



Electrochemical behavior of lansoprazole at a multiwalled carbon nanotubes–ionic liquid modified glassy carbon electrode and its electrochemical determination

LI-HONG LIU^{1,2}, WEI YOU¹, XUE-MEI ZHAN¹ and ZUO-NING GAO^{1*}

¹College of Chemistry and Chemical Engineering, Ningxia University, Yinchuan, 750021, China and ²Department of Chemistry, Heihe College, Heilongjiang 164300, China

(Received 12 December 2012, revised 3 May 2013)

Abstract: The electrochemical behavior of lansoprazole (LNS) was investigated at a glassy carbon electrode (GCE) and the GCE modified by a gel containing multiwalled carbon nanotubes (MWCNTs) and a room-temperature ionic liquid (RTIL) of 1-butyl-3-methylimidazolium hexafluorophosphate (BMIMPF₆) in 0.10 M phosphate buffer solution of pH 6.8. It was found that an irreversible anodic oxidation peak with an E_{pa} of 1.060 V_{SCE} appeared at the MWCNTs–RTIL/GCE. Under the optimized experimental conditions a linear calibration curve was obtained over the concentration range from 5.0 μ M to 0.20 mM by differential pulse voltammetry with a limit of detection (LOD , $S/N = 3$) of 0.28 μ M. In addition, the novel MWCNTs–RTIL/GCE was also characterized by electrochemical impedance spectroscopy and the proposed method was successfully applied in the quantitative electrochemical determination of LNS content in commercial tablet samples. The determination results met the determination requirements.

Keywords: lansoprazole; MWCNTs; RTIL; 1-butyl-3-methylimidazolium hexafluorophosphate; electrochemical determination.

INTRODUCTION

Lansoprazole (LNS, chemically known as (*R/S*)-2-[[3-methyl-4-(2,2,2-trifluoroethoxy)pyridin-2-yl]methylsulfinyl]-1*H*-benzo[*d*]imidazole, is a benzimidazole derivative (tradename Takepron[®]), the structure of which is shown in Fig. 1, which is related to omeprazole. LNS is a permanent, potent and non-reversible proton pump inhibitor that suppresses gastric acid secretion through an interaction with (H⁺/K⁺)-adenosine triphosphatase (ATPase) in the secretory membranes of the gastric parietal cells.¹ LNS is effective in the treatment of various peptic diseases, including duodenal ulcers, peptic ulcer, reflux esophagitis and

*Corresponding author. E-mail: gaozn@nxu.edu.cn
doi: 10.2298/JSC121216059L

Zollinger–Ellison syndrome,^{2,3} and its therapeutic effect excels omeprazole.⁴ Like the most compounds of this class, LNS is acid labile and reversibly transformed to sulfenamides in acidic media.^{5,6} Thus it must be administered in the form of enteric coated granules in capsules to prevent gastric decomposition and improve its systematic bioavailability.⁷ Various techniques have been developed for the studies of LNS in pharmaceutical dosage forms, human serum and plasma, including spectrophotometry,^{8–13} high-performance liquid chromatography with ultraviolet detection,^{14–17} liquid chromatography coupled with tandem mass spectrometry (LC/MS),¹⁸ thin-layer chromatography with fluorescence¹⁹ or ultraviolet detection,²⁰ capillary electrophoresis,^{21,22} flow analysis²³ and flow injection analysis.²⁴ In addition, a few of electrochemical techniques have been reported, including cathodic polarography,²⁵ adsorptive stripping square-wave voltammetry at a hanging mercury drop electrode,^{26,27} anodic voltammetry^{28,29} and alternating current polarography at a dropping mercury electrode.³⁰ However, the methods related to spectrophotometry, chromatography, capillary electrophoresis and flow analysis require time-consuming manipulation steps, expensive instruments and special training. The electrochemical methods mentioned above involving a mercury electrode have environmental pollution issues and mostly discuss only the electrochemical reduction of LNS. For these reasons, herein, a rapid, simple and accurate electrochemical method was developed using a glassy carbon electrode (GCE) modified with multi-walled carbon nanotubes (MWCNTs) and a room-temperature ionic liquid (RTIL), *i.e.*, 1-butyl-3-methylimidazolium hexafluorophosphate (BMIMPF₆) (MWCNTs–RTIL/GCE).

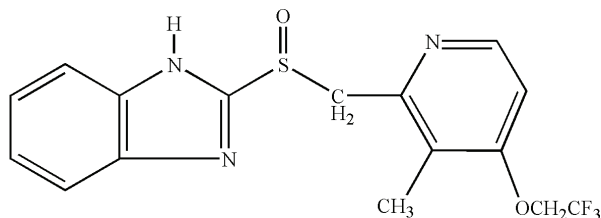


Fig. 1. Structure of lansoprazole.

Carbon nanotubes (CNTs), discovered by Iijima³¹ in 1991 using transmission electron microscopy, have a special structure, and mechanical, electronic and chemical properties,^{32,33} for which reasons they are widely applied in chemical, physical and materials science. When used as electrode-modifying materials, CNTs have the ability to promote charge-transfer reactions.^{34–38} RTILs are compounds consisting entirely of ions that exist in the liquid state at around room temperature.^{39,40} They have good chemical and physical properties, such as good chemical and thermal stability, negligible vapor pressure, high conductivity, good biocompatibility, low toxicity and a wide electrochemical window.^{41–46} Accord-

ing to the literature,⁴⁷ MWCNTs are untangled after treatment with RTILs, mainly because of cross-linking of the nanotube bundles mediated by local molecular ordering of the RTIL resulting from “cation- π ” interactions between imidazolium and nanotubes. At the present, the research and application of MWCNTs–RTIL modifiers have been reported. According to the above facts, a combination of MWCNTs and an RTIL could be favorable for the fabrication of modified electrode. Such electrodes could be successfully applied in the electrocatalysis of bioelectrochemical reactions, the fabrication of biosensors and the detection of the various kinds of biomolecules.^{48–61}

As a continuation of previous work,^{62–68} the use of MWCNTs and the ionic liquid BMIMPF₆, based on their synergy to form a novel composite thin-film material at a GCE, is described herein for the electrochemical determination of LNS in commercial tablet form.

EXPERIMENTAL

Apparatus

All electrochemical experiments were carried out using an Electrochemistry Workstation CHI660A (CHI Instrument, USA). A personal computer was used for data storage and processing. The working electrodes used in voltammetry experiments were a CHI104 glassy carbon electrode with 3 mm diameter and glassy carbon electrode modified by MWCNTs and room temperature ionic liquid (RTIL–MWCNTs/GCE). A platinum wire and a saturated calomel electrode (SCE) served as the auxiliary and the reference electrodes, respectively. All potentials measured and reported in this work were *versus* SCE.

Reagents

Lansoprazole (Batch No. 4090401, Purity > 99 %), was from Kangya Pharmaceutical Ltd. (Ningxia Hui Autonomous Region, China) and used without further purification. Lansoprazole tablets (batch No. 080801; labeled value of 15 mg per tablet) were from ShengFan Pharmaceuticals Ltd. (Henan province, China). 1-Butyl-3-methylimidazolium hexafluorophosphate (BMIMPF₆, purity > 99 %) was obtained from Shanghai Chengjie Chemical Co. Ltd., China). The MWCNTs (provided by prof. Fei Wei, Chemical Engineering College of Tsinghua University, China) were functionalized to give carboxylic carbon nanotubes following a literature procedure.⁶⁹ Unless otherwise stated, a 0.10 M Na₂HPO₄–NaH₂PO₄ buffer solution (PBS) of pH 6.8 was used as the supporting electrolyte. All other chemicals were of analytical grade and used as received. All solutions were prepared in doubly distilled water and thoroughly flushed with high purity nitrogen to remove oxygen from the solutions in the electrochemical cell. All experiments were performed at room temperature.

Fabrication of modified electrodes

Before the modification, a glassy carbon electrode was polished with 0.3 μm $\alpha\text{-Al}_2\text{O}_3$ slurry on the polishing micro-cloth, rinsed thoroughly with distilled water and ultrasonically successively in acetone and doubly distilled water for 10 min to remove any remaining polishing alumina. 0.50 mg mL⁻¹ of homogeneous black suspension was prepared by dispersing 1 mg of functionalized MWCNTs into 2 mL of *N,N*-dimethyl formamide (DMF) /H₂O (1:1) aqueous solution with the aid of ultrasonic stirring for 15 min, then 12 μL of the black MWCNTs suspension was dropped directly on GCE surface with a microsyringe and the solvent was evaporated under the infrared lamp to obtain MWCNTs/GC. 12 mg of MWCNTs

mixed with 200 μL of BMIMPF_6 was ground for about 20 min in a mortar to give a viscous MWCNTs–RTIL gel, and then a proper amount of the gel was transferred on the cleaned electrode surface by mechanically rubbing, thus a MWCNTs–RTIL/GCE was fabricated.

The influence of the amount of the MWCNTs dispersion, from 1–15 μL , on the oxidation peak currents of LNS was examined by CV. On increasing the amount of the MWCNTs dispersion, the number of the catalytic sites for LNS oxidation increased, whereby the oxidation peak current increased gradually. When the amount of MWCNTs dispersion exceeded 15 μL , the cast film was thicker and blocked electron transfer. Due to uncompensated resistive effects or to a lowering of the charge transfer rate, the peak currents decreased. In addition, solvent evaporation required a longer waiting time. Therefore, 12 μL of MWCNTs dispersion was cast on the GCE to fabricate the MWCNTs/GCE.

The ratio of BMIMPF_6 to MWCNTs was optimized through observing the peak current of 50 μM of LNS in 0.10 M PBS by CV. The experimental results indicated that the peak currents of LNS remained essentially constant in the range of BMIMPF_6 –MWCNTs ratio of 200/13 to 200/9 $\mu\text{L mg}^{-1}$. When more (or less) of the RTIL was employed, the gel for fabricating the modified electrode was not well formed. Hence a BMIMPF_6 –MWCNTs ratio of 200/12 $\mu\text{L mg}^{-1}$ was chosen as appropriate. Furthermore, the thickness of MWCNTs–RTIL modified layer was controlled by the minimum redox potential difference (ΔE_p) and the maximum peak current (I_p) of $\text{K}_3[\text{Fe}(\text{CN})_6]$ at the modified electrode.

RESULTS AND DISCUSSION

Electrochemical impedance spectroscopy (EIS) of the bare GCE and the modified electrode

Electrochemical impedance spectroscopy can generally provide useful information on the impedance changes of the electrode surface during the fabrication process.^{70,71} By using the $\text{Fe}(\text{CN})_6^{3-/4-}$ redox couple as an electrochemical probe, the Nyquist plots of the different electrodes as shown in Fig. 2 with frequencies ranging from 1 Hz to 100 kHz were obtained. It was found from the curves in Fig. 2 that the interfacial electron transfer resistance was nearly to zero at MWCNTs/GCE, which indicated that the MWCNTs formed high electron conduction pathways between the electrode and the electrolyte.⁷² At high frequencies near the origin, MWCNTs–RTIL/GCE represented an obvious smaller semicircle than that of the bare GCE and RTIL/GCE, which is related to good ionic conductivity and the least charge-transfer resistance of MWCNTs–RTIL/GCE. At low frequencies, MWCNTs–RTIL/GCE represented a linear tail with a maximal slope among the different electrodes, which indicated that the MWCNTs–RTIL/GCE obviously improved the diffusion of ferricyanide toward the electrode surface, as reported in the literature.⁷³

Cyclic voltammetric behavior of lansoprazole

The cyclic voltammetric behavior of MWCNTs–RTIL/GCE, MWCNTs/GCE and the bared GCE in 0.10 mM LNS were investigated at a scanning rate of 50 mV s^{-1} in 0.10 M of PBS over the potential range of 0–1.20 V, as shown by the curves in Fig. 3. From these curves, it could be seen that a large and well-

-defined anodic peak appeared at 1.06 V at the MWCNTs–RTIL/GCE (Fig. 3a). No corresponding reduction peak was observed in the reverse scan, indicating the irreversibility of the electrochemical oxidation reaction.

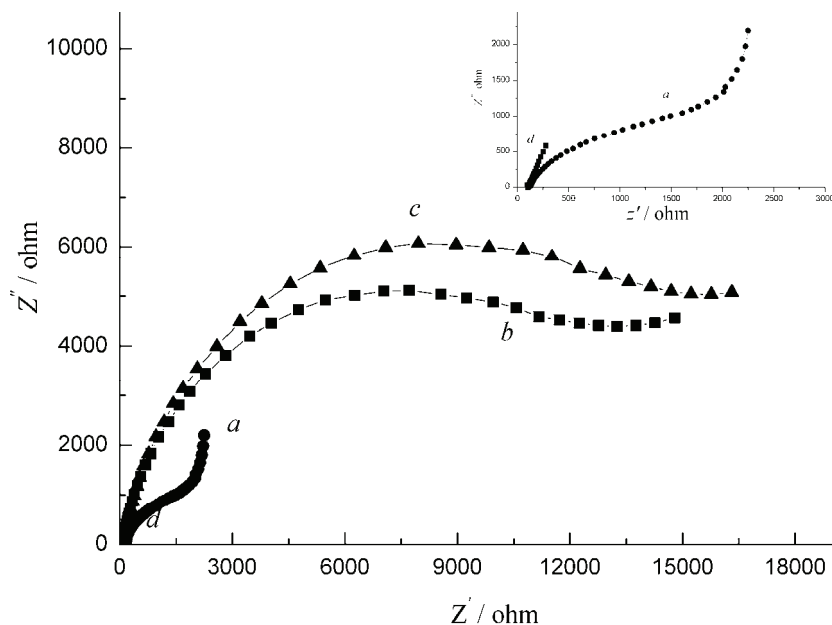


Fig. 2. Complex plane plots of a) MWCNTs–RTIL/GCE, b) bare GCE, c) RTIL/GCE and d) MWCNTs/GCE in 1.0 mM $\text{Fe}(\text{CN})_6^{3-/4-}$ + 0.10 M KCl. Frequency range: 1–10⁵ Hz.

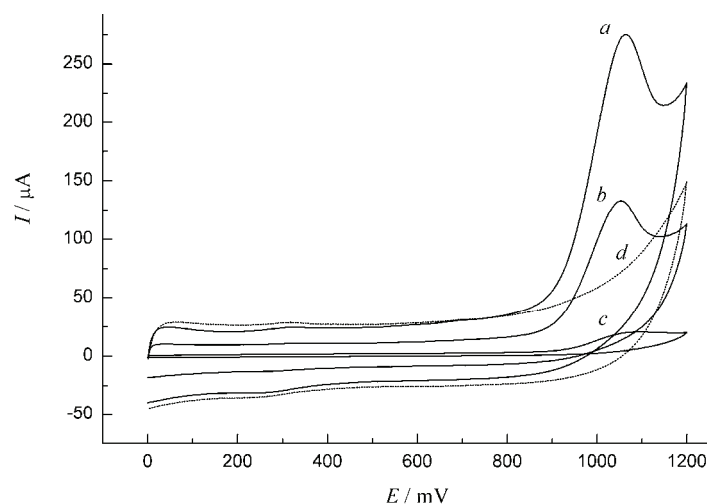


Fig. 3. Cyclic voltammograms of a) MWCNTs–RTIL/GCE, b) MWCNT/GCE and c) GCE in the presence and d) MWCNTs–RTIL/GCE in the absence of 0.10 mM of lansoprazole in 0.10 M PBS (pH 6.8). Scan rate: 50 mV s⁻¹.

By comparison MWCNTs/GCE and the bare GCE, it is seen that the LNS oxidation peak potential is hardly shifted, but the peak current increased by almost two times in contrast to that at the MWCNTs/GCE and fifteen times to that at the bare GCE, which indicated that the electrochemical oxidation reaction of LNS could be improved significantly by the MWCNTs–RTIL/GCE, which is based on the synergy of MWCNTs and RTIL. This may be explained as follows: first, the electrochemical oxidation of LNS occurred easily at thermodynamically favorable potentials and the reaction rate increased kinetically at the MWCNTs–RTIL/GCE; secondly, the MWCNTs themselves, with nano-scaled dimensions, have a particular electronic structure, high electrical conductivity and topological defects present on their surfaces, which can be readily and completely used as an electrochemical sensing unit, yielding higher sensitivity, and can bear both basal plane sites and edge plane like sites/defects in their structures, which may have caused the electrocatalytic efficiency during the electro-oxidation process.^{74–76} Finally, MWCNTs are untangled after treatment with RTIL, mainly because of cross-linking of the nanotube bundles mediated by local molecular ordering of the RTIL resulting from “cation– π ” interactions between imidazolium and the nanotubes.⁴⁷ Thus, the MWCNTs–RTIL gel can act as a promoter to increase the heterogeneous electron transfer rate, and catalyze very well the lansoprazole electrochemical oxidation reaction.

The effects of the experimental conditions on the peak current and potential of the catalytic oxidation

The effect of various media on the peak current and potential of the catalytic oxidation of LNS could be easily observed from CV. The voltammetric behaviors of LNS at scanning rate 50 mV s^{-1} in different electrolytes, such as aqueous NaCl, CH_3COONa , NaNO_3 , Na_2SO_4 and $\text{CH}_3\text{COONa}-\text{CH}_3\text{COOH}$, Britton–Robinson buffer solution and $\text{Na}_2\text{HPO}_4-\text{NaH}_2\text{PO}_4$ (PBS), were investigated. The experimental results showed that in 0.10 M aqueous PBS, LNS had a relative well-defined oxidation peak; thus, 0.10 M PBS was chosen as the supporting electrolyte.

The effect of pH on the anodic peak current and the peak potential for 0.10 mM LNS were studied in 0.10 M PBS over the pH range 5.5–10.0 to avoid degradation and the results are shown in Fig. 4. From Fig. 4, curve a, it could be seen that the anodic peak potentials shifted linearly in the negative direction up to pH 8.0 (inset plot in Fig. 4) with the linear equation being:

$$E_p / \text{mV} = -60\text{pH} + 1502 \quad (R = 0.9989) \quad (1)$$

The correlation coefficient was 0.9989. The slope of -60 mV pH^{-1} is very similar to the theoretical value of 59 mV pH^{-1} , which indicated that the number of electrons transferred and the number of proton participating in the electrochemical oxidation reaction were the same. The intercept of the two segments, which

occurred at pH 8.0 may be related to the pK_a of LNS⁷⁷ and are in accordance with literature data.²⁸ Fig. 4, curve b shows that the anodic peak current varies with change in pH values. The peak current reaches its maximum at pH 6.5; thus, pH 6.8 was chosen for the further experiment.

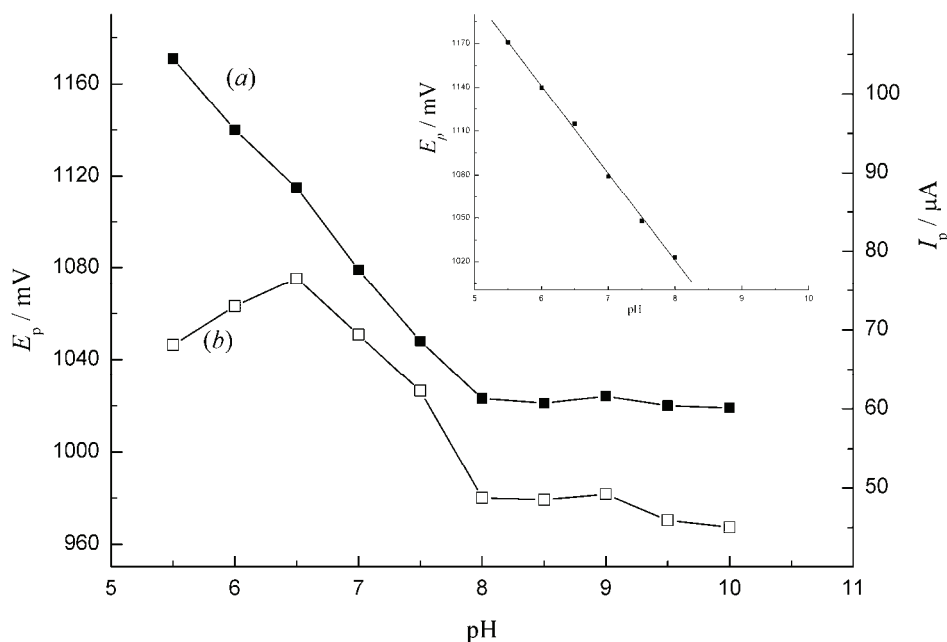


Fig. 4. Effect of pH on a) E_p and b) I_p of 0.10 mM lansoprazole at a MWCNTs–RTIL/GCE by CV. The inset plot is the dependence of pH on E_p from pH 5.5 to pH 8.0. Scan rate: 50 mV s⁻¹.

The effect of the scan rate in CV experiments with 0.10 mM LNS at the MWCNTs–RTIL/GCE is as follows. With increasing potential scanning rate, the peak current increased and the peak potential shifted positively, which implied irreversibility of the electrode reaction processes. The oxidation peak current *versus* the square root of the scan rate was a straight line as shown in Fig. 5, curve b, as expected for a diffusion-controlled electrode reaction process. The linear regression equation is expressed as:

$$I_{pa} / \mu A = 29.88 + 10.19v^{1/2} / (mV^{1/2} s^{-1/2}) \quad (R = 0.9987) \quad (2)$$

The oxidation peak potential (E_{pa}) shifted in the positive direction with increasing scan rate (v), and the relationship between E_{pa} / V and $v / V s^{-1}$ was in accordance with the following equation:

$$E_{pa} / mV = 894.5 + 88.88 \log v \quad (R = 0.9929) \quad (3)$$

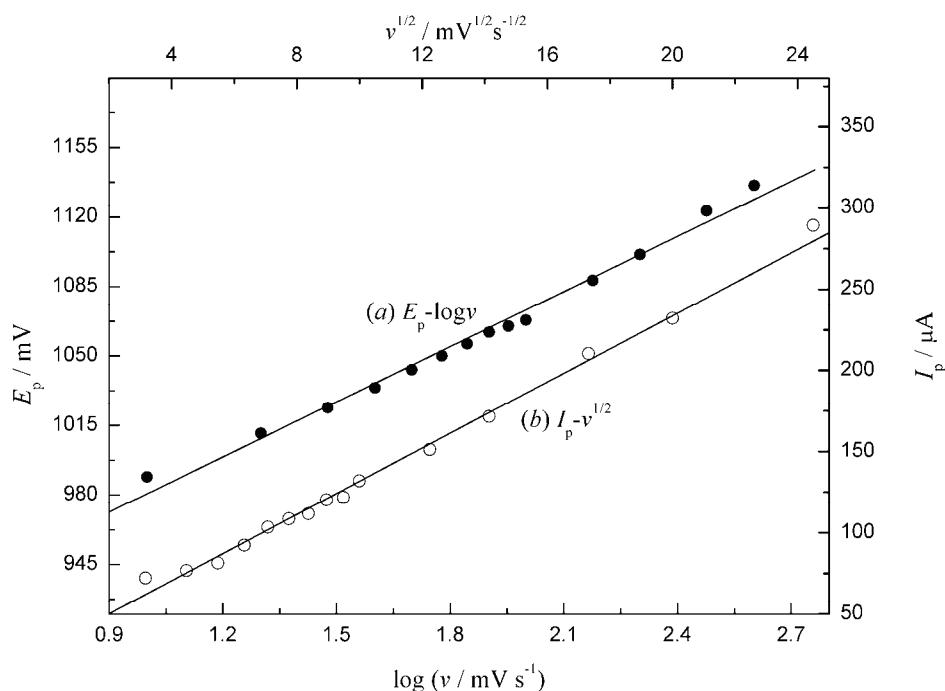


Fig. 5. a) Dependence of the peak potential on the logarithm of the scan rate ($\log v$) and b) dependence of the peak current on the square root of the scan rate ($v^{1/2}$).

In brief, the electrode reaction process the most probably one-electron and one-proton irreversible electrochemical oxidation reaction, which indicated that the oxidation occurs mainly on the benzimidazole, and its metabolites may be 5'-hydroxy-lansoprazole and lansoprazole sulfone. It is likely that the generation of a radical cation from the oxidation of lansoprazole (*e.g.*, by rearrangement, fragmentation or addition of water) occurs before it can be reduced back to neutral, which is in accord with the literature.²⁸

Electrochemical kinetics

Diffusion coefficient. The real area of the electrode and the apparent diffusion coefficient of LNS were determined by chronocoulometry (CC).⁷⁸

$$Q = \frac{2nFAcD^{1/2}t^{1/2}}{\pi^{1/2}} + Q_{dl} + Q_{ads} \quad (6)$$

where, Q is the total charge, n is the number of electrons transferred in the electrochemical oxidation reaction, A is the electrode surface area (cm^2), c is the concentration of the electro-active species in the solution (M), D is the diffusion coefficient ($\text{cm}^2 \text{s}^{-1}$) and t is the time (ms). The real area of the MWCNTs–RTIL/GCE was determined to be 0.498 cm^2 from the slopes of Q vs. $t^{1/2}$ curves

using 5.0 mM $\text{Fe}(\text{CN})_6^{3-}$ as a model compound. As the number of electron transferring of LNS was calculated to be one and the concentration (c) was 0.10 mM, the diffusion coefficient (D) could be calculated to be $1.9 \times 10^{-2} \text{ cm}^2 \text{ s}^{-1}$.

Electrode reaction rate constant, k_f . The rate constant (k_f) of the electrode could be determined by chronoamperometry (CA) using the following:⁷⁹

$$I(t) = nFAk_f c \left[1 - \frac{2H\sqrt{t}}{\sqrt{\pi}} \right] \quad (7)$$

where:

$$H = \frac{k_f}{D_{\text{Ox}}^{1/2}} + \frac{k_b}{D_{\text{Rd}}^{1/2}} \quad (8)$$

For an irreversible electrochemical oxidation reaction, the reduction rate constant, k_b , is 0, therefore:

$$H = k_f / D_{\text{Ox}}^{1/2} \quad (9)$$

When t approaches zero, a plot of $I(t)$ vs. $t^{1/2}$ gives a good straight line. Therefore, k_f could be calculated to be $7.20 \times 10^{-2} \text{ s}^{-1}$ from the slope and the intercept of the CA curve.

In order to check the electrochemical responses of the MWCNTs-RTIL/GCE for LNS, time-steady-state current response curves were determined and the experimental results are shown in Fig. 6. The current response signals of the

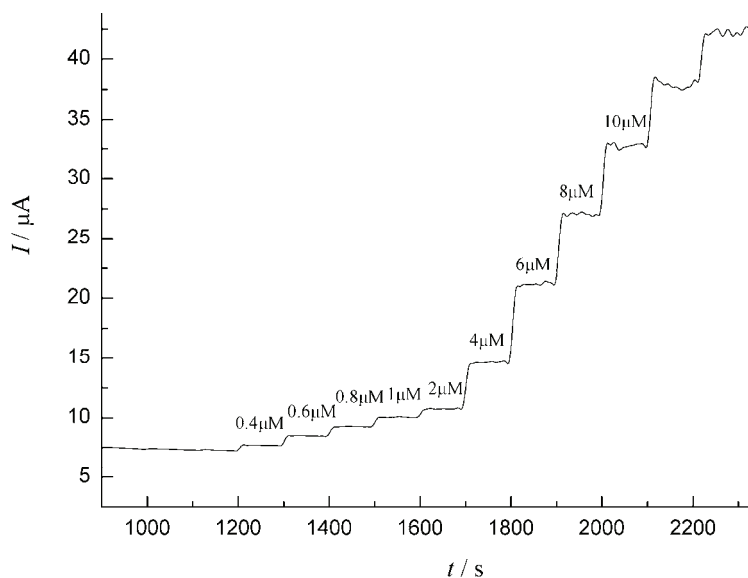


Fig. 6. Time-dependent steady state currents obtained at the RTIL-MWCNTs/GCE while increasing the LNS concentration at 0.998 V at a stirring rate of 100 rpm.

MWCNTs–RTIL/GCE are proportional to the LNS concentrations. The response time was less than four seconds and the least response concentration was 0.4 μM . Thus, the electrode could be used for the quantitative electrochemical determination of LNS having both a low detection limit and a high sensitivity.

Application of the electrochemical determination

Differential pulse voltammetric (DPV) behavior of LNS. The DPV behaviors of 0.10 mM LNS at the MWCNTs–RTIL/GCE, MWCNT/GCE and GCE in 0.10 M PBS under the optimized experimental conditions (amplitude, 65 mV, pulse width, 0.05 s, and scanning potential increment, 4 mV) were examined. An irreversible oxidation peak of LNS at the MWCNTs–RTIL/GCE appeared around 0.960 V, and the LNS itself showed a more sensitive DPV response at the MWCNTs–RTIL/GCE in contrast to that at the bare GCE and at the MWCNTs/GCE. The degree of increase was in quite good agreement with that of CV.

The peak currents of electrocatalytic oxidation of LNS with variation of its concentration were investigated at the MWCNTs–RTIL/GCE. A linear calibration curve was obtained over the concentration range 5.0 μM –0.20 mM with the linear regression equation:

$$I_{\text{pa}} / \mu\text{A} = 4.641 + 192.3(c / \text{mM}) \quad (R = 0.9972) \quad (10)$$

The limit of detection (LOD) was 0.28 μM according to $S/N = 3$ ($n = 10$).

Under the optimized experimental conditions, the direct determination of 50 μM LNS in 0.10 M PBS was checked in the presence of some common compounds and ions found in pharmaceutical formulations. The determination results showed that within a relative error of $\pm 5\%$, 200-fold of K^+ , Na^+ , Cl^- , NO_3^- , SO_4^{2-} and 100-fold of glucose, saccharose did not affect the LNS current response, which suggested that the proposed voltammetric method had excellent selectivity toward LNS.

In order to examine the reproducibility and the stability of the MWCNTs–RTIL/GCE, the determinations were performed ten times using one MWCNTs–RTIL/GCE; a relative standard deviation (RSD) of 1.7 % was obtained. The oxidation peak currents for LNS at six independent MWCNTs–RTIL/GCEs were measured, the current response deviated by only 4.3 %. The proposed modified electrode was stored at ambient temperature over a period of 2 h, then dipped in distilled water or activated in PBS blank solution; the current response of LNS deviated by less than 3.0 %. These experimental results showed the good reproducibility and stability of the modified electrode.

Compared with other reported methods^{8–24} and the reported electrochemical methods^{25–30} (Table I), it is clear that the fabrication of MWCNTs–RTIL/GCE is simple, easy and reproducible. The procedure for the determination of LNS is rapid, inexpensive and pollution-free and requires neither sample pretreatment nor any time-consuming derivatization reaction or deposition steps. Although the

minimum detectability, sensitivity and accuracy of the proposed method may be not as good as those reported^{8–30} in the determination of LNS for complicated samples, it is believed that the reported method, as a simpler, quicker, less time consuming method, could still be an alternative in LNS determination in commercial pharmaceuticals preparations.

TABLE I. Comparison the characteristics of the proposed method with those of other reported electrochemical methods for the determination of LNS

Linear detection range, mol dm ⁻³	LOD / mol dm ⁻³	Reference
1.145×10 ⁻⁷ –3.25×10 ⁻⁵	8.59 × 10 ⁻⁸	25
1.0×10 ⁻⁹ –5.0×10 ⁻⁸	2.5×10 ⁻¹⁰	26
1.0×10 ⁻⁹ –5.0×10 ⁻⁸	2.5×10 ⁻¹⁰	27
2.0×10 ⁻⁷ –5.0×10 ⁻⁵	1.0×10 ⁻⁸	28
5.73×10 ⁻⁶ –5.15×10 ⁻⁵	5.41 × 10 ⁻⁷	29
1.145×10 ⁻⁶ –5.73×10 ⁻⁵	5.4 × 10 ⁻⁸	30
5.0×10 ⁻⁶ –2.0×10 ⁻⁴	2.8×10 ⁻⁷	This work

Determination of LNS in commercial LNS tablets

In order to ascertain its potential application in the analysis of commercial tablet samples, the proposed method was employed to determine the LNS content in LNS tablets. Ten LNS tablets with a labeled amount of 15 mg per tablet were homogeneously ground into a powder in a mortar. Subsequently, the required amount of the powder was accurately weighed, dissolved in doubly distilled water, transferred quantitatively into a 100 mL volumetric flask and made up to the mark with doubly distilled water. Finally, a known amount of the sample solution was added into 0.10 M pH 6.8 PBS solution and determined by DPV.

The proposed method was successfully applied to the quantitative electrochemical determination of LNS in commercial tablets, evidencing 15 mg LNS per tablet with a relative standard deviations of 1.20–2.91 % based on the average of six replicate measurements. The accuracy was also judged by applying the standard addition method and the mean recoveries were 97.6–100.3 %. The results of these determination implied that there were no significant differences between the proposed method and the reported conventional methods with respect to reproducibility, accuracy, and precision. In other words, the proposed method is convenient and efficient for the determination of LNS with the advantages of simplicity, sensitivity and rapidity.

CONCLUSIONS

The electrochemical behavior, electrochemical kinetics and the quantitative electrochemical determination of LNS were investigated for the first time by several electrochemical methods based on the application of a MWCNTs–RTIL/GCE. A well-defined irreversible electrocatalytic oxidation peak was obtained. The electrocatalytic oxidation reaction of LNS at a MWCNTs–RTIL/GCE is a

diffusion-controlled electrode reaction process involving the transfer of one electron accompanied by the participation of one proton. Additionally, the electrochemical kinetic parameters were determined. From the obtained results, an accurate and precise method was proposed, which could be an alternative method for the quantitative electrochemical determination of LNS in commercial pharmaceutical formulations.

Acknowledgements. This work was financially supported by the Natural Science Foundation of Ningxia, China (NZ1147), and the Scientific Research Fund of Heilongjiang Provincial Education Department, China (12511347).

ИЗВОД

ЕЛЕКТРОХЕМИЈСКО ПОНАШАЊЕ И ДЕТЕКЦИЈА ЛАНСОПРАЗОЛА НА ЕЛЕКТРОДИ
ОД СТАКЛАСТОГ УГЉЕНИКА МОДИФИКОВАНОЈ ВИШЕСЛОЈНИМ УГЉЕНИЧНИМ
НАНО-ЦЕВИМА У ЈОНСКОЈ ТЕЧНОСТИ

LI-HONG LIU^{1,2}, WEI YOU¹, XUE-MEI ZHAN¹ и ZUO-NING GAO¹

¹*College of Chemistry and Chemical Engineering, Ningxia University, Yinchuan, 750021, China и*

²*Department of Chemistry, Heihe College, Heilongjiang 164300, China*

Електрохемијско понашање лансопразола је испитивано на електроди од стакластог угљеника (GCE) и на истој електроди модификованој гелом који је садржао вишеслојне угљеничне нано-цеви (MWCNTs) у ниско-температурној јонској течности (RTIL) 1-бутил-3-метилимидазолијум-хексафлуорофосфат (BMIMPF₆). Испитивања су вршена у 0,10 М фосфатном пуферу рН 6,8. Утврђено је да се на електроди MWCNTs–RTIL/GCE појављује иреверзибилни анодни струјни максимум на потенцијалу 1,060 V_{ЗКЕ}. Применом методе диференцијалне пулсне волтаметрије, под оптимизованим експерименталним условима добијена је линеарна калибрациона крива у опсегу концентрација од 5,0 µМ до 0,20 mM са границом детекције (*LOD*, *S/N*=3) од 0,28 µМ. Осим тога, електрода MWCNTs–RTIL/GCE је карактерисана спектроскопијом електрохемијске импеданције. Предложена метода је успешно примењена за квантитативно електрохемијско одређивање садржаја лансопразола у комерцијалним таблетама.

(Примљено 12. децембра 2012, ревидирано 3. маја 2013)

REFERENCES

1. W. F. James, *Am. J. Med.* **117** (2004) 14
2. A. E. Zimmermann, B. G. Katona, *Pharmacotherapy* **17** (1997) 308
3. D. Jaspersen, K. L. Diehl, H. Schoepner, P. Geyer, *Aliment. Pharmacol. Ther.* **12**(1998)49
4. G. Coruzzi, M. Adami, G. Bertaccini, *Gen. Pharmacol.* **26** (1995) 1027
5. P. Richardson, C. J. Hawkey, W. A. Stack, *Drugs* **56** (1998) 307
6. G. Sachs, J. M. Shin, C. Briving, B. Wallmark, S. Hersey, *Annu. Rev. Pharmacol. Toxicol.* **35** (1995) 277
7. C. M. Spencer, D. Faulds, *Indian Drugs.* **48** (1994) 404
8. A. V. Kasturf, P. G. Yeole, A. P. Sherje, *Asian J. Chem.* **19** (2007) 3612
9. A. A. Syed, A. Syeda, *Bull. Chem. Soc. Ethiop.* **21** (2007) 315
10. N. Rahman, Z. Bano, S. N. H. Azmi, M. Kashif, *J. Serb. Chem. Soc.* **71** (2006) 1107

11. A. A. M. Wahbi, O. A. Razak, A. A. Gazy, H. Mahgoub, M. S. Moneeb, *J. Pharm. Biomed. Anal.* **30** (2002) 1133
12. A. A. M. Moustafa, *J. Pharm. Biomed. Anal.* **22** (2000) 45
13. N. Ozaltin, *J. Pharm. Biomed. Anal.* **20** (1999) 599
14. H. Katsuki, A. Hamada, C. Nakamura, K. Arimori, M. Nakano, *J. Chromatogr., B* **757** (2001) 127
15. T. Uno, N. Y. Furukori, T. Takahata, K. Sugawara, T. Tateishi, *J. Chromatogr., B* **816** (2005) 309
16. K. V. S. P. Rao, G. V. Kumar, K. V. Kumari, L. D. Srinivas, G. Prabhakar, *Asian J Chem.* **18** (2006) 798
17. M. Miura, H. Tada, T. Suzuki, *J. Chromatogr., B* **804** (2004) 389
18. M. Song, X. Gao, T. J. Hang, A. D. Wen, *J. Pharm. Biomed. Anal.* **48** (2008) 1181
19. K. K. Pandya, V. D. Mody, M. C. Satia, I. A. Modi, R. I. Modi, B. K. Chakravarthy, T. P. Gandhi, *J. Chromatogr., B* **693** (1997) 199
20. A. P. Argekar, S. S. Kunjir, *J. Planar Chromatogr.-Mod. TLC* **9** (1996) 296
21. A. Tivesten, S. Folestad, V. Schonbacher, K. Swenson, *Chromatographia* **49** (1999) S7
22. D. Dogrukol-Ak, M. Tuncel, H. Y. Aboul-Enein, *Chromatographia* **54** (2001) 527
23. C. I. C. Silvestre, J. L. M. Santos, J. L. F. C. Lima, M. A. Feres, E. A. G. Zagatto, *Microchem. J.* **94** (2010) 60
24. D. Yenicali, D. Dogrukol-Ak, M. Tuncel, *J. Pharm. Biomed. Anal.* **36** (2004) 145
25. C. Yardimci, N. Ozaltin, *Analyst* **126** (2001) 361
26. A. Radi, *Microchem. J.* **73** (2002) 349
27. A. Radi, *Anal. Lett.* **35** (2002) 2449
28. A. Radi, *J. Pharm. Biomed. Anal.* **31** (2003) 1007
29. F. Belal, N. El-Enany, M. Rizk, *J. Food Drug Anal.* **12** (2004) 102
30. N. El-Enany, F. Belal, M. Rizk, *J. Biochem. Biophys. Methods* **70** (2008) 889
31. S. Lijima, *Nature* **354** (1991) 56
32. P. M. Ajayan, *Chem. Rev.* **99** (1999) 1787
33. T. W. Odom, J. L. Huang, P. Kim, C. M. Lieber, *Nature* **391** (1998) 62
34. J. M. Nugent, K. S. V. Santhanam, A. Rubio, P. M. Ajayan, *Nano Lett.* **1** (2001) 87
35. X. Dai, G. G. Wildgoose, R. G. Compton, *Analyst* **131** (2006) 901
36. C. Hu, X. Chen, S. Hu, *J. Electroanal. Chem.* **586** (2006) 77
37. R. Antiochia, I. Lavagnini, *Anal. Lett.* **39** (2006) 1643
38. F. Ricci, A. Amine, D. Moscone, G. Palleschi, *Anal. Lett.* **36** (2003) 1921
39. J. S. Moulthrop, R. P. Swatloski, G. Moyna, R. D. Rogers, *Chem. Commun.* **12** (2005) 1557
40. H. M. Lou, S. Dai, P. V. Bonnesen, A. C. Buchanan, J. D. Holbery, N. J. Bridges, R. D. Rogers, *Anal. Chem.* **76** (2004) 3078
41. T. Welton, *Chem. Rev.* **99** (1999) 2071
42. M. Kosmulski, R. A. Osteryoung, M. Ciszowska, *J. Electrochem. Soc.* **147** (2000) 1454
43. P. Yu, Y. Q. Lin, L. Xiang, L. Su, J. Zhang, L. Q. Mao, *Langmuir* **21** (2005) 9000
44. P. Wassercheid, W. Keim, *Angew. Chem. Int. Ed.* **39** (2000) 3772
45. A. A. Ensafi, H. Karimi-Maleh, *Drug Test. Anal.* **3** (2011) 325
46. J. G. Huddleston, H. D. Willauer, R. P. Swatloski, A. E. Visser, R. D. Rogers, *Chem. Commun.* **16** (1998) 1765
47. T. Fukushima, A. Kosaka, Y. Ishimura, T. Yamamoto, T. Takigawa, N. Ishii, T. Aida, *Science* **300** (2003) 2072

48. A. M. Kazemi S. M. A. Khalilzadeh, H. Karimi-Maleh, M. B. P. Zanousi, *Int. J. Electrochem. Sci.* **8** (2013) 1938
49. M. Fouladgar, H. Karimi-Maleh, *Ionics* **19** (2013) 1163
50. A. A. Ensafi, H. Bahrami, H. Karimi-Maleh, *Mater. Sci. Eng., C* **33** (2013) 831
51. H. Beitollah, M. Goodarzian, M. A. Khalilzadeh, H. Karimi-Maleh, M. Hassanzadeh, M. Tajbakhsh, *J. Mol. Liq.* **173** (2012) 137
52. T. Tavana. M. A. Khalilzadeh, H. Karimi-Maleh, A. A. Ensafi, H. Beitollah, D. Zareyee, *J. Mol. Liq.* **168** (2012) 69
53. S. Salmanpour, T. Tavana, A. Pahlavan, M. A. Khalilzadeh, A. A. Ensafi, H. Karimi-Maleh, H. Beitollah, E. Kowsari, *Mater. Sci. Eng., C* **32** (2012) 1912
54. A. A. Ensafi, M. Lzadi, B. Rezaei, H. Karimi-Maleh, *J. Mol. Liq.* **174** (2012) 42
55. A. A. Ensafi, M. Izadi, H. Karimi-Maleh, *Ionics* **19** (2013) 137
56. M. Asnaashariisfahani, H. Karimi-Maleh, H. Ahmar, A. A. Ensafi, A. R. Fakhari, M. A. Khalilzadeh, F. Karimi, *Anal Methods* **4** (2012) 3275
57. M. Keyvanfard, R. Shakeri, H. Karimi-Maleh, K. Alizad, *Mater. Sci. Eng., C* **33** (2013) 811
58. A. Mokhtari, H. Karimi-Maleh, A. A. Ensafi, H. Beitollahi, *Sens. Actuators, B* **169** (2012) 96
59. H. Yaghoobian, H. Karimi-Maleh, M. A. Khalilzadeh, F. Karimi, *J. Serb. Chem. Soc.* **74** (2009) 1443
60. A. A. Ensafi. H. Karimi-Maleh, *J. Electroanal. Chem.* **640** (2010) 75
61. H. Beitollahi, H. Karimi-Maleh, H. Khabazzadeh, *Anal. Chem.* **80** (2008) 9848
62. Z. N. Gao, Y. Q. Sun, W. You, *Chin. J. Anal. Chem.* **37** (2009) 553 (in Chinese)
63. X. M. Zhan, L. H. Liu, Z. N. Gao, *J. Solid State Electrochem.* **15** (2011) 1185
64. Y. Q. Sun, W. You, Z. N. Gao, *Acta Pharm. Sin.* **43** (2008) 396 (in Chinese)
65. X. M. Zhan, W. You, Z. N. Gao, *Chin. J. Pharm. Anal.* **29** (2009) 1543 (in Chinese)
66. J. W. Chen, C. Q. Duan, Z. N. Gao, *Chin. J. Anal. Chem.* **40** (2012) 447 (in Chinese)
67. L. H. Liu, C. Q. Duan, Z. N. Gao, *J. Serb. Chem. Soc.* **77** (2012) 483
68. Y. M. Zhang, C. Q. Duan, Z. N. Gao, *J. Serb. Chem. Soc.* **78** (2013) 281
69. S. C. Tsang, Y. K. Chen, P. J. F. Harris, M. L. H. Green, *Nature* **372** (1994) 159
70. J. J. Feng, G. Zhao, J. J. Xu, H. Y. Chen, *Anal. Biochem.* **342** (2005) 280
71. M. R. Shahmiri, A. Bahari, H. Karimi-Maleh, R. Hosseinzadeh, N. Mirnia, *Sens. Actuators, B* **177** (2013) 70
72. C. L. Xiang, Y. J. Zou, L. X. Sun, F. Xu, *Electrochem. Commun.* **10** (2008) 38
73. *Impedance Spectroscopy: Theory, Experiment, and Applications*, 2nd ed., E. Barsoukov, J. R. Macdonald, Eds., Wiley, Hoboken, NJ, 2005, p. 258
74. P. J. Britto, K. S. V. Santhanam, A. Rubio, J. A. Alonso, P. M. Ajayan, *Adv. Mater.* **11** (1999) 154
75. M. Musameh, N. Lawrence, J. Wang, *Electrochem. Commun.* **7** (2005) 14
76. C. E. Banks, R. G. Compton, *Analyst* **131** (2006) 15
77. B. Delhotal Landes, J. P. Petite, B. Flouvat, *Clin. Pharmacokinet.* **28** (1995) 458
78. A. J. Bard, L. R. Faulkner, *Electrochemical Methods Fundamentals and Applications*, Wiley, New York, 1980, p. 200
79. H. Q. Wu, Y. F. Li, *Electrochemical Kinetics*, China Higher Education Press, Beijing, and Springer, Berlin, 1998, p. 96.