e-ISSN: 2687-6698 **Research Article**

Turkish Journal of Analytical Chemistry
www.turkjac.org
2019
TurkJAC

Electrochemical determination of antiviral drug Famciclovir in human serum samples at boron-doped diamond electrode

Çiğdem Kanbeş Dindar[1]*

[1] Ankara University, Faculty of Pharmacy, Department of Analytical Chemistry, Ankara, 06560, Türkiye

Abstract

A new electrochemical method using differential pulse voltammetry at a boron-doped diamond electrode (BDDE) was developed for the quantitative determination of famciclovir in the pH range of 2.0–10.0. The experimental results from the pH and scan rate studies showed that the oxidation behavior of famciclovir at BDDE was irreversible and diffusion-controlled. The anodic peak current was also observed to be linear over the concentration range of 0.5–12 μM and 6–100 μM in pH 4.7 acetate buffer solution (ABS) for standard drug solution and human serum, respectively, as obtained using the differential pulse voltammetry (DPV) at BDDE. Limits of detection were found as 0.022 μM and 0.42 μM for standard drug solution and human serum, respectively. The repeatability, reproducibility, selectivity, precision, and accuracy of the developed method in all media were investigated and calculated. This method was successfully applied for the analysis of famciclovir in human serum samples.

Keywords: Boron-doped diamond electrode, differential pulse voltammetry, Famciclovir, human serum samples

1. Introduction

Nucleoside analogs are a pharmacological classes of compounds with cytotoxic, immunosuppressive, and antiviral properties [1]. Thus, nucleoside analogs can be used as therapeutic drugs, including several antiviral products used to inhibit viral replication in infected cells. In addition to these, drug resistance can develop rapidly in a short time as a result of a mutation during the treatment of various viruses [2]. To overcome the resistance that develops against one of the nucleoside analog drugs, a new drug (e.g., famciclovir, penciclovir, and valaciclovir) from the same drug group is employed throughout treatment. Famciclovir (Fig. 1) is an antiviral drug that distinguishes out among nucleoside analog treatments due to its low toxicity and high selectivity [3]. Famciclovir is also a penciclovir prodrug with increased oral bioavailability of approximately 77% [4]. It is used to treat the symptoms of herpes zoster (commonly known as shingles), a herpes virus infection of the skin, and recurrent herpes virus infections of the mucous membranes (lips and mouth) [5]. Famciclovir's structure and mechanism of activity are quite similar to other nucleoside analogs, such as the more widely used acyclovir.

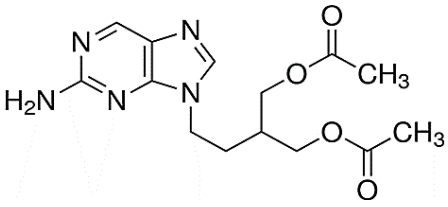

Figure 1. Chemical structure of famciclovir

Electrochemical techniques have been proved to be excellent procedures for monitoring organic compounds in pharmaceutical forms and biological samples [6]. In these techniques, the quantitative analysis method is developed by taking advantage of the fact that many active compounds in dosage forms can be easily oxidized or reduced unlike excipients [7]. The interest in experimental electrochemical techniques in the field of drug detection is due to their relatively short analysis time, simplicity, and low cost compared to other techniques [8].

While developing a new electrochemical-based analytical method in drug detection, studies were performed by modifying carbon electrodes with various nanomaterials such as metal/metal oxide [9], metal-

Citation: Ç. Kanbeş Dindar, Electrochemical determination of antiviral drug Famciclovir in human serum samples at boron-doped diamond electrode, Turk J Anal Chem, 4(1), 2022, 37–43.

https://doi.org/10.51435/turkjac.1105730

***Author of correspondence:** ckdindar@ankara.edu.tr
Tel: + 90 (312) 203 31 81
Fax + 90 (312) 213 10 81
Received: April 19, 2022
Accepted: June 14, 2022

organic framework [10,11], polymer [12], graphene [9,13], carbon nanotube [14], carbon fiber [15], and fullerene [16] are the most current research topics. Nevertheless, due to the use of extra chemical materials in both the synthesis and modification stages of these materials, the development of electrochemical methods using modified electrodes is far from the development of green analytical chemistry methods that will contribute to the reduction of the human footprint on Earth [17]. Moreover, obtaining the same modified surface, creating stable surfaces for a long time, and acquiring low reproducible results are the biggest difficulties encountered in the use of modified electrodes.

Due to their inherent high thermal conductivity, chemical inertness, and wide electrochemical potential range, boron–doped diamond electrodes (BDDE) outperform other carbon-based electrodes such as glassy carbon and carbon paste [18–21]. As a result, a method with a low limit of detection (LOD) might be developed and used in drug analysis without the requirement for costly and time-consuming modifications to improve sensitivity [22–26].

In the literature, there are only a few analytical methods used for determining famciclovir such as RP-HPLC [27–31], UPLC-MS/MS [31,32], UV-VIS spectroscopy [33,34], MIP-voltammetry [35], potentiometry [36], and spectrofluorimetry [37,38] from pharmaceutical preparations. When the sensitivity of the method developed in this study was compared to the voltammetric approach as previously described using carbon paste electrode (CPE), the suggested study has provided the lower LOD values [35]. Furthermore, the proposed novel method's sample and electrode preparation procedure are simpler, more practical, and less expensive. Moreover, although the previously described method was utilized for the analysis of pharmacological forms, this work showed that it could also be performed with human serum samples. Therefore, this study aims to propose the development of an electrochemical method for famciclovir quantification in human serum samples using the differential pulse voltammetric method at BDDE. The electrochemical behavior of the drug was also investigated at BBDE using cyclic voltammetry (CV) and DPV techniques in terms of buffer solution and pH. Moreover, the change of the electrochemical behavior depending on the scan rate was examined. The proposed method could be an eco-friendly alternative to chromatographic techniques in therapeutic drug monitoring without any time-consuming evaporation, adsorption, extraction, and separation steps before drug assay.

2. Experimental

2.1. Apparatus

All the electrochemical measurements were carried out with an AUTOLAB 204 PGSTAT electrochemical analyzer (Eco Chemie, Utrecht, The Netherlands), equipped with a three-electrode system that included the Ag/AgCl (BAS, 3 M NaCl) reference electrode, the BDDE (Windsor Scientific Ltd.; 3 mm diameter) working electrode, and the platinum wire auxiliary electrode. The clean electrode surface was obtained using alumina powder and a polishing cloth before each measurement. Cyclic voltammetry (CV) and differential pulse voltammetry (DPV) were employed for investigating the oxidation behavior of famciclovir. The parameters of step potential: 10 mV; modulation amplitude: 50 mV; modulation time: 50 ms; interval time: 500 ms were chosen for the measurement of famciclovir with DPV.

2.2. Chemicals

Famciclovir was kindly supplied by Neutec Drug A.S., (Istanbul, Turkey). The stock solution of 1×10^{-2} M famciclovir was prepared in double-distilled water. H_2SO_4 solutions (0.1 M and 0.5 M) and Britton-Robinson (BR) buffer solutions were prepared using H_3BO_4, CH_3COOH, and H_3PO_4 (0.04 M, pH 2.0–10.0), phosphate buffer solutions were prepared using K_2HPO_4 and KH_2PO_4 (PBS, 0.1 M, pH 2.0, 3.0, 5.0, 6.0, 7.0, 8.0), and acetate buffer solutions were prepared using CH_3COOH and $CH_3COONa.3H_2O$ (ABS, 0.1 M, pH 3.7, 4.7, 5.7), which were preferred as supporting electrolytes and prepared in distilled water. Synthetic human serum samples were purchased from Sigma-Aldrich. Required solutions were prepared with high-purity chemicals.

2.3. Analysis of human serum samples

Human serum samples were stored frozen till analysis in a -20 °C refrigerator. 1.0 mL of famciclovir from the stock solution (1.0×10^{-2} M), 3.6 mL of serum, and 5.4 mL of acetonitrile were added to the test tube for precipitating the protein to obtain the 1.0×10^{-3} M standard serum solution. To eliminate protein residue, tubes were sonicated for 15 minutes and then centrifuged at 5000 rpm for 20 minutes. For electrochemical experiments, the supernatant was prepared in a selected buffer and then added to the cell. Within a given concentration range, a calibration plot was obtained. The serum recovery test was performed using the standard addition method and repeating the procedure at least five times from the point on the calibration chart with the best reproducibility.

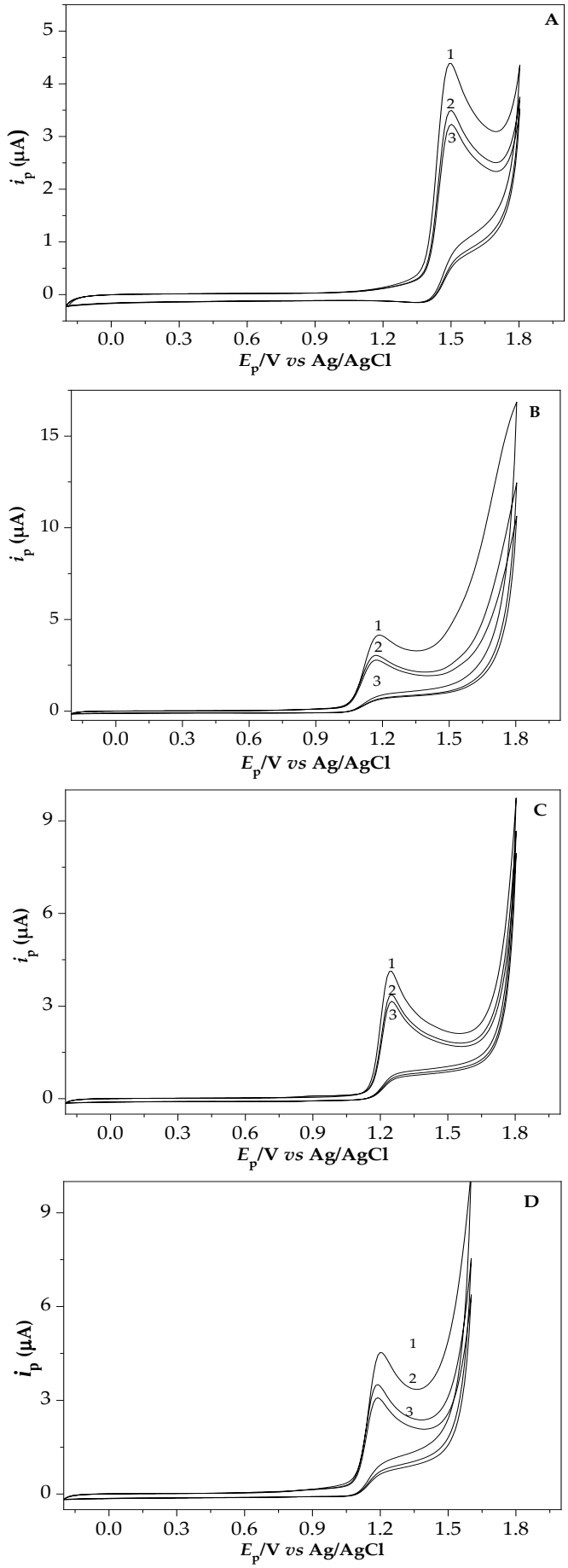

Figure 2. Repetitive cyclic voltammograms of 1.0 × 10⁻⁴ M famciclovir solutions in (a) 0.1 M H_2SO_4; (b) pH 8.0 BR buffer solution; (c) pH 4.7 ABS (d) pH 7.0 PBS, as obtained at a scan rate of 100 mVs^{-1}.

3. Results and discussion

3.1. Electrochemical behavior of famciclovir on the BDDE

Experiments were carried out using CV and DPV to study the redox process of famciclovir on the BDDE surface.

In order to determine the anodic oxidation behavior of famciclovir, repetitive cyclic voltammograms of 1.0 × 10⁻⁴ M famciclovir solutions in (a) 0.1 M H_2SO_4; (b) pH 8.0 BR buffer solution; (c) pH 4.7 ABS (d) pH 7.0 PBS were obtained at a scan rate of 100 mVs^{-1} (Fig. 2). Famciclovir exhibited a single well–defined oxidation peak for anodic direction while no peak was obtained for cathodic direction in all electrolyte mediums, which proved the irreversible oxidation reaction on BDDE. Moreover, as depicted in Fig. 2, when the intensity of the peaks obtained as a result of the scans was examined, it was found that the intensity of the peaks in the first scan was higher compared to other scans, and electrode surface contamination may be the reason for the decrease in the peak density.

Since the best peak shape and highest current were obtained in pH 4.7 AB solution, scanning rate studies and quantification of the drug analysis were carried out in this buffer solution. To evaluate whether the surface interaction mechanism is under the control of diffusion or adsorption or both, scan rate studies were carried out by CV using 1.0 × 10⁻⁴ M famciclovir in pH 4.7 ABS buffer solution in the scan rate range of 5–1000 mVs^{-1} (Fig.3). Linear response for the BDDE was found with the square root of the scan rate as follows:

$$I_P(\mu A) = 0.31 v^{\frac{1}{2}}(mVs^{-1}) + 0.018 \; (r = 0.997) \qquad (1)$$

For BDDE, a plot of the logarithm of the peak current versus the logarithm of the scan rate revealed a linear line with a slope of 0.47. The obtained value of the slope is close to the theoretical value of 0.5, which is assumed the diffusion-controlled process for an ideal reaction of solution species. The equation found in experimental data was;

$$log I_P(\mu A) = 0.48 \; log v \; (mVs^{-1}) - 0.464 \; (r = 0.996) \qquad (2)$$

Considering the change in scan rate values from 5 mV/s to 1000 mV/s, it was observed that there was a 60-mV shift towards positive potential values related to the irreversibility of the electrode reaction.

In the pH range of 2.0–10.0, changes in the graph of pH values against the measured current values (Fig. 4A) and the potential values of the anodic oxidation peak (Fig. 4B) were indicated.

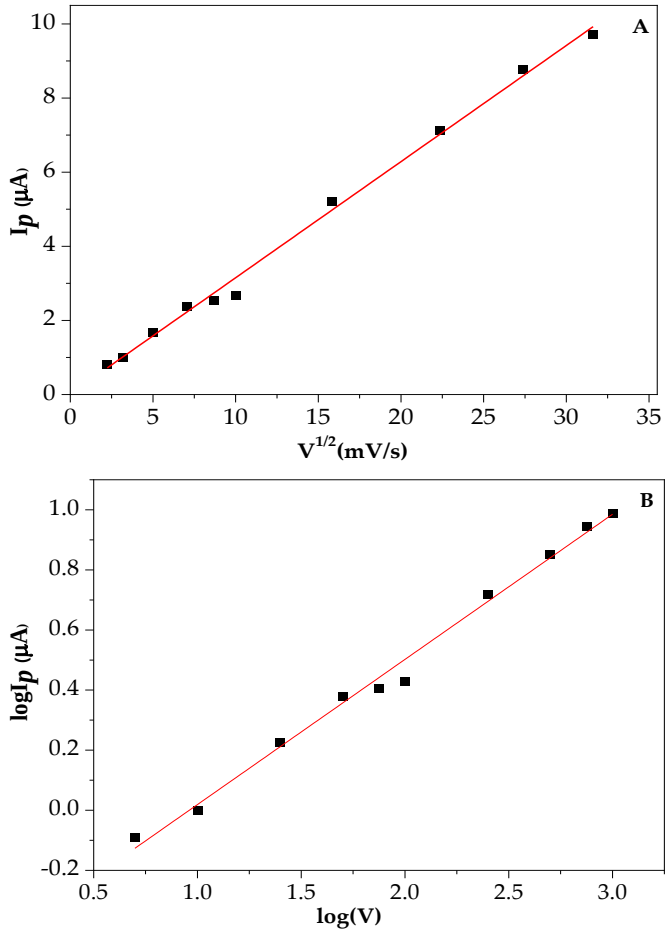

Figure 3. I_P *vs* $v^{1/2}$ (A) and log I_P *vs* log v (B) graphs of 1.0 × 10⁻⁴ M famciclovir in pH 4.7 ABS obtained in the range of 5–1000 mV/s

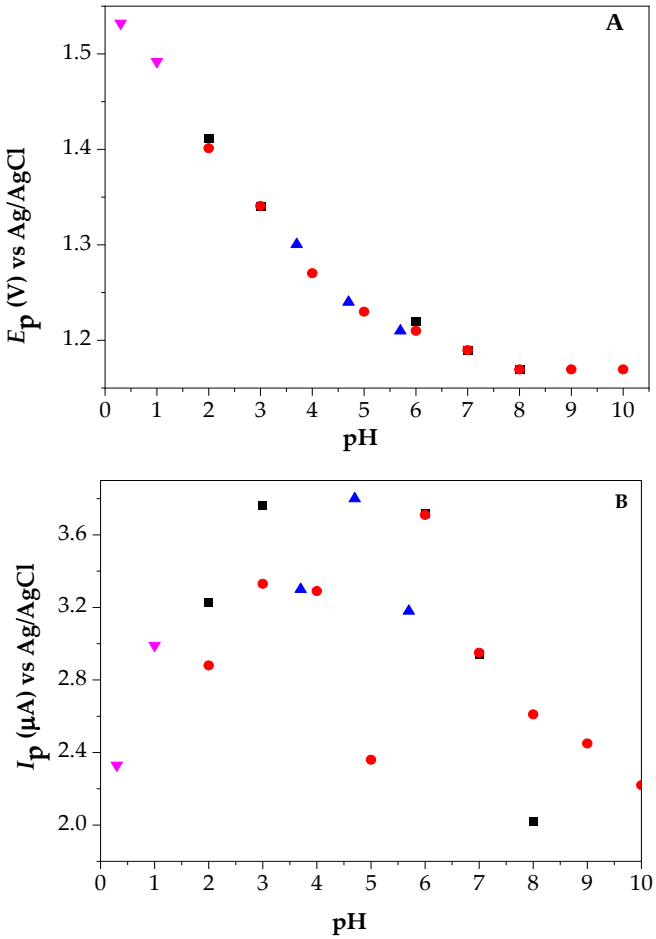

Figure 4. Effects of the pH on the famciclovir peak potential (A) and peak current (B) in different supporting electrolytes, (●) Britton–Robinson buffer; (▲) phosphate buffer; (■) acetate buffer; (▼) H_2SO_4 solutions (0.1 M and 0.5 M). These experiments were performed using DPV with the famciclovir concentration of 1 × 10⁻⁴ M

When the peak heights were obtained in different pH solutions, it was seen that the values obtained in pH 3.0 PBS, pH 4.7 ABS, pH 6.0 PBS, and pH 6.0 BR buffer solutions were very close to each other. However, the peak obtained in pH 4.7 ABS was slightly higher but has more reproducible values. The peak potential value of pH 4.7 was also found lower than other pH values, which indicated that famciclovir oxidizes more easily at this pH medium. Thus, pH 4.7 ABS was used as working pH in further studies. The peak potential of famciclovir seems to be pH-independent between pH 8.0 and 10.0 means that there are no proton transfer steps before the electron transfer rate-determining step. Furthermore, the plot of the peak potential (E_P) vs. pH gave two straight lines (Fig. 4A). The first linear line of Ep vs pH 2.0 to 5.0 was observed to be linear with a slope indicating that the electrochemical reaction contained an equivalent number of protons and electrons. On the other hand, the slope of the change in drug peak potential between pH 5.0–8.0 indicates that the number of protons in the electrochemical reaction is half the number of electrons. In addition, the intersection point of Ep-pH lines was found to be around 5, and this value was determined to be compatible with the monograph pKa value of the drug [39].

$$E_P(mV) = -64.3\,pH + 1535.8; \quad r = 0.9960\ (pH\ 2.0 - 5.00\ with\ DPV) \tag{3}$$

$$E_P(mV) = -22.3\,pH + 1348.5; \quad r = 0.9914\ (\text{pH } 5.00 - 8.00 \text{ with DPV}) \tag{4}$$

3.2. Analytical performance parameters

To evaluate the analytical performance of the developed method, parameters such as specificity, linearity, linear dynamic range (LDR), precision, accuracy, the limit of detection (LOD), and limit of quantification (LOQ) were calculated under optimized conditions. Thus, the linear relationship between changing the drug molecule concentration and the measured current value was used to determine these parameters. The experiments were carried out in pH 4.7 ABS, where the best peak symmetry and the highest peak current were obtained. The linearity was achieved in the concentration range of 0.5–12 µM (Fig. 5). The following was the related equation between peak current and concentration:

$$i_p\,(\mu A) = 0.045\ C\,(\mu M) - 0.00894\ (n{:}\,10,\ r = 0.9987) \tag{5}$$

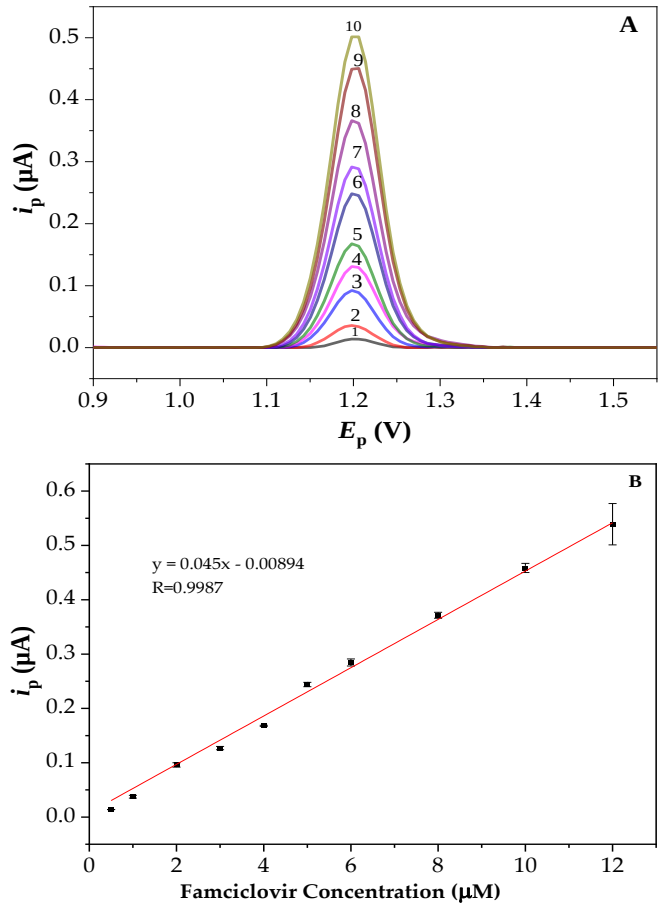

Figure 5. Calibration curve of DP voltammograms for famciclovir (standard solution) in different concentration ranges from 0.5 µM to 12 µM (A) and calibration curve of standard famciclovir (B) in pH 4.7 ABS

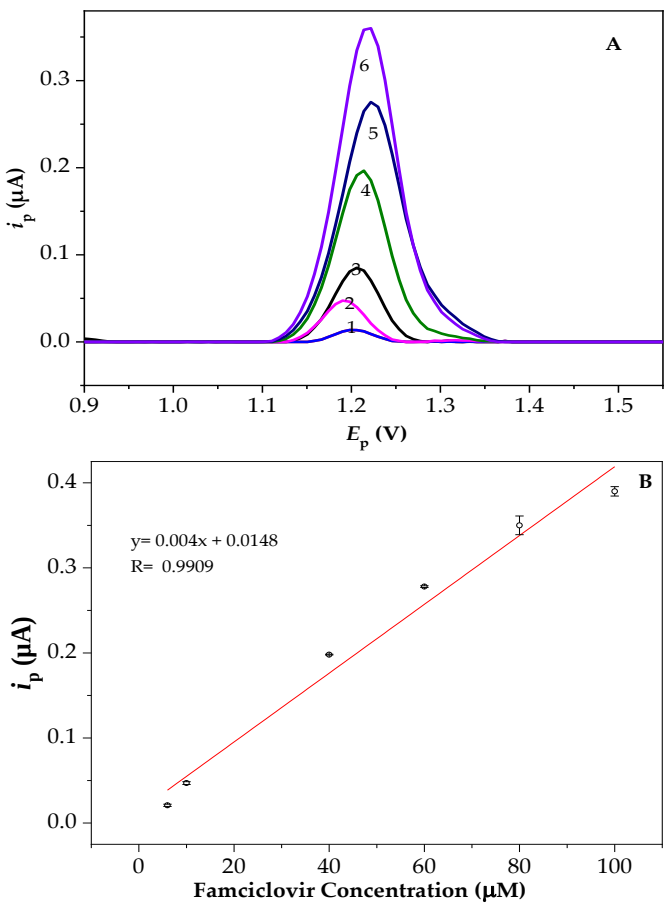

Figure 6. DP voltammograms of serum samples in different concentration ranges from 6 µM to 100 µM (A) and calibration curve of serum samples (B) in pH 4.7 ABS

Statistical data of the calibration are given in Table 1. Repeated measurements of the famciclovir peak potential and peak current within and between days illustrate the developed method's precision. The formulas of 3 s/m and 10 s/m were used to determine the LOD and LOQ values, where "s" represents the standard deviation of the response and "m" indicates the slope of the calibration curve. The LOD and LOQ values (Table 1) indicated the sensitivity of the method. The performance of the developed method is also compared with the previous analytical methods.

As can be seen from Table 2, the developed method is the most superior in terms of sensitivity while most other methods include time-consuming sample preparation, high consumption of harmful solvents, and expensive equipment.

Table 1. Correlation data for famciclovir calibration was produced using DPV at BDDE from standard solution and serum samples

Parameters	Standard	Serum
Anodic potential (mV)	1206	1210
Linearity dynamic range (µM)	0.5–12	6–100
Slope (µA M^{-1})	0.045	0.004
Intercept (µA)	–0.00894	0.0148
Correlation coefficient (*r*)	0.9987	0.9909
LOD (µM)	0.022	0.42
LOQ (µM)	0.066	1.38
Intra-day precision of peak current (RSD%)*	1.51	1.09
Inter-day precision of peak current (RSD%)*	1.63	2.36

* Each value is the mean of five experiments

3.3. Determination of famciclovir in spiked biological samples

Drug detection from serum samples is a time-consuming process that necessitates the use of expensive organic solvents and other reagents. To demonstrate the applicability of the proposed techniques to human serum samples, the calibration equation was obtained for spiked biological samples.

Table 2. Comparison of the analytical performance of BDDE electrode for the determination of famciclovir with other analytical methods reported previously

Analytical Method	Linearity range	LOD	Sample	Ref.
HPLC	5–40 g/mL	0.18 µg/mL	tablets	[27]
HPLC	5–40 µg/mL	0.19 µg/mL	tablets	[28]
HPLC	20–240 µg/mL	0.60 µg/mL	tablets	[29]
UPLC-MS/MS	0.1–10 µg/L	0.02 µg/kg	chicken muscle samples	[31]
UV-spectrophotometry	2–10 µg/mL	-	tablets	[33]
MIP-voltammetry	2.5 µM–1.0 mM	0.75 µg/mL	tablet	[35]
Spectrofluorimetry	100–1000 ng/mL	0,051 g/mL	tablets	[37]
Spectrofluorimetry	2–100 ng/mL	0.56 ng/mL	drug	[38]
DPV	0.5 – 12 µM 6 – 100 µM	0.022 µM 0.42 µM	Human serum	This study

The preparation of the samples and measurements of famciclovir are explained in Section 2. Calibration equation parameters and related validation parameters are indicated in Table 1. The DP voltammograms obtained from spiked serum samples at different concentrations of famciclovir with BDDE is shown in Fig. 6. No oxidation substances, as well as extra noise peak, was monitored from human serum samples in the potential range where the analytical peak emerged (Fig. 6).

The peak current was linearly related to famciclovir concentrations over the range of 6 μM to 100 μM (A) for DPV measurements.

$$I_p\,(\mu A) = 0.004C\,(\mu M) + 0.0148\ (n{:}6,\ r = 0.9909)$$

The proposed procedures achieved repeatable results that were simple to use, and sensitive enough to detect famciclovir in human serum samples (Table 3).

Table 3. Results of recovery studies in developed DPV method in BDDE from serum samples

Parameters	DPV
Added concentration (μM)	20
Found concentration (μM)	21.69
Average recovered %	108.47
Number of experiments	5
RSD% of recovery	4.04
Bias%	8.47

4. Conclusion

It was shown for the first time in this study that famciclovir is oxidized irreversibly on a boron-doped diamond electrode. The obtained results indicated that the electrochemical method developed in this study could be applied for the determination of famciclovir in conventional electrolytes as well as in more complex matrices such as human serum samples. Thus, the developed DPV technique enables a more convenient and efficient application of famciclovir analysis in human body fluids. The proposed method for drug analysis has several advantages, including simplicity, sensitivity, reproducibility, ease of sample preparation, and quick analysis.

Acknowledgments

Çiğdem Kanbeş Dindar thanks the Scientific and Technological Research Council of Turkey (TUBITAK) under the BIDEB/2218-National Postdoctoral Research Fellowship Program for Turkish Citizens.

References

[1] Y. Altun, B. Dogan-Topal, B. Uslu, S.A. Ozkan, Anodic behavior of sertindole and its voltammetric determination in pharmaceuticals and human serum using glassy carbon and boron-doped diamond electrodes, Electrochim Acta, 54, 2009, 1893–1903.

[2] Y. Altun, B. Uslu, S.A. Ozkan, Electroanalytical characteristics of lercanidipine and its voltammetric determination in pharmaceuticals and human serum on boron-doped diamond electrode, Anal Lett, 43, 2010, 1958–1975.

[3] S. Armenta, S. Garrigues, M. de la Guardia, Green Analytical Chemistry, TrAC - Trends Anal Chem, 27, 2008, 497–511.

[4] A.M. Ashrafi, M. Gumustas, K. Vytřas, D. Nematollahi, B. Uslu, T. Mikysek, R. Jirásko, S.A. Ozkan, Determination and detailed mechanism study of antiviral drugfosamprenavir using carbon paste electrode in the presenceof Triton X-100, Electrochim Acta, 109, 2013, 381–388.

[5] N. Baig, M. Sajid, T.A. Saleh, Recent trends in nanomaterial-modified electrodes for electroanalytical applications, TrAC - Trends Anal Chem, 111, 2019, 47–61.

[6] Y. Chang, B.J. Venton, Optimization of graphene oxide-modified carbon-fiber microelectrode for dopamine detection, Anal Methods, 12, 2020, 2893–2902.

[7] H. Chen, J.L. Lawler, D.J. Filman, J.M. Hogle, D.M. Coen, Resistance to a nucleoside analog antiviral drug from more rapid extension of drug-containing primers, MBio, 12, 2021, 1–16.

[8] Z. Djerada, C. Feliu, C. Tournois, D. Vautier, L. Binet, A. Robinet, H. Marty, C. Gozalo, D. Lamiable, H. Millart, Validation of a fast method for quantitative analysis of elvitegravir, raltegravir, maraviroc, etravirine, tenofovir, boceprevir and 10 other antiretroviral agents in human plasma samples with a new UPLC-MS/MS technology, J Pharm Biomed Anal, 86, 2013, 100–111.

[9] B. Dogan-Topal, B. Bozal-Palabiyik, B. Uslu, S.A. Ozkan, Multi-walled carbon nanotube modified glassy carbon electrode as a voltammetric nanosensor for the sensitive determination of anti-viral drug valganciclovir in pharmaceuticals, Sens Actuators B Chem, 177, 2013, 841–847.

[10] B. Dogan, S. Tuncel, B. Uslu, S.A. Özkan, Selective electrochemical behavior of highly conductive boron-doped diamond electrodes for fluvastatin sodium oxidation, Diam Relat Mater, 16, 2007, 1695–1704.

[11] Famvir_PM, Product monograph PrFAMVIR® (famciclovir) 125mg, 250 mg and 500 mg film-coated. Antıvıral agent, Novartis Pharm Canada Inc, 2016, 1–31.

[12] O.A. Farghaly, R.S. Abdel Hameed, A.A.H. Abu-Nawwas, Analytical application using modern electrochemical techniques, Int J Electrochem Sci, 9, 2014, 3287–3318.

[13] A.S. Gaballa, S.M. Teleb, E.M. Nour, Preparation and spectroscopic studies on charge-transfer complexes of famciclovir drug with different electron acceptors, J Mol Struct, 1024, 2012, 32–39.

[14] N.A. El Gohary, A. Madbouly, R.M. El Nashar, B. Mizaikoff, Synthesis and application of a molecularly imprinted polymer for the voltammetric determination of famciclovir, Biosens Bioelectron, 65, 2015, 108-114.

[15] R.A.V. Hodge, Famciclovir and Penciclovir. The Mode of Action of Famciclovir Including Its Conversion to Penciclovir, Antivir Chem Chemother, 4, 1993, 67–84.

[16] A. Karasakal, S.T. Ulu, D.O. Unal, Spectrofluorimetric determination of famciclovir in pure and pharmaceutical preparations, Opt Spectrosc, 119, 2015, 318–321.

[17] S.B. Kondawar, P.T. Patil, Conducting Polymer Nanocomposites for Sensor Applications, Conducting Polymer Hybrids, Editors: V. Kumar, S. Kalia, H. C. Swart, 2017, Switzerland, Springer.

[18] D. Kul, M. Gumustas, B. Uslu, S.A. Ozkan, Electroanalytical characteristics of antipsychotic drug ziprasidone and its determination in pharmaceuticals and serum samples on solid electrodes, Talanta, 82, 2010, 286–295.

[19] H.M. Lotfy, M.M.A. El-Moneim Abosen, M.G. EL-Bardicy, Stability-indicating methods for the determination of famciclovir in the presence of its alkaline-induced degradation product, Drug Test Anal, 2, 2010, 188–199.

[20] P. Mu, N. Xu, T. Chai, Q. Jia, Z. Yin, S. Yang, Y. Qian, J. Qiu, Simultaneous determination of 14 antiviral drugs and relevant metabolites in chicken muscle by UPLC-MS/MS after QuEChERS preparation, J Chromatogr B, 1023–1024, 2016, 17–23.
[21] C.M. Perry, A.J. Wagstaff, Famciclovir, Drugs, 50, 1995, 396–415.
[22] N.V.V.S.S. Raman, K.A. Harikrishna, A.V.S.S. Prasad, K.R. Reddy, K. Ramakrishna, Development and validation of a stability-indicating RP-LC method for famciclovir, J Pharm Biomed Anal, 50, 2009, 797–802.
[23] L. Ren, S. Qi, I.M. Khan, S. Wu, N. Duan, Z. Wang, Screening and application of a broad-spectrum aptamer for acyclic guanosine analogues, Anal Bioanal Chem, 413, 2021, 4855–4863.
[24] M.S. Rezk, R.M. El Nashar, Dissolution testing and potentiometric determination of famciclovir in pure, dosage forms and biological fluids, Bioelectrochemistry, 89, 2013, 26–33.
[25] O. Selcuk, Y. Demir, C. Erkmen, S. Yıldırım, B. Uslu, Analytical methods for determination of antiviral drugs in different matrices: recent advances and trends, Crit Rev Anal Chem, 2021, 1–32.
[26] A. Şenocak, Fast, Simple and sensitive determination of coumaric acid in fruit juice samples by magnetite nanoparticles-zeolitic ımidazolate framework material, Electroanalysis, 32, 2020, 2330–2339.
[27] A. Şenocak, E. Korkmaz, A. Khataee, E. Demirbas, A facile and synergetic strategy for electrochemical sensing of rutin antioxidant by Ce–Cr doped magnetite@rGO, Mater Chem Phys, 275, 2022, 125298.
[28] A. Şenocak, S.O. Tümay, İ. Ömeroğlu, V. Şanko, Crosslinker polycarbazole supported magnetite MOF@CNT hybrid material for synergetic and selective voltammetric determination of adenine and guanine, J Electroanal Chem, 905, 2022, 115963.
[29] D. Simpson, K.A. Lyseng-Williamson, Famciclovir: A review of its use in herpes zoster and genital and orolabial herpes, Drugs, 66, 2006, 2397–2416.
[30] K.E. Squires, An introduction to nucleoside and nucleotide analogues, Antivir Ther, 6, 2001, 1–14.
[31] G. Srinubabu, C.A.I. Raju, N. Sarath, P.K. Kumar, J.V.L.N.S. Rao, Development and validation of a HPLC method for the determination of voriconazole in pharmaceutical formulation using an experimental design, Talanta, 71, 2007, 1424–1429.
[32] G. Srinubabu, B. Sudharani, L. Sridhar, J.V.L.N. Seshagiri Rao, Development and validation of liquid chromatographic and UV derivative spectrophotometric methods for the determination of famciclovir in pharmaceutical dosage forms, Chem Pharm Bull, 54, 2006, 819–822.
[33] K. V. Subrahmanyam, P. Mohanraj, V.S. Saravanan, N. Gopal, UV spectrophotometric determination of famciclovir, Asian J Chem, 19, 2007, 4911–4913.
[34] B.D. Topal, S.A. Özkan, B. Uslu, Direct electrochemistry of native and denatured alpha-2-Macroglobulin by solid electrodes, J Electroanal Chem, 719, 2014, 14–18.
[35] B. Uslu, S.A. Ozkan, Electroanalytical application of carbon based electrodes to the pharmaceuticals, Anal Lett, 40, 2007, 817–853.
[36] B. Uslu, S.A. Özkan, Anodic voltammetry of abacavir and its determination in pharmaceuticals and biological fluids, Electrochim Acta, 49, 2004, 4321–4329.
[37] B. Uslu, S.A. Özkan, Z. Şentürk, Electrooxidation of the antiviral drug valacyclovir and its square-wave and differential pulse voltammetric determination in pharmaceuticals and human biological fluids, Anal Chim Acta, 555, 2006, 341–347.
[38] B. Uslu, B.D. Topal, S.A. Ozkan, Electroanalytical investigation and determination of pefloxacin in pharmaceuticals and serum at boron-doped diamond and glassy carbon electrodes, Talanta, 74, 2008, 1191–1200.
[39] B. Vellaichamy, P. Periakaruppan, S.K. Ponnaiah, A new in-situ synthesized ternary CuNPs-PANI-GO nano composite for selective detection of carcinogenic hydrazine, Sensors Actuators B Chem, 245, 2017, 156–165.