Research Article

3D spongy-like Au film for highly stable solid contact potentiometric ion selective electrode: application to drug analysis
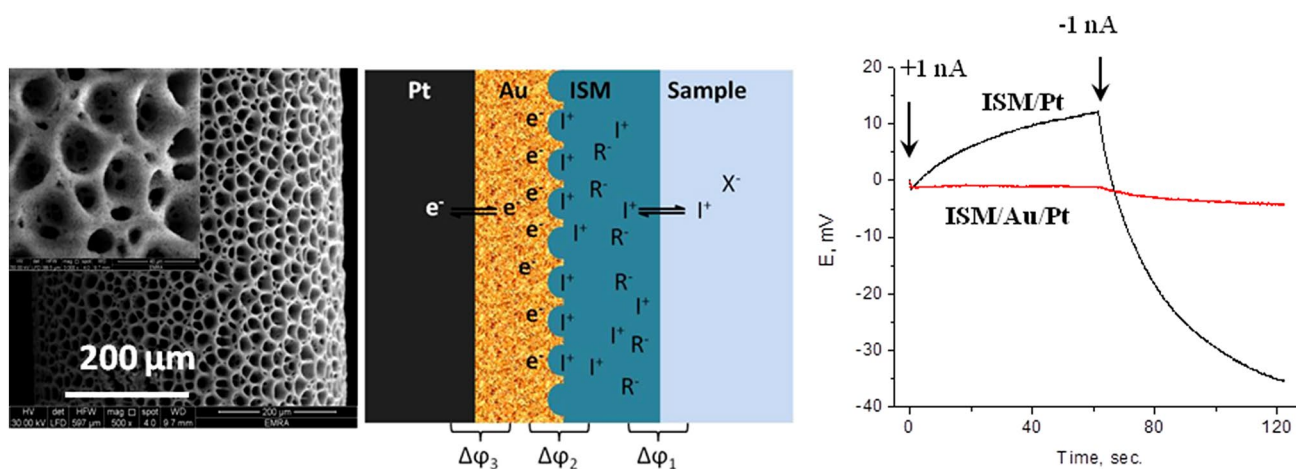
Emad Mohamed Hussien[1] · Abeer Rashad Derar[1]

Abstract

Potentiometric ion selective electrodes with simple design and high potential stability are required for in-line process, clinical and quality control analysis. The objective of this work is to develop a high-surface-area Au nanostructure solid-contact (SC) platform for high stable ion selective electrode for drug analysis. Memantine, a pharmaceutical compound prescribed for Alzheimer's disease, with challenging measurable analytical characteristics, was selected as a model for this purpose. Internal solid-contact with a high surface area was prepared by direct electrochemical deposition of Au-nanostructures onto a Pt electrode (500 μm diameter and 3 mm long). The proposed design combines the small size with the high surface area that is necessary for stable potential response. Cyclic voltammetry, impedance electrochemical spectroscopy and chronopotentiometry were used to evaluate electrochemical properties of the Au film. The Au-nanostructure SC electrode was coated with a membrane cocktail containing a lipophilic ion exchanger. The electrode exhibited a Nernstian response (58.5 ± 1 mV/decade) to memantine over a wide concentration range (1×10^{-5}–1×10^{-2} M). The electrode showed high potential stability (0.03 μV/s), wide pH working range (3.0–8.0) and high selectivity to memantine $\left(\log k_{i,j}^{pot} \leq -2.38 \right)$. The electrode was applied for direct determination of memantine in pharmaceutical dosage form, human urine and surface water with high accuracy (± 2%) and precision (RSD ≤ 1.5%).

Graphical abstract

✉ Emad Mohamed Hussien, emadhussien@yahoo.com | [1]Department of Pharmaceutical Chemistry, National Organization for Drug Control and Research (NODCAR), P.O Box 29, 9 Abou-Hazem str, Giza, Egypt.

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1 Introduction

Memantine is an antagonist of *N*-methyl-D-aspartate receptors [1]. It is described for treatment of moderate to severe Alzheimer's disease. Memantine is an alicyclic aliphatic compound with a primary amine group (Fig. 1). Direct UV absorption and fluorescence analysis of memantine is challenging due to absence of chromophoric groups and the weak UV absorbance of the primary amine group. Derivatization reactions were proposed to impart measurable characteristics to memantine to enable UV, fluorescence and liquid chromatographic quantification [2–10]. Unfortunately, however, derivatization reactions involve highly reactive compounds that require high precautions and special safety measures. In addition, derivatization reactions add extra steps to the analytical method and, hence, prolong the experimental time scale. Memantine has relatively high thermal stability that has enabled its determination using gas chromatography [11]. The drawback of this method is however the extraction step that uses environmentally unfavorable organic solvents before injection. Other methods including LC-MS/MS [12, 13] and HPLC with refractive index [14, 15] have been proposed. Obviously, these methods either use expensive instrumentations (LC-MS/MS) or use non selective detector (refractive index). Therefore, developing of simple, rapid and selective analytical method free from derivatization or mandatory extraction steps is demanded.

A simple solution that can meet these requirements is to use ion selective electrodes. Indeed, several conventional PVC membrane ion selective electrodes with different types of ion exchangers were proposed for determination of memantine in pharmaceutical formulation [16–18]. Although the proposed electrodes exhibited a wide linear range with satisfactory sensitivity and selectivity, the liquid contact electrode requires special skills for preparation and handling which limits its application for quality control and on-line process analysis.

On contrary, ion selective electrodes ISEs with an internal solid contact have attracted a great attention over the past decades due to their small size, low cost and ease of preparation [19]. In solid contact ion selective electrodes the internal filling solution which is necessary for conventional ion selective membrane electrode is eliminated, and the sensing membrane is casted directly on electronic conductor. Such configuration manifests potential instability and weak reproducibility due to the absence of stable process that secures a reversible transition between electron and ionic conductivity at the solid contact interface [20, 21]. Great efforts have been devoted over the past decade to enhance potential stability by improving the internal solid contact using carbon based materials[22–25], gold nanoparticles [26, 27] and redox substances [28–30]. Most of these approaches have focused on determination of inorganic ions and none of them considered the application to important pharmaceutical compounds.
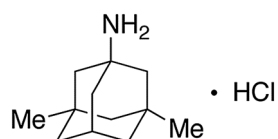
In this paper, a new all-solid-state ISE based on a highly porous Au nanostructures as ion-to-electron transducer was prepared. The electrode was prepared by one-step electrochemical deposition of Au onto a Pt microelectrode (500 µm diameter and 3 mm long). The proposed electrode has the advantage of small size, high surface area and large double layer capacitance which are necessary for stable potential response [31]. Memantine was selected as a model pharmaceutical compound for studying the Au/ Pt as a solid contact platform for preparation high stable ion selective electrode for drugs analysis. The ion selective electrode was prepared by dip coating process. The electrode exhibited satisfactory potentiometric characteristics with remarkable potential stability compared to bare Pt as internal solid contact. The electrode was employed for selective determination of memantine in pharmaceutical dosage form, human urine and surface water. The electrode is suitable for in-line monitoring with high accuracy.

2 Experimental

2.1 Materials

Memantine hydrochloride (MEM) drug substance (purity = 98%) was kindly provided by Techno Pharmaceutical, Alexandria, Egypt. Ebixa Tablets (10 mg/tablet) Rottendorf Pharma GmbH, Denmark, was obtained from a local pharmacy. Poly(vinyl chloride) (PVC) of high molecular weight was from Sigma-Aldrich, St. Louis, USA. 2-Nitrophenyl octylether (oNPOE) was purchased from Fluka, Switzerland. Potassium tetrakis(4-chlorophenyl) borate (TCPB) was purchased from Alfa Aesar, Heysham, England. Potassium hexacyanoferrate was from Riedel-De Haen, Hannover, Germany. Hydrogen tetrachloroaurate (III) hydrate (HAuCl$_4$.H$_2$O) was purchased from Alfa Aesar, Thermofisher, Germany. All reagents were of analytical grade and bidistilled water was used throughout the experiments unless otherwise stated.

Fig. 1 Chemical structure of memantine HCl

2.2 Preparation of Au-nanostructure structure solid conatact

A Pt wire (500 μm diameter and 5 cm long) was inserted into a capillary glass tube; 3 mm of the Pt wire was left protruding out at one end of the tube to serve as internal contact solid contact for ion selective electrode preparation. With the Pt wire fixed at this position, the glass tube was heat sealed around it. The other end of the Pt was used for connection to the instrument. The Pt was cleaned using diamond polishing suspension 15.0 μm, 3.0 μm and 1.0 μm (BASi, USA). Au nanostructures were deposited by applying a potential of -3.0 V in 5.0 mM $HAuCl_4$ for 90 Sec. [27], The Au-nanostructures/Pt wire was dipped into the membrane cocktail several times to get a uniform plastic film. The membrane cocktail consists of 33.0 wt% PVC of high molecular weight, 1 wt% potassium tetrakis (4-chlorophenyl)borate and 66 wt% 2-Nitrophenyl octylether in THF. The ISM/Au-nanostructure/Pt electrode was left for 24 h at room temperature to allow solvent evaporation. Afterwards, the electrode was conditioned for 12.0 h in 1×10^{-3} M memantine HCl, unless otherwise stated.

2.3 Morphological characterization

Scanning electron microscopy (FEI Company, Netherlands) was used for the morphological characterization of the Au-nanostructure layer. No sample pre-treatment was performed prior to SEM imaging. The SEM analysis was carried out at the Central Laboratories Sector of The Egyptian Mineral Resources Authority using SEM Model Quanta 250 FEG (Field Emission Gun) with accelerating voltage 30.0 K.V., magnification14x up to 1,000,000 and resolution for Gun.1n.

2.4 Electrochemical measurements

2.4.1 Potentiometric measurements

All potentiometric measurements were performed using a Jenway 3510 pH/mV meter (England) and Ag/AgCl (3 M) as a reference electrode. The potentiometric response of the electrode was studied in the concentration range from 1×10^{-6} to 1×10^{-3} M memantine HCl by successive addition of memantine HCl (1×10^{-2} M) to 50.0 mL bidstilled water. Potential of higher concentrations (5×10^{-3} and 1×10^{-2} M) were recorded by dipping the electrode in each solution separately. The calibration graphs were constructed by plotting the electrode potential *vs.* − log [conc., M]. The pH sensitivity of the electrode was studied for 1×10^{-4} and 1×10^{-3} M memantine HCl by changing the pH of the solution using HCl and NaOH, 0.01 M each. The pH change was recorded using a Cyberscan 500

digital pH meter (Eutech Instruments, Thermo Scientific, USA). The selectivity was studied using fixed interference method [32]. In this method, the potential of the electrode is measured in a solution of constant concentration of the interfering ion (1×10^{-2} M) and varying concentration of the target ion (memantine). The potential of the electrode was plotted against the logarithm of the concentration of memantine. The intersection of the extrapolation of the linear portions of this plot indicates memantine concentration which is used to calculate the selectivity coefficient by the Nikolsky-Eisenman equation [32]. The electrode was stored in 1×10^{-3} M memantine HCl solution and kept at room temperature between measurements. All potential measurements were recorded under constant stirring at room temperature (25.0 ± 1 °C).

2.4.2 Cyclic voltammetry

The cyclic voltammetric (CV) measurements were performed using SP-150 potentiostat (BioLogic Science Instrument, France) provided with EC-Lab (windows v11.02) software. A Pt auxiliary electrode and Ag/AgCl reference electrode (3 M KCl) were purchased from BASi (USA). The CV was recorded in a 5.0 mM hexacyanoferrate aqueous solution.

2.4.3 Electrochemical impedance spectroscopy (EIS)

The EIS was performed using the same SP-150 potentiostat and EC-Lab software that was used for CV studies. The impedance spectra were recorded in the frequency range from 20 kHz–0.1 Hz. using a sinusoidal excitation signal (amplitude = ± 10 mV) superimposed on the electrode potential (E = 220 mV) in 5.0 mM hexacyanoferrate aqueous solution. The charge transfer resistance was determined from the complex impedance plot (Imaginary Z versus Real Z) by fitting a circle through the points that represent the electrode-solution interphase using the EC-Lab software.

2.4.4 Chronopotentiometric studies

Constant current potentiometric measurements were performed using the same potentiostat. A constant current of ± 1.0 nA was applied for 60 s each, while monitoring the electrode potential. The measurements were performed in 1×10^{-3} M memantine HCl at room temperature.

2.5 Sample preparations and analytical applications

2.5.1 Pharmaceutical dosage form

Fifteen tablets of memantine hydrochloride were finely ground in a mortar. An accurately weighed amount of the powder (equivalent to 108 mg memantine HCl) was transferred to 50-mL measuring flask, dissolved in 25.0 ml bidistilled water and sonicated for 15 min. The flask was completed to mark with bidistilled water; this solution was marked as stock sample solution. Sample solutions (50.0 mL each) with different concentrations were prepared by dilution from the stock sample solution. The concentration of memantine in each solution was determined by the standard addition method [33].

2.5.2 Spiked human urine

Human urine was taken from healthy donors and used shortly after collection. Urine samples were used without pretreatment. Spiked human urine was prepared by spiking 5.0 ml urine with memantine hydrochloride and diluting to 50.0 mL using bidistilled water.

2.5.3 Tap water

Spiked tap water was prepared by spiking tap water (50.0 mL) with 108 mg memantine HCl. Stock sample solution and sample solutions with different concentrations were prepared as in the pharmaceutical dosage form.

3 Results and discussion

3.1 Characterization of the Au/Pt electrode

3.1.1 Morphology of the solid contact

Figure 2 shows an SEM picture of Au film electrochemically deposited onto a 500 μm diameter Pt wire. The thickness of
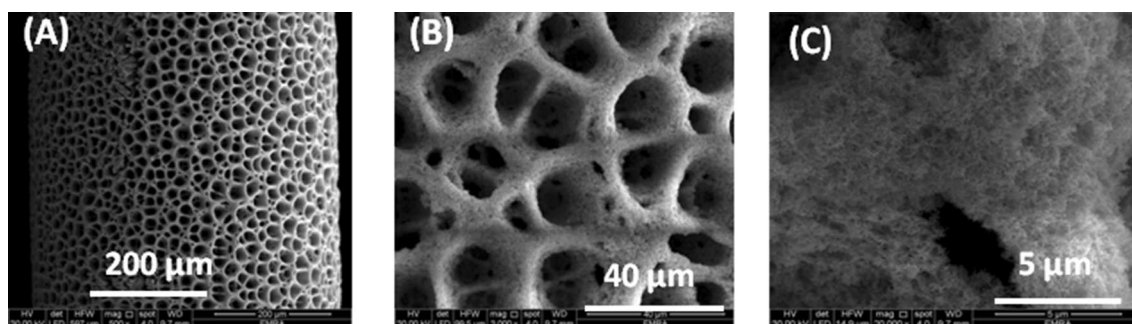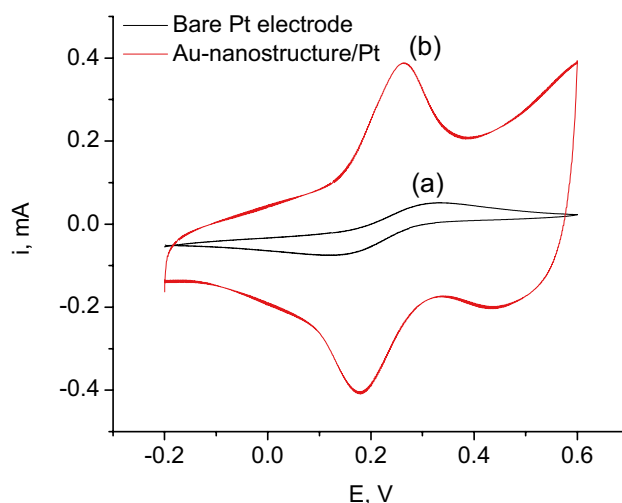
Fig. 3 Cyclic voltammograms for (**a**) Pt and (**b**) Au-nanostructure/Pt electrodes in 5.0 mM hexacyanoferrate solution in 100 mM KCl at 100 mV/s scan rate

the Au film is estimated to be ≤ 17 μm (calculated from the Pt diameter before and after deposition) (Fig. 2A). The Au film is highly porous with a pore diameter ranging from 20 μm down to a few nanometers for small pores (Fig. 2B). Figure 2C shows that the surface of the film is coral-like surface with remarkable Au-nanostructures. Such morphology reflects the high surface area of the electrodeposited Au film.

3.1.2 Cyclic voltammetric

Typical cyclic voltammograms for Pt and Au-nanostructure/Pt electrodes in hexacyanoferrate solution is shown in Fig. 3. As it can be seen from the CV, the capacitive current of the Au-nanostructure/Pt electrode is higher than that of bare Pt electrode. This confirms the high surface area of the Au-nanostructure/Pt electrode compared to bare Pt electrode. It is observed that the reduction peak is slightly shifted to more positive potential and the oxidation peak is slightly shifted towards

Fig. 2 SEM image of (**A**) Pt wire (500 μm diameter) with electrodeposited Au-nanostructures

more negative potential. As a result, the peak to peak separation is reduced from 200 mV for Pt electrode to 80 mV for Au-nanostructure/Pt electrode suggesting fast electron transfer for the Au-nanostructure/Pt electrode. The current of the reduction and oxidation peaks are peak shaped. This is due to the depletion of the hexacyanoferrate within the pores of the Au-nanostructure/Pt before it becomes diffusion limited at the electrode surface indicating the high porosity of the Au-nanostructure/Pt structure.

3.1.3 EIS

Electrochemical impedance spectra were conducted for the Pt and Au-nanostructure/Pt electrodes (Fig. 4). The impedance spectrum of the Pt electrode showed a high frequency semicircle arising from the charge transfer resistance in parallel with the double layer capacitance of the electrode. The charge transfer resistance was estimated
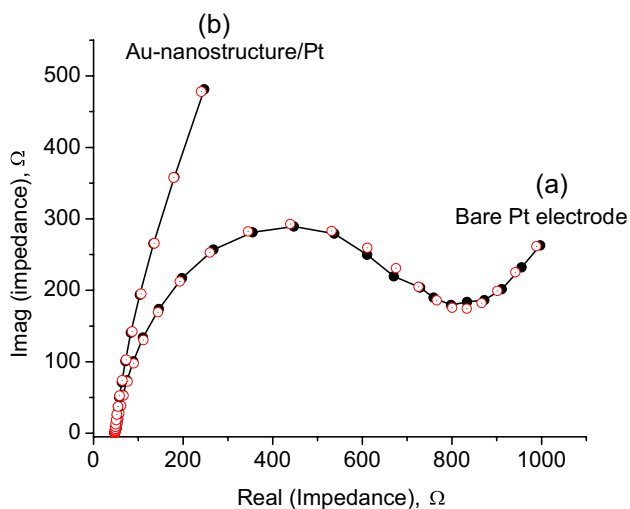
to be 700 Ohm. In contrast, the high frequency semicircle disappeared in case of Au-nanostructure/Pt indicating an easy electron transfer. While, a slightly curved line was observed at low frequency; most likely due to the high double layer capacitance of the Au/solution interface. The high double layer capacitance is due to the high surface of the electrodeposited Au film. These results are in consistence with the surface morphology revealed by SEM and the electrochemical properties obtained by CV.

3.1.4 Response characteristics of the ISM

ISMs with different compositions were prepared and calibrated using pure memantine solution. The effect of ISM composition on the potential response is summarized in Table 1. All electrodes gave linear response with a Nernstian slope between 57.0 and 59.5 mV/decade over the concentration range from 1×10^{-5} to 1×10^{-2} with nearly comparable detection limit 2.5×10^{-6}. Also, the effect of ISM thickness on the potentiometric response was investigated. ISMs with different thickness were obtained by repeatedly (3, 4 and 5 times) dipping the electrode in the membrane composition solution. The variation in membrane thickness, as a result of increasing number of dipping, showed no significant effect on the magnitude of the potentiometric response. Therefore, in this work a coated wire electrode formed by repeatedly dipping (4 times) the electrode in the membrane composition was chosen as optimal membrane thickness for further characterizations. Figure 5 shows the calibration curve and the corresponding potentimetric time trace of the electrode. From the potential time trace curve it is clear that the electrode exhibited a fast response time; a stable potential response was obtained ≤ 10 s.

3.1.5 Chronopotentiometric measurements

The potential stability of the proposed SC electrode was investigated using reversal current chronopotentiometry. In this method an external current was applied to the electrode while the electrode potential was monitored.

Fig. 4 Impedance spectra recorded for (**a**) Pt and (**b**) Au-nanostructure/pt electrodes in 5.0 mM hexacyanoferrate solution. The spectra are recorded at $E_{dc} = 0.22$ mV and ac $= \pm 10$ mVpp in the frequency range from 20 kH to 0.1 Hz. Open red circles represent the fitted values

Table 1 Potentiometric response of memantine all-solid-state ISE with variable composition

Electrode	%Composition (w/w)						
	Plasticizer	PVC	TCPB	Slope ± SD, mV/decade[a]	Linearity, M	DL, M	r^2
I	33.0	66.5	0.5	57.0±1.2	5.0×10^{-5}– 1.0×10^{-2}	3.3×10^{-6}	0.9987
II	33.0	66.0	1.0	58.7±0.9	1.0×10^{-5}– 1.0×10^{-2}	2.5×10^{-6}	0.9991
III	33.0	65.5	1.5	57.7±0.6	5.0×10^{-5}– 1.0×10^{-2}	4.0×10^{-6}	0.9989

[a]Three determinations

Fig. 5 Potentiometric time trace obtained during the calibration of memantine using the Au/Pt electrode (**A**) and corresponding calibration graph (**B**)
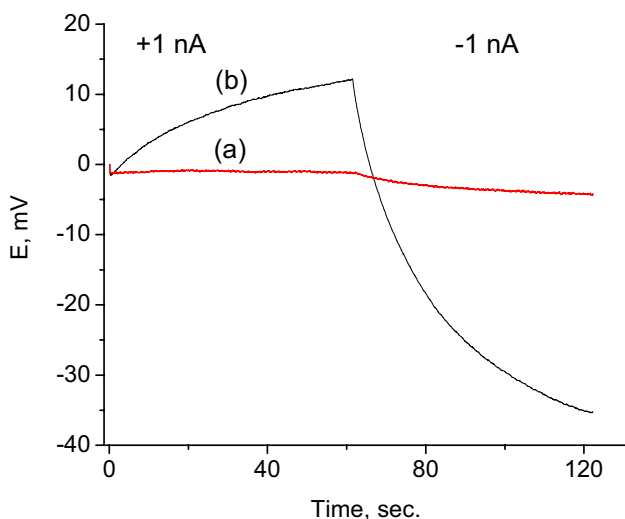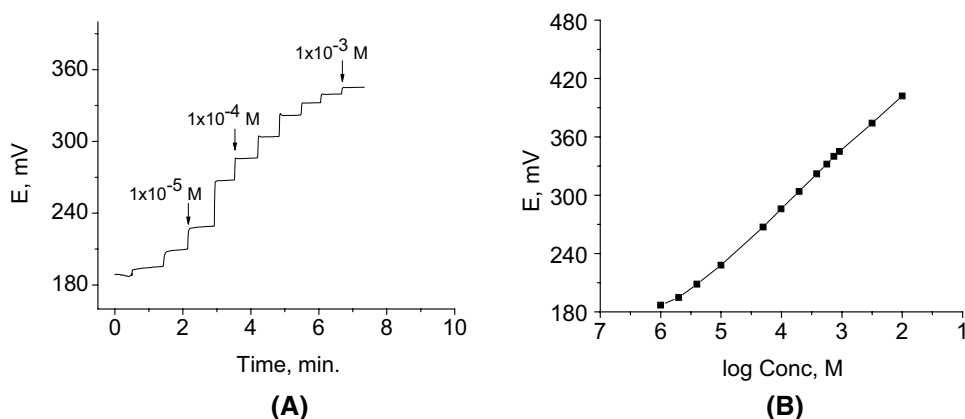

(A)

(B)

Fig. 6 Chronopotentiograms for memnatine ISEs: (**a**) ISM/Au-nanostructuer/Pt and (**b**) ISM/Pt electrodes. Applied current: +1 nA for 60 s and −1 nA for 60 s

Figure 6 shows the effect of an external current of ±1 nA on the potential stability of ISM/Pt and ISM/Au-nanostructure/Pt electrodes. It is clear that the potential stability of the electrode is improved in presence of Au layer as interface relative to bare Pt wire. This phenomenon is attributed to the electrical double capacitance where the Au- nanostructurere represents an electrical capacitor with one side carries charge in the form of ions from the ISM and the other side formed by electrons from the solid contact [23, 31]. The higher double layer capacitance is due to the high surface area provided by the spongy-like structure of the Au layer. The effect of increasing the interfacial ISM/SC on the potential stability has been previously reported for inorganic ions [22–25, 34].

3.1.6 Potential stability

The potential stability of the electrode was investigated by monitoring the potential of the electrode in 1×10^{-3} M memantine HCl for 60 min. The ISM/Au-nanostructure/Pt electrode showed a very high stable potential with a potential drift limited to 0.03 μV/s. Whereas, the ISM/Pt electrode showed a positive drift of 6 μV/s (200 times higher than that for the ISM/Au-nanostructure/Pt electrode). Moreover, the potential stability and reproducibility was tested daily over 7 days. The ISM/Au-nanostructure/Pt showed a high reproducibility, the electrode retained its initial potential (within ±2 mV variation) after 7 days. On the other hand, the ISM/Pt electrode exhibited a great nonlinear potential shift. About +60 mV shift in potential reading was observed after 24 h, and +95 mV shift was observed after 2 days. This instability of the ISM/Pt is due to the poor double layer capacitance of the ISM/Pt interface. The potential stability is shown in (Fig. 7).

3.1.7 Memory effect and reproducibility

Electrode memory occurs when the potential reading of the electrode in a given concentration of the analyte is not obtained again after exposing the electrode to another different concentration of the same target analyte. Here, the ISM/Au-nanostructure/Pt electrode was exposed alternately to memantine solutions of 1×10^{-3} and 1×10^{-4} M for 1 min each (Fig. 8A). As a result, the electrode potential was immediately dropped and jumped alternately by a value of 57.5 ± 1.0 mV, indicating a high reproducibility of the ISM/Au-nanostructure/Pt electrode with negligible hysteresis. Moreover, the electrode was exposed to bidistilled water and then again to 1×10^{-3} M memantine solution. The difference between the potential values reported before and after exposing to water was negligible (±1 mV).
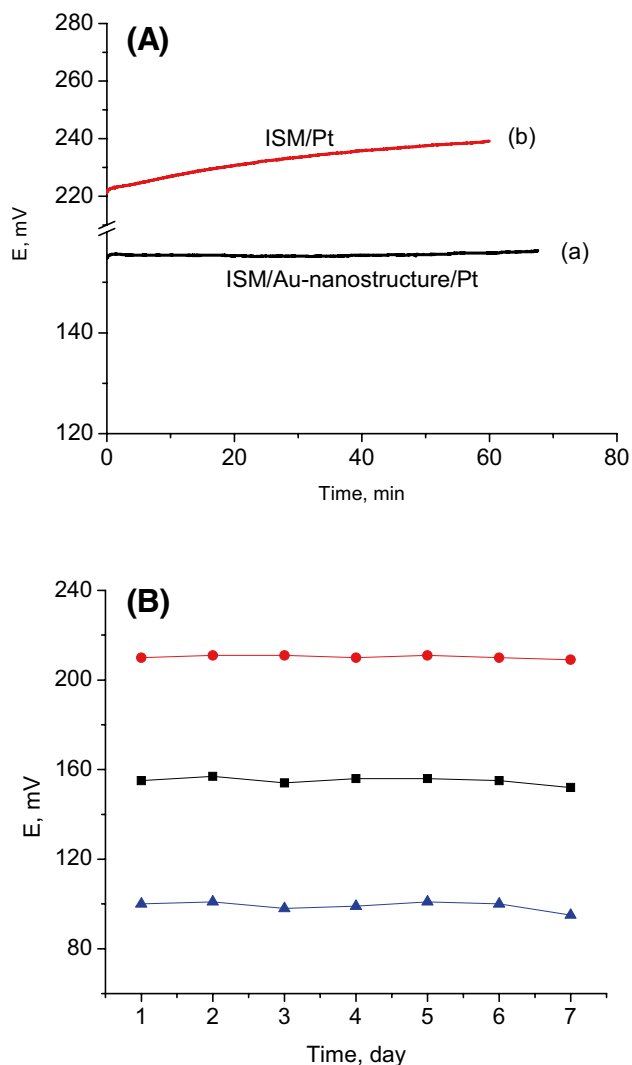
Fig. 7 (**A**) Potential stability of ISM/Pt and ISM/Au-nanostructure/Pt electrodes in 1×10^{-3} M memantine HCl over 60 min. (**B**) the potential stability of ISM/Au-nanostructure/Pt electrode over 7 days (3 electrodes)

Fig. 8 Hysteresis and reproducibility: (**A**) ISM/Au-nanostructure/Pt electrodes with alternate change of memantine concentrations and (**B**) ISM/Pt and ISM/Au-nanostructure/Pt electrodes in 1×10^{-3} M memantine solution and water

In contrast, the ISM/Pt failed to retain its potential after exposing to water. A potential difference of 16 mV was observed when the electrode was exposed to water for 1 min, indicating a high hysteresis and, hence, poor reproducibility of the ISM/Pt electrode (Fig. 8B).

3.1.8 Effect of PH

The effect of changing the pH of memantine solutions 1×10^{-3} M and 1×10^{-4} M on the potential response of the electrode is shown in (Fig. 9). The potential of the electrode is not affect by changing the pH of the solution
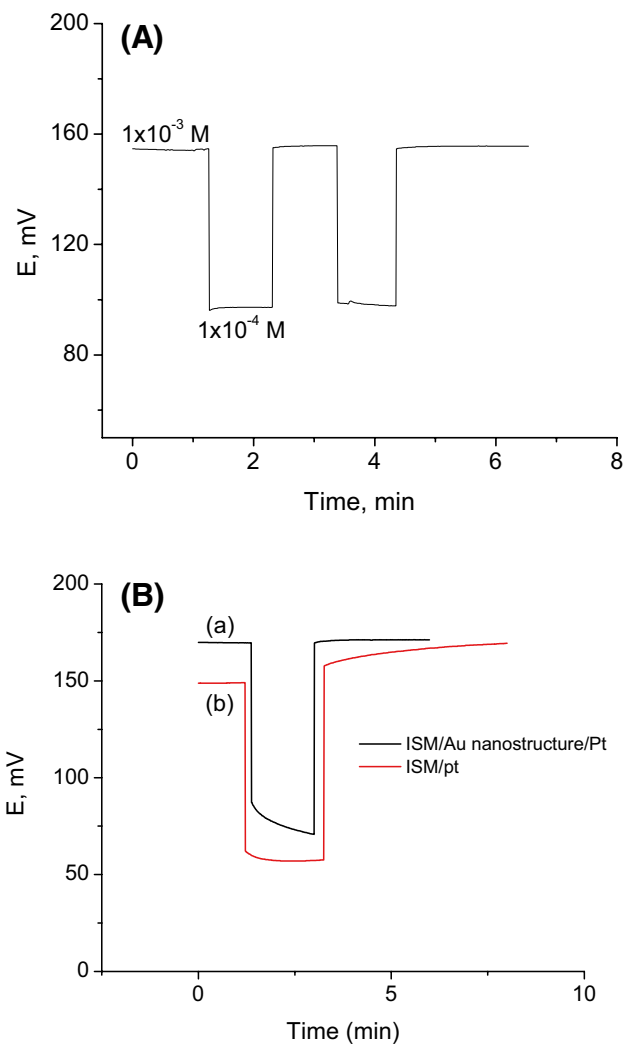
in the pH range from 3.0 to 8.0. A slight response to H^+ was observed at pH ≤ 3.0. Whereas, a dramatic change in the potential response of the electrode was observed at pH ≥ 8.0; this is due to deprotonation and precipitation of memantine as a base at higher pH values.

3.1.9 Selectivity

The influence of an interfering ion on the electrode response can be quantified by means of a selectivity coefficient $k_{i,j}^{pot}$. A high value of $k_{i,j}^{pot}$ refers to a high con-
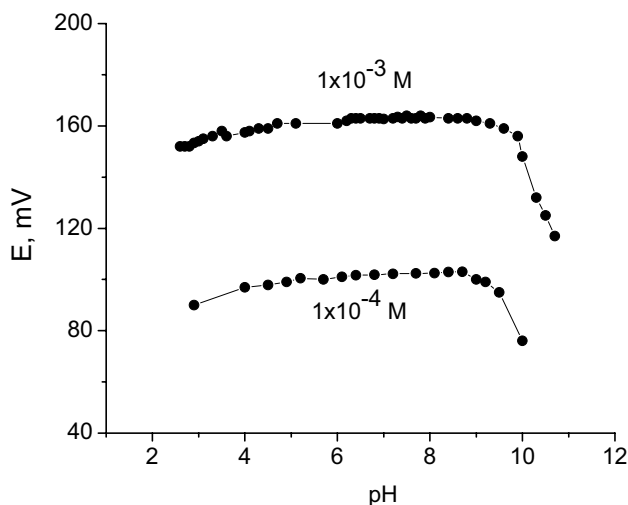
Fig. 9 Effect of pH of on the electrode response for ISM/Au-nano-structure/Pt electrode

Table 2 Potentiometric selectivity coefficient of memantine all-solid-state ISE

Interferent	$logk_{i,j}^{pot}$
K$^+$	−2.70
Na$^+$	−2.52
Ca^{2+}	−2.32
Mg^{2+}	−2.11
NH$_4^+$	−3.10
Mannitol	−2.76
Aspartam	−2.83
DL-Lysine HCl	−2.62
L-Arginine HCl	−2.52
L-Leucine	−2.48
L-Alanine	−2.38

tribution of an interfering ion to the electrode potential. In this work, the selectivity coefficient was determined by the fixed interference method [32]. The selectivity coefficients are reported in Table 2. The selectivity coefficients are tabulate as logarithm of $k_{i,j}^{pot}$ due to the low values of $k_{i,j}^{pot}$. It is clear that the electrode has a high selectivity to memantine over the tabulated interfering compounds.

3.1.10 Analytical application

The proposed electrode was applied successfully for determination of memantine in drug substance,

pharmaceutical dosage form, spiked human urine and and using the standard addition method. The high stability and fast response time of the solid contact enabled satisfactory accuracy and precision. The accuracy of the potentiometric measurements was investigated by determination of memantine at five different concentration levels 4.32, 8.64, 12.96, 17.28 and 21.60 µg/mL. The mean recovery data obtained at each concentration level was within ± 2%. The %RSD (n=5) calculated at each level was ≤ 1.5%. Table 3 summarizes the accuracy and precision of the ISM/Au-nanostructure/Pt electrode for determination of memantine in the drug substance and pharmaceutical formulation. The accuracy and precision of the proposed method was compared statistically to that of an official method by calculating the student t- and F-ratio tests. In the official method [11], the sample was treated by sodium hydroxide and extracted by toluene followed by injection in GC instrument. Atypical GC chromatogram is shown in supplementary information: Fig. 10. The sample was repeated six times and the mean of the results was compared to that of the proposed method using the t-test. The calculated t value was less than the tabulated value at 95 confidence limit; indicating that the two methods are equivalent.

The precision of the two methods were compared using the F-ratio test. The calculated F value is less than the tabulated one at 95% confidence indicating that the precision of the proposed method is equivalent to the official one.
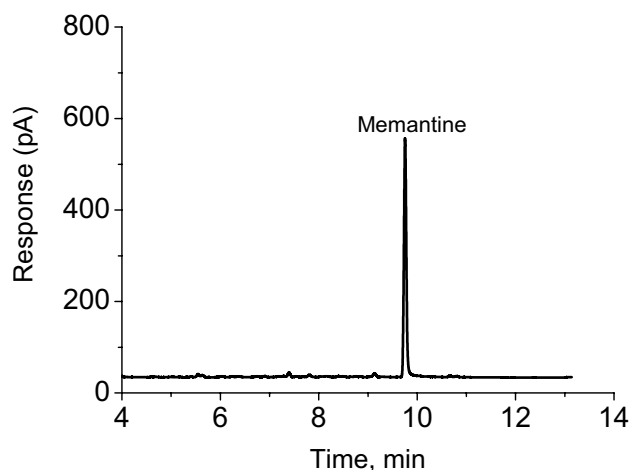
The potentiometric method was extended for determination of memantine in spiked human urine and tap water. Previous results showed that the execreted memantine concentration in urine is between 2 and 4 µg/mL (in time interval between 25 and 75 h) [7], which is suitable for potentiometrc quantification limit. The electrode was also employed for determination of memantine in spiked drinking tap water. The accuracy and precision are presented in Table 3.

4 Conclusion

A solid contact ion selective electrode with high surface area was investigated as a platform for stable potential ion selective electrodes for drug analysis. The internal solid contact was prepared by electrochemical deposition of Au layer onto a Pt microelectrode (500 µm diameter and 3 mm long). The SEM revealed that the Au layer is highly porous with a coral-like surface morphology that guarantees a high solid contact surface area. The electrochemical properties of the Au layer was

Table 3 Accuracy and precision of memantine all-solid-state ISE for determination of memantine in pharmaceutical dosage form, spiked human urine and tap water

	Taken µmg/mL	Found ± SD µmg/mL	Recovery %	RSD[a] %	Official method Recovery±%RSD[a]
MEM drug substance	4.32	4.24 ± 0.044	98.08	1.04	
	8.64	8.57 ± 0.053	99.19	0.62	
	12.96	12.85 ± 0.167	99.12	1.30	
	17.28	16.94 ± 0.226	98.06	1.33	
	21.6	21.35 ± 0.201	98.86	0.94	
Memantine tablet	4.32	4.20 ± 0.063	97.21	1.50	
	12.96	12.56 ± 0.159	96.93	1.26	
	21.6	20.69 ± 0.226	95.77	1.09	96.5±1.2
		t-test	1.26		
		F-ratio test	2.91		
Spiked human urine	12.96	12.32 ± 0.237	95.05	1.92	
	17.28	16.52 ± 0.239	95.58	1.44	
	21.6	20.39 ± 0.275	94.39	1.35	
Spike tap water	12.96	12.68 ± 0.225	97.86	1.77	
	17.28	16.87 ± 0.237	97.63	1.40	
	21.6	21.35 ± 0.201	98.86	0.94	

[a]Relative standard deviation (n = 5)

[b]Tabulated t-value for $P = 0.05$ and 5 degrees or freedom is 2.57

[c]Tabulated F-value for $n_1 = n_2 = 5$ is 5.05

Fig. 10 Typical GC chromatogram for separation of memantine

characterized by cyclic voltammetry, electrochemical impedance spectroscopy and reversal current chronopotentiometry. The results showed that Au/Pt solid contact electrode has large double layer capacitance, fast charge transfer and high potential stability compared to the bare Pt solid contact electrode. The electrode exhibited a Nernstian response of 58.5 ± 1 mV/decade over a wide concentration range of memantine with high potential reproducibility and selectivity for memantine. The electrode is small in size, portable and can be produced on a large scale using screen printed technology. The electrode was used for determination of memantine in pharmaceutical dosage form, spiked urine and tap water with high accuracy and precision.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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