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Research Article

Electrooxidation of Indomethacin at Multiwalled Carbon Nanotubes-Modified GCE and Its Determination in Pharmaceutical Dosage Form and Human Biological Fluids

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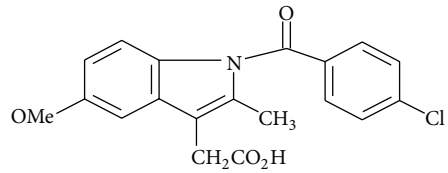
A simple, rapid, selective, and sensitive electrochemical method for the direct determination of indomethacin was developed. The electrochemical behavior of indomethacin was carried at multiwalled carbon nanotube- (MWCNTs-) modified glassy carbon electrode (GCE). The cyclic voltammetric results indicated that MWCNT-modified glassy carbon electrode remarkably enhanced electrocatalytic activity towards the oxidation of indomethacin in slightly acidic solutions. It led to a considerable improvement of the anodic peak current for indomethacin and could effectively accumulate at this electrode and produce two anodic peaks at 0.720 V and 0.991 V, respectively, and one reduction peak at 0.183 V. The electrocatalytic behavior was further exploited as a sensitive detection scheme for the determination of indomethacin by differential-pulse voltammetry (DPV). Under optimized conditions, the concentration range and detection limit were 0.2 to 6.0 μM and 13.2 nM, respectively. The proposed method was successfully applied to determination of Indomethacine in pharmaceutical samples. The analytical performance of this sensor has been evaluated for detection of analyte in human serum and urine as real samples.

1. Introduction

Indomethacin, (Scheme 1) {1-(p-chlorobenzoyl)-5-methoxy-2-methyl-3-indolylacetic acid} (INM), a nonsteroidal anti-inflammatory drug, is usually regarded as the father figure in the family of nonsteroidal agents. It relieves pain and reduces inflammation and fever. It is slightly more toxic but in certain circumstances more effective than aspirin. INM has two additional modes of actions [1] with clinical importance. It inhibits motility of polymorphonuclear leukocytes and, like salicylates, uncouples oxidative phosphorylation in cartilaginous (and hepatic) mitochondria. These additional effects account as well for the analgesic and the anti-inflammatory properties. Generally, overdose in humans causes drowsiness, dizziness, severe headache, mental confusion, numbness of limbs, nausea and vomiting, severe gastrointestinal bleeding, and cerebral edema and cardiac arrest, its fatal outcome is seen in children. For these reasons, it is important to analyze INM in real samples.

The widespread use of INM and the need for clinical and pharmacological study require fast and sensitive analytical techniques to determine the presence of INM in pharmaceutical formulations and biological fluids. Until now, the most common techniques for the determination of INM in commercial dosage form were based on spectrofluorometric [2], phosphorimetric [3], spectrophotometric [4], preconcentration, and voltammetric [5], chemometric near infrared spectroscopy and X-ray powder diffractometry [6], photofluorometric [7], and high-performance liquid chromatographic (HPLC) methods [8]. But these methods are time consuming, are solvent usage intensive, and require expensive devices and maintenance. The advantages of electroanalytical methods in analysis ofdrugs are their simplicity,



Scheme 1: Chemical structure of indomethacin.

high sensitivity, low cost, and relatively short analysis time as compared to the other routine analytical techniques.

Carbon nanotubes (CNTs) continue to receive remarkable attention in electrochemistry [9, 10]. Since their discovery by Iijima [11] in 1991 using transmission electron microscopy, CNTs have been the subject of numerous investigations in chemical, physical, and material areas due to their novel structural, mechanical, electronic, and chemical properties [12]. Subtle electronic properties suggest that CNTs have the ability to promote charge transfer reactions when used as an electrode [13]. The modification of electrode surfaces with multiwalled carbon nanotubes (MWCNTs) for use in analytical sensing has been documented to result in low detection limits, high sensitivities, reduction of over potentials, and resistance to surface fouling. MWCNTs have been introduced as electrocatalysts [14–16] and CNTs-modified electrodes have been reported to give super performance in the study of a number of biological species [17].

To the best of our knowledge, electrochemical behavior and determination of INM in pharmaceuticals and biological fluids at multiwalled carbon nanotubes-modified glassy carbon electrode have not been reported yet. The objective of the present work is to develop a convenient and sensitive method for the determination of INM, based on the unusual properties of MWCNTs-modified glassy carbon electrode. The ability of the modified electrode for voltammetric response of selected compound was evaluated. Finally, this modified electrode was used for the analysis of INM in pharmaceutical samples, urine samples, and human serum samples. The resulted biosensor exhibited high sensitivity, rapid response, good reproducibility, and freedom of other potentially interfering species.

2. Experimental

2.1. Reagents. Pure INM was obtained from Sigma-Aldrich, India, and used as received. A stock solution of 1×10^{-3} M was made in double distilled water and little alkali was added to get clear solution. Multiwalled carbon nanotubes were procured from Sigma-Aldrich (>90%.: 10–15 nm, I.D.: 2–6 nm, length: 0.1–10 μm). The phosphate buffers from pH 3.0 to 10.20 were prepared in doubly distilled water as described by Christian and Purdy [18]. The tablets with brand name Microcid (M/s Micro labs Ltd, India) were purchased from local market. Other reagents used were of analytical or chemical grade and their solutions were prepared with doubly distilled water.

2.2. Apparatus. Electrochemical measurements were carried out on a CHI1110A electrochemical analyzer (CH Instrument Company, USA) coupled with a conventional three-electrode cell. A three-electrode cell was used with a Ag/AgCl as reference electrode, a Pt wire as counterelectrode, and a glassy carbon electrode with a diameter of 2 mm (modified and unmodified). These were used as working electrodes, respectively. All the used electrodes were obtained from CHI Co. and all the potentials in this paper are given against the Ag/AgCl (3 M KCl). The pH of solution was measured with an Elico LI120 pH meter (Elico Ltd., India).

2.3. Preparation of MWCNTs-Modified Electrode. Multiwalled carbon nanotubes were refluxed in the mixture of concentrated H_2SO_4 and HNO_3 (1 : 3) for 4-5 h, then washed with doubly distilled water, and dried in vacuum at room temperature. The MWCNTs suspension was prepared by dispersing 2 mg MWCNTs in 10 mL of acetonitrile using ultrasonic agitation to obtain a relative stable suspension. The GCE was carefully polished with 0.30 and 0.05 μM α-alumina slurry on a polishing cloth and then washed in an ultrasonic bath of methanol and water, respectively. The cleaned GCE was coated by casting 15 μL of the black suspension of MWCNT and dried in the air. The electroactive areas of the MWCNT-modified GCE and the bare GCE were obtained by cyclic voltammetry (CV) using 1.0 mM $K_3Fe(CN)_6$ as a probe at different scan rates. For a reversible process, the Randles-Sevcik formula [19] has been used as follows:

$$i_{pa} = \left(2.69 \times 10^5\right) n^{3/2} A {D_R}^{1/2} \mathrm{Co}\, \nu^{1/2}, \quad (1)$$

where i_{pa} referred to the anodic peak current, n is the number of electrons transferred, A is the surface area of the electrode, D_R is the diffusion coefficient, ν is the scan rate, and Co is the concentration of $K_3Fe(CN)_6$. For 1.0 mM $K_3Fe(CN)_6$ in 0.1 M KCl electrolyte, $n = 1$, $D_R = 7.6 \times 10^{-6}$ cm^2 s^{-1}; then, from the slope of the plot of i_{pa} versus $\nu^{1/2}$ relation, the electroactive area was calculated. In bare GCE, the electrode surface area was found to be 0.0586 cm^2 and, for MWCNT-modified GCE, the surface area was nearly 3.0–3.50 times greater.

2.4. Analytical Procedure. The MWCNT-modified GCE was first activated in phosphate buffer (pH 6.0) by cyclic voltammetric sweeps between 0 and 1.4 V until stable cyclic voltammograms were obtained. Then, electrode was transferred into another 10 mL of phosphate buffer (pH 6.0) containing proper amount of INM. After accumulating for 180 s at open circuit under stirring and following quiet for 10 s, potential scan was initiated and cyclic voltammograms were recorded between +0.2 and +1.4, with a scan rate of 50 mVs^{-1}. All measurements were carried out at room temperature of 25 ± 0.1°C.

2.5. Tablet Assay Procedure. Ten pieces of INM tablets were powdered in a mortar. A portion equivalent to a stock solution of a concentration of about 1.0 mM was accurately weighed and transferred into a 100 mL calibrated flask and

diluted with double distilled water. The content of the flask was sonicated for complete dissolution. Appropriate solutions were prepared by taking suitable aliquots of the clear supernatant liquid and diluting them with phosphate buffer solutions. Each solution was transferred to the voltammetric cell and analyzed by standard addition method. To study the accuracy of the proposed method and to check the interferences from excipients used in the dosage form, recovery experiments were carried out. The concentration of INM was calculated using standard addition method.

2.6. Recovery Studies in Spiked Human Serum Sample. Serum samples, obtained from healthy individuals (after having obtained their written consent), were stored frozen until assay. The type and amount of solvent for protein precipitating were optimized by recording the voltammograms of spiked serum solutions. After gentle thawing, an aliquot volume of sample was fortified with INM dissolved in double distilled water to achieve final concentration of 1.0×10^{-3} M and treated with 0.5 mL of acetonitrile as serum protein precipitating agent and then the volume was completed to 2 mL with the same serum sample. Then it was centrifuged 10 min at 4000 rpm to get rid of protein residues and upper supernatant liquid was transferred in the voltammetric cell containing phosphate buffer as supporting electrolyte, leaving behind residue. Voltammograms were recorded in pure acetonitrile and methanol as a serum protein precipitating agents. Also, different amounts of acetonitrile were tried. The best results were obtained with 0.5 mL acetonitrile.

3. Results and Discussion

3.1. Cyclic Voltammetric Behavior of INM. The cyclic voltammograms of INM at (a) blank CVs of MWCNT-modified GCE, (b) bare CVs of MWCNT-modified GCE, (c) and MWNCTS-modified GCE were shown in Figure 1. It can be seen that the oxidation peak at the bare GCE was weak and broad due to slow electron transfer, while the response was considerably improved at the MWCNT-modified GCE. At the bare GCE, the peak was at about 0.817 V but, on the MWCNT-modified GCE, the peaks appeared at about 0.720 V and 0.991 V. This was attributed to the electrocatalytic effect caused by MWCNTs.

The reduction peak was observed in the reverse scan at 0.182 V, but the condition for reversible process was ($E_p - E_{p1/2}$) = 59/n mV, but we got these values lesser and, hence, we considered that electrochemical reaction was a totally irreversible process. The voltammograms corresponding to the first anodic cycle and peak A were generally recorded. Peak A was more intense than peak B.

3.2. Influence of pH. The electrode reaction might be affected by the pH of the medium. The electrooxidation of 1.0×10^{-3} M INM was studied over the pH range 3.0–10.2 in phosphate buffer solution by cyclic voltammetry. At pH 3, one oxidation and one reduction peak appeared and, at pH 5, two oxidation peaks and one reduction peak appeared sharply. The results showed that maximum peak current was

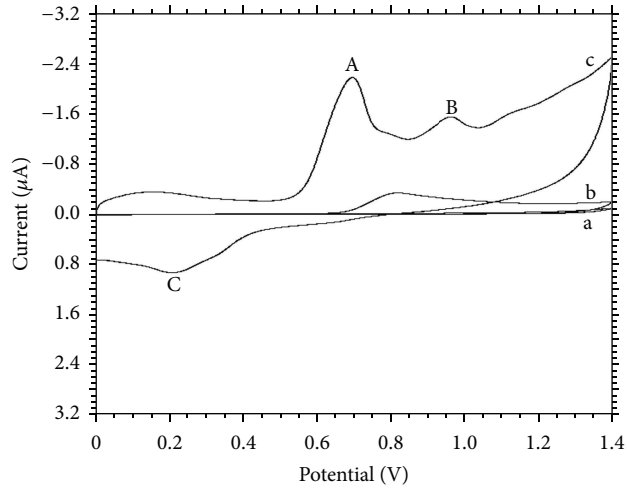


Figure 1: Cyclic voltammograms of 1.0 mM INM on MWCNT-modified GCE. (a) Blank CVs of MWCNT-modified GCE. (b) Bare CVs of MWCNT-modified GCE. (c) MWNCTS-modified GCE Scan rate: 50 mVs^{-1}; supporting electrolyte: 0.2 M phosphate buffer with pH 6.0; accumulation time: 180 s (at open circuit); volume of MWCNTs suspension: 15 μL.

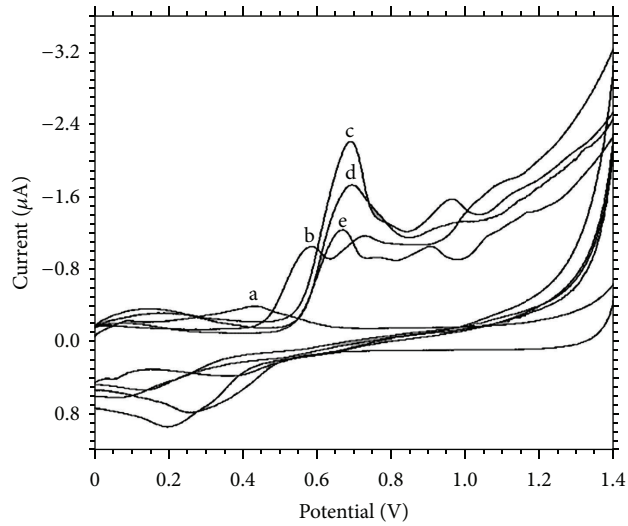


Figure 2: Influence of pH on the shape of anodic peak. pH: 3.0 (a), 5.0 (b), 6.0 (c), 7.0 (d), and 10.0 (e). Other conditions are as in Figure 1.

obtained in phosphate buffer with pH 6.0 (Figure 2). Hence, we selected pH 6.0 for remaining studies. Within the range of pH 3.0 to 6.0, peak current (Figure 3(a)) dramatically increased. Above pH 6, the peak current decreased. The peak potential was pH dependent from pH 5.0 after and before peak potential was almost pH dependent as shown in Figure 3(b).

3.3. Influence of Scan Rate. Useful information involving electrochemical mechanism could be acquired from the relationship between peak current and scan rate. Therefore, the electrochemical behavior of INM at different scan rates,

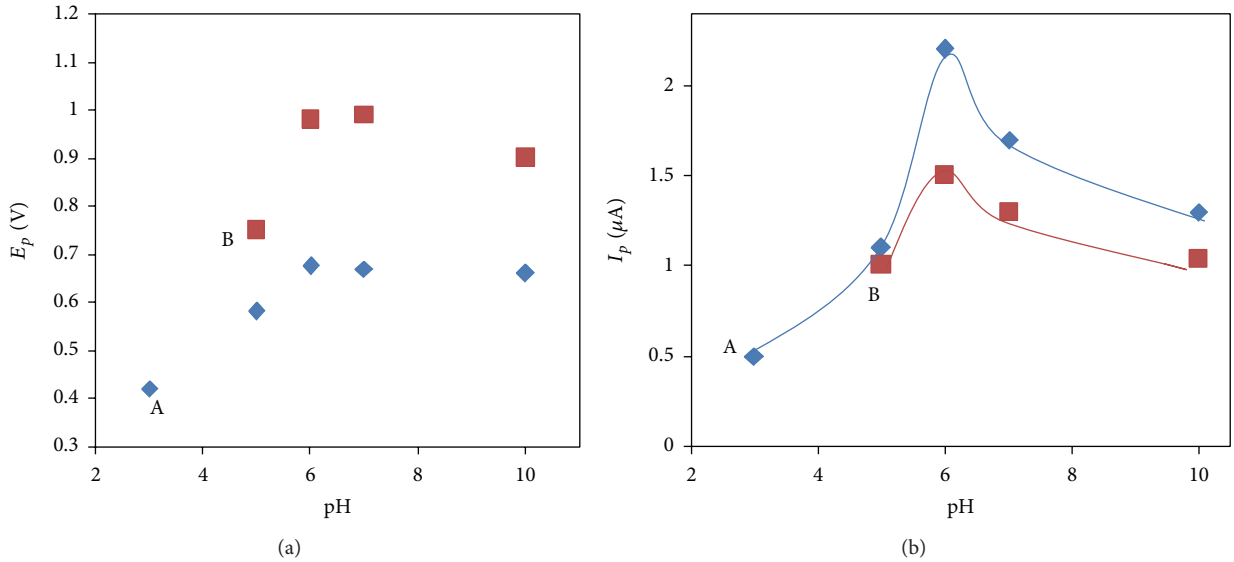


FIGURE 3: (a) Influence of pH on the peak potential of INM for peaks A and B. Other conditions are as in Figure 1. (b) Variation of peak currents of peaks A and B with pH. Other conditions are as in Figure 1.

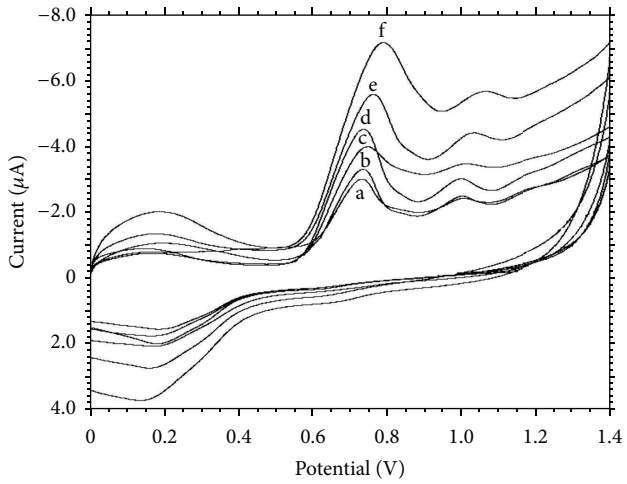


FIGURE 4: Cyclic voltammograms of 1.0 μM INM on MWCNT-modified GCE with different scan rates. (a) to (f) were 10, 50, 100, 150, 200, and 300 mVs^{-1}, respectively. Other conditions are as in Figure 1.

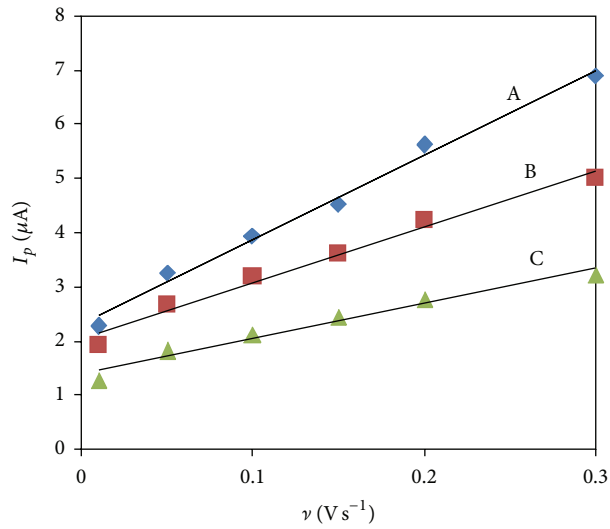


FIGURE 5: Dependence of the oxidation peak current of peaks A and B on the scan rate.

10 to 300 mVs^{-1} (Figure 4), was studied. There was a good linear relationship between peak current and scan rate. The equations representing were $I_p = 15.67\nu + 2.291$; $r = 0.990$, $I_p = 10.33\nu + 2.031$; $r = 0.983$, and $I_p = 6.465\nu + 1.382$; $r = 0.967$, for peak A, peak B, and peak C, respectively, as shown in Figure 5. In addition, there was a linear relation between log I_p and log ν, corresponding to the following equations: $\log I_p = 0.315 \log \nu + 0.950$; $r = 0.947$, $\log I_p = 0.272 \log \nu + 0.803$; $r = 0.961$, and $\log I_p = 0.269 \log \nu + 0.619$; $r = 0.978$, as shown in Figure 6. The slopes of peak A, peak B, and peak C were 0.315, 0.272, and 0.269 and were very close to the theoretically expected value of 0.5 for a diffusion-controlled process [20].

The peak potential shifted to more positive values with increasing scan rates. The linear relation between peak potential and the logarithm of scan rate could be expressed as $E_p = 0.817 + 0.048 \log \nu$; $r = 0.900$, $E_p = 0.062 + 1.074 \log \nu$; $r = 0.905$, and $E_p = 0.129 - 0.045 \log \nu$; $r = 0.910$, for the peaks A, B, and C, respectively (Figure 7).

For irreversible electrode process according to Laviron [21], E_p is defined by the following equation:

$$E_p = E^{0'} + \left(\frac{2.303RT}{\alpha nF}\right) \log\left(\frac{RTk^0}{\alpha nF}\right) + \left(\frac{2.303RT}{\alpha nF}\right) \log \nu, \quad (2)$$

Table 1: Recovery test of INM in tablets.

Added (M)	Found (M)[a]	Recovery (%)	S.D. ± R.S.D. (%)
3.0×10^{-6}	2.98×10^{-6}	99.33	0.064 ± 0.045
5.0×10^{-6}	5.02×10^{-6}	100.4	0.299 ± 0.207
8.0×10^{-6}	7.89×10^{-6}	101.39	0.085 ± 0.061
1.0×10^{-5}	0.998×10^{-5}	99.09	0.268 ± 0.192
3.0×10^{-5}	3.102×10^{-5}	103.4	0.629 ± 0.445
5.0×10^{-5}	4.989×10^{-5}	99.78	0.760 ± 0.261
8.0×10^{-5}	8.021×10^{-5}	100.26	0.320 ± 0.652

[a]Average of five determinations.

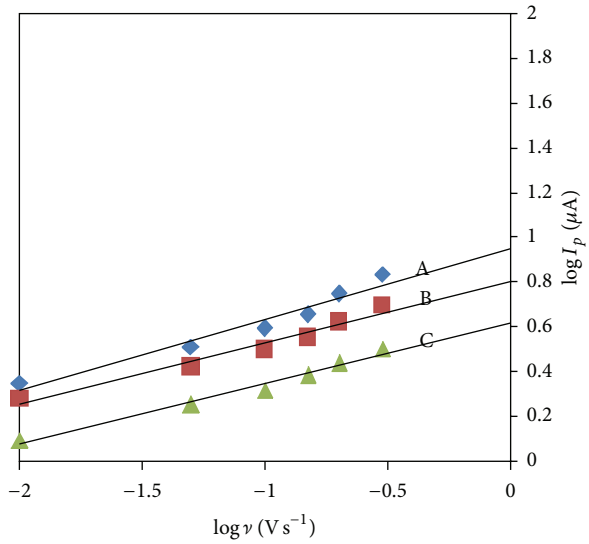


Figure 6: Dependence of the logarithm of peak current on logarithm of scan rate for peaks A and B.

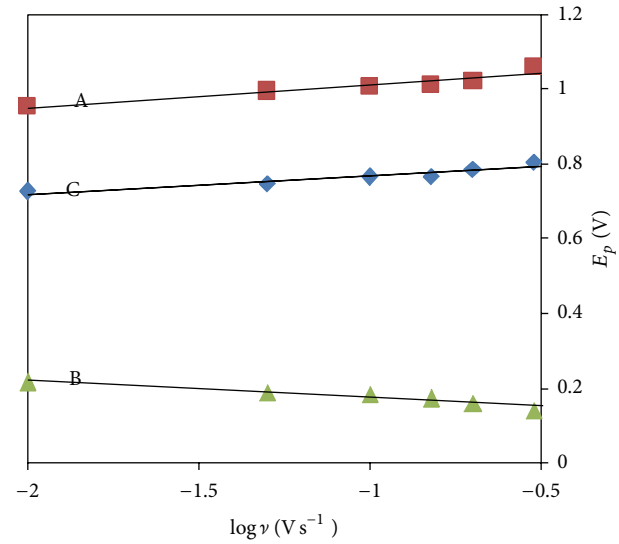


Figure 7: Relationship between peak potential and logarithm of scan rates for the peaks A and B.

Table 2: Influence of potential Interferents on the voltammetric response of 1.0×10^{-5} M INM.

Samples	Interferents	Concentration (1.0×10^{-4} M)	Signal change (%)
1	Glucose	1.0	+4.23
2	Starch	1.0	+2.61
3	Sucrose	1.0	+4.45
4	Citric acid	1.0	−2.84
5	Magnesium stearate	1.0	+6.68
6	Talk	1.0	+5.36
7	Gum acacia	1.0	+0.32
8	Ascorbic acid	1.0	+9.39
9	Lactic acid	1.0	+6.39
10	Tartaric acid	1.0	+6.79
11	Oxalic acid	1.0	+10.9

where α was the transfer coefficient, k^0 the standard heterogeneous rate constant of the reaction, n the number of electrons transferred, ν the scan rate, and E^0 is the formal redox potential. Other symbols had their usual meanings. Thus, the value of αn could be easily calculated from the slope of E_p versus $\log \nu$. In this system for peak A, the slope was 0.048, taking $T = 298$, $R = 8.314$, and $F = 96{,}480$, and αn was calculated to be 1.23. According to Bard and Faulkner [22],

$$\alpha = \frac{47.7}{E_p - E_{p/2}} \text{mV}, \tag{3}$$

where $E_{p/2}$ was the potential where the current was at half the peak value. So, from this, we had got the value of α to be 0.7061. Further, the number of electrons (n) transferred in the electrooxidation of INM was calculated to be 1.742~2. The value of k^o could be determined from the intercept of the above plot if the value E^o was known. The value of E^o in (2) can be obtained from intercept E_p versus ν curve by extrapolating to the vertical axis at $\nu = 0$ [23]. For peak A, the intercept for E_p versus $\log \nu$ plot was 0.817, E^o was obtained to be 0.8403, and the k^o was calculated to be 1.6821×10^3 s^{-1}.

Table 3: Determination of INM in urine samples.

Sample	Spiked (10^{-5} M)	Found[a] (10^{-5} M)	Recovery (%)	S.D. ± R.S.D (%)
1	0.4	0.403	100.3	0.019 ± 0.014
2	0.6	0.589	98.6	0.017 ± 0.012
3	0.8	0.768	97.5	0.015 ± 0.011
4	2.0	2.004	100.2	0.036 ± 0.026
5	4.0	4.105	102.6	0.155 ± 0.109

[a]Average of five determinations.

Table 4: Results obtained for INM analysis from spiked human serum sample.

Sample	Indomethacin (M)	Level determined[a] (M)	Recovery (%)	R.S.D (%)
1	8×10^{-5}	7.99×10^{-5}	99.91	1.05
2	6×10^{-5}	6.04×10^{-5}	100.47	0.74
3	3×10^{-5}	2.95×10^{-5}	99.50	0.67

[a]Average of five determinations.

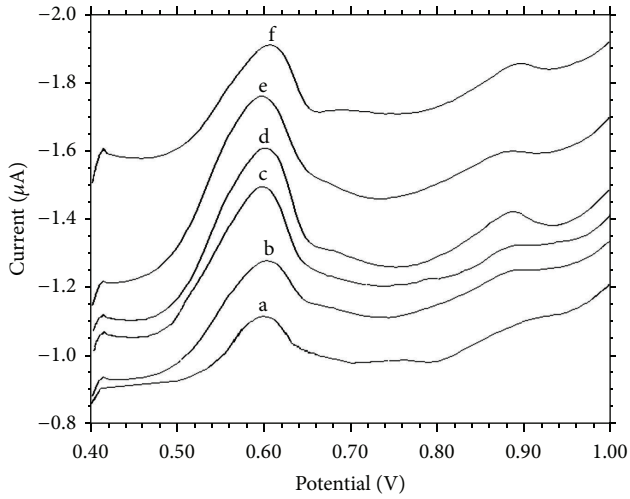


Figure 8: Differential-pulse voltammograms of MWCNT-modified GCE in INM solution at different concentrations: 0.2 (1), 1.0 (2), 2.0 (3), 4.0 (4), 6.0 (5), and 8.0 (6) μM.

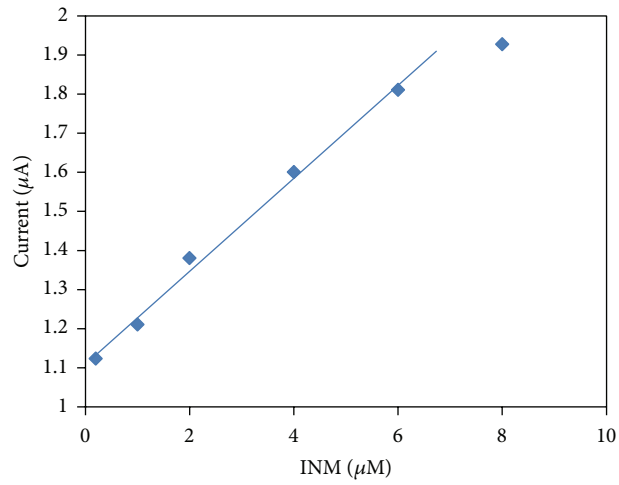
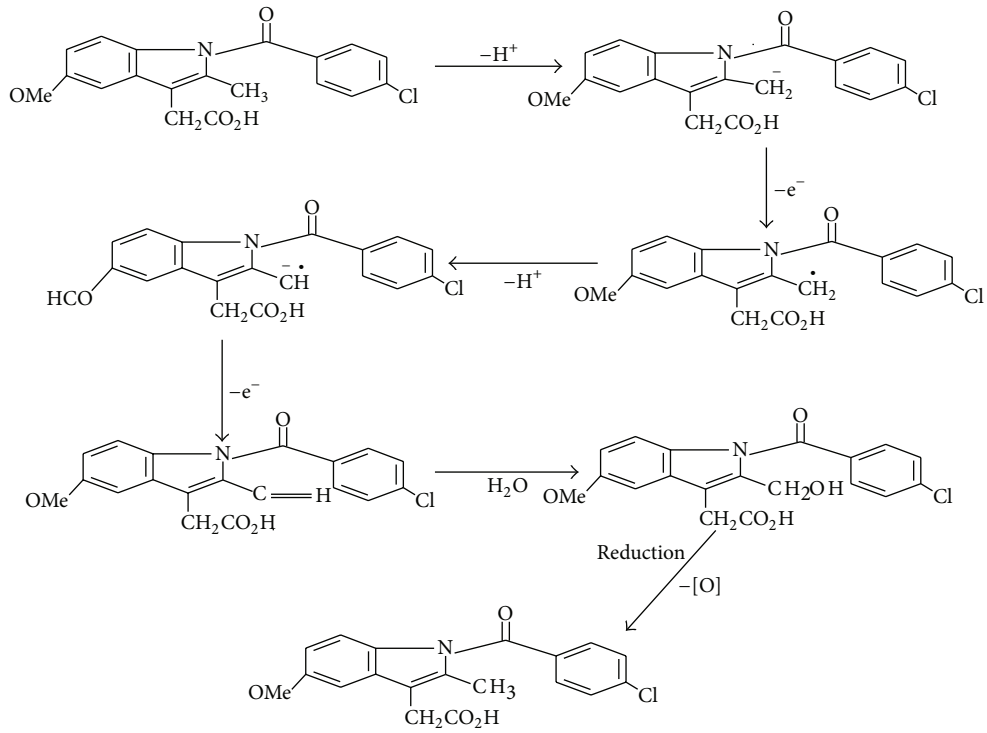


Figure 9: Plot of the peak current against the concentration of INM.

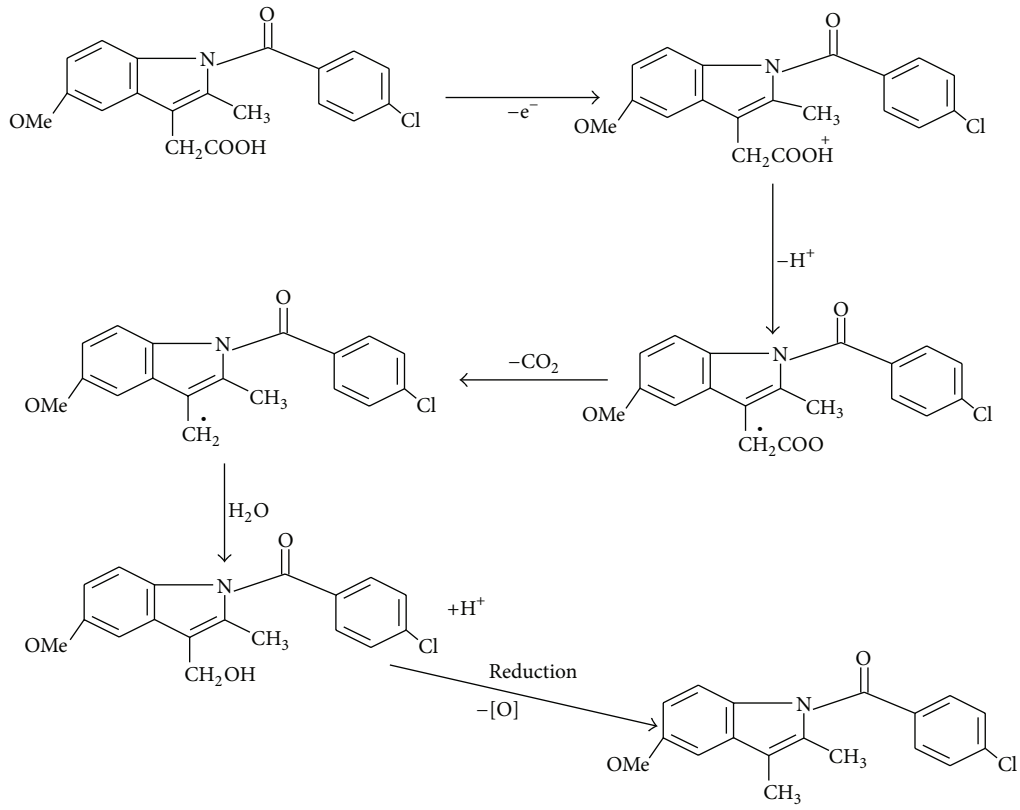
Similarly for the peak B n was found to be 0.818 $\approx$ 1, k^o was 1.7127×10^3 s^{-1}, also for the peak C, n was found to be 0.8378 $\approx$ 1, and k^o was 1.13×10^{-3} s^{-1}.

3.4. Mechanism. The INM contained indole moiety with three substituent groups OCH_3, CH_2COOH, and CH_3. A CH_3site for electrooxidation took place for peak A. Methyl group simultaneously lost two protons and two electrons and the indole substituent alcohol was formed which on reduction of the INM was formed as shown in Scheme 2. The second site for the oxidation was at CH_2COOH. Due to the loss of a proton and electron, a 3-substituted alcohol was formed which, on reduction of a methyl group, gets attached to the molecule as shown in Scheme 3.

3.5. Calibration Curve. In order to develop a voltammetric method for determining the drug, we selected differential-pulse voltammetric mode, because the peaks were sharper and better defined at lower concentration of INM than those obtained by cyclic voltammetry with a lower background current, resulting in improved resolution. According to the obtained results, it was possible to apply this technique to the quantitative analysis. The phosphate buffer solution of pH 6.0 was selected as supporting electrolyte for the quantification as it gave maximum peak current at pH 6.0. The peak at about 0.717 V, the differential-pulse voltammograms obtained, showed that the peak current increased linearly with increase in concentration of INM, as shown in Figure 8. Using the optimum conditions described above, linear calibration curve was obtained for INM in the range of 0.2 to 6.0 μM. (Figure 9): the linear equation was I_p (μA) = 0.113C + 1.117 (r = 0.987, C is in μM). Deviation from linearity



Scheme 2: Probable mechanism for the oxidation and reduction of INM for peak A.



Scheme 3: Probable mechanism for the oxidation and reduction of INM for peak B.

was observed for more concentrated solutions, due to the adsorption of INM or its oxidation product on the electrode surface. Related statistical data of the calibration curves were obtained from the five different calibration curves. The limit of detection (LOD) and quantification (LOQ) were 13.2 nM and 44.2 nM, respectively. The LOD and LOQ were calculated using the following equations:

$$\text{LOD} = 3\frac{s}{m}\ ; \qquad \text{LOQ} = 10\frac{s}{m}, \tag{4}$$

where s was the standard deviation of the peak currents of the blank (five runs) and m was the slope of the calibration curve.

In order to study the reproducibility of the electrode preparation, a 1.0×10^{-5} M INM solution was measured with the same electrode (renewed every time) for every several hours within day, and R.S.D. of the peak current was 0.24% (number of measurements = 5). As to the between reproducibility, it was similar to that of within day if the temperature was kept almost unchanged. Owing to the adsorption of INM or its oxidative products onto the electrode surface, the current response of the modified electrode would decrease after successive use. In this case, the electrode should be modified again.

3.6. Tablet Analysis. In order to evaluate the applicability of the proposed method in the pharmaceutical sample analysis, one commercial medicinal sample containing INM was used as to detect INM in tablets (50 mg per tablet). The procedure for the tablet analysis was followed as described in the procedural Section 2.5. The detected content was 49.86 mg per tablet with 97.2% recovery.

The recovery tests of INM ranging from 3.0×10^{-6} to 8.0×10^{-5} M was performed using cyclic voltammetry. Recovery studies were carried out after the addition of known amount of the drug to various preanalyzed formulations of INM. The results are listed in Table 1. The recoveries in different samples were found to lie in the range from 99.09% to 103.4% and the standard deviation and relative standard deviation are listed in Table 1.

3.7. Interference. The tolerance limit was defined as the maximum concentration of the interfering substance that caused an error less than ±5% for determination of INM. Under the optimum experimental conditions, the effects of potential interferents on the voltammetric response of 1.0×10^{-5} M INM were evaluated. The experimental results (Table 2) showed that hundredfold excess of glucose, starch, sucrose, citric acid, and gum acacia did not interfere with the voltammetric signal of INM. However, magnesium stearate, talk, ascorbic acid, lactic acid, tartaric acid, and oxalic acid had apparent influence on the voltammetric signal of INM.

4. Detection of INM in Urine Samples

The developed cyclic voltammetric method for the determination INM in urine samples. The recoveries from urine were measured by spiking drug-free urine with known amounts of INM. The urine samples were diluted 100 times with the phosphate buffer solution before analysis without further pretreatments. A quantitative analysis could be carried out by adding the standard solution of INM into the detecting system of urine sample. The calibration graph was used for the determination of spiked INM in urine samples. The detection results of five urine samples obtained were listed in Table 3. The recovery determined was in the range from 97.5% to 102.63% and the standard deviation and relative standard deviation are listed in Table 3.

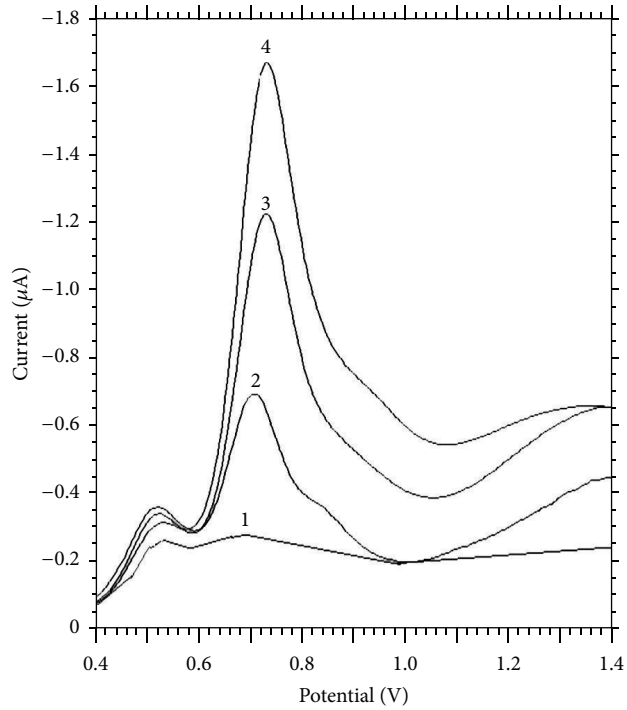


Figure 10: DPV obtained for the determination of indomethacin in human serum samples; (1) blank serum extract, (2) extract containing 3.0×10^{-5} M indomethacin, (3) extract containing 6.0×10^{-5} M indomethacin, and (4) extract containing 8.0×10^{-5}.

4.1. Determination of INM in Spiked Serum Samples. The possibility of applying the proposed method for the determination of INM in human serum was tested. Serum samples were spiked with INM to achieve final concentrations of 8.0×10^{-5}, 6.0×10^{-5}, and 3.0×10^{-5} M. The amount of INM in human serum was calculated from the related linear regression equations (Table 4). Typical DPV curves examined in serum are reported in Figure 10. The generally poor selectivity of voltammetric techniques could pose difficulties in the analysis of biological samples, which contained oxidizable substances. As could be seen from Figure 8, no oxidation of compounds present in serum occurred where the analytical peak appeared. The percentage recovery of INM was determined by comparing the peak currents of known amount of drug concentrations in serum with their equivalents in related calibration curves. The results of these analyses are summarized in Table 4. Good recoveries of INM were achieved from this type of matrix. Analysis of serum

samples by DPV involved only protein precipitation and centrifugation; no time-consuming extraction and evaporation steps were required.

5. Conclusions

A multiwalled carbon nanotube-modified glassy carbon electrode has been successfully developed for electrocatalytic oxidation of INM in phosphate buffer solution. When the potential was made to move, it produced two anodic peaks at 0.717 V and 0.991 V and one cathodic peak at 0.183 V in 0.2 M pH 6.0 phosphate buffer. MWCNTs showed electrocatalytic action for the oxidation of INM, characterized by the peak current, which was probably due to the larger surface area of MWCNTs. Suitable oxidation and reduction mechanisms were proposed. The peak at about 0.717 V was suitable for analysis and the peak current was linear to concentrations over a certain range under the selected conditions. This sensor can be used for voltammetric determination of selected analyte as low as 13.2 nM with good reproducibility. The modified electrode has been used to determine INM in pharmaceutical samples. The proposed method offered the advantages of accuracy and time-saving as well as simplicity of reagents and apparatus. In addition, the results obtained in the analysis of INM in spiked human urine and serum samples demonstrated the applicability of the method for real sample analysis.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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