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# Electrochemical Behavior of Carbon Nanotube/Mn(III) Salen Doped Carbon Paste Electrode and Its Application for Sensitive Determination of N-acetylcysteine in the Presence of Folic Acid

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A novel electrochemical sensor for the selective and sensitive detection of N-acetylcysteine (NAC) in presence of large excess of folic acid (FA) at physiological pH was developed by the bulk modification of carbon paste electrode (CPE) with carbon nanotubes (CNTs) and Mn(III) salen. Large peak separation, good sensitivity and stability allow this modified electrode to analyze NAC individually and simultaneously along with FA. Applying square wave voltammetry (SWV), a linear dynamic range of $5.0\times10^{-8}$- $3.35\times10^{-4}$ M with detection limit of 35.0 nM was obtained for NAC. Finally, the proposed method was applied to the determination of NAC and FA in some real samples.

**Keywords:** N-Acetylcysteine, Folic Acid, Carbon Paste Electrode, Carbon Nanotube

## 1. INTRODUCTION

Electrode surface modification is a field of paramount importance in the modern electrochemistry especially due to the various application possibilities of modified electrodes [1-15]. In recent years, chemically modified carbon paste electrodes have received increasing attention due to their potential applications in various analysis and also due to its relative ease of electrode preparation and regeneration [16-31].

Since the report of carbon microtubules which is known as carbon nanotube (CNT) in 1991 by Iijima [32], there has been enormous interest on exploring and developing the unique mechanical, chemical and electrical properties of CNT, such as extremely high mechanical strength, high chemical

stability and high electrical conductivity [33]. Although CNT is considered chemically inert, owing to their atomic structure, CNT behaves electrically as a metal or as a semiconductor. The subtle electronic properties suggest that CNT has the ability to promote electron transfer [34, 35]. The pentagonal defects and extra dimensional curvature present at the tips can enhance electron transfer rate when used as electrodes in some chemical reactions [36]. The electrodes based on CNT have been proved to have excellent electrochemical properties, such as wide potential window and small background current. The electrodes modified with CNT showed well-behaved electrochemical response and electrocatalytic activities compared with traditional carbon electrodes. As the CNT modified electrodes showed very stable electrochemical behaviors, it could be used to catalyze the electrochemical reaction of some bio-molecules and organic molecules [37-60]. The experimental results of CNT modified electrodes indicate that once the CNT is treated with nitric acid, carboxyl groups will be introduced onto the open ends of CNT and the electrode activity was enhanced [61-78].

N-acetylcysteine (NAC) is a pharmaceutical drug used primarily as a mucolytic agent since it is able to cleave disulfide bonds, converting them into two sulfhydryl groups. This reduces the chain length, which thins the mucus and so makes it easier to eliminate. NAC can also be very effective as an antidote in cases of acetaminophen poisoning [79]. In addition, this drug has an antioxidant action, and some authors have even suggested that NAC can aid in the complexation and elimination of heavy metals, as well as preventing some types of cancer [80].

This sulfhydryl compound has been determined by chromatographic[81], spectrophotometric [82], fluorimetric [83], potentiometric [84] and electrochemical methods [85,86]. With respect to its relatively large oxidation overpotential, the corresponding voltammetric signals on the surface of unmodified electrodes are usually weak. In order to decrease the undesirable anodic overpotential in the electrochemical oxidation of NAC, various chemically modified electrodes have been constructed [87-91].

Several chronic diseases (for example, gigantocytic anemia, leucopoenia, mentality devolution, psychosis, heart attack, and stroke), especially those concerned with malformation during pregnancy and carcinogenic processes, are related to the deficiency of folic acid (FA) [92] which is a water-soluble vitamin. Since FA is detected in biological fluids at very low concentration, i.e. 0.003μgmL$^{-1}$ (for pancreatic cancerous patients) [93], a highly specific and sensitive assay is called for. Among the different methods for determination of FA electrochemical methods are found to be very promising [94-104].

Studies showed that taking NAC reduces the possibility of pregnant women miscarrying. NAC may suppress oxidative stress, according to a 2008 study published in the "Reproductive BioMedicine Online" journal [105]. Oxidative stress happens when free radicals attack and destroy healthy brain cells. This may begin a cascade of changes in the body that causes a miscarriage. Humans convert NAC into the antioxidant, glutathione. The study found that NAC and FA supplements significantly increased the take-home baby rate of participants compared to taking FA alone.

Also, Yilmaz et al. [106] showed that FA and NAC therapies decreased plasma homocysteine, and increased endothelium–dependent dilation (EDD). Results showed that there was no significant difference in improving EDD between the FA and the NAC group. In patients with high homocysteine, FA and NAC lowered plasma homocysteine levels and improved endothelial function [106]. The

effects of both treatments in improvement of EDD were similar. These compounds can be used simultaneously for treatment of EDD and can presence in both plasma and urine samples. Result shows that NAC plus FA was associated with a significant increase in the treatment of EDD as compared with FA alone [106].

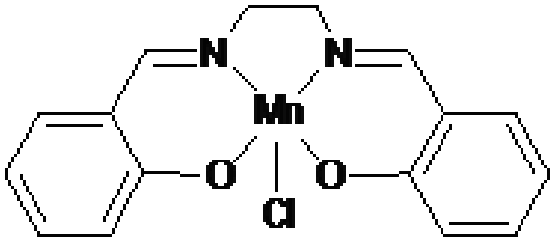
To the best of our knowledge, all previously published electrochemical studies have dealt with individual determination of NAC and FA, or simultaneous determination of NAC or FA with other drugs and no study has reported the simultaneous electrocatalytic determination NAC and FA by using any kind of modified electrodes and specially modified carbon nanotube paste electrode. Thus, in this paper, we described initially the preparation and suitability of a Mn(III) salen modified carbon nanotube paste electrode (MSCNPE) as a new electrode in the electrocatalysis and determination of NAC in an aqueous buffer solution. Then we evaluated the analytical performance of the modified electrode in quantification of NAC in the presence of FA.

## 2. EXPERIMENTAL

### *2.1. Apparatus and chemicals*

The electrochemical measurements were performed with an Autolab potentiostat/galvanostat (PGSTAT 302-N, Eco Chemie, the Netherlands). The experimental conditions were controlled with General Purpose Electrochemical System (GPES) software. A conventional three electrode cell was used at 25 ± 1 °C. An Ag/AgCl/KCl (3.0 M) electrode, a platinum wire, and the MSCNPE were used as the reference, auxiliary and working electrodes, respectively. A Metrohm 710 pH meter was used for pH measurements.

All solutions were freshly prepared with double distilled water. NAC, FA and all other reagents were of analytical grade from Merck (Darmstadt, Germany). The buffer solutions were prepared from orthophosphoric acid and its salts in the pH range of 2.0-11.0. Multiwalled carbon nanotubes (purity more than 95%) with o.d. between 10 and 20 nm, i.d. between 5 and 10 nm, and tube length from 0.5 to 200 μm were prepared from Nanostructured & Amorphous Materials, Inc. Mn(III) (salen) Cl (Scheme 1) was synthesized in our laboratory.




**Scheme 1.** Structure of Mn(III) (salen) Cl

*2.2. Preparation of the electrode*

The MSCNPEs were prepared by hand mixing 0.01 g of MS with 0.89 g graphite powder and 0.1 g CNTs with a mortar and pestle. Then, ~ 0.7 mL of paraffin oil was added to the above mixture and mixed for 20 min until a uniformly-wetted paste was obtained. The paste was then packed into the end of a glass tube (ca. 3.4 mm i.d. and 15 cm long). A copper wire inserted into the carbon paste provided the electrical contact. When necessary, a new surface was obtained by pushing an excess of the paste out of the tube and polishing with a weighing paper.

For comparison, MS modified CPE electrode (MS-CPE) without CNTs, CNTs paste electrode (CNPE) without MS, and unmodified CPE in the absence of both MS and CNTs were also prepared in the same way.

*2.3. Procedure of real Samples Preparation*

Five NAC tablets (labeled 600 mg) were grinding. Then, the tablet solution was prepared by dissolving 600 mg of the powder in 100 mL water by ultrasonication. Then, different volume of the diluted solution was transferred into a 10 mL volumetric flask and diluted to the mark with phosphate buffer (pH 7.0). The NAC content was analyzed by the proposed method using the standard addition method.

Five FA tablets (labeled 1 mg) were grinding. Then, the tablet solution was prepared by dissolving 1 mg of the powder in 100 mL water by ultrasonication. Then, different volume of the diluted solution was transferred into a 10 mL volumetric flask and diluted to the mark with phosphate buffer (pH 7.0).

Urine samples were stored in a refrigerator immediately after collection. Ten milliliters of the sample was centrifuged for 15 min at 2000 rpm. The supernatant was filtered out using a 0.45 μm filter. Then, different volume of the solution was transferred into a 10 mL volumetric flask and diluted to the mark with phosphate buffer (pH 7.0). The diluted urine sample was spiked with different amounts of NAC and FA.

## 3. RESULT AND DISCUSSION

*3.1. Electrochemical properties of modified MS-CNPE*

To the best of our knowledge there is no prior report on the electrochemical properties and, in particular, the electrocatalytic activity of MS in aqueous media. Therefore, we prepared MS-CNPE and studied its electrochemical properties in PBS (pH 7.0) using CV (Fig.1A). It should be noted that one of the advantages of MS as an electrode modifier is its insolubility in aqueous media. Experimental results showed reproducible, well-defined, anodic and cathodic peaks with $E_{pa}$, $E_{pc}$ and $E^{\circ\prime}$ of 0.64, 0.52 and 0.58 V *vs.* Ag/AgCl/KCl (3.0 M) respectively. The observed peak separation potential, $\Delta E_p = (E_{pa} - E_{pc})$ of 120 mV, was greater than the value of 59/n mV expected for a reversible system [107],

suggesting that the redox couple of MS in MS-CNPE has a quasi-reversible behavior in aqueous medium. The effect of the potential scan rate (ν) on electrochemical properties of the MCS-CNPE was also studied by CV. Plots of the both anodic and cathodic peak currents ($I_p$) were linearly dependent on ν in the range of 10 to 900 mV $s^{-1}$ (Fig. 1B), indicating that the redox process of MS at the modified electrode is diffusionless in nature [107].

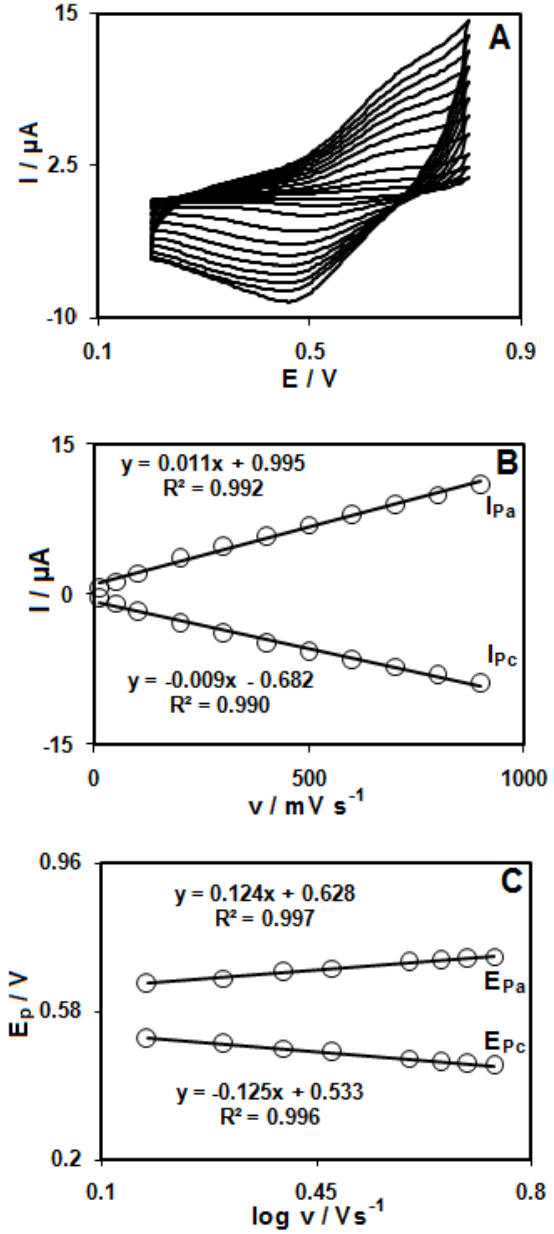



**Figure 1.** (A) CVs of MS-CNPE in 0.1M PBS (pH 7.0), at various scan rates, from inner to outer, 10, 50, 100, 200, 300, 400, 500, 600, 700, 800 and 900 mV $s^{-1}$. (B) Variation of $I_p$ *vs.* scan rate; (C) Variation of $E_p$ vs. the logarithm of the high scan rates.

The apparent charge transfer rate constant, $k_s$, and the charge transfer coefficient, α, of a surface-confined redox couple can be evaluated from CV experiments by using the variation of anodic and cathodic peak potentials with logarithm of scan rate, according to the procedure of Laviron [108]. Fig. 1C shows such plots, indicating that the $E_p$ values are proportional to the logarithm of scan rate for ν values higher than 1.5 V $s^{-1}$ (Fig. 1C). The slopes of the plots in Fig. 1C can be used to extract the kinetic parameters $\alpha_c$ and $\alpha_a$ (cathodic and anodic transfer coefficients, respectively). The slope of the linear segments are equal to $-2.303RT/\alpha nF$ and $2.303RT/(1-\alpha)nF$ for the cathodic and anodic peaks, respectively. The evaluated value for the α is 0.5.

Also, Eq. 1 can be used to determine the electron transfer rate constant between modifier (MS) and CNPE:

$$\log k_s = \alpha \log (1-\alpha) + (1-\alpha) \log \alpha - \log (RT/nF\nu) - \alpha (1-\alpha)\, nF\Delta E_p/2.3RT \qquad (1)$$

where $(1-\alpha)n_\alpha = 0.5$, ν is the sweep rate and all other symbols having their conventional meanings. The value of $k_s$ was evaluated to be 6.9 $s^{-1}$ using Eq. (1).

*3.2. Electrocatalytic oxidation of NAC at a MS-CNPE*

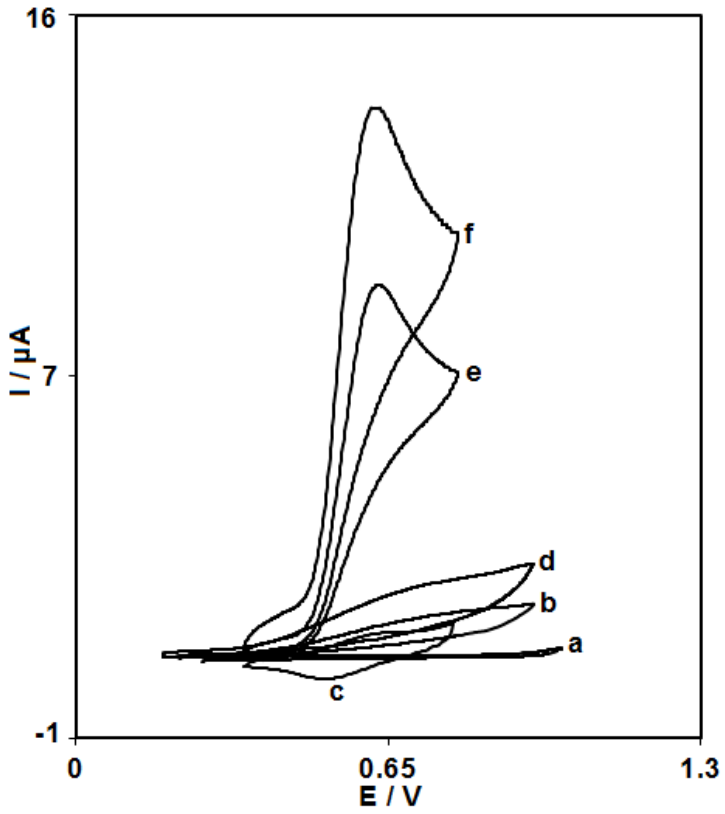



**Figure 2** CVs of (a) unmodified CPE in 0.1 M PBS (pH 7.0) at scan rate of 10 mV $s^{-1}$; (b) as (a) + 50.0 µM NAC; (c) as (a) at the surface of MSCNPE; (d) as (b) at the surface of CNPE; (e) as (b) at the surface of MSCPE; (f) as (b) at the surface of MSCNPE.

Fig. 2 depicts the cyclic voltammetric responses from the electrochemical oxidation of 50.0 µM NAC at MS-CNPE (curve f), MS modified CPE (MS-CPE) (curve e), CNPE (curve d) and bare CPE (curve b). As can be seen, the anodic peak potential for the oxidation of NAC at MS-CNPE (curve f) and MS-CPE (curve e) is about 640 mV, while at the CNPE (curve d) peak potential is about 740 mV, and at the bare CPE peak potential is about 790 mV for NAC (curve b). From these results it is concluded that the best electrocatalytic effect for NAC oxidation is observed at MS-CNPE (curve f). For example, the results show that the peak potential of NAC oxidation at MS-CNPE (curve f) shifted by about 100 and 150 mV toward the negative values compared with that at a CNPE (curve d) and bare CPE (curve b), respectively.

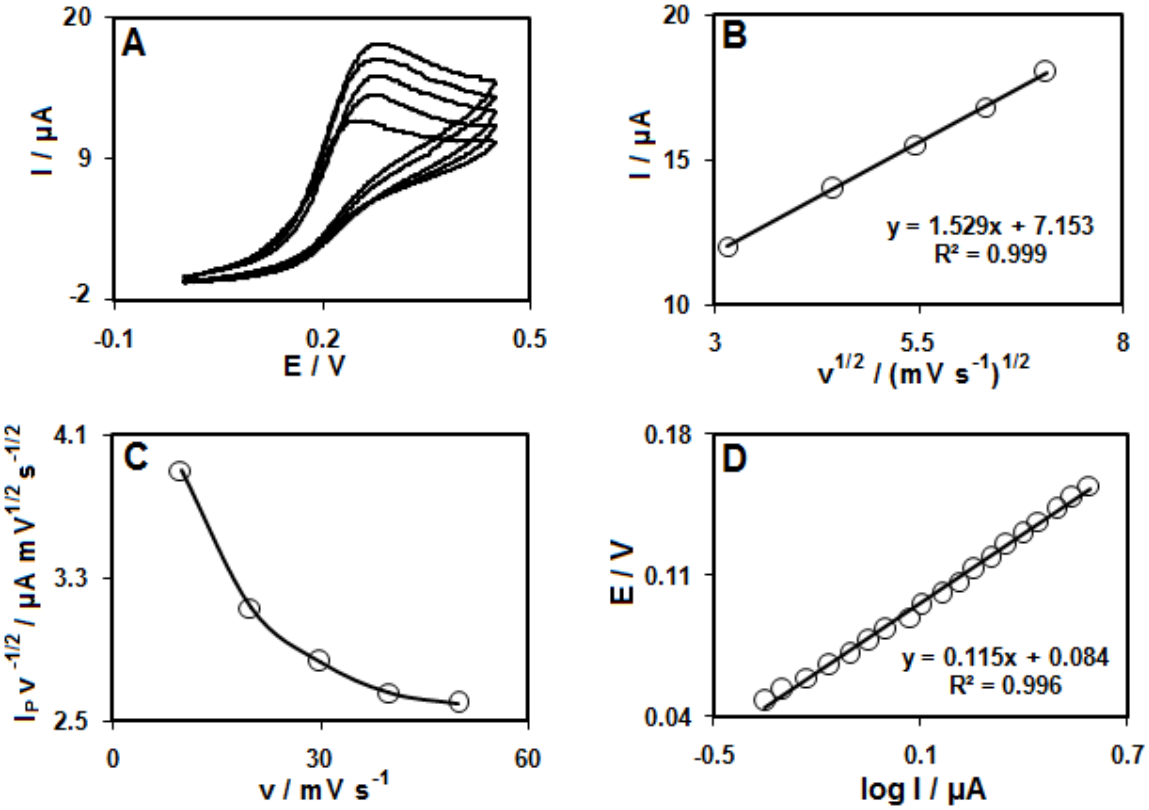



**Figure 3.** (A) CVs of MSCNPE in 0.1 M PBS (pH 7.0) containing 30.0 µM NAC at various scan rates correspond to 10, 20, 30, 40 and 50 mV $s^{-1}$, respectively. (B) Variation of anodic peak current vs. $v^{1/2}$; (C) Normalized current ($I_p/v^{1/2}$) *vs.* v; and (D) Tafel plot derived from the CV at the scan rate of 10 mV $s^{-1}$.

Similarly, when we compared the oxidation of NAC at the MS-CPE (curve e) and MS-CNPE (curve f); there is a dramatic enhancement of the anodic peak current at MS-CNPE relative to the value obtained at the MS-CPE. In the other words, the data obtained clearly show that the combination of CNTs and mediator (MS) definitely improve the characteristics of NAC oxidation. The MS-CNPE in 0.1 M PBS (pH 7.0), without NAC in solution, exhibits a well-behaved redox reaction (curve c) upon

the addition of 50.0 µM NAC, there is a dramatic enhancement of the anodic peak current (curve f) indicating a strong electrocatalytic effect [107].

The effect of scan rate on the electrocatalytic oxidation of NAC at the MSCNPE was investigated by cyclic voltammetry (CV) (Fig. 3A). As can be observed in Fig. 3, the oxidation peak potential shifted to more positive potentials with increasing scan rate, confirming the kinetic limitation in the electrochemical reaction. Also, a plot of peak height ($I_p$) vs. the square root of scan rate ($\nu^{1/2}$) was found to be linear in the range of 10-50 mV $s^{-1}$, suggesting that, at sufficient overpotential, the process is diffusion rather than surface controlled (Fig. 3B). A plot of the scan rate-normalized current ($I_p/\nu^{1/2}$) vs. scan rate (Fig. 3C) exhibits the characteristic shape typical of an EC´process [107].

Fig. 3D shows the Tafel plot for the sharp rising part of the voltammogram at the scan rate of 10 mV $s^{-1}$. If deprotonation of NAC is a sufficiently fast step, the Tafel plot can be used to estimate the number of electrons involved in the rate determining step. A Tafel slope of 0.115 V was obtained which agrees well with the involvement of one electron in the rate determining step of the electrode process [107], assuming a charge transfer coefficient, α of 0.49.

### *3.3. Chronoamperometric measurements*

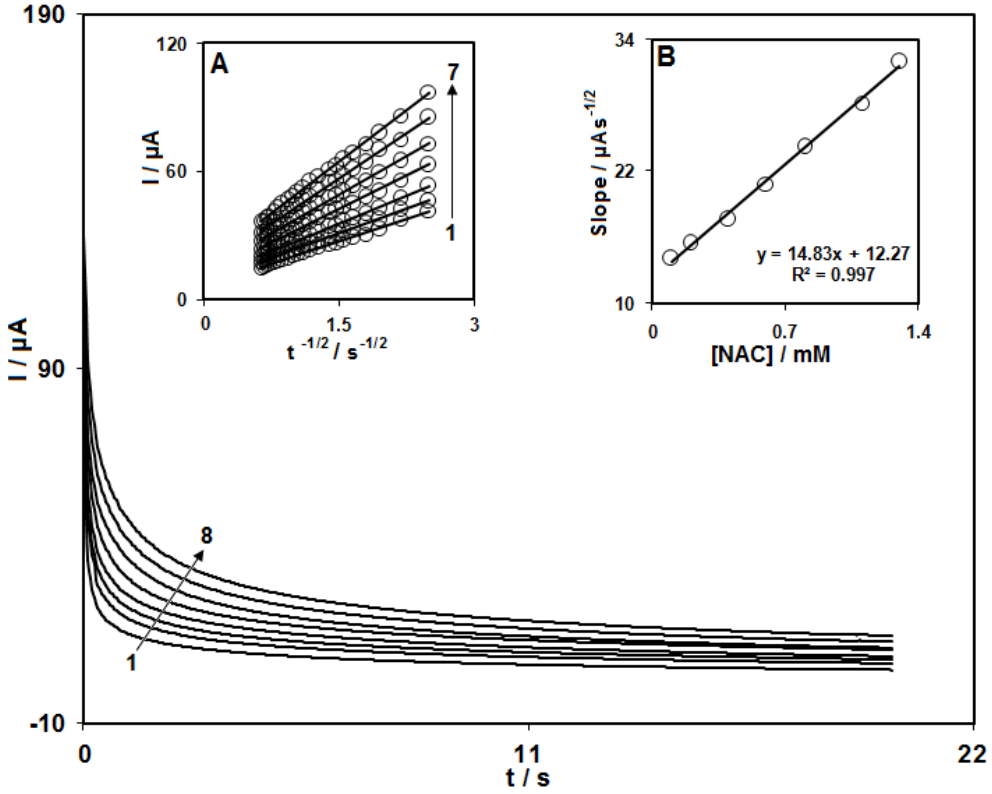



**Figure 4.** (A) Chronoamperograms obtained at MSCNPE in 0.1 M PBS (pH 7.0) for different concentration of NAC. The numbers 1–8 correspond to 0.0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.1 and 1.3 mM of NAC. Insets: (A) Plots of I vs. $t^{-1/2}$ obtained from chronoamperograms 2–8. (B) Plot of the slope of the straight lines against NAC concentration.

Chronoamperometric measurements of NAC at MSCNPE were carried out by setting the working electrode potential at 0.7 V vs. Ag/AgCl/KCl (3.0 M) for the various concentration of NAC in PBS (pH 7.0) (Fig.4). For an electroactive material (NAC in this case) with a diffusion coefficient of D, the current observed for the electrochemical reaction at the mass transport limited condition is described by the Cottrell equation [107]. Experimental plots of I vs. $t^{-1/2}$ were employed, with the best fits for different concentrations of NAC (Fig. 4A). The slopes of the resulting straight lines were then plotted vs. NAC concentration (Fig. 4B). From the resulting slope and Cottrell equation the mean value of the D was found to be $9.14 \times 10^{-6}$ $cm^2/s$.

### *3.4. Calibration plot and limit of detection*

SWV method was used to determine the concentration of NAC. The plot of peak current vs. NAC concentration consisted of two linear segments with slopes of 0.494 and 0.059 μA $\mu M^{-1}$ in the concentration ranges of 0.05 to 17.0 μM and 17.0 to 335.0 μM, respectively. The decrease in sensitivity (slope) of the second linear segment is likely due to kinetic limitation [107]. The detection limit (3σ) of NAC was found to be 35.0 nM. This value is comparable with values reported by other research groups for electrocatalytic oxidation of NAC at the surface of chemically modified electrodes by other mediators (Table 1).

**Table 1**. Comparison of the efficiency of some modified electrodes used in the electrocatalysis of NAC.

| Electrode | Modifier | Sensitivity ( μA μM-1) | pH | Electrooxidation peak potential vs. Ag/AgCl in the presence of modifier (mV) | Scan rate (mV/s) | LOD (M) | LDR (M) | Diffusion coefficient/ (cm2 s−1) | Electron transfer coefficient (α) | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|
| Carbon paste | 2,7-bis(ferrocenyl ethyl)fluoren-9-one | 0.4216 | 7.0 | 320 | 10 | $5.2 \times 10^{-8}$ | $7.0\times10^{-8}$-$3.0\times10^{-4}$ | $2.87\times 10^{-5}$ | 0.43 | 30 |
| Carbon paste | Catechol | 0.06 | | 400 | 20 | $1.0\times10^{-5}$ | $3.0\times10^{-5}$-$2.0\times10^{-3}$ | $3.4\times10^{-5}$ | - | 31 |
| Carbon paste | N-(3,4-dihydroxyphenethyl)-3,5-dinitrobenzamide | 0.1032 | 7.0 | 215 | 20 | $2.0\times10^{-7}$ | $5.0\times10^{-7}$-$2.0\times10^{-4}$ | $5.1\times10^{-4}$ | 0.59 | 33 |
| Carbon paste | Mn(III) salen | 0.494 | 7.0 | 640 | 10 | $3.5\times10^{-8}$ | $5.0\times10^{-8}$-$3.35\times10^{-4}$ | $9.14\times10^{-6}$ | 0.49 | This work |

### *3.5. Simultaneous determination of NAC and FA*

To our knowledge, no paper has used the modified carbon nanotube electrode and specially modified carbon nanotube paste electrode for simultaneous determination of NAC and FA and this work is the first report for simultaneous determination of NAC and FA using modified carbon nanotube paste electrode.

This was performed by simultaneously changing the concentrations of NAC and FA, and recording the SWVs. The voltammetric results showed well-defined anodic peaks at potentials of 560

and 760 mV, corresponding to the oxidation of NAC and FA, respectively, indicating that simultaneous determination of these compounds is feasible at the MSCNPE as shown in Fig. 5.

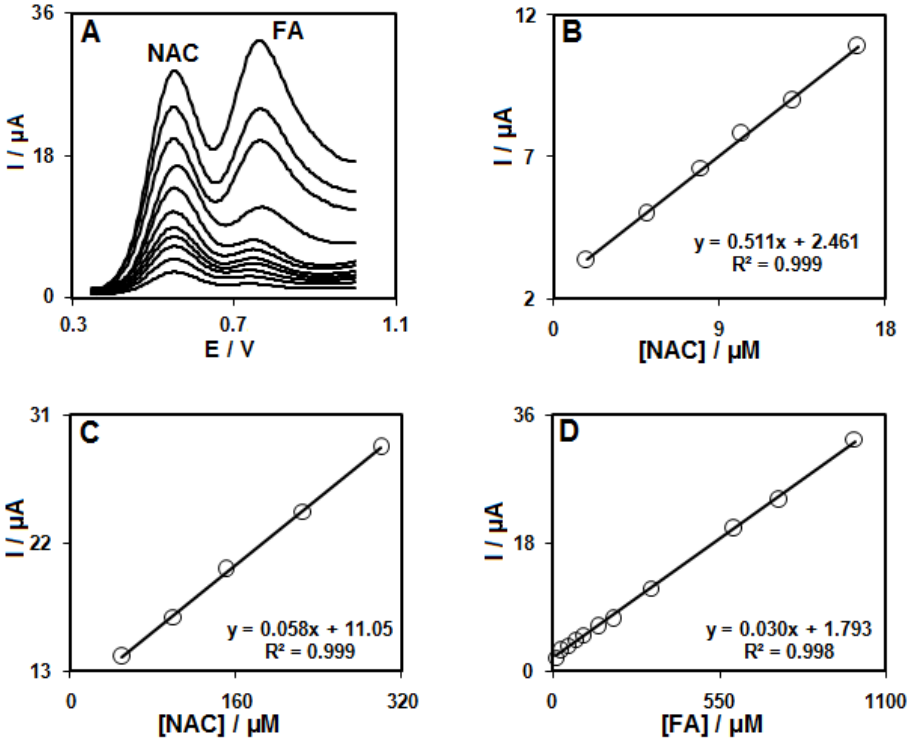



Figure 5. (A) SWVs of MSCNPE in 0.1 M PBS (pH 7.0) containing different concentrations of NAC+FA in µM, from inner to outer: 2.0+10.0, 5.0+25.0, 8.0+50.0, 10.0+75.0, 13.0+100.0, 16.5+150.0, 50.0+200.0, 100.0+325.0, 150.0+600.0, 225.0+750.0 and 300.0+1000.0 respectively. (B) plots of $I_p$ vs. NAC concentration in the first linear segment; (C) as (B) in the second linear segment and (D) plot of $I_p$ vs. FA concentrations.

*3.6. The repeatability and stability of MSCNPE*

The electrode capability for the generation of a reproducible surface was examined by cyclic voltammetric data obtained in optimum solution pH 7.0 from five separately prepared MSCNPEs. The calculated RSD for various parameters accepted as the criteria for a satisfactory surface reproducibility (about 1–4%), which is virtually the same as that expected for the renewal or ordinary carbon paste surface [30]. However we regenerated the surface of MSCNPE before each experiment according to our previous results.

In addition, the long-term stability of the MSCNPE was tested over a three-week period. When CVs were recorded after the modified electrode was stored in atmosphere at room temperature, the peak potential for NAC oxidation was unchanged and the current signals showed less than 2.3% decrease relative to the initial response. The antifouling properties of the modified electrode toward NAC oxidation and its oxidation products were investigated by recording the cyclic voltammograms of the modified electrode before and after use in the presence of NAC. Cyclic voltammograms were

recorded in the presence of NAC after having cycled the potential 17 times at a scan rate of 10 mV $s^{-1}$. The peak potentials were unchanged and the currents decreased by less than 2.4%. Therefore, at the surface of MSCNPE, not only the sensitivity increase, but the fouling effect of the analyte and its oxidation product also decreases.

### *3.7. Real sample analysis*

#### *3.7.1. Determination of NAC and FA in pharmaceutical preparations*

In order to evaluate the analytical applicability of the proposed method, also it was applied to the determination of NAC and FA in NAC and FA tablets. Based on the repeated square wave voltammetric responses (n=5) of the diluted analytes and the samples that were spiked with specified concentration of NAC and FA, measurements were made for determination of NAC and FA concentrations in the pharmaceutical preparations. The results are listed in table 2.

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 3). The results in table 2 show the relative standard derivations (RSD %) and the recovery rates of the spiked samples are acceptable. Also, the data in table 3 indicate that the results obtained by utilizing MSCNPE are in good agreement with those declared in the label of the preparations. Thus, the modified electrode can be efficiently used for individual or simultaneous determination of NAC and FA in pharmaceutical preparations.

**Table 2.** The application of MSCNPE for simultaneous determination of NAC and FA in pharmaceutical preparations (n=5)

| Sample | Spiked (μM) | | Expected (μM) | | Found (μM) | | Recovery (%) | | RSD (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NAC | FA | NAC | FA | NAC | FA | NAC | FA | NAC | FA |
| NAC tablet | 0 | 0 | 25.0 | 0 | 24.8 | 0 | 99.2 | - | 3.3 | - |
| | 2.5 | 20.0 | 27.5 | 20.0 | 27.0 | 19.8 | 98.2 | 99.0 | 2.8 | 1.8 |
| | 5.0 | 30.0 | 30.0 | 30.0 | 30.4 | 29.5 | 101.3 | 98.3 | 1.9 | 2.6 |
| | 7.5 | 40.0 | 32.5 | 40.0 | 31.9 | 40.4 | 98.1 | 101.0 | 1.6 | 2.1 |
| | 10.0 | 50.0 | 35.0 | 50.0 | 35.5 | 49.1 | 101.4 | 98.2 | 3.5 | 1.7 |
| FA tablet | 0 | 0 | 0 | 30.0 | 0 | 31.1 | - | 103.7 | - | 3.2 |
| | 5.0 | 5.0 | 5.0 | 35.0 | 5.1 | 34.7 | 102.0 | 99.1 | 3.1 | 1.6 |
| | 10.0 | 10.0 | 10.0 | 40.0 | 9.9 | 41.1 | 99.0 | 102.7 | 1.9 | 2.3 |
| | 15.0 | 15.0 | 15.0 | 45.0 | 14.8 | 46.1 | 98.7 | 102.4 | 2.4 | 3.5 |
| | 20.0 | 20.0 | 20.0 | 50.0 | 20.7 | 49.3 | 103.5 | 98.6 | 2.9 | 1.7 |

**Table 3.** Comparison of the total values of NAC and FA of some pharmaceutical preparations obtained using MSCNPE with declared values in the labels of samples (n=5)

| Sample | Declared value | Found value | RSD% |
|---|---|---|---|
| NAC tablet (mg per tablet) | 600.0 | 597.8 | 2.6 |
| FA tablet (mg per tablet) | 1.0 | 1.01 | 2.5 |

*3.7.2. Determination of NAC and FA in urine samples*

**Table 4.** The application of MSCNPE for simultaneous determination of NAC and FA in urine samples (n=5)

| Sample number | Spiked (μM) | | Found (μM) | | Recovery (%) | | RSD (%) | |
|---|---|---|---|---|---|---|---|---|
| | NAC | FA | NAC | FA | NAC | FA | NAC | FA |
| 1 | | | | | | | | |
| | 5.0 | 15.0 | 4.9 | 15.2 | 98.0 | 101.3 | 3.4 | 2.2 |
| | 7.5 | 20.0 | 7.7 | 19.8 | 102.7 | 99.0 | 2.9 | 1.7 |
| | 10.0 | 25.0 | 10.3 | 24.5 | 103.0 | 98.0 | 1.6 | 3.3 |
| | 12.5 | 30.0 | 12.2 | 30.3 | 97.6 | 101.0 | 2.8 | 3.1 |
| 2 | | | | | | | | |
| | 5.0 | 20.0 | 5.1 | 19.8 | 102.0 | 99.0 | 1.9 | 3.1 |
| | 10.0 | 30.0 | 9.9 | 29.1 | 99.0 | 97.0 | 2.4 | 2.9 |
| | 20.0 | 40.0 | 19.5 | 41.1 | 97.5 | 102.7 | 3.5 | 1.8 |
| | 30.0 | 50.0 | 31.1 | 49.7 | 103.7 | 99.4 | 3.2 | 1.6 |

In order to evaluate the analytical applicability of the proposed method, also it was applied to the determination of NAC and FA in urine samples. The results for determination of the two species in real samples are given in table 5. Satisfactory recovery of the experimental results was found for NAC and FA. The reproducibility of the method was demonstrated by the mean relative standard deviation (R.S.D.).

## 4. CONCLUSION

A novel modified carbon nanotube paste electrode was fabricated and applied to determine NAC and FA. The modified electrode shows excellent electrocatalytic activity for the oxidation of NAC and FA. Moreover, the modified electrode presented wide linear range, low detection limit and high stability for simultaneous determination NAC and FA, suggesting this electrode as a good and attractive candidate for practical applications.

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