Journal of Pharmaceutical Analysis 7 (2017) 258–264

Contents lists available at ScienceDirect

Journal of Pharmaceutical Analysis

journal homepage: www.elsevier.com/locate/jpa

Original Research Article

Electrochemical determination of an anti-hyperlipidimic drug pitavastatin at electrochemical sensor based on electrochemically pre-treated polymer film modified GCE

Umar J. Pandit[a,*], Gowhar A. Naikoo[b,*], Mehraj Ud Din Sheikh[a], Gulzar A. Khan[a], K.K. Raj[a], S.N. Limaye[a]

[a] Department of Chemistry, Dr. Harisingh Gour University, Sagar, M.P., India
[b] Department of Mathematics and Sciences, College of Arts and Applied Sciences, Dofar University, Salalah, Oman

ARTICLE INFO

Keywords:
Pitavastatin
Electrochemical sensor
Adsorptive stripping voltammetry
Biological fluids
Pharmaceutical formulations

ABSTRACT

An electrochemically pretreated silver macroporous (Ag MP) multiwalled carbon nanotube modified glassy carbon electrode (PAN-Ag MP-MWCNT-GCE) was fabricated for the selective determination of an anti-hyperlipidimic drug, pitavastatin (PST). The fabricated electrochemical sensor was characterized by cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). The fabricated electrode was employed in quantifying and determining PST through differential pulse adsorptive stripping voltammetry (DPAdSV) and CV. The electrode fabrication proceeded with remarkable sensitivity to the determination of PST. The effect of various optimized parameters such as pH, scan rate (v), accumulation time (t_{acc}), accumulation potential (U_{acc}) and loading volumes of Ag MP-MWCNT suspension were investigated to evaluate the performance of synthesized electrochemical sensor and to propose a simple, accurate, rapid and economical procedure for the quantification of PST in pharmaceutical formulations and biological fluids. A linear response of PST concentration in the range 2.0×10^{-7}–1.6×10^{-6} M with low detection (LOD) and quantification (LOQ) limits of 9.66 ± 0.04 nM and 32.25 ± 0.07 nM, respectively, were obtained under these optimized conditions.

1. Introduction

In recent years, the improvement in electrochemical techniques has made these techniques used in the field of pharmaceutical, environmental and biological sample analysis predominantly because of their high sensitivity, low instrumentation cost with relatively shorter analysis time and removal of tedious extraction procedures, as compared with other analytical techniques [1]. Electrochemical techniques have been proven to be advantageous for developing very sensitive and selective methods for the determination of pharmaceutical, organic molecules and metal ions in samples of diverse origin [2]. Electrochemical techniques have the advantage of determining the biomolecular interactions and electrode mechanism of pharmaceuticals which provide an insight of the metabolic fate of drug molecules [3]. Electrochemical methods, such as differential pulse voltammetry (DPV), stripping analysis and square wave voltammetry (SWV), have higher sensitivity which made it possible to trace analytes as low as picogram level with shorter analysis time as compared to the time-consuming chromatographic methods [4]. The features that prove the dominance of DPV over other electroanalytical techniques are the rapid speed of analysis, lower consumption of electroactive species and fewer problems with fouling of the electrode surface [5].

The electro-analytical techniques have gained more importance with the discovery of carbon nanotubes (CNTs) [6]. CNTs as electrochemical sensors in view of their unique geometrical, mechanical, electronic and chemical properties have gained considerable attention [7]. The advantage of CNTs-based sensors has been the target of a large variety of applications, predominantly for solid-state chemical and biological sensors [8,9]. A number of pharmaceutical molecules have been determined and quantified at electrode surfaces modified with CNTs [10–15]. The use of CNTs as electrode material has resulted in low detection limit, high sensitivity, reduction of overpotential and resistance to surface blockage [16].

Another advancement in electrochemical techniques has been the use of chemically modified electrodes (CMEs) that have been widely considered as sensitive and selective analytical sensors for determination of trace amounts of biologically important and environmentally toxic compounds [17–19]. CMEs are bestowed with the ability to

Peer review under responsibility of Xi'an Jiaotong University.
* Corresponding author.
E-mail addresses: umarche@gmail.com (U.J. Pandit), gowhar@du.edu.om (G.A. Naikoo).

http://dx.doi.org/10.1016/j.jpha.2017.03.002
Received 27 June 2016; Received in revised form 5 March 2017; Accepted 12 March 2017
Available online 19 March 2017

catalyze the electrode process by significantly decreasing the needed overpotential. These electrodes are capable of enhancing the selectivity in the electrochemical techniques by selective interaction of electron mediator with the analyte in a coordinating fashion [20–22].

Pitavastatin (PST), 7-[2-Cyclopropyl-4-(4-fluoro-phenyl)-quinolin-3-yl]-3,5-dihydroxy-hept-6-enoic acid, is an anti-hyperlipidemic drug that works by inhibiting conversion of HMG-CoA to mevalonic acid in hepatocytes, through competitive blockade of HMG-CoA reductase, the rate-limiting enzyme in cholesterol biosynthesis [23,24]. The quantification of pitavastatin has been reported by many analytical techniques [25–29]; however, these methods are either costlier or time consuming. The present study was focused on developing a simple, economical and highly sensitive method for the quantification of pitavastatin in pharmaceutical formulations and biological samples.

2. Experimental

2.1. Apparatus and reagents

All the electrochemical measurements were performed at ambient temperature of 298 K (25 °C) on a computer-controlled NOVA software version 1.10.1.9 Metrohm Autolab B.V. PGSTAT128N equipped with a conventional three-electrode system consisting of an Ag/AgCl (saturated KCl) reference electrode, platinum wire as counter electrode and a bare and modified glassy carbon electrode (GCE) as working electrode. pH measurements were performed with Systronic digital μpH meter model-361.

PST was purchased from Genetix Biotech Asia (P) Limited (New Delhi, India) and used without further purification. Standard stock solution of PST (5×10^{-3} mol/L) was prepared in methanol and stored under refrigeration. MWCNTs (surface area $< 200\ m^2/g$) were purchased from Sigma and used without further pre-treatment. 0.1 M phosphate buffer of varying pH was prepared by dissolving appropriate volumes of 0.1 M Na_2HPO_4 and NaH_2PO_4. The pH adjustments were achieved by 0.1 M HCl for lower pH and 0.1 M NaOH for higher pH. Pitava containing 2 mg PST each tablet (Zydus Cadila, India) and Flovas having 1 mg PST strength per tablet (IPCA Laboratories Ltd., India) were purchased from local pharmacy. All other chemicals and reagents used were of analytical grade. Double distilled water was used in all experimental measurements.

2.2. Preparation of modified electrodes

Silver macroporous monolith was synthesized via a reported sol-gel method (Supplementary material) [30]. This synthesized Ag MP material and MWCNTs (5 mg each) of equal weight were dissolved in 10 mL DMF and sonicated for 30 min to get a homogenized suspension. Prior to the electrode modification, GCE was mechanically polished to mirror like appearance by polishing with alumina powder (Al_2O_3, 0.05 μm and 0.3 μm) and cleaned by ultrasonicating in 1:1 mixture of 0.1 M HCl and HNO_3 for 10 min and dried at room temperature. 15 μL of the prepared Ag MP and MWCNT suspension was cast onto the pre-cleaned surface of GCE and allowed the solvent to evaporate at room temperature. The electrode was washed with distilled water and designated as Ag MP-MWCNT-GCE. Electrochemical pretreatment of the fabricated Ag MP-MWCNT-GCE was achieved by performing 20 consecutive cycles in 0.5 mM polyaniline solution by cyclic voltammetry in potential range from −0.5 to +2.0 V at a sweep rate of 50 mV/s. The electrode was washed with distilled water to remove any unadsorbed material and the electrode was designated as PAN-Ag MP-MWCNT-GCE. After the electropolymerization, the modified electrode was rinsed thoroughly with distilled water and then dried in air at room temperature.

2.3. Real sample preparation

Ten tablets from each brand (Pitava and Flovas) were homogenized to fine powder and appropriate weight (50 mg of Pitava and 100 mg of Flovas) of this powder was dissolved in 10 mL of methanol. The resulting solutions were first sonicated in an ultrasonicator bath for 10 min and then centrifuged for 15 min at 3000 rpm. The clear supernatant was pipetted out and diluted with appropriate volumes of supporting electrolyte and stored until assay.

Blood and urine samples were collected from healthy volunteers after acquiring their formal consents. Blood samples were allowed to stand for 30 min to coagulate at room temperature. After coagulation of blood, samples were centrifuged for 20 min at 2000 rpm for serum separation. The supernatant serum generated was carefully separated using clean pipette. Urine samples were added with 1.5 mL acetonitrile for protein removal and vortexed for 60 s. The mixture was centrifuged for 15 min at 2000 rpm and supernatant was taken out. Both serum and urine samples were diluted 10 times with 0.1 M phosphate buffer and stored in refrigeration for further analysis.

2.4. Analytical procedure

5 mL of the supporting electrolyte (0.1 M phosphate buffer, pH 6.5 ± 0.2) was taken in voltammetric cell and deoxygenated by purging nitrogen gas for 300 s. Suitable aliquots of standard PST solution were added to the supporting electrolyte immediately after recording the voltammogram of blank. The solution was again deoxygenated with purified nitrogen for 120 s. All voltammograms were scanned and recorded in negative potential from −0.7 to −1.8 V at a scan rate of 150 mV/s. The recording of voltammogram was repeated until a stable peak height was achieved.

3. Results and discussion

3.1. Electrochemical characterization of modified electrodes

The modified and bare electrodes were characterized by cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) techniques employing $Fe(CN)_6^{3-/4-}$ probe. CV measurements on 1.0×10^{-3} M $K_3Fe(CN)_6$ probe in 0.1 M KCl produced a reversible couple with increased peak currents at modified electrodes compared to bare GCE. The electro-active surface area of all the electrodes was calculated employing Randles-Sevcik [31] equation

$$I_{pa} = 0.4463\left(\frac{F^3}{RT}\right)^{1/2} n^{3/2} A_0 D_0^{1/2} C\upsilon^{1/2}$$

where I_{pa} is anodic peak current, n is the number of electrons transferred, A_0 is surface area of electrode in cm^2, ν is scan rate (mV/s), D_0 and C are diffusion coefficient and concentration of probe, respectively, and all other terms have their usual meanings. For 1.0 mM $K_3Fe(CN)_6$ in 0.1 M KCl at T = 298 K, n = 1 and $D_0 = 7.6\times10^{-6}\ cm^2/s$. The surface area was calculated from the slope of plot of I_{pa} versus $\upsilon^{1/2}$ and was found as 0.0278 cm^2, 0.0517 cm^2, 0.0874 cm^2 and 0.1053 cm^2 for GCE, MWCNT-GCE, Ag MP-MWCNT-GCE and PAN-Ag MP-MWCNT-GCE, respectively.

EIS is an effective method for probing the changes in the surface of the modified electrodes. Fig. 1 shows Nyquist plot of EIS at GCE, MWCNT-GCE, Ag MP-MWCNT-GCE and PAN-Ag MP-MWCNT-GCE in 5×10^{-3} M $Fe(CN)_6^{3-/4-}$ in 0.1 M KCl. The diameter of semicircle domains at high frequency region in the Nyquist plot provides the electron transfer resistance (R_{ct}) at the electrode surface and is used to define the interface properties of the electrode [32]. The semicircle in high-frequency regions obtained for modified electrodes was smaller compared to that of bare GCE, indicating decreased impedance at modified electrodes. R_{ct} at bare GCE, MWCNT-GCE,

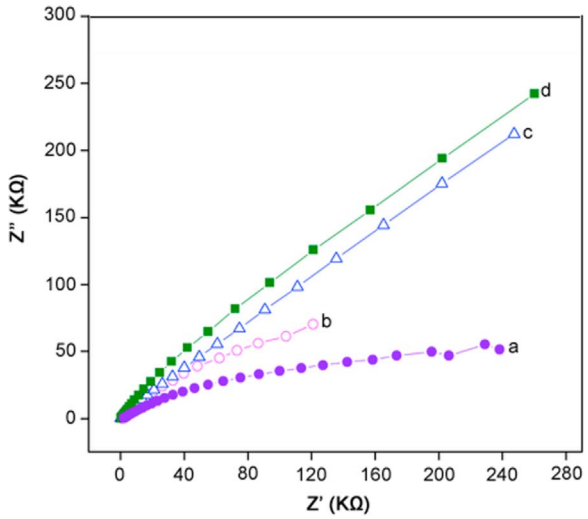


Fig. 1. Nyquist plots of EIS at (a) bare GCE, (b) MWCNT-GCE, (c) Ag MP- MWCNT-GCE and (d) PAN-Ag MP-MWCNT-GCE in 5.0×10^{-3} M $Fe(CN)_6^{3-/4-}$ probe. Frequency range: 10^{6}–10^{-1} Hz.

Ag MP-MWCNT-GCE and PAN-Ag MP-MWCNT-GCE obtained were 47.06 kΩ, 31.28 kΩ, 26.71 kΩ and 16.67 kΩ, respectively. The decreased impedance at modified electrodes is a consequence of very low R_{ct}, resulting in increased peak currents [33].

3.2. Electrochemical behaviour of drug at modified electrode

The electrochemical behaviour of PST at bare and modified electrodes was investigated by CV and differential pulse adsorptive stripping voltammetry (DPAdSV) in 0.1 M phosphate buffer (pH = 6.5 ± 0.2). PST produces well-defined reduction peak in 0.1 M phosphate buffer of 6.5 ± 0.2 pH at the surface of modified electrode. To elucidate the uniqueness and sensitivity of modified electrode, the electrochemical behaviour of 4.0×10^{-7} M PST was investigated at four different working electrodes. Fig. 2 shows the resulted cyclic voltammograms of PST at bare GCE, MWCNT-GCE, Ag MP-MWCNT-GCE and PAN-Ag MP-MWCNT-GCE in phosphate buffer supporting electrolyte. The increase in peak current at PAN-Ag MP-MWCNT-GCE indicates strong accumulation of PST with increased electron transfer between PST and the electrode surface. This can be explained by the fact that MWCNT and porous silver increased the surface area of electrode and polyaniline enhanced the electron transfer

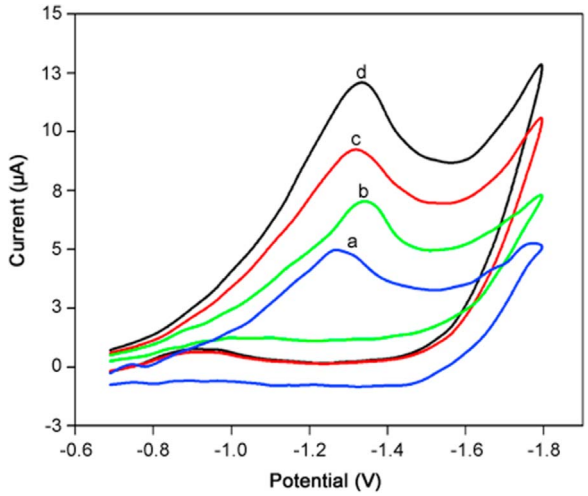


Fig. 2. Cyclic voltammograms of 4.0×10^{-7} M PST at (a) bare GCE, (b) MWCNT-GCE, (c) Ag MP-MWCNT-GCE and (d) PAN-Ag MP-MWCNT-GCE in 0.1 M phosphate buffer with pH 6.5 ± 0.2.

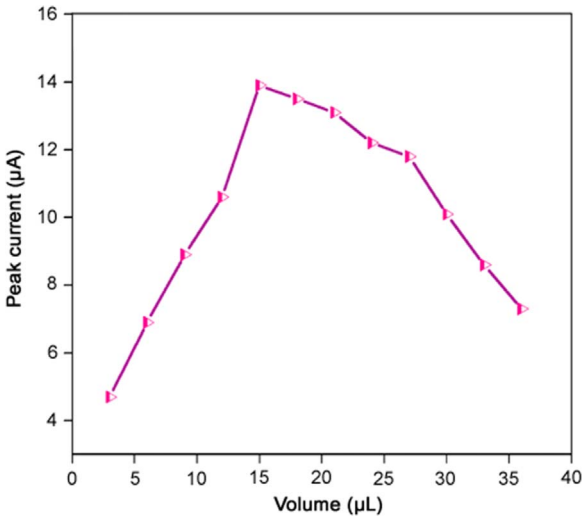


Fig. 3. Variation of peak current (I_p) of 4.0×10^{-7} M PST with different loading volumes of Ag MP-MWCNT on GCE.

process. The reduction peak at −1.31 V vs. Ag/AgCl for PST was an irreversible one, as on reversing the potential no anodic peak corresponding to the reduction process was observed even at positive potential. The irreversible nature of the electrode process was further established by increasing scan rates which resulted in shift of peak potential to negative values with increased peak currents [34].

3.3. Optimization of experimental parameters

3.3.1. Optimization of varying Ag MP-MWCNT dosages

For acquiring maximum sensitivity of PAN-Ag MP-MWCNT modified GCE towards the determination of PST, varying volumes of Ag MP-MWCNT suspension were applied on GCE prior to the electrochemical pretreatment of modified electrode. For this purpose several electrodes were designed and varying dosages of Ag MP-MWCNT suspension were directly cast onto the clean and polished surface of GCE followed by its electrochemical pretreatment in 0.5 M polyaniline solution. Fig. 3 shows variation of peak current of 4.0×10^{-7} M PST with increasing volumes of Ag MP-MWCNT suspension. Initially the peak current jumped rapidly, reaching its maximum when 15 μL suspension was used and thereafter the peak current stabilized. However, at higher volumes, a decrease in peak current was observed. This may be a consequence of increasing thickness of nanoparticle film resulting in decreasing electron transfer rate. Hence, for maximal sensitivity, 15 μL Ag MP-MWCNT suspension was loaded on GCE surface.

3.3.2. Influence of accumulation time and potential

When considering the adsorptive property of drug, it becomes important to study the effect of both accumulation time (t_{acc}) and accumulation potential (U_{acc}). Fig. 4 shows adsorptive stripping voltammograms of 4.0×10^{-7} M PST at different accumulation time ranging from 0 to 180 s at PAN-Ag MP MWCNT-GCE while the Fig. 4 inset plot represents the variation of peak current with accumulation time. The initial increase in peak current up to 60 s indicates much of the drug is adsorbed at the surface of electrode and thereafter the peak current tends to be almost stable, indicating the amount of drug adsorbed at electrode surface tends to be a limiting value. Moreover, the impact of accumulation potential on voltammetric peak current was studied over the range from −1.0 V to +0.5 V. Considerable increments of peak currents were observed for 4.0×10^{-7} M PST towards positive potential and acquired maximum peak current value at −0.1 V and afterwards peak current decreased sharply. Hence for maximum analytical sensitivity, t_{acc} of 60 s and U_{acc} of −0.1 V were applied in further investigations.

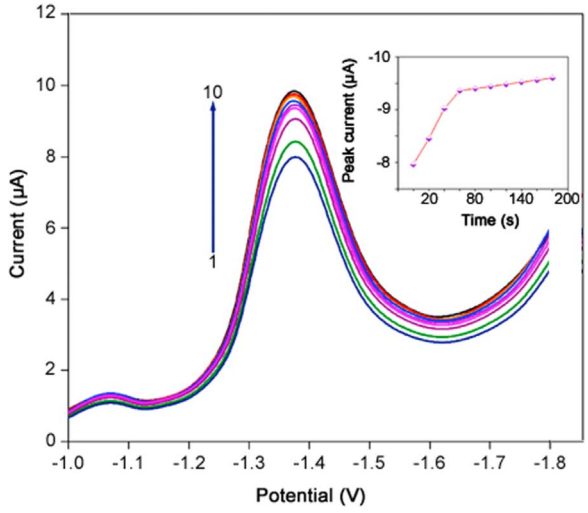


Fig. 4. Adsorptive stripping voltammograms of 4.0×10^{-7} M PST at (1) 0 s, (2) 20 s, (3) 40 s, (4) 60 s, (5) 80 s, (6) 100 s, (7) 120 s, (8) 140 s, (9) 160 s, and (10) 180 s accumulation time. Inset: Variation of peak current with accumulation time.

3.3.3. Influence of pH

The pH of supporting electrolyte exerts a substantial effect on the electrochemical redox property of an analyte; moreover, important information regarding the involvement of protons and electrons participating in the electrode process can be acquired by studying the drug under different pH conditions. Taking the above facts into account, the electrochemical reduction process of PST was studied in terms of varying pH (Fig. 5) of supporting electrolyte (0.1 M phosphate buffer). It was observed that peak potential varied linearly with pH of supporting electrolyte; this dependence of peak potential on pH indicates involvement of protons in the electrode reaction process [16]. Fig. 6 shows shift of peak potential to more negative potential with increasing pH, while peak current intensity increases only up to pH 6.5 ± 0.2, and decreases at higher pHs. The slope of 54.77 mV/pH obtained for the plot in Fig. 5 lies close to the theoretical value (59 mV/pH) expected for a redox process involving an equal number of protons and electrons. Thus, all electrochemical measurements of PST were performed an optimal pH of 6.5 ± 0.2.

3.3.4. Influence of scan rate

Scan rate studies are helpful in drawing very useful information such as electrochemical reaction mechanism, diffusion or adsorption

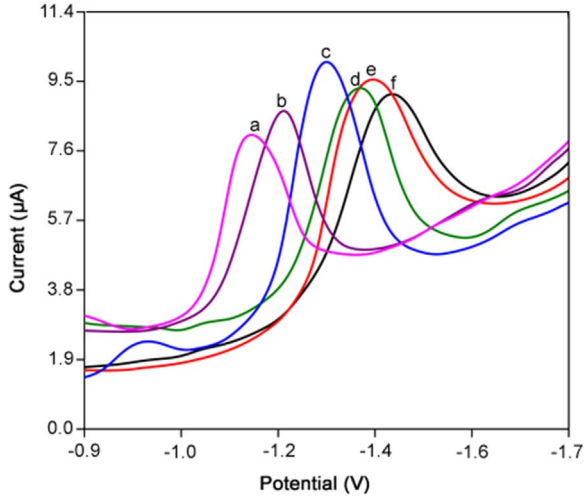


Fig. 5. Adsorptive stripping voltammograms of 4.0×10^{-7} M PST at pH (a) 4.5, (b) 5.5, (c) 6.5, (d) 7.5, (e) 8.5, and (f) 9.5 in 0.1 M phosphate buffer.

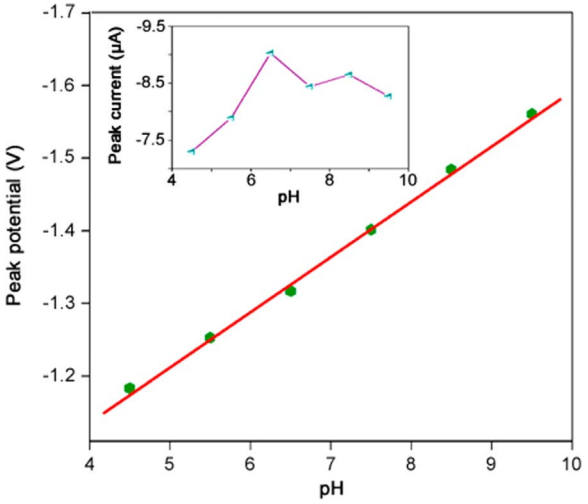


Fig. 6. Dependence of peak potential (E_p) of 4.0×10^{-7} M PST on pH of supporting electrolyte. Inset: Variation of peak current (I_p) with pH.

controlled nature, reversible or irreversible nature of electrode process. The influence of scan rate on reduction peak of 4.0×10^{-7} M PST at PAN-Ag MP-MWCNT-GCE was studied over the range of 25–200 mV/s. As depicted in Fig. 7, the increase in scan rates leads to increment in peak current (I_p) with shift of peak potential (E_p) to more negative potentials indicating irreversible nature of electrode process [35]. The scan rate of 150 mV/s was selected as suitable for determination of PST as it was sufficiently rapid for routine analysis, produced sharper and well-defined voltammetric responses. Linear relationships were also observed for log I_p vs. log υ (Fig. 8A) with a linear equation slope of 0.89 close to theoretical value of 1.0 for a typical adsorption controlled process [36–38]. Linear relationship between E_p and log υ(Fig. 8B) was observed, signifying that electron transfer is not fast [39]. The adsorption controlled nature of the electrode process was further verified by obtaining linear graph between I_p and potential scan rate (v) (Fig. 8C).

3.4. Chronocoulometric behaviour and plausible redox mechanism

In view of adsorption-controlled nature of electro-reduction of PST, the chronocoulometric behaviour of PST was examined to determine the number of electrons transferred in the electrode process and to determine the surface coverage (Γ*) of PST at the electrode surfaces. The number of electrons transferred can be estimated by performing

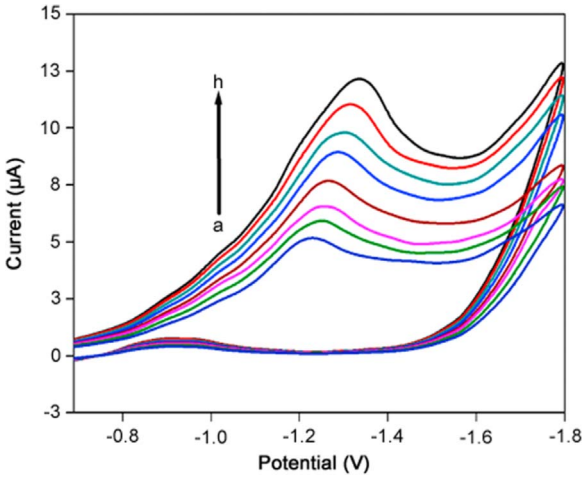


Fig. 7. Cyclic voltammograms of 4×10^{-7} M PST at 25, 50, 75, 100, 125, 150, 175 and 200 mV/s scan rate (a→h) in 0.1 M phosphate buffer (pH 6.5).

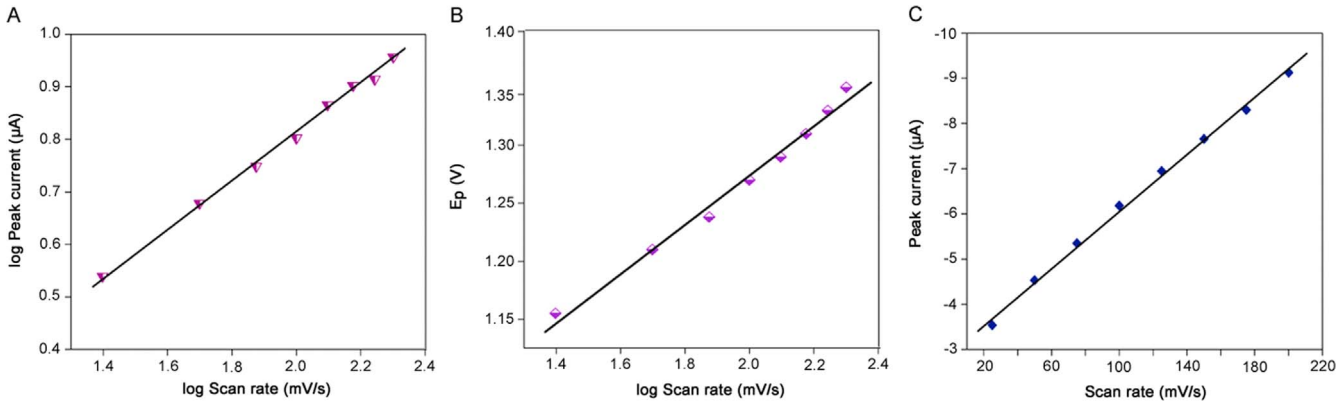
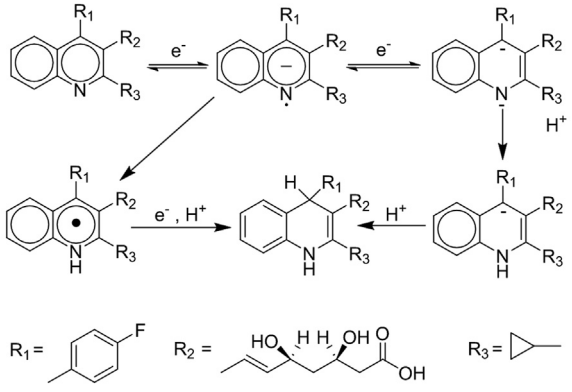


Fig. 8. (A) Plot of logarithm of peak current *vs*. logarithm of scan rate (mV/s), (B) variation of peak potential (E_p) with logarithmic of scan rate, and (C) variation of peak current (I_p) with potential scan rate (mV/s).



Scheme 1. Probable electrode reaction mechanism of electro-reduction of PST at modified electrode surface.

controlled potential coulometry from the charge consumed at desired concentration of PST. The electrolysis was performed at the optimized pH for three concentrations of PST (15 μg/mL, 25 μg/mL and 40 μg/mL) by placing the solution in voltammetric cell and continuously stirring and purging with nitrogen gas during electrolysis against Ag/AgCl reference electrode. The number of electrons transferred was calculated using the equation $Q = nFN$, where Q is charge consumed in coulombs, F is Faraday's constant and N is the number of moles of analyte. The number of electrons transferred for three different concentrations was calculated to be 2.07, 1.96 and 2.03, indicating the reduction of PST at PAN-Ag MP-MWCNT-GCE is a two-electron process. Based on the results obtained in CV, DPAdSV and controlled potential electrolysis, the probable electrochemical reduction mechanism of PST is shown in Scheme 1.

Chronocoulometry was further employed for the determination of diffusion coefficient and Q_{ads} of PST at the electrode surfaces from Q vs. $t^{1/2}$ plots employing Anson equation [40]. The plot of Q vs. $t^{1/2}$ in absence and presence of PST showed linear relationships and was almost parallel, which further supports the adsorptive controlled nature of electrode process. Surface coverage of PST for all the electrodes was calculated by using the following equation,

$$Q_{ads} = nFA\Gamma^{o}$$

The calculated values of diffusion coefficient and surface coverage of PST at different electrode surfaces are listed in Table 1. It was observed that PAN-Ag MP-MWCNT-GCE showed maximum surface coverage for PST, which is a collective effect of Ag MP, MWCNT and polyaniline increasing both surface area and electron transfer rate, thus favoring kinetics of PST reduction.

Table 1
Diffusion coefficient and surface coverage values of PST at different electrode surfaces.

Electrodes	Diffusion coefficient (10^{-6} cm^2/s)	Surface coverage (10^{-11} mol/cm^2)
GCE	4.17 ± 0.05	0.53
MWCNT-GCE	5.12 ± 0.07	1.26
Ag MP-MWCNT-GCE	5.98 ± 0.08	3.73
PAN-Ag MP-MWCNT-GCE	6.95 ± 0.05	8.51

3.5. Analytical applications

3.5.1. Calibration curve

In order to examine the feasibility of the proposed method as analytical tool for the trace determination of PST, DPAdS voltammograms were recorded at least 5 times under the optimized conditions at the modified electrode surface. The reduction peak currents were found proportional to the concentrations of PST over the range from 2×10^{-7} M to 1.6×10^{-6} M in 0.1 M phosphate buffer of pH 6.5 ± 0.2. Deviation from linearity was observed both at higher as well as lower concentrations of PST; this may be due to adsorption of PST or its reduction product at the electrode surface. Fig. 9 shows DPAdS voltammograms of different concentrations of PST under the optimized method with inset representing the calibration plot of the same. The

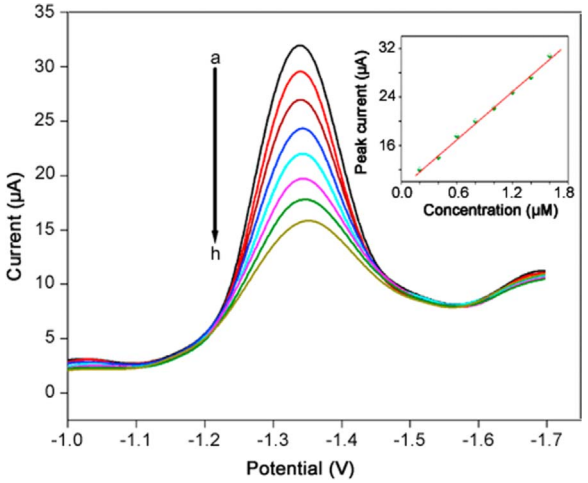


Fig. 9. DPAdS voltammograms of (a) 1.6 μM, (b) 1.4 μM, (c) 1.2 μM, (d) 1.0 μM, (e) 0.8 μM, (f) 0.6 μM, (g) 0.4 μM, and (h) 0.2 μM of PST in 0.1 M phosphate buffer of *p*H 6.5. Inset: Variation of peak currents with concentrations of PST.

Table 2
Regression data of calibration plot for PST using DPAdSV.

Parameters	DPAdSV
Peak potential E_p (V)	−1.31
pH	6.5
Buffer type/strength (M)	Phosphate/0.1
U_{acc} (V)	−0.1
t_{acc} (s)	60
Linearity range (μM)	0.2–1.6
Slope (μA/μM)	6.59
Intercept (μA)	4.60
Correlation coefficient	0.992
LOD (nM)	9.66 ± 0.04
LOQ (nM)	32.25 ± 0.07

regression data of calibration plot obtained by the developed electrochemical method for the determination of PST are presented in Table 2. The limit of detection (LOD) and limit of quantification (LOQ) were calculated using the equations [34] $LOD=\frac{3s}{m}$; $LOQ=\frac{10s}{m}$, where s is standard deviation and m is slope of the calibration plot. The calculated LOD was found to be 9.66 ± 0.04 nM and LOQ was amounted to be 32.25 ± 0.07 nM.

For practical application and validation of the proposed method, intra-day (over a single day) and inter-day (after 5 days) recovery measurements were performed with three different concentrations (6.0×10^{-7} mol/L, 8.0×10^{-7} mol/L and 1.0×10^{-6} mol/L) of PST. DPAdSV method was employed for recovery measurements and standard addition method was used on each concentration with five replicates to achieve better accuracy and precision. The recovery results varied between 97.50 and 99.00 for intra-day and 96.66–99.00 for inter-day recovery measurements. The results of recovery measurements are shown in Table 3.

3.5.2. Reproducibility and stability of modified electrode

The reproducibility and stability of modified PAN-Ag MP-MWCNT-GCE was examined by performing ten successive cyclic voltammograms of 4.0×10^{-7} M PST solution. The relative standard deviation of peak current was 2.98%. For long-term stability, the modified electrodes were stored under refrigeration for two weeks. It was observed that the electrode retained almost 96.08% of its initial response. The results indicated acceptable reproducibility and stability of the modified electrode for the determination of PST.

3.5.3. Interference studies

The possible interference of some common excipients was investigated to access the sensitivity of the proposed method. The tolerance limit was defined as the maximum concentration of interferent which causes an error less than ± 5%. The adsorptive stripping voltammograms of 4.0×10^{-7} M PST were recorded in presence of various interferents. It was noticed that glucose, sucrose and cellulose (up to 60-fold excess), Na^+, K^+, Ca^{2+} and Cl^- (up to 80-fold excess) and talc, starch and dextrose (up to 100 fold excess) did not interfere in the determination of PST. Thus we indicate that the proposed method offers good sensitivity for the determination of PST.

Table 3
Analytical precision and recovery data for intra- and inter-day recovery measurements.

Parameters	Intra-day			Inter-day		
Added[a] (μM)	0.60	0.80	1.00	0.60	0.80	1.00
Found (μM)	0.59	0.78	0.99	0.58	0.79	0.99
Recovery (%)	98.33	97.50	99.00	96.66	98.75	99.00
SD	0.005	0.015	0.006	0.007	0.005	0.009
RSD (%)	0.90	1.95	0.66	1.25	0.70	0.91

[a] Average of five determinations.

Table 4
Results of determination of PST in pharmaceutical samples.

Parameters	DPAdSV[a]		HPTLC[b] [26]		Spectrophotometry[c] [27]
	Pitava	Flovas	Pitava	Flovas	Pitava
Label claim (mg)	2	1	1	1	1
Amount found (mg)	1.980[d]	0.984[d]	0.998	0.998	1.010
Recovery (%)	99.01	97.72	99.83	99.80	101.35 ± 0.99[e]
RSD (%)	1.43	1.50	0.03	0.13	ND
LOD	9.66 nM		10 ng		0.298 mg/mL
LOQ	32.25 nM		30 ng		ND

[a] Present method;
[b] Average of four determinations;
[c] Applied method B;
[d] Mean of five determinations;
[e] Average of six determinations;
ND: Not determined.

Table 5
Precision and accuracy of assay of PST in spiked biological samples.

Sample	Added conc. (μM)	Found conc. (μM)	Recovery (%)	RSD(%)
Serum	0.6	0.597	99.50	1.21
	0.8	0.799	99.80	0.57
	1.0	1.011	101.10	0.60
	1.2	1.195	99.580	1.91
Urine	0.6	0.583	97.20	1.27
	0.8	0.802	100.20	0.84
	1.0	0.998	99.80	0.92
	1.2	1.198	99.80	1.14

3.5.4. Determination of PST in real samples

To validate the practical applications of the optimized electrochemical procedure, it was successfully applied for the determination of PST in real samples (pharmaceutical preparations and biological fluids). The unknown or spiked PST amount was calculated using standard addition method. The results indicated excellent precision and accuracy towards the determination of PST under the optimized conditions. A mean recovery of 99.01% for Pitava and 97.72% for Flovas was achieved by the present work. The detailed results of the pharmaceutical analysis compared with some other reported analytical methods [26,27] are presented in Table 4.

The proposed method was further subjected for accuracy measurements by analyzing drug-free and spiked biological (serum and urine) fluids. In absence of drug no peak was observed corresponding to PST. The fluids were then spiked with known concentrations of PST, and by using standard addition method, the amount of drug recovered was determined. The results were subjected to statistical analysis for reliability of data and are presented in Table 5. The recovery were between 99.50%–101.10% and 97.20%–100.20% for serum and urine samples, respectively.

4. Conclusion

An efficient green synthetic sol-gel protocol was adopted for synthesizing silver macroporous (Ag MP) material and applied in fabricating an electrochemically pretreated glassy carbon electrode. The modified PAN-Ag MP-MWCNT-GCE exhibited several advantageous features such as simple preparation procedure, increased surface area, excellent electrocatalytic activity, better electron transfer rate and strong adsorption towards an anti-hyperlipidimic drug pitavastatin. Such features resulted in higher sensitivity and increased electrochemical activity for determining PST in pharmaceutical and biological samples. Different experimental conditions and instrumental parameters were optimized for proposing a simple, highly sensitive and accurate method for determin-

ing PST as low as 9.66 nM concentration. The studies thus open an opportunity to adopt the present method for pharmacokinetic studies and quality control and assurances laboratories.

Conflicts of interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors are highly grateful to UGC-SAP, SIC and Department of Chemistry, Dr. H.S.G., (Central) University, Sagar, India for providing necessary lab facilities and required instrumentation.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jpha.2017.03.002.

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