPE (B), ICPE (C), and INCPE (D). It can be seen that most carbon microparticles and CNTs at the surface of CPE and NCPE are isolated and can be discernible, while the surface of ICPE and INCPE are relatively uniform, and the carbonaceous materials become indiscernible. There is no conducting media available between carbon microparticles in CPE, and charges could not be propagated because of the block of non-conductive binder. In the case of IL-based electrodes, no separated carbon particles could be observed, and IL was embedded in the carbon particles. It can be attributed to the binding and blanketing effect of IL (vide infra).

Cyclic voltammetry studies

CNT-based electrodes have shown that these electrodes are capable of improving the kinetics of the electrode processes and therefore enhance sensitivity of the measurements [34,

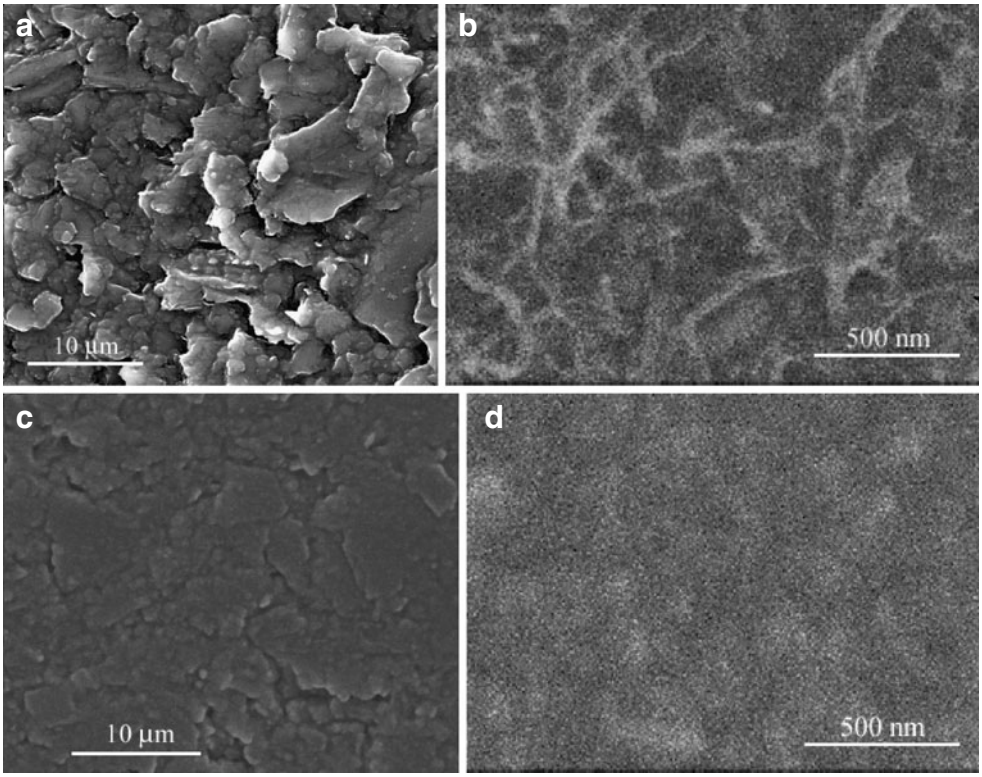


Fig. 1 SEMs of the surface of CPE (**a**), NCPE (**b**), ICPE (**c**), and INCPE (**d**)

35]. Figure 2a and b show typical cyclic voltammograms of 2.0 mM dextromethorphan in PBS recorded using CPE (a), NCPE (b), ICPE (c), and INCPE (d) at a potential sweep rate of 10 mV s^{-1}. In the positive-going sweep, only one anodic peak appeared in each voltammogram, and in the reverse one, no peak appeared. This indicates that dextromethorphan is electroreactive on the carbon-based electrode and is oxidized irreversibly via a direct heterogeneous electron-transfer process. It is observed that the substrate current response were much larger at the IL-based electrodes than at the others. This remarkable round background response at the IL-based electrode is definitely due to the accessible capacitance of the IL at the carbon surface [33, 34]. However, the resolving power from peak current by deducting background response was prominently improved in the case of IL-based electrodes. The anodic peak current obtained using the employed working electrodes increased in the manner of INCPE>ICPE>>NCPE>CPE, although ICPE represent a very broad peak. Also, the anodic peak potential for these electrodes shifted to more negative values in the manner of INCPE<ICPE<NCPE<CPE. Therefore, both CNT and IL improve the oxidation process, and the nanocomposite made with CNT and IL represent an anodic peak with the corresponding highest current at lowest potential. This means that CNTs and IL enhanced and catalyzed the oxidation process from both kinetic and thermodynamic points of view. Also, based on the results, it should be noted that the catalytic efficiency of CNT toward the electrooxidation process is more important than that for IL.

CNTs have electrocatalytic efficiency during the electrooxidation process. CNTs are known to have a distinct structure and thus may represent different electrochemical

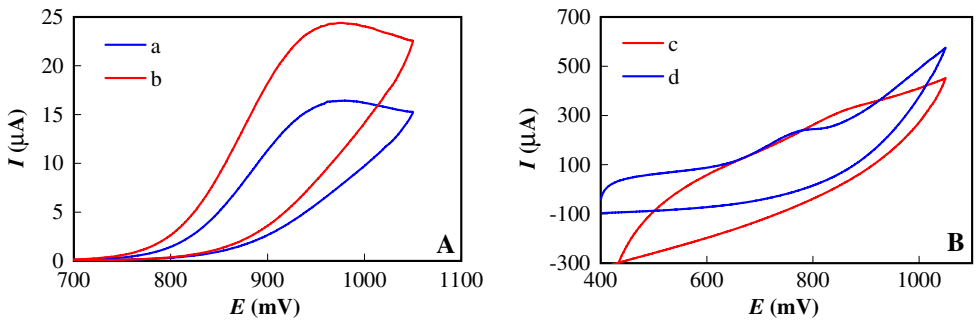


Fig. 2 **a** Cyclic voltammograms of 2.00 mM dextromethorphan in PBS using CPE (*a*) and NCPE (*b*). The potential sweep rate was 10 mV s^{-1}. **b** Cyclic voltammograms of 2.00 mM dextromethorphan in PBS using ICPE (*c*) and INCPE (*d*). The potential sweep rate was 10 mV s^{-1}

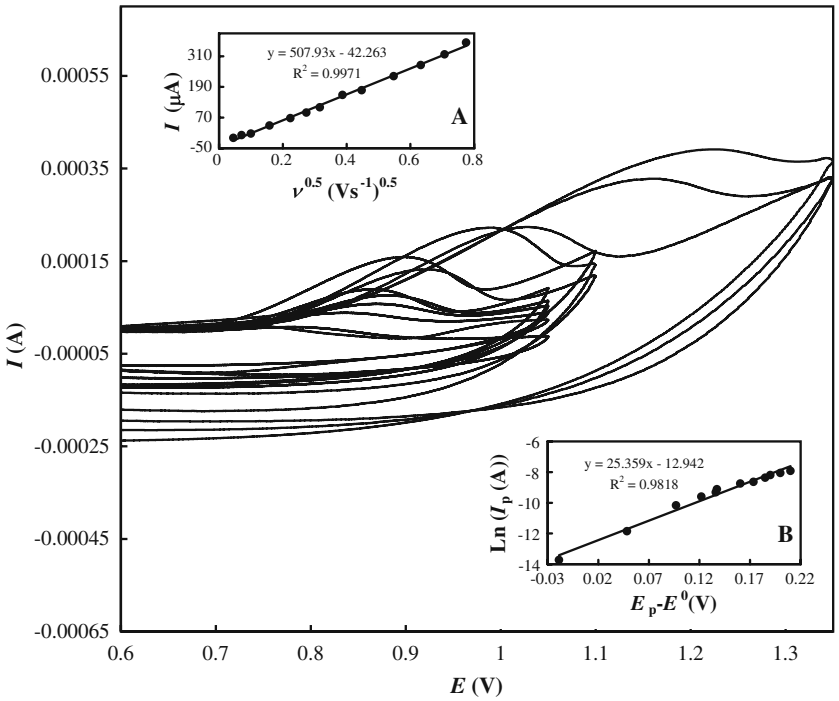


Fig. 3 Main plot: Cyclic voltammograms of 2.0 mM dextromethorphan in PBS using INCPE recorded at various potential sweep rates of 2, 5, 10, 25, 50, 75, 100, 150, 200, 300, 400, 500, and 600 mV s^{-1}. *Inset a*: dependency of the peak current on the square root of the corresponding potential sweep rate. *Inset b*: dependency of $\left(E_p - E^{0'}\right)$ on the natural logarithm of the potential sweep rate

properties from the other carbon-based materials. This electrochemical behavior has been related to different CNT characters. Generally, CNT bears two kinds of carbons: sidewall and tube ends. The tube end atoms show excellent electrochemical properties, with reversible electrochemistry and low redox potentials [35]. This behavior is attributed to the oxygenated species formed from the dangling bonds of sp2 carbons at the ends of the tubes [36] and/or edge plane-like of highly oriented pyrolitic graphite which represents the electrocatalytic activity of CNTs [37]. On the other hand, the electrocatalytic activity of CNT was related to surface electronic structure of nanotube layers and better wetting properties due to porous structure of bundle CNTs [38].

Enhancement of the electrochemical behavior of IL-based electrodes can be related to its enhanced conductivity (with respect to non-conductivity of organic binder) [39]. In another words, due to the good solubility and high viscosity, the IL can form a layer on the carbon particles and can fill in the void spaces between carbon particles (see also Fig. 1), so the conductivity of the IL-based electrodes was greatly enhanced compared with that of the traditional CPE. Also, IL can be a better solvent and extract the analyte from the solution to the electrode surface.

Based on the presented results and twine-by-twine comparing cyclic voltammograms recorded using different electrode employed in this study, it is revealed that both CNT and IL cause the electrooxidation process to be occur and the nanocomposite made with both species represent a synergistic effect due to the combination of CNTs and IL with unique characteristics. The behavior of the nanocomposite can be related to: (1) the inherently perfect electrochemical characteristic of CNTs, (2) solvent and extraction effects of IL, (3) notable improvement of the conductive performance of the IL-carbonaceous species due to a mixed electronic (carbonaceous species) and ionic (IL) conductions, (4) proper interactions between CNTs and IL. ILs and CNTs can easily form homogeneous bucky paste due to their cation–π interaction [40] and/or non-covalent π–π interaction between the imidazole group of IL and CNT side wall [41], and (5) increasing the real surface area of the nanocomposite. However, it should be noted that surface area increment is not the sole reason of the nanocomposite behavior, because real surface area increment can enhance only the electrooxidation current (kinetic point of view). Moreover, the probable interaction of

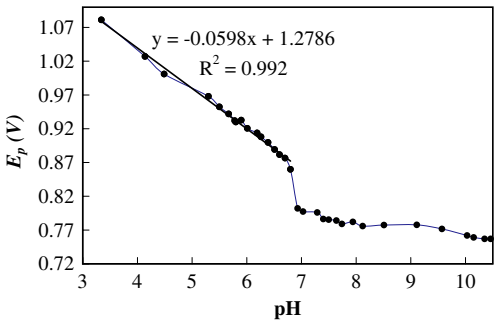
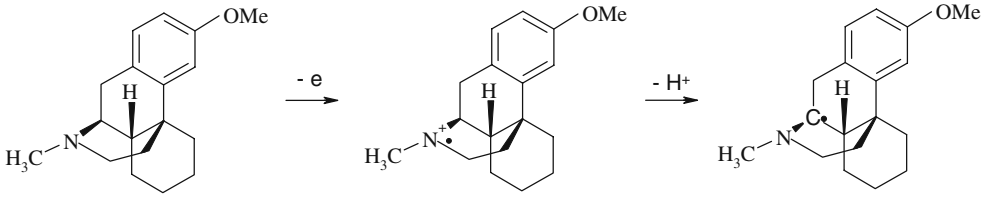


Fig. 4 Dependency of peak potential on solution pH. The data obtained from cyclic voltammograms recorded at various pH of 3.34 to 10.46 using INCPE

Scheme 2 A proposed reaction for the electrooxidation of dextromethorphan



dextromethorphan with CNT and IL should be considered. Because dextromethorphan in the working pH is neutral (vide infra), it may interact with both imidazole group of IL and CNT sidewall via hydrophobic attractions. Based on the present results and explanations, INCPE was used for further investigations of dextromethorphan electrooxidation process and its determination.

It has been shown in the previous studies that CNT-modified electrodes can accelerate the kinetics and/or favor the thermodynamics of the electrode processes and enhance sensitivity of the measurements [29, 30, 42]. The effect of various weight percentages of CNT mixed with carbon microparticles to prepare CNT-modified paste electrodes was checked. It was observed that the paste which was prepared with more than 10wt.% of CNT and IL as the binder, had not a "pasty" form, and it was very difficult to pack firmly into the cavity at the end of the Teflon tube. This can be related to the strong non-covalent π-π interaction between the imidazole group of IL and CNT side wall (vide supra). Also, it was observed (data not shown) that addition of CNT up to 10 wt.% causes increment of the anodic current of dextromethorphan electrooxidation. Therefore, the maximum sensitivity will be obtained for the electrode containing 10 wt.% of CNT.

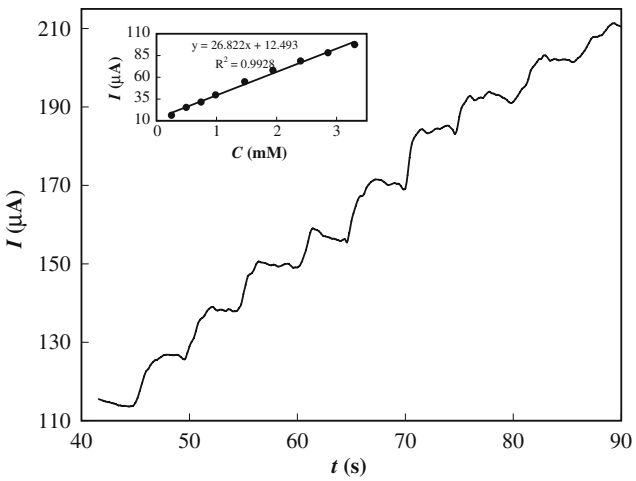


Fig. 5 Main plot: An amperogram obtained using INCPE during successive addition of dextromethorphan into PBS at a potential step of 900 mV. *Inset*: dependency of the transient current on dextromethorphan concentration

The effect of potential sweep rate was also studied. Figure 3 shows cyclic voltammograms of 2.0 mM dextromethorphan in PBS using INCPE in the range of 2 to 600 mV s^{-1}. Along with the potential sweep rate increase, the peak current increased and the peak potential shifted to more positive values, confirming the irreversible nature of the reaction processes. In addition, the peak current depends linearly on the square root of the corresponding potential sweep rate (Fig. 3, inset a). This result indicates that a mass transport phenomenon has occurred via diffusion in the oxidation process. From the slope of the linear dependency of the anodic peak current on the square root of the potential sweep rate and using the Randles–Sevcik equation for totally irreversible electron-transfer processes [43]:

$$I_p = 2.99 \times 10^5 n\,\alpha^{0.5} A\,C\,D^{0.5}\,\nu^{0.5} \quad (1)$$

where α is the electron-transfer coefficient; n is the number of exchanged electron; A is the surface area of the working electrode; C and D are the bulk concentration and diffusion coefficient of the electroreactant species, respectively, and ν is the potential sweep rate; the diffusion coefficient of dextromethorphan has been obtained as 3.449×10^{-6} cm^2 s^{-1}, using α=0.65 (vide infra). For irreversible diffusion-controlled processes, the peak potential is proportional to ln I_p within the following equation [43]:

$$I_p = 0.227\,nFAC^*k^0 \exp\left[-\alpha F/RT\left(E_p - E^{0'}\right)\right] \quad (2)$$

where I_p, k^0, and $E^{0'}$ are the peak current, standard rate constant, and formal potential (obtained from extrapolation of the peak current to the potential sweep rate of zero), respectively. Figure 3, inset b represents the dependency of

Table 1 The determined parameters for the calibration curve of dextromethorphan and accuracy and precision (n=3) using INCPE

Linear range (M)	3.0×10^{-5}–3.3×10^{-3}
Slope (mA M^{-1})	26.82
Intercept (μA)	12.49
LOD (μM)	8.81
LOQ (μM)	29.36
RSD (%)	1.73
Bias (%)[a]	0.79

[a] The value was reported for 4.98×10^{-4} M dextromethorphan.

ln I_p on $(E_p - E^{0'})$ obtained from the voltammograms recorded at various potential sweep rates using INCPE. Using this plot and based on Eq. 2, the values of the electron-transfer coefficient and standard rate constant were obtained as 0.65 and 1.67×10^{-3} cm s^{-1}, respectively.

The effect of pH on the electrochemical behavior of dextromethorphan was investigated using INCPE in a wide range of pH of 3.3 to 10.5. Figure 4 shows the change of peak potential with respect to the solution pH. The plot shows that at pH>6.93, the peak potential remains almost constant. In the range of 3.34<pH<6.80, however, the peak potential shifted to less positive values when pH increases. Therefore, it is possible to estimate pK_b value for dextromethorphan, as pK_b=6.80. Moreover, a linear displacement of the peak potential with the pH of the solution was obtained with a slope of 59.8 mV/pH unit in the pH range of 3.34–6.80. This result indicates that, in the electrooxidation of the drug, the same electron and proton are involved.

Coulometry studies

Controlled-potential coulometry was performed in PBS containing 0.2 mM dextromethorphan using INCPE at 900 mV. The electrolysis progress was monitored by CV. The extrapolated charge consumption for total electrolysis of the solution, after corrections for background/charging currents, was derived, and the number of exchanged electrons for peak was found to be one. Therefore, accompanied with the studies of pH effect, dextromethorphan oxidized on INCPE surfaces via one one-proton one-electron process in one step.

Dextromethorphan bears two functional groups of amine and ether (Scheme 1). It has been reported that saturated ethers are not simply oxidized [44]. Therefore, the amine functional group can be oxidized [44], and based on the results, a reaction is proposed for the electrooxidation of dextromethorphan (Scheme 2).

Analytical part

In order to develop a simple and time-saving method for the analysis of dextromethorphan in pure form as well as pharmaceutical formulations, amperometry technique was employed. Typical amperometric signals obtained during successive increments of dextromethorphan to PBS using INCPE are depicted in Fig. 5. Gentle stirring for a few seconds was needed to promote solution homogenization after each injection. The electrode response was quite rapid and proportional to the dextromethorphan concentration. The corresponding calibration curve for the amperometric signals is shown in the inset of Fig. 5. The limit of detection (LOD) and quantitation (LOQ) of the procedure were calculated according to the 3 SD/m and 10 SD/m criteria, respectively, where SD is the standard deviation of the intercept and m is the slope of the calibration curve [45]. The determined parameters for the calibration curve of the drug, accuracy, and precision, LOD and LOQ, and the slope of calibration curve are reported in Table 1. The value of

Table 2 Determination and recovery of dextromethorphan in commercial tablet, oral drops, and syrup

Sample	Amount labeled	Amount added	Amount found	Recovery (%)	RSD (%) for n=3	Bias (%)
Syrup-sample 1	15 (mg/5 ml)	–	15.21 (mg/5 ml)	101.45	1.2	1.45
Syrup-sample 1	–	15 (mg/5 ml)	15.91 (mg/5 ml)	106.07	2.01	6.07
Syrup-sample 1	–	15 (mg/5 ml)	14.91 (mg/5 ml)	99.40	2.01	−0.6
Syrup-sample 2	15(mg/5 ml)	–	15.42 (mg/5 ml)	102.80	5.29	2.80
Syrup-sample 2	–	15 (mg/5 ml)	15.52 (mg/5 ml)	103.47	4.05	3.47
Syrup-sample 2	–	15 (mg/5 ml)	14.88 (mg/5 ml)	99.20	4.91	−0.8
Drop-sample 1	4 (mg/ml)	–	4.08 (mg/ml)	102.00	3.34	2.00
Drop-sample 1	–	4 (mg/ml)	4.11 (mg/ml)	102.75	2.85	2.75
Drop-sample 1	–	4 (mg/ml)	4.01 (mg/ml)	100.25	3.10	0.25
Drop-sample 2	4 (mg/ml)	–	4.12 (mg/ml)	103.00	4.77	3.00
Drop-sample 2	–	4 (mg/ml)	4.09 (mg/ml)	102.25	2.22	2.25
Drop-sample 2	–	4 (mg/ml)	3.89 (mg/ml)	97.25	4.81	−2.75
Tablet-sample 1	15 (mg)	–	15.12 (mg)	100.80	4.17	0.8
Tablet-sample 1	–	15 (mg)	15.15 (mg)	101.00	3.52	1.00
Tablet-sample 1	–	15 (mg)	15.13 (mg)	100.87	2.75	0.87
Tablet-sample 2	15 (mg)	–	15.29 (mg)	101.93	5.08	1.93
Tablet-sample 2	–	15 (mg)	15.22 (mg)	101.47	4.03	1.47
Tablet-sample 2	–	15 (mg)	14.85 (mg)	99.00	5.21	−1.00

LOD obtained using the present method is comparable with that obtained using capillary electrophoresis equipped with a diode-array detector [46] and is lower than that reported using an immobilized enzyme reactor [47].

The applicability of the proposed amperometric method for the sample dosage form was examined by analyzing tablets, syrup, and oral drops. It was found that the amounts of the drug determined using this method are in good agreement with the reported values. The values of experimentally determined drugs and declared values in the pharmaceutical forms are reported in Table 2.

In order to evaluate the accuracy of the proposed method and to know whether the excipients in pharmaceutical dosage forms show any interference with the analysis, the proposed amperometric method was checked by recovery experiments using the standard addition method. After addition of known amounts of pure drug to various pre-analyzed formulations of dextromethorphan, the mixtures were analyzed by the proposed method. The recovery of dextromethorphan was calculated using the corresponding regression equations of previously plotted calibration plots. The results of recovery experiments using the developed assay procedure are presented in Table 2. The results indicate the absence of interference from commonly encountered pharmaceutical excipients used in the selected formulations. Therefore, the method can be applied to the determination of dextromethorphan in pharmaceutical forms without any interference from inactive ingredients.

In order to investigate the selectivity of the method, the interference effects of pseudoephedrine, glucose, lactose, fructose, starch, magnesium stereate, saccharin sodium, sodium benzoate, citric acid, menthol, ammonium chloride, and sodium citrate were tested. All the compounds are not electroreactive on INCPE (and other carbon-based electrodes employed in this work) in the potential range employed. Therefore, these compounds have almost no influences on the current responses of dextromethorphan.

Conclusion

The electrochemical behavior of dextromethorphan in PBS on various carbonaceous paste electrodes prepared with mineral oil or IL as the binder using cyclic voltammetry was studied. Dextromethorphan was hardly oxidized, and from the investigated electrodes, the nanocomposite made with CNTs, IL, and carbon microparticles oxidized it with the highest current and lowest potentials. This was related to the interaction of IL with CNTs in a synergistic manner. Both the specific characteristics of CNTs such as, particular electronic structure, high electrical conductivity, and topological defects present on their surfaces and the advantages of IL such as high conductivity, extraction effects, contributed to the performance of INCPE, compared with the other electrodes. The kinetic parameters such as the standard rate constant and the electron-transfer coefficient for the electrooxidation of dextromethorphan on INCPE and the diffusion coefficient of dextromethorphan, were determined. An amperometric procedure was optimized and applied for quantification of dextromethorphan in bulk as well as pharmaceutical forms. The simplicity, convenience, selectivity, and short time of analysis are the main advantages of these procedures.

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