Int. J. Electrochem. Sci., 12 **(2017)** 8868 – 8877, doi: 10.20964/2017.10.63

International Journal of ELECTROCHEMICAL SCIENCE
www.electrochemsci.org

Electrochemical Determination of Gliclazide on Magnetic Core-Shell Fe_3O_4@SiO_2 Functionalized Multiwall Carbon Nanotubes Modified Glassy Carbon Electrode

Mohammad Reza Ganjali[1,2,*], *Hadiseh Salimi*[3], *Somayeh Tajik*[4], *Hadi Beitollahi*[4,*], *Alireza Badiei*[5,6], *Ghodsi Mohammadi Ziarani*[7]

[1] Center of Excellence in Electrochemistry, School of Chemistry, College of Science, University of Tehran, Tehran, Iran
[2] Biosensor Research Center, Endocrinology & Metabolism Molecular-Cellular Sciences Institute, Tehran University of Medical Sciences, Tehran, Iran
[3] Department of Chemistry, Graduate University of Advanced Technology, Kerman, Iran
[4] Environment Department, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran
[5] School of Chemistry, College of Science, University of Tehran, Tehran, Iran
[6] Nanobiomedicine Center of Excellence, Nanoscience and Nanotechnology Research Center, University of Tehran, Tehran, Iran
[7] Department of Chemistry, Faculty of Science, Alzahra University, Tehran, Iran
[*]E-mail: ganjali@khayam.ut.ac.ir (MR Ganjali); h.beitollahi@yahoo.com (H. Beitollahi)

Received: 30 June 2017 / *Accepted:* 8 August 2017 / *Published:* 12 September 2017

The report covers the construction of a novel modified glassy carbon electrode (GCE), using magnetic core-shell Fe_3O_4@SiO_2 and multi-walled carbon nanotubes (MWCNTs). The resulting device was then tested as a tool for the sensitive and selective analysis of traces of gliclazide (GLZ). The effects of different parameters, i.e. pH of the test solution, and the scan rate applied during the electrochemical determination process on the performance of the resulting electrode were also assessed. The results obtained under the optimal conditions showed the response of the electrode to gliclazide to be linear over a rather wide range of 5.0×10^{-6} to 8.0×10^{-4} M, and a detection limit of as low as 2.1×10^{-6} M (pH=7.0). The proposed sensor was successfully applied for the determination of gliclazide in real samples.

Keywords: Gliclazide, Magnetic core-shell Fe_3O_4@SiO_2/MWCNT nanocomposite, Glassy carbon electrode, Voltammetry

1. INTRODUCTION

Diabetic peripheral neuropathy (DPN), one of the most common complications associated with diabetes, results in significant decreases in quality of life [1-3]. This complication of diabetes confers profound biochemical, morphological, functional, and structural changes upon the nerve tissues of both experimental animals and patients [4]. Although the precise mechanism underlying the onset of DPN remains unclear, abnormalities secondary to hyperglycemia have been reported to contribute to the development of DPN in experimental diabetes [5]. Excess glucose passively diffuses into nerve cells and is metabolized to sorbitol and other polyols via activated aldose reductase (AR). The accumulation of intracellular sorbitol and fructose increases osmotic stress and impairs Na^+, K^+-ATPase activity in nerve cells, and depletes these cells of protective factors [6]. Therefore, decreasing blood glucose levels, inhibiting polyol pathway activation, and enhancing antioxidant defense are logical therapeutic approaches for treating DPN.

A sulfonylurea antihyperglycemic agent, gliclazide (GLZ) is a common medicine for treating type 2 diabetes. The compound has also proven to be an antioxidant [7]. An ideal medicine for diabetes is expected to both control the levels of glucose and deal with the secondary effects of the disease. GLZ has been found to offer therapeutic effects for preventing such secondary complications as diabetic peripheral neuropathy. *In vivo* studies have proven that upon oral administration, the compound is fully absorbed by the body [8], yet at very slow and varied absorption rates most probably arising from due to its low and pH-dependent solubility in aqueous media. In the light of the above and given that GLZ has low solubility in water almost insoluble in water and has limited solubility in acetone, developing sensitive and specific analytical tools and methods for determining its concentration is very importance [9-11]. The available methods require rather complicated procedures, expensive instruments and are time-consuming [12-18].

Electroanalytical tools and techniques, on the other hand, present advantages like ease of use, high sensitivity and selectivity, reasonable cost, negligible background currents, wide applicable potential ranges, as well as, ease of fabrication and quickly renewable surfaces [19-29]. From the range of electrodes that can be used for electrochemical determinations, GCEs have proven to be stable and robust tools. GCEs have found widespread applications due to their excellent biocompatibility, negligible surface fouling, and rather low residual currents in wide potential windows. In electroanalytical techniques, the redox course of the analyte occurs at high over potential owing to the slow electron transfer rate at conventional electrodes [30-33]. Conventional GCEs, have however shown poor results when used for the determination of analytes, and hence their modification has become an interesting area of research. The results of many studies have shown that modification of the surface of the electrodes can lead to substantial diminishes in over potentials, as well as enhanced electron transfer rates [34-51].

Nanomaterials have been generally applied in fabrication electrochemical sensors or biosensors. Recently, carbon nanotubes (CNTs) because of the unique properties of such as antisurface fouling, high sensitivity, a large edge plane/basal plane ratio, high surface-to-volume ratio, high ability to promote electron transfer, good electrical conductivity, and high chemical stability and tubular structure have been extensively applied for the improvement of chemically modified electrodes [52-

57]. Currently, carbon nanotubes/metal oxides have been widely reported. Metal oxides are active and durable electrocatalysts for biosensors. Recently, magnetic iron oxide nanoparticles (MNPs) have received much attention due to their inherent properties such as large specific surface area and fast response under applied external magnetic field, their superparamagnety, high coercively and low Curie temperature [58-60]. In recent times, modified magnetic nanoparticles have been increasingly applied to as support for preparation of magnetic nanocatalyst. However, an inert silica (SiO_2) nanoparticle coating on the surface of MNPs prevents their aggregation, improves their chemical stability, and provides better protection against toxicity [61].

As mentioned above, developing the optimal tools and conditions for the determination of GLZ in biological fluids is of great importance and hence the current study was directed toward the application of a Fe_3O_4@SiO_2/MWCNT nanocomposite for modifying a GCE for use in the voltammetric determination of GLZ. The resulting sensor proved to possess good electrocatalytic tendencies towards GLZ, and offered enhanced selectivity and sensitivity, as well as reproducibility of the results. Evaluations on the analytical behavior of the modified electrode towards the analyte in real samples were also made and the results proved to be acceptable.

2. EXPERIMENTAL

2.1. Apparatus and chemicals

An Autolab PGSTAT 302N, Eco Chemie potentiostat/galvanostat was used for the analytical measurements and the General Purpose Electrochemical System (GPES) software was used for controlling the experimental conditions. A three-electrode setup was used at 25 ± 1 °C. An Ag/AgCl/KCl (3.0 M) electrode, a platinum wire, and the Fe_3O_4@SiO_2/MWCNT/GCE were used as the reference, auxiliary and working electrodes, respectively. A Metrohm 710 pH meter was employed for pH measurements. Fe_3O_4@SiO_2/MWCNT was synthesized in our laboratory.

Double distilled water was used to prepare the solutions prior to any experiment. Analytical grade samples of all reagents were procured from Merck Co. (Darmstadt, Germany). Orthophosphoric acid and its salts were used to prepare buffers with pH values in the range of 2.0-9.0.

2.2. Preparation of modified electrode

The bare glassy carbon electrode was coated with Fe_3O_4@SiO_2/MWCNT nanocomposite as follows. A stock solution of Fe_3O_4@SiO_2/MWCNT nanocomposite in 1 mL aqueous solution was prepared by dispersing 1 mg Fe_3O_4@SiO_2/MWCNT nanocomposite with ultrasonication for 1 h, and a 5 µl aliquot of the Fe_3O_4@SiO_2/MWCNT/H_2O suspension solution was casted on the carbon working electrodes, and waiting until the solvent was evaporated in room temperature.

2.3. Preparation of real samples

Five 10 mg GLZ tablets (Pursina Company, Iran) were grinded, and then 50 mg of the resulting powder was dissolved in 25 mL water under sonication. Next various quantities of the solution were

transferred to and diluted to the mark in a 25 mL flask, using a phosphate buffer solution (pH=7.0). The GLZ content was analyzed by the proposed method using the standard addition method.

The urine samples were stored in a refrigerator upon collection. Prior to use 10 mL of each sample was centrifuged at 2000 rpm for 15 min and using a 0.45 μM filter the supernatant was treated, before various quantities of it were transferred to a 25 mL flask and diluted using a PBS (pH=7.0). The so-prepared samples were eventually spiked with various amounts of GLZ.

3. RESULTS AND DISCUSSION

3.1. Electro-oxidation of GLZ at a Fe_3O_4@SiO_2/MWCNT/GCE

Since the behavior of GLZ in electrochemical reactions in aqueous media is a function of pH, and hence optimizing thus variable is critical step for obtaining the best electrocatalytic results. Consequently, the cyclic voltammograms of GLZ in different solutions diluted with 0.1 M PBS with various pH values in the range of 2.0-9.0 were obtained and studied using the Fe_3O_4@SiO_2/MWCNT/GCE. It was found that the electrocatalytic oxidation of GLZ at the surface of Fe_3O_4@SiO_2/MWCNT/GCE was more favored under neutral conditions than in acidic or basic medium. Thus, the pH 7.0 was chosen as the optimum pH for electrocatalysis of GLZ oxidation at the surface of Fe_3O_4@SiO_2/MWCNT/GCE.

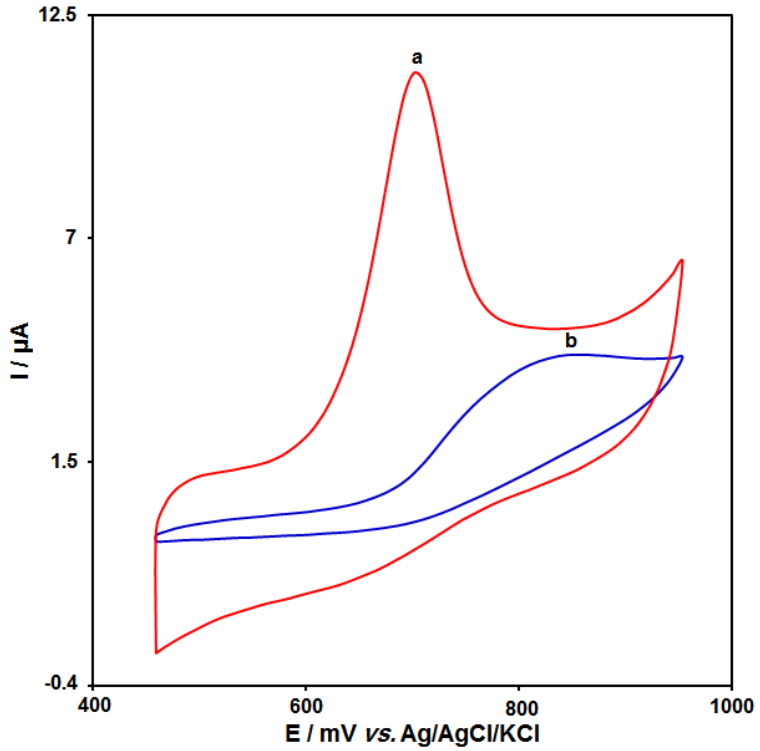

Figure 1. CVs of (a) Fe_3O_4@SiO_2/MWCNT/GCE and (b) bare GCE in 0.1 M PBS (pH 7.0) in the presence of 100.0 μM GLZ at the scan rate 50 mVs^{-1}.

Fig. 1 depict the cyclic voltammetric responses for the electrochemical oxidation of 100.0 μM GLZ at Fe_3O_4@SiO_2/MWCNT/GCE (curve a) and bare GCE (curve b). The anodic peak potential for the oxidation of GLZ at Fe_3O_4@SiO_2/MWCNT/GCE (curve a) is about 700 mV compared with 860 mV for that on the bare GCE (curve b). Similarly, when the oxidation of GLZ at the Fe_3O_4@SiO_2/MWCNT/GCE (curve a) and bare GCE (curve b) are compared, an extensive enhancement of the anodic peak current at Fe_3O_4@SiO_2/MWCNT/GCE relative to the value obtained at the bare GCE (curve b) is observed. In other words, the results clearly indicate that the Fe_3O_4@SiO_2/MWCNT nanocomposite improve the GLZ oxidation signal.

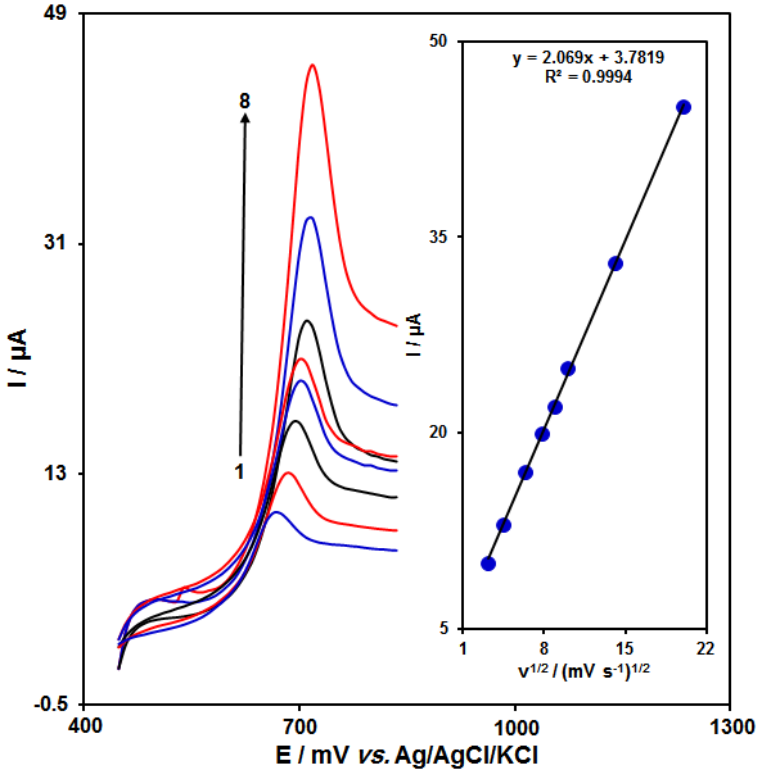

Figure 2. LSVs of Fe_3O_4@SiO_2/MWCNT/GCE in 0.1 M PBS (pH 7.0) containing 250.0 μM GLZ at various scan rates; numbers 1-8 correspond to 10, 20, 40, 60, 80, 100, 200 and 400 mV s^{-1}, respectively. Inset: Variation of anodic peak current vs. $v^{1/2}$.

The results obtained on the effect of the potential scan rates on the oxidation current of GLZ (Fig. 2) showed that upon increasing this parameter the peak current is enhanced. Based on the linear relationship between the anodic peak current (I_p) and the square root of the scan rate ($v^{1/2}$), which was the case from 10 to 400 mV s^{-1}, the oxidation process was concluded as being diffusion controlled [12, 14, 32, 62].

3.2. Chronoamperometric measurements

Chronoamperometric test using the developed electrode were performed at a working electrode potential of 0.8 V and using different GLZ in PBS (pH=7.0) solutions (Fig.3). Given that for an

electroactive material, the electrochemical current observed under mass transport limited conditions, is given by Cottrell's equation [60, 62].

$$I = nFAD^{1/2}C_b\pi^{-1/2}t^{-1/2} \quad (1)$$

where D and C_b are the diffusion coefficient ($cm^2\ s^{-1}$) and the bulk concentration (mol cm^{-3}), respectively. Experimental plots of I vs. $t^{-1/2}$ were employed, with the best fits for different concentrations of GLZ (Fig. 3A).

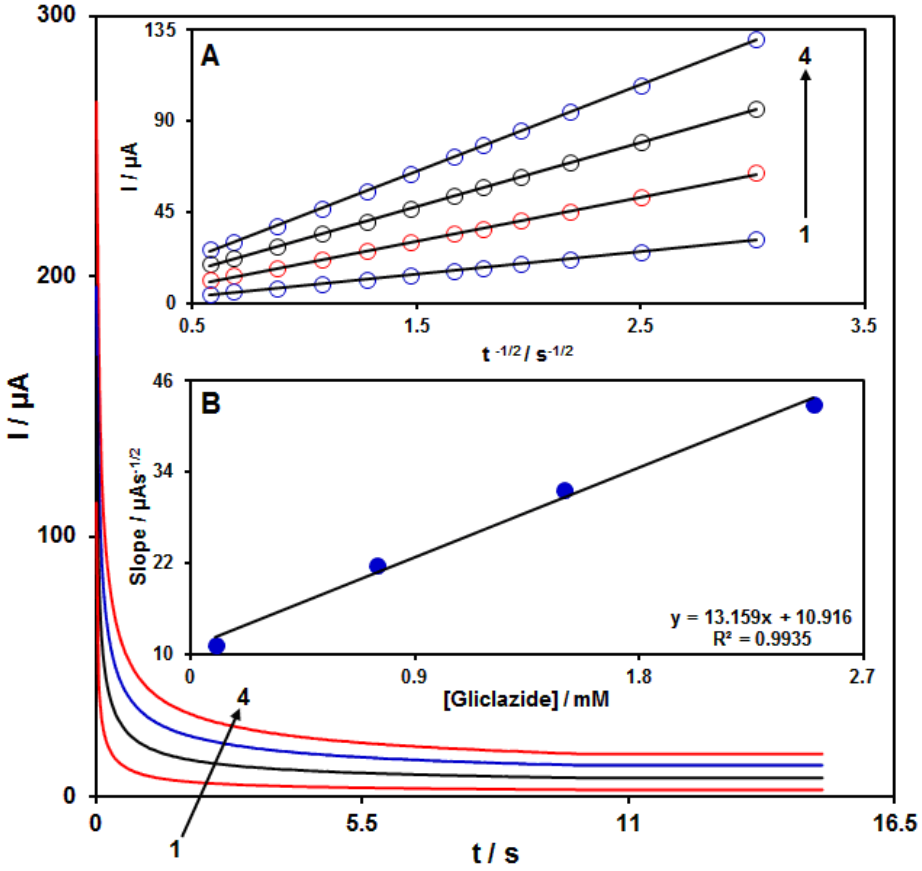

Figure 3. Chronoamperograms obtained at Fe_3O_4@SiO_2/MWCNT/GCE in 0.1 M PBS (pH 7.0) for different concentration of GLZ. The numbers 1–4 correspond to 0.1, 0.75, 1.5 and 2.5 mM of GLZ. Insets: (A) Plots of I vs. $t^{-1/2}$ obtained from chronoamperograms 1–4. (B) Plot of the slope of the straight lines against GLZ concentration.

The slopes of the resulting straight lines were then plotted vs. GLZ concentration (Fig. 3B). From the resulting slope and Cottrell equation [51, 52, 54] the mean value of the D was found to be 1.48×10^{-5} cm^2/s.

3.3. Calibration plot and limit of detection

The peak current of GLZ oxidation at the surface of the modified electrode can be used for determination of GLZ in solution. Therefore, differential pulse voltammetry (DPV) experiments were done for different concentrations of GLZ (Fig. 4). The oxidation peak currents of GLZ at the surface of

a modified electrode were proportional to the concentration of the GLZ within the ranges 5.0 to 800.0 µM. The detection limit (3σ) of GLZ was found to be 2.1×10^{-6} M. This values are comparable with values reported by other research groups for determination of GLZ by different methods (table 1).

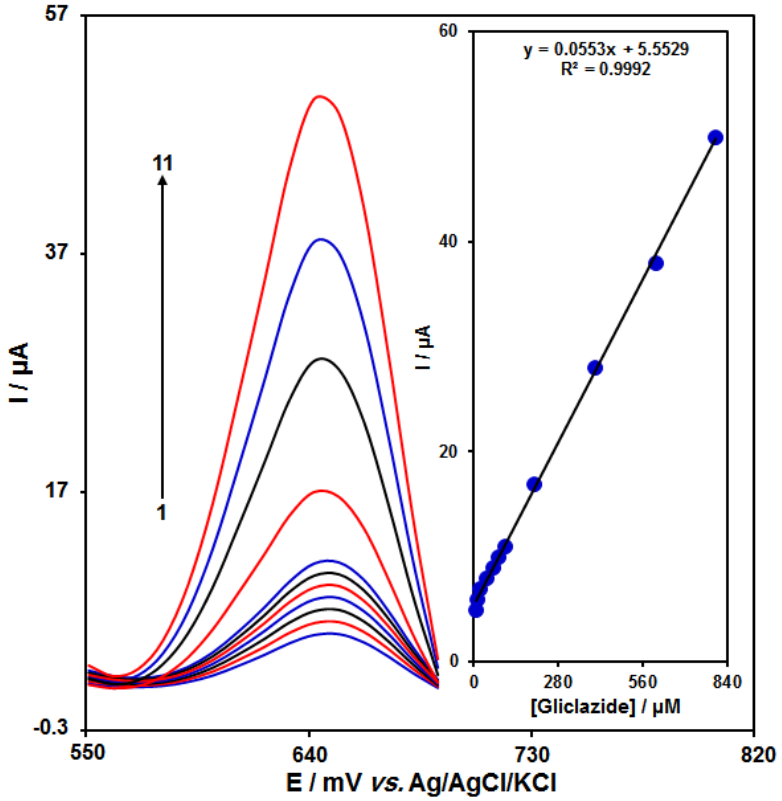

Figure 4. DPVs of Fe_3O_4@SiO_2/MWCNT/GCE in 0.1 M (pH 7.0) containing different concentrations of GLZ. Numbers 1–11 correspond to 5.0, 10.0, 20.0, 40.0, 60.0, 80.0, 100.0, 200.0, 400.0, 600.0 and 800.0 µM of GLZ. Inset: Plot of the electrocatalytic peak current as a function of GLZ concentration in the range of 5.0-800.0 µM.

Table 1. Comparison of the efficiency of some methods used in detection of GLZ.

Method	LOD	LDR	Ref.
Micellar electrokinetic chromatography	40 µg/ml	128-192 µg/ml	[63]
Liquid chromatographic	4.5 ng/ml	20-750 ng/ml	[64]
Asymmetric membrane capsule	0.12 µg/ml	0.12-12 µg/ml	[65]
Spectrophotometric	0.05 µg/ml	0.5-4 µg/ml	[66]
Voltammetry	-	1.0×10^{-5}- 5.0×10^{-5} M	[67]
Voltammetry	1.2×10^{-11} nM	5.0×10^{-11}- 4.0×10^{-10} M	[68]
Voltammetry	2.1×10^{-6} M	5.0×10^{-6}- 8.0×10^{-4} M	This work

3.4. Analysis of real samples

To ascertain if the method based on using the developed electrode can be confidently used for the determination of GLZ content of pharmaceutical and urine samples, studies were performed and the results are presented in table 2, which show that the recovery of GLZ has been acceptable. The reproducibility of the method was demonstrated by the mean relative standard deviation (R.S.D.).

Table 2. The application of Fe_3O_4@SiO_2/MWCNT/GCE for determination of GLZ in GLZ tablets and urine samples (n=5). All concentrations are in µM.

Sample	Spiked	Found	Recovery (%)	R.S.D. (%)
Gliclazide tablet	0	10.0	-	3.5
	2.5	12.2	97.6	1.7
	5.0	15.3	102.0	2.9
	7.5	17.4	99.4	2.4
	10.0	20.3	101.5	2.6
Urine	-	-	-	-
	5.0	4.9	98.0	1.6
	15.0	15.5	103.3	2.7
	25.0	25.2	100.8	3.5
	35.0	34.8	99.4	2.4

4. CONCLUSIONS

A sensitive and selective modified GCE was developed for the analysis of GLZ. The modification was performed using a nanocomposite of MWCNTs and magnetic core-shell Fe_3O_4@SiO_2 (Fe_3O_4@SiO_2/MWCNTs/GCE). The results obtained clearly show that the combination of MWCNTs and magnetic core-shell Fe_3O_4@SiO_2 definitely improves the sensitivity of modified electrode to GLZ determination. The high sensitivity of GLZ could be attributed to the excellent electrocatalytic activity of magnetic core-shell Fe_3O_4@SiO_2, large specific surface area of the multiwalled carbon nanotubes, and good conductivity of the nanocomposite. The differential pulse voltammetric response of the electrode to GLZ was linear in the range 5.0–800.0 µM with a detection limit of 2.1 µM under the optimum conditions.

ACKNOWLEDGEMENT
The authors are grateful to the Research Council of University of Tehran for the financial support of this work.

References

1. S.K. Bajpai, N. Chand, S. Tiwari, and S. Soni, *Int. J. Biol. Macromol.* 93 (2016) 978.
2. H. Yao, J. Feng, Q. Zheng, Y. Wei, S. Wang, and W. Feng, *Life Sci.* 161 (2016) 60.
3. S.P. Chan, and S. Colagiuri, *Diabetes Res. Clin. Prac.* 110 (2015) 75.
4. K.K. Clemens, E. McArthur, S.N. Dixon, J.L. Fleet, I. Hramiak, and A.X. Garg, *Can. J. Diabetes* 39 (2015) 32.
5. K.L. Farmer, C. Li, and R.T. Dobrowsky, *Pharmacol. Rev.* 64 (2012) 880.
6. Z.J. Ma, R. Chen, and H.Z. Ren, *Meta Gene.* 2 (014) 50.
7. L. Rochette, M. Zeller, and Y. Cottin, *Biochim. Biophys. Acta* 1840 (2014) 2709.
8. M. Karakaya, M. Kurekci, B. Eskiyurt, Y. Sert, and C. Cirak, *Spectrochim. Acta A* 135 (2015) 137.
9. V. K. Sharma, and B. Mazumdar, *Acta Pol. Pharm.* 71 (2014) 153.
10. J.W. Albers, and R. Pop-Busui, *Curr. Neurol. Neurosci. Rep.* 14 (2014) 473.
11. L. Maggi, A. Canobbio, G. Bruni, G. Musitelli, and U. Conte, *J. Drug Deliv. Sci. Technol.* 26 (2015) 17.
12. S. Tajik, M.A. Taher, and H. Beitollahi, *Sens. Actuators B* 197(2014) 228.
13. H. Zhang, J. Zhang, and J. Zheng, *Measurement* 59 (2015) 177.
14. S. Mohammadi, H. Beitollahi and A. Mohadesi, *Sens. Lett.,* 11(2013) 388.
15. H. Filik, G. Cetintas, S.N. Koc, H. Gulce, and I. Boz, *Russ. J. Electrochem.* 50 (2014) 243.
16. Z. Taleat, M. Mazloum Ardakani, H. Naeimi, H. Beitollahi, M. Nejati, and H.R. Zare, *Anal. Sci.* 24 (2008) 1039.
17. L. Yang, H. Li, H. Liu, and Y. Zhang, *Int. J. Electrochem. Sci.* 12 (2017) 1.
18. H. Beitollahi and I. Sheikhshoaie, *Int. J. Electrochem. Sci.,* 7 (2012) 7684.
19. H. Sun, S. Zhao, and F. Qu, *Measurement* 45 (2012) 1111.
20. M. Mazloum-Ardakani, H. Beitollahi, B. Ganjipour, and H. Naeimi, *Int. J. Electrochem. Sci.,* 5(2010) 531.
21. V. Mani, M. Govindasamy, S.M. Chen, B. Subramani, A. Sathiyan, and J.P. Merlin, *Int. J. Electrochem. Sci.* 12 (2017) 258.
22. P. Norouzi, M. R. Ganjali, and P. Matloobi, *Electrochem. Commun.* 7 (2005) 333.
23. X.P. Hong, and J.Y. Ma, *Chin.Chem. Lett.* 24 (2013) 329.
24. P. Norouzi, M. R. Ganjali, and L. Hajiaghababaei, *Anal. Lett.* 39 (2006) 1941.
25. K. Movlaee, M.R. Ganjali, M. Aghazadeh, H. Beitollahi, M. Hosseini, S. Shahabi, and P. Norouzi, *Int. J. Electrochem. Sci.* 12 (2017) 305.
26. M.R. Majidi, R.F. Baj, and M. Bamorowat, *Measurement* 93 (2016) 29-35.
27. H. Karimi-Maleh, A.A. Ensafi, H. Beitollahi, M.A. Khalilzadeh, and P. Biparva, *Ionics* 18 (2012) 687.
28. M. Hasheminejad, and A. Nezamzadeh-Ejhieh, *Food Chem.* 172 (2015) 794.
29. T. Alizadeh, M.R. Ganjali, M. Akhoundian, and P. Norouzi, *Microchim. Acta* 183 (2016) 1123.
30. M.R. Akhgar, H. Beitollahi, M.Salari, H. Karimi-Maleh, and H. Zamani, *Anal. Methods* 4 (2012) 259.
31. H. Karimi-Maleh, A.A. Ensafi, and A.R. Allafchian, *J. Solid State Electrochem.* 14 (2010) 9.
32. H. Beitollahi, A. Gholami and M.R. Ganjali, *Mater. Sci. Engin. C* 57 (2015) 107.
33. H. Beitollahi, S. Tajik and P. Biparva, *Measurement,* 56 (2014) 170.
34. P. Norouzi, M. R. Ganjali, A. Sepehri, and M. Ghorbani, *Sens. Actuators B* 110 (2005) 239.
35. P. Norouzi, V. K. Gupta, B. Larijani, S. Rasoolipour, F. Faridbod and M. R. Ganjali, *Talanta* 131, (2015) 577.
36. P. Norouzi, M.R. Ganjali, T. Alizadeh, and P. Daneshgar, *Electroanalysis* 18 (2006) 947.
37. H. Karimi-Maleh, F. Tahernejad-Javazmi, V.K. Gupta, H. Ahmar, M.H. Asadi, *J. Mol. Liq.* 196 (2014) 258.

38. S. Jafari, F. Faridbod, P. Norouzi, A. S. Dezfuli, D. Ajloo, F. Mohammadipanah and M. R. Ganjali, *Anal. Chim. Acta* 895 (2015) 80.
39. P. Norouzi, B. Larijani, F. Faridbod, and M.R. Ganjali, *Int. J. Electrochem. Sci.* 5 (2010) 1550.
40. J. T. Mehrabad, M. Aghazadeh, M. R. Ganjali, P. Norouzi, *Mater. Lett.* 184 (2016) 223.
41. I Karimzadeh, M Aghazadeh, T Dourudi, M. R. Ganjali, and P. H. Kolivand *Curr. Nanoscience* 13 (2017) 167.
42. M. Aghazadeh, M. G. Maragheh, M. R. Ganjali, and P. Norouzi, *Inorganic and Nano-Metal Chemistry* 27 (2017) 1085.
43. H. Karimi-Maleh, M.R. Ganjali, P. Norouzi, A. Bananezhad, *Mater. Sci. Eng. C*, 73 (2017) 472.
44. P. Norouzi, H. Haji-Hashemi, B. Larijani, M. Aghazadeh, E. Pourbasheer and M. R. Ganjali, *Curr. Anal. Chem.* 13 (2017) 70.
45. P. Norouzi, B. Larijani, M. R. Ganjali and F. Faridbod, *Int. J. Electrochem. Sci.* 9 (2014) 3130.
46. P. Norouzi, B. Larijani, F. Faridbod and M. R. Ganjali, *Int. J. Electrochem. Sci.* 8 (2013) 6118.
47. M. Aghazadeh, I. Karimzadeh, M. R. Ganjali, M. M. Morad, *Mater. Lett.* 196 (2017) 392.
48. V.K. Gupta, P. Norouzi, H. Ganjali, F. Faridbod, and M.R. Ganjali, *Electrochim. Acta* 100 (2013) 29.
49. P. Norouzi, P., B. Larijani, M. Ganjali, and F. Faridbod, *Int. J. Electrochem. Sci*. 7 (2012) 10414.
50. I. Karimzadeh, M. Aghazadeh, M. R. Ganjali, P. Norouzi, and T. Doroudi, *Mater. Lett*. 189 (2017) 290.
51. H. KarimiMaleh, M. Keyvanfard, K. Alizad, M. Fouladgar, H. Beitollahi, A. Mokhtari, and F. Gholami-Orimi, *Int. J. Electrochem. Sci.* 6 (2011) 6141.
52. M. MazloumArdakani, B. Ganjipour, H. Beitollahi, M.K. Amini, F. Mirkhalaf, H. Naeimi, and M. Nejati-Barzoki, *Electrochim. Acta* 56 (2011) 9113.
53. D. Hedman, and J. Andreas Larsson, *Carbon* 116 (2017) 443.
54. H. Beitollahi, M.A. Taher, M. Ahmadipour and R. Hosseinzadeh, *Measurement*, 47 (2014) 770.
55. N. George, P.K. Bipinbal, B. Bhadran, A. Mathiazhagan, and R. Joseph, *Polymer* 112 (2017) 264.
56. H. Karimi-Maleh, A.A. Ensafi, H. Beitollahi, V. Nasiri, M.A. Khalilzadeh, and P. Biparva, *Ionics* 18 (2012) 687.
57. N. Sciortino, S. Fedeli, P. Paoli, A. Brandi, P. Chiarugi, M. Severi, and S. Cicchi, *Int. J. Pharm.* 521 (2017) 69.
58. H. Tan, K. Huang, Y. Bao, Y. Li, and J. Zhong, *J. Alloys Compd.* 699 (2017) 812.
59. J. Xu, Z. Cao, X. Liu, H. Zhao, X. Xiao, J. Wu, X. Xu, and J.L. Zhou, *J. Hazard. Mater.* 317 (2016) 656.
60. Sh. Jahani, and H. Beitollahi, *Anal. Bioanal. Electrochem.* 8 (2016) 158.
61. L. Zhou, S. Pan, X. Chen, Y. Zhao, B. Zou, and M. Jin, *Chem. Eng. J.* 257 (2014) 10.
62. A.J. Bard, and L.R. Faulkner, Electrochemical Methods Fundamentals and Applications, 2001, second ed, (Wiley, New York).
63. A. Doomkaew, B. Prutthiwanasan, and L. Suntornsuk, *J. Pharm. Biomed. Anal.* 102 (2015) 119.
64. S. AbuRuz, J. Millership, and J. McElnay, *J. Chromatography B* 817 (2005) 277.
65. Y. Yang, Z. Zhao, Y. Wang, L. Yang, D. Liu, X. Yang, and W. Pan, *Int. J. Pharm.* 506 (2016) 340.
66. N. El-Enany, *I. Farmaco* 59 (2004) 63.
67. A.E. Radi, and S. Eissa, *Electroanalysis* 22 (2010) 2991.
68. H. Hrichi, Mo. Radhouan Louhaichi, L. Monser, and N. Adhoum, *Sens. Actuators B* 204 (2014) 42.