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VOLTAMMETRIC DETERMINATION OF VARDENAFIL ON MODIFIED ELECTRODES CONSTRUCTED BY GRAPHITE, METAL OXIDES AND FUNCTIONALIZED MULTI-WALLED CARBON NANOTUBES

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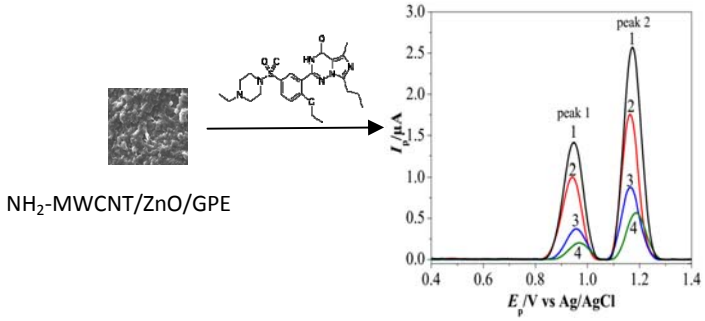
The voltammetric behavior of the vardenafil was investigated by means of square wave stripping voltammetry (SWSV), differential pulse stripping voltammetry (DPSV) and cyclic voltammetry (CV) on the modified electrodes constructed by graphite, metal oxide and functionalized multi-walled carbon nanotubes (MWCNT).Different experimental conditions were optimized such as pH and electrolyte type, accumulation potential and accumulation time for both techniques and step potential, pulse amplitude and frequency for SWSV. In the optimum conditions a linear relationship has been constructed in the concentration range of 0.02 to 1.0 mg/L and 0.01 to 0.5 mg/L for SWSV and DPSV in pH 3.0 phosphate buffer solution, respectively. Limit of detection (LOD) values for vardenafil determinations were13.6 µg/L and 4.38 µg/L for SWSV and DPSV, respectively. Quantifications were performed on commercial pharmaceutical tablets and synthetic blood serum using both techniques. The relative errors were +5.0% and –3.0% for SWSV and DPSV, respectively in the determination of vardenafil active ingredient in Levitra® tablet. SWS and DPS voltammetric determination of synthetic blood serum spiked with 50.0 µg/L vardenafil exhibited 100.8% and 104.4% recovery, respectively. Interference effects of some organic species such as ascorbic acid, uric acid, dopamine, glucose have also been investigated.



INTRODUCTION

Vardenafil is an effective and selective phosphodiesterase type 5 inhibitor used for the treatment of erectile dysfunction, which turns out to be a problem for a wider group of men (one in five men) having negative physical, social, mental and emotional effects on the patients leading also to erosion of self-esteem and emotional distress.[1,2] Since the drugs are metabolized in body fluids, in order to determine the drug components, their oxidation-reduction behavior should be understood carefully. Electrochemical methods are among the most widely preferred methods for the determination of drug components via their oxidation-reduction behaviors. These methods have advantageous compared to other analytical methods in various respects. Among these are their low operational cost, higher selectivity and sensitivity, higher accuracy and consistency as

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** Supplementary information on http: //web.icf.ro/rrch or http: //revroum.lev.ro/

well as easier use and the ability of miniaturization.[3-6] The sensitivity and selectivity of the electrochemical quantification depend on various factors, but the most important and vital of them are the electrodes used. Up to now, several methods were recommended for the determination of vardenafil such as atomic emission spectroscopy,[7] liquid chromatography with UV detection,[8-10] fluorescence detection,[11] chemiluminescence detection,[12] tandem mass spectrometry,[13-14] gas chromatography/mass spectrometry[15] and voltammetry.[16-18] In voltammetric studies, researchers used glassy carbon electrode,[16] carbon paste electrode[17] and pencil graphite electrode[18], respectively. The developed methods in this study are as sensitive as these voltammetric techniques in the literature studies.

Carbon-based electrodes are one of the most-widely used electrodes during the experimental design due to the unique advantages. Carbon electrodes can display both metallic and semi-metallic character depending on their design and therefore have a wide range of applicability. The surface chemistry of carbon electrodes makes it superior to many other electrodes.[19]One of the most used carbon-based electrodes is the carbon pastes composed of a mixture of electrically conductive graphite powder and a pasting liquid, such as mineral oil, paraffin oil, bromo-naphthalene, tricresyl phosphate, etc.[20,21] Their surface can be quickly renewed through removing the surface layer[22] and moreover, they have fast response and low background current. Their most significant advantages are the possibility of modifying surface through a variety of modifiers that provides a wider surface area.[20] Advances in nanotechnology have enabled the fabrication of popular electrodes in terms of electrochemistry. Among these electrodes ZnO nanoparticles are quite promising and attracted great attention in different fields such as optics, optoelectronics and sensors thanks to their semiconducting, piezoelectric and pyroelectric properties. ZnO nanoparticles provide several advantages such as high surface area, non-toxicity and good electro-activity.[23] Moreover, it has a good biocompatibility which allows it to be used in biosensor design as well.[24] Another significant modifier is the carbon nanotubes. After their discovery in 1991, CNTs turned out to be one of the most popular modification materials thanks to their high chemical stability, conductivity, tensile strength as well as their smaller size, which increase the surface area considerably. Similar to ZnO nanoparticles, CNTs also have a good biocom-patibility which makes them preferable in biosensing applications.[4, 25]

In this work, two voltammetric techniques (SWSV and DPSV) were suggested for sensitive determination of vardenafil using modified electrode based on graphite, metal oxide (ZnO) and $–NH_2$ functionalized multi-walled carbon nanotubes. The proposed modified electrode has remarkable advantages such as in terms of simplicity of paste preparation, low cost, easy surface renewal, fairly good stability, low residual current, easy portability and miniaturization. The new constructed electrode was also used for the determination of vardenafil in tablet formulation and serum samples to exhibit the applicability of the method.

RESULTS AND DISCUSSION

The voltammetric behavior of the vardenafil was assessed by the electroanalytical techniques of SWSV, DPSV and CV on the modified electrodes constructed by graphite, metal oxides and NH_2–functionalized multi-walled carbon nanotubes. The surface morphologies of the CNT composite electrodes having graphite, Fe_2O_3 and ZnO nanoparticles were imaged by a SEM. Vardenafil peak current and peak potentials were recorded at different buffer systems within the pH of 2.0 to 10.0 to determine the appropriate supporting electro-lyte. SW voltammetric instrumental parameters such as frequency (f), step potential (ΔE_s) and amplitude (ΔE) were optimized at pH 3.0 phosphate buffer solution. Accumulation potential (E_{acc}) and accumulation time (t_{acc}) were also optimized for both SWSV and DPSV in the same medium. Vardenafil in tablet and synthetic serum samples was then determined by both SWSV and DPSV techniques using the fabricated modified electrode. Finally, the interference effects of some electro-active organic species have been investigated.

Modification of GPE

Composite electrodes containing graphite and metal oxides, which are bare electrodes, consisting of 70% graphite and 30% mineral oil mixture were firstly prepared. Then, the modified graphite paste electrodes (GPE) consisting of 5% ZnO or Fe_2O_3 and 65% graphite were prepared using the same mineral oil ratio. DPS voltammograms recorded on the modified ZnO/GP and Fe_2O_3/GP electrodes at pH 5.0 B-R buffer solution were displayed in Figure 1.

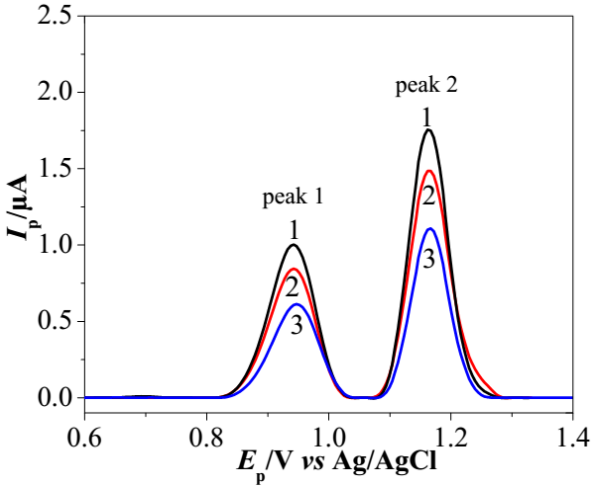

Fig. 1 – DPS voltammograms for 5.0 mg/L vardenafil at ZnO/GPE (1), bare GPE (2), Fe_2O_3/GPE (3) (E_{acc} = 0 mV, t_{acc} = 60 s, ΔE_s= 5 mV, ΔE = 50 mV, pH 5.0 B-R buffer).

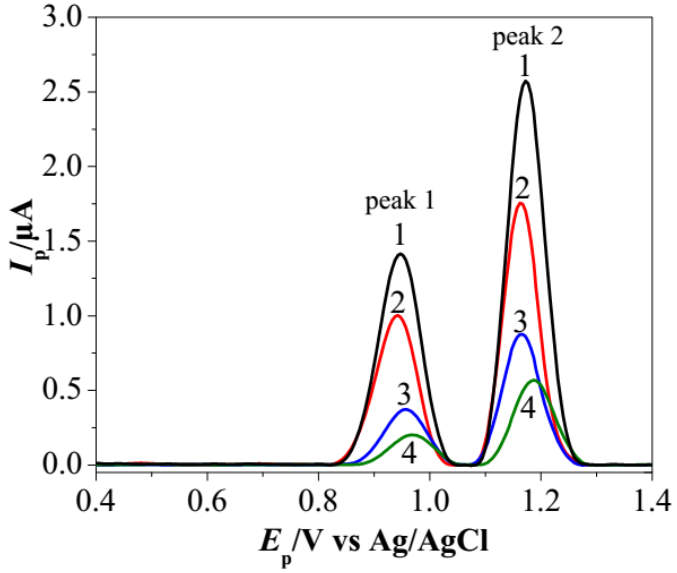

Fig. 2 – Determination of 5.0 mg/L vardenafil by DPS voltammetry on different modified electrodes: NH_2–MWCNT/ZnO/GPE (1), ZnO/GPE (2), MWCNT/ZnO/GPE (3), COOH–MWCNT/ZnO/GPE (4) (E_{acc} = 0 mV, t_{acc} =60 s, ΔE_s = 5 mV, ΔE = 50 mV, pH 5.0 B–R buffer).

The highest peak current for vardenafil was obtained with a modified electrode prepared with 5% ZnO, 65% graphite and 30% mineral oil. For the construction of this electrode, ZnO and graphite powders had been mixed in mineral oil homogeneously on the watch glass. The paste had plugged in the hollow of the electrode, dried, then polished with abrasive. Since the modified electrode prepared with 5% ZnO nanoparticles had showed a peak increment by 23.6% comparing to the bare GPE the subsequent works were carried out on a carbon paste electrode containing 5% ZnO and 65% graphite.

To improve the signal of the vardenafil, additional modifications were made using the suspensions of the MWCNT and MWCNT with -COOH and -NH_2 functional groups. 0.5 mg MWCNT powders and 1 mL dimethylformamide (DMF) were stirred in the ultrasonic bath for 2 hours and the suspensions were then applied to the surfaces of ZnO/GPE (5% ZnO and 65% graphite) using a drip-dry method. The composite film electrodes coated with 10 μL of MWCNT, COOH-MWCNT or NH_2-MWCNT was then dried at room temperature for overnight and measurements were carried out in pH 5.0 phosphate buffer solution. Figure 2 shows DPS voltammograms of vardenafil on the constructed composite electrodes. It was obvious that the sensitivity of the NH_2-MWCNT/ZnO/GPE was higher than that of

ZnO/GP, MWCNT/ZnO/GP and COOH/MWCNT/ZnO/GP electrodes. In other words, vardenafil peak current sensitivity obtained on NH_2-MWCNT/ZnO/GPE was 158% more intense compared to the MWCNT/ZnO/GPE. This may be due to the interaction of $–NH_2$ functional group onto the ZnO/GPE surface and sulfonyl phenyl group in the vardenafil molecule. NH_2-MWCNT film coated ZnO/GPE was selected for further studies.In addition the dripping amount of NH_2–MWCNT suspension solution was optimized using 4, 6, 8, 10 and 12 µL NH_2–MWCNT solution and optimum volume was found as 10 µL. Differences between surfaces of ZnO/GP and NH_2-MWCNT/ZnO/GP electrodes were also shown (Suppl 1).

pH and scan rate effects on vardenafil signal at NH_2-MWCNT/ZnO/GPE

SWS and DPS voltammograms were recorded for 5.0 mg/L vardenafil on the NH_2-MWCNT/ZnO/GPE over a wide pH range (pH 2.0 – 10.0). Despite the observation of a single oxidation peak within the pH ranges of 2.0 to 5.0, two oxidation peaks were obtained within the pHs of 6.0 to 8.0. At pH values of 9.0 to 10.0, a single electro-oxidation peak was again appeared due to overlapping of these two peaks. The voltammograms obtained using both techniques are quite similar. The SWS and DPS voltammograms obtained in different pH values on the NH_2-MWCNT/ZnO/GPE are shown in Figure 3.

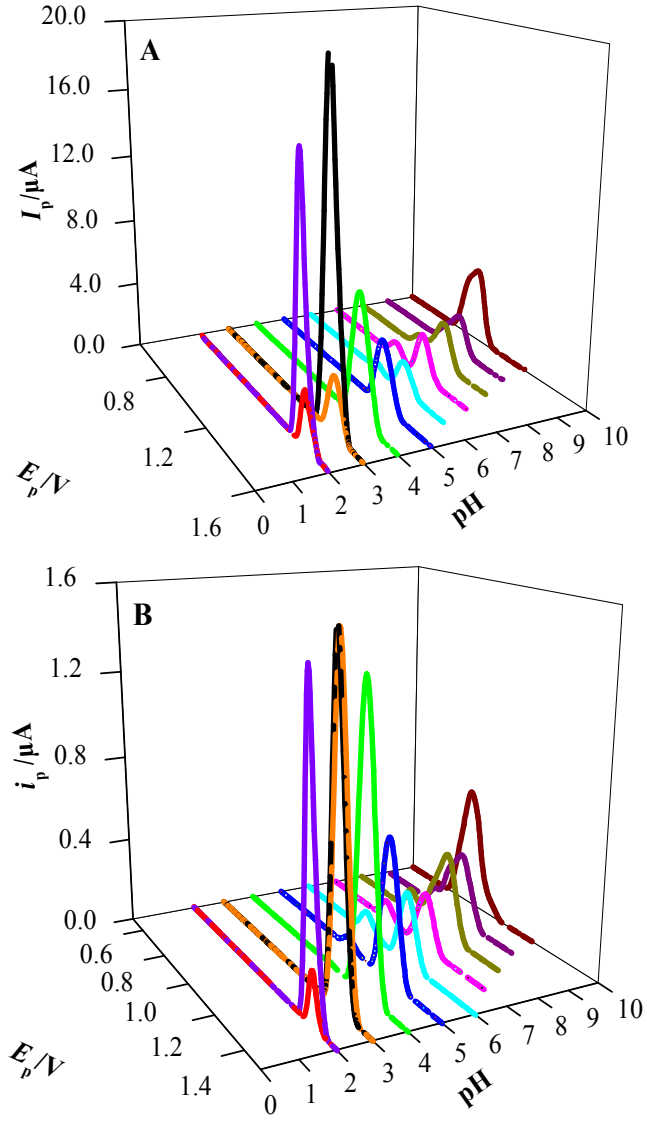

Fig. 3 – SWS (A) and DPS (B) voltammograms of 5.0 mg/L vardenafil at NH_2-MWCNT/ZnO/GPE at different pH values (pH 2.0 – 10.0 BR and pH 2.0 and 3.0 phosphate buffer solutions). Experimental conditions: E_{acc} = 0 mV, t_{acc} = 60 s, f = 100 Hz, ΔE_s = 5 mV, ΔE = 50 mV.

As shown in Figure 3, the maximum peak current was appeared at pH 3.0 in phosphate buffer for both techniques and pH 3.0 phosphate buffer was selected as a supporting electrolyte for further studies.

The peak potentials (E_p) versus pH were plotted in the direction of the data obtained and the related equations are given below:

E_p (mV) = – 64.1 pH + 1438.4 (mV) r = 0.9765 (pH 5–8) Peak 1 (SWSV)
E_p (mV) = – 58.1 pH + 1570.7 (mV) r = 0.9970 (pH 2–8) Peak 2 (SWSV)
E_p (mV) = – 52.6 pH + 1232.9 (mV) r = 0.9792 (pH 5–8) Peak 1 (DPSV)
E_p (mV) = – 56.6 pH + 1489.4 (mV) r = 0.9975 (pH 2–8) Peak 2 (DPSV)

It can be assumed that the potential shift of about 60 mV per unit of pH was close to the theoretical value of 59 mV, so that protons and electrons involved in the electro-oxidation process for both peaks are equal.

For scan rate studies, cyclic voltammetry was used for 50.0 mg/L vardenafil at different scan rates between 5–500 mV/s in pH 3.0 phosphate buffer solution, between the potential window of 0–1600 mV, using NH_2-MWCNT/ZnO/GPE and obtained a single well-defined oxidation peak (peak 2) for vardenafil (Suppl. 2).

The influence of the potential scan rates (v) on the E_p of vardenafil was studied in the range of 5–500 mV/s and the following correlation was obtained:

$$E_p\ (V) = 0.049 \log v\ (V/s) + 1.415 (r = 0.9989)$$

The shift of the E_p to the more positive values by increasing the scan rate observed that vardenafil electro-oxidation reaction is irreversible. On the other hand, scan rate studies showed that the linear relationship had existed between the peak current (i_p) and the square root of the scan rate ($v^{1/2}$).

$$i_p\ (\mu A) = 0.21\ v^{1/2}\ (V/s) - 0.48 (r = 0.9898)$$

The linear appearance of the graph showed that mass transfer to the electrode surface is diffusion controlled. The logarithm of the peak current (log i_p) is also plotted against the logarithm of the scan rate (log v).

$$\log (i_p) = 0.76 \log v\ (mV/s) - 1.33\ \ (r = 0.9966)$$

If this slope is 0.5, mass transfer to the electrode surface is theoretically controlled by diffusion and when it is 1.0 this process is adsorption controlled. The slope in the above equation is 0.76 and it is between 0.5 and 1.0 that indicates that mass transfer to the electrode surface is mixed controlled. In other words, both diffusion and adsorption are effective for the mass transfer to the modified electrode surface.

Optimization of experimental conditions

The effect of frequency (f), pulse amplitude (ΔE) and step potential (ΔE_s) that are important instrumental parameters in SWS voltammetry have been optimized firstly in pH 3.0 phosphate buffer solution. Then before proceeding to analytical determinations accumulation potential (E_{acc}) and accumulation time (t_{acc}) were also optimized for DPSV and SWSV in the same buffer. For these studies 5.0 mg/L vardenafil concentration was selected. Frequency studies were carried out in the range of 10 – 200 Hz. A linear relationship was obtained between 10 – 60 Hz. Also the best signal was monitored for 60 Hz (Suppl. 3). ΔE and ΔE_s studies were investigated in the ranges of 10 – 80 mV and 1 – 10 mV, respectively. Optimum values were 40 mV for ΔE and 9 mV ΔE_s (Suppl. 3).

E_{acc} studies were performed in the range of 0 – 700 mV and 0 – 600 mV with t_{acc} of 60 s for SWSV and DPSV, respectively. Optimum responses were seen when E_{acc} values were 300 mV and 400 mV (Suppl. 4). Behind these studies the last experimental parameter, t_{acc}, was optimized and found as 250 s and 300 s (Suppl. 4).

Calibration and validation studies

Increasing amounts of vardenafil were recorded using SWS and DPS voltammetry in pH 3.0 phosphate buffer solution to establish the calibration curve under optimum conditions (Figure 4).

A linear correlation was obtained between 0.02 to 1.0 mg/L and 0.02 to 0.5 mg/L vardenafil concentration for SWSV and DPSV, respectively, using the NH_2-MWCNT/ZnO/GPE.

i_p (μA) = 5.28C (mg/L) + 0.236 (r = 0.9987; SWSV)
i_p (μA) = 1.71C (mg/L) – 0.011 (r = 0.9991; DPSV)

Vardenafil determination by SWS voltammetric technique indicates that LOD and limit of quantification (LOQ) values were 13.6 μg/L and 44.9 μg/L, respectively. In DPS voltammetry, LOD

and LOQ values were found to be 4.38 µg/L and 13.30 µg/L, respectively. The equations LOD = $3S_b/m$ and LOQ = $10S_b$/m were used in the calculation of the LOD and LOQ values.[26,27] Here, S_b is the standard deviation (n=7) of the peak current of the lowest observed amountand m is the slope of the calibration graphs.

Relative standard deviation % (RSD %) values of within day and between day precision of NH_2-MWCNT/ZnO/GPE were also calculated for 0.02 mg/L vardenafil using five repetitive measurements (Table 1). The regression data of the calibration curve and required validation results were summarized in Table 1.

Tablet and serum analysis of vardenafil by SWSV and DPSV

Quantification of vardenafil was performed on commercial pharmaceutical tablet and synthetic blood serum samples using both SWSV and DPSV.

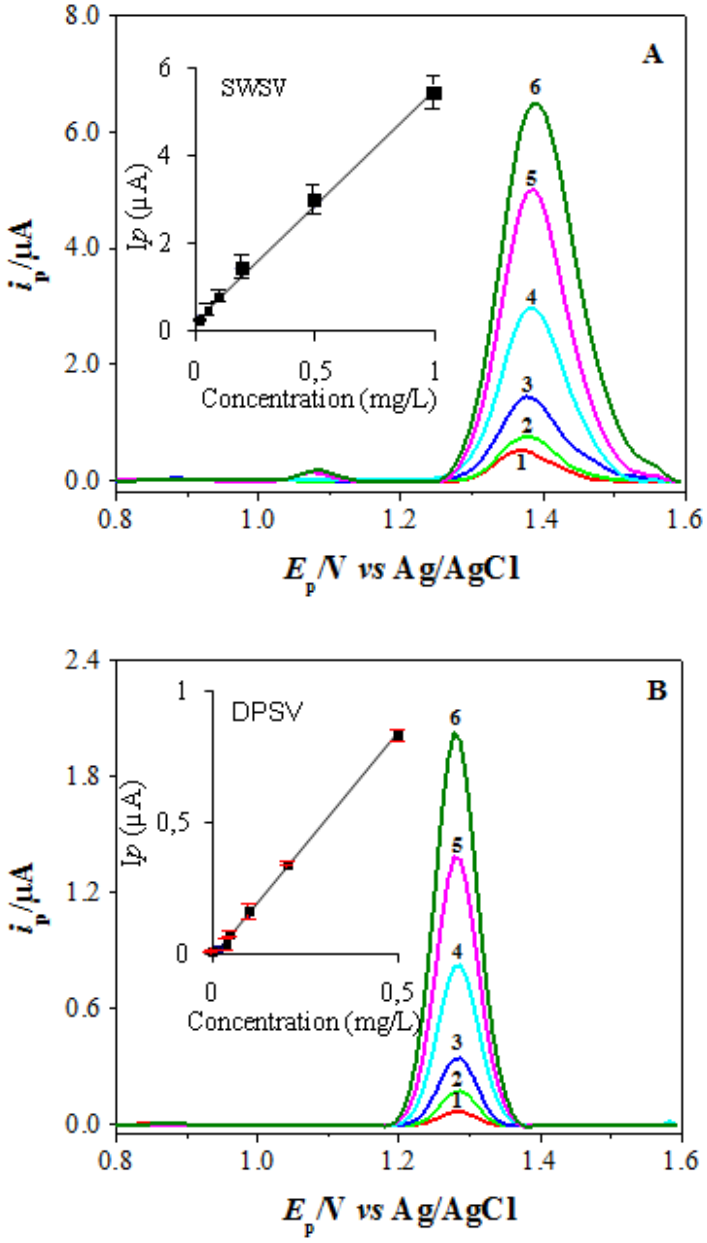

Fig. 4 – SWS (A) and DPS (B) voltammograms of vardenafil to obtain the calibration graph under the optimum experimental conditions. For SWSV: 0.02 mg/L (1), 0.05 mg/L (2), 0.1 mg/L (3), 0.2 mg/L (4), 0.5 mg/L (5), 1.0 mg/L (6). For DPSV: 0.01 mg/L (1), 0.02 mg/L (2), 0.05 mg/L (3), 0.1 mg/L (4), 0.2 mg/L (5), 0.5 mg/L (6).

Table 1

Regression data of calibration curve of vardenafil from standard solutions by SWSV and DPSV at NH_2-MWCNT/ZnO/GPE

	SWSV	**DPSV**
Measured potential (mV)	1375	1280
Linear range (mg/L)	0.02 – 1.0	0.01 – 0.5
Slope (μA L/mg)	5.28	1.74
Intercept (μA)	0.24	-0.011
Correlation coefficient (r)	0.997	0.999
Standard error of slope	0.24	0.025
Standard error of intercept	0.06	0.005
LOD (μg/L)	13.6	4.38
LOQ (μg/L)	44.88	13.3
Within day precision of current (RSD %)*	1.81	0.96
Within day precision of potential (RSD %)*	0.69	0.30
Between days precision of current (RSD %)*	3.44	1.76
Between days precision of potential (RSD %)*	0.73	0.45

*n = 5

Table 2

Determination of vardenafil in Levitra® tablets by SWS and DPS voltammetry

	SWSV	**DPSV**
Labelled quantity (mg)	20.0	20.0
Amount found* (mg ± mg)	19.4 ± 0.35	21.0 ± 0.45
RSD (%)	1.9	1.2
Relative error (%)	+3.0	-5.0
Amount added (mg)	20.0	20.0
Found* (mg ± mg)	20.5 ± 0.39	20.6 ± 0.27
Average recovery (%)	102.5	103.0
RSD (%)	1.9	1.3
Relative error (%)	–2.5	-3.0

(*n = 5 and t: 95% confidence level)

Results obtained from tablet dosage form were presented in Table 2. The relative standard deviation which was a measure of precision obtained by SWSV and DPSV were found to be 1.9 and 1.2, respectively. Relative error values found to be +3.0% and –5.0%, respectively. Recovery studies were also performed to show the accuracy of these methods. Calculations were performed from the peak increments with standard vardenafil additives. 20 mg of vardenafil spiked to the tablet sample solutions were analyzed by SWSV and DPSV with relative errors of –2.5% and –3.0%, respectively. The low RSD % values and low relative errors reflect the high precision and accuracy of developed voltammetric techniques.

Synthetic blood serum was spiked with vardenafil and then analyzed by SWSV and DPSV in pH 3.0 phosphate buffer solution using NH_2-MWCNT/ZnO/GPE. The recoveries obtained from the synthetic blood serum samples were 100.8% and 104.4% for SWSV and DPSV, respectively at 95% confidence level, as presented in Table 3.The low relative errors (–0.8% and –4.4%) and RSD % values (1.9 – 1.2%) confirm the high accuracy and precision of the recommended methods.

Table 3

Determination of vardenafil from synthetic serum samples by SWS and DPS voltammetry

	SWSV	**DPSV**
Amount added (μg/L)	50.00	50.00
Amount found* (μg/L ± μg/L)	50.04 ± 0.77	50.22 ± 1.59
Recovery (%)	100.8	104.4
RSD (%)	1.9	1.2
Relative error (%)	–0.8	-4.4

(* n = 5 and t: 95% confidence level)

Table 4

1.0 mg/L vardenafil assayed in the presence of some interfering species*

Interfering species	**Recovery (%) by SWSV**			**Recovery (%) by DPSV**		
	1:1 (m/m)	**1:5 (m/m)**	**1:10 (m/m)**	**1:1 (m/m)**	**1:5 (m/m)**	**1:10 (m/m)**
Ascorbic acid	101.70 ± 3.90	95.38 ± 3.52	93.42 ± 2.47	101.07±3.13	98.06 ±2.61	95.79 ±1.82
Uric acid	99.36 ± 0.59	99.74 ± 1.24	94.23 ± 1.54	100.14±0.48	97.15 ±0.79	92.72 ±0.21
Dopamine	97.73 ± 1.82	90.19 ± 2.25	87.50 ± 0.97	98.71 ± 1.75	93.14 ±0,38	91.37 ±0.96
Glucose	101.35 ± 1.96	100.30 ±0.27	99.85 ± 0.69	99.78 ± 1.54	100.44±1.25	100.33±1.09

*1.0 mg/L vardenafil is assayed in the presence of 1.0, 5.0 and 10.0 mg/L of interfering species (n=3)

Interference effects in the determination of vardenafil

Vardenafil determinations have been carried out in the presence of some organic species to clarify the selectivity of the developed techniques. Percent recoveries were calculated by comparing the peak current ratio of 1.0 mg/L vardenafil to that the peak currents in the presence of 1:1, 1:5 and 1:10 mass ratio of the interfering species. Interference effect of certain electro-active organic species such as ascorbic acid, uric acid and dopamine and non-electro-active species such as glucose have been investigated (Table 4). It was concluded that no significant change could be observed in the peak intensities of vardenafil for SWSV and DPSV when interfering species are taken equal to the mass, that is, when both species are 1.0 mg/L. 1.0 mg/L vardenafil was also determined in the presence of 5.0 mg/L of ascorbic acid, glucose or uric acid with less than 5% tolerance limit. On the other hand, dopamine causes the interference effect within the 10% tolerance limit for both techniques.

The interference effect on vardenafil can be assessed within 10% tolerance limit when 1.0 mg/L vardenafil was quantified in the presence of 10.0 mg/L ascorbic acid. Since it did not give any peak around the vardenafil, the least interference effect was recorded in the presence of glucose.

Electro-oxidation mechanism of vardenafil

The number of electrons transferred for the vardenafil electrode reaction could be calculated using the following equation.[28]

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

where, F is the Faraday constant (96,480 C/mol), T is the temperature in Kelvin, R is the universal gas constant (J/K mol), α is the electron transfer coefficient and n is the number of electrons transferred in the electrode reaction. Vardenafil gave a single well-defined oxidation peak at

different scan rates which belongs to peak 2.Peak potentials (E_p) plotted against the logarithm of scan rates (log v) had exhibited a slope of 49 mV/s. If it is substituted in the above corresponding equation, αn value could be calculated as 1.2. Since the α value for an irreversible reactions may be accepted as 0.5,[29,30] the electrons associated in the vardenafil oxidation is found nearly 2.

According to the pH study, 50 – 60 mV/pH potential shifts of vardenafil peaks, towards the less positive potential direction, shows that proton and electron numbers are equal and so 2 protons should be involved in the electro-oxidation process. Results are in accordance with the literature studies.[16-18]

EXPERIMENTAL

Apparatus

Electrochemical analyzers of Autolab PGSTAT 302 (Eco Chemie, Netherlands) and Software (GPES) 4.9 were used for electrochemical measurements. Nano-structured carbon paste electrodes or carbon-based electrodes modified with Fe_2O_3 and ZnO were used as a working electrode. Ag/AgCl (3 M NaCl) was used as a reference electrode and platinum wire was used as a counter electrode. pH measurements were made using a combined glass electrode, Model 526 (WTW, Austria) pH meter. A Zeiss Evo 40 scanning electron microscope (SEM) was used to image the surface morphology of the constructed electrodes (Suppl 1).

Reagents and Chemicals

Vardenafil was kindly supplied by Bayer (Leverkusen, Germany) and Levitra® tablets (20 mg per tablet) were obtained from a local pharmacy. NH_2-MWCNTs, COOH-MWCNTs and nonfunctional MWCNTs were purchased from DropSens. ZnO nanoparticles (<50 nm (TEM)), Fe_2O_3 nanoparticles (<50 nm particle size) and mineral oil (d=0.84 g/mL) were obtained from Aldrich. Graphite powder and DMF were purchased from Merck. Synthetic blood serum (Hemoglobin, ≤ 20 mg/dL) was provided from Sigma-Aldrich. The buffer components used to study the pH effect were phosphate buffer for pH 2.0 – 3.0 and Britton-Robinson (BR) buffer for pH 2.0 – 10.0. Since the vardenafil is a readily soluble organic compound in water, it was prepared in aqueous solution as 500 mg/L.

Preparation of tablet and synthetic blood serum solutions containing vardenafil

A single Levitra® tablet containing 20 mg of the vardenafil active ingredient was dissolved in 100 mL of volumetric flask to have a final concentration of 200 mg/L vardenafil. The prepared sample was then mixed in an ultrasonic bath for about 2 hours at room temperature. The stock solution was allowed to stand at room temperature. SWS and DPS voltammograms were recorded using NH_2-MWCNT/ZnO/ GPE and vardenafil in Levitra® tablets were calculated from the peak increments with standard vardenafil additives.

1 mL of the 500 mg/L vardenafil stock solution was added to the 9 mL of the synthetic blood serum samples to obtain a sample having a 50 mg/L of vardenafil. It was stirred at room temperature for about 1 hour in an ultrasonic bath and allowed to stand for 12 hours, then analyzed by voltammetric techniques.

CONCLUSION

In this study, two voltammetric techniques (SWSV and DPSV) were developed for the determination of vardenafil from bulk solution, commercial tablets and serum samples. For this purpose ZnO and NH_2 functionalized MWCNT modified GPE was designed. All parameters for preparing the modified electrode and for the experiments were optimized. The number of transferred electrons was investigated according to the scan rate studies. Vardenafil determination on the NH_2-MWCNT/ZnO/GPE by SWS and DPS voltammetry displayed that LOD values were 13.6 µg/L and 4.38 µg/L, respectively. All required validation studies were performed. Interference effects of some organic species such as ascorbic acid, uric acid, dopamine, glucose have also been investigated. Good recovery results were obtained when the techniques were applied to the tablet and serum samples.

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