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Development and Characterization of a Modified Carbon Paste Electrode for Acyclovir Detection

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The pharmaceutical and medical industries have focused on acyclovir because it treats viral infections. This study shows voltammetric acyclovir detection using a modified carbon paste electrode (CPE) with CdO/Fe3O4 magnetic nanoparticles. EDS and XRD were used to analyze magnetic CdO nanoparticles. A relative standard deviation (RSD%) of less than 4.3% for the electrode response indicated an accurate approach. The modified electrode worked well for ACV determination in tablet, blood serum, and urine samples, with relative recovery (RR%) values of 94.5% to 103.9%.

Keywords: Modified Carbon Paste Electrode, Acyclovir Detection, Electrochemical Characterization, Analytical Chemistry, Sensor Development.

1. Introduction

A nucleoside analogue developed in the late 1970s, cyclovir, is effective against herpesviruses like VZV and HSV. The drug prevents virus replication in host cells by suppressing viral DNA synthesis. Acyclovir is a staple in herpes simplex virus treatment, especially in people with compromised immune systems or recurrent infections, due to its favorable pharmacokinetic profile and selective viral replication action.

Analytical approaches for acyclovir have pros and cons. Traditional methods like HPLC are commonly used because to their sensitivity and specificity. Acyclovir can be quantified reliably by HPLC by swiftly isolating it from other components in complex biological matrices. It may not be available in all clinical settings due to the need for specialized equipment and sample preparation. Mass spectrometry and enzyme-linked immunosorbent assays (ELISAs) can evaluate multiple samples simultaneously and deliver speedy results, making them promising substitutes. Therapeutic drug monitoring (TDM) optimizes dosages, minimizes toxicity, and ensures therapeutic efficacy, hence these methods are crucial.

Recently developed bioanalytical methods and analytical technologies like Ultra-High-

Performance Liquid Chromatography (UHPLC) have improved acyclovir detection. These methods reduce solvent and operation costs while improving analytical speed and resolution. Modern sample preparation procedures including solid-phase extraction (SPE) and liquid-liquid extraction (LLE) have reduced sample preparation time. This is crucial because clinical laboratory turnaround times affect patient treatment.

Acyclovir's pharmacokinetics and pharmacodynamics have helped researchers understand its medicinal uses. Understanding the medicine's ADME profiles helps improve dosing regimens, especially in sensitive groups like youngsters and those with renal impairments. Drug dosage and distribution must be carefully considered due to limited oral bioavailability. Outpatient oral acyclovir treatment is more common than inpatient intravenous treatment for severe infections. Recent research on how genetic variations in drug-metabolizing enzymes affect acyclovir pharmacokinetics shows the promise of customized medicine in antiviral treatment.

Acyclovir's efficacy and novel formulations must be studied due to the increased frequency of herpesvirus infections and antiviral resistance. Acyclovir in combination with other antivirals or adjuvants may improve treatment outcomes and reduce resistance. Clinical antiviral drug levels must be closely monitored as novel herpesvirus strains emerge and their public health effects are discovered.

2. REVIEW OF LITERATURE

Ashrafi, Amirmansoor & Richtera, Lukáš. (2019) Simvastatin was measured using a MWCNT-CPE-modified carbon paste electrode. AFM, SEM, and SECM were used to characterize the constructed electrodes. We made multiple electrodes with varied MWCNT mass percentages to find the best paste amount. MWCNT-CPE with 25% (w/w) MWCNT mass was best. The developed electrode was used to perform differential pulse voltammetry (DPV) and sensitive analysis of SIM in pharmaceutical dose form and spiked human plasma sample. The electrode is more sensitive than the glassy carbon electrode (GCE) and carbon paste. The quantification and detection limits were $8 \times 10{-}7$ and $2.4 \times 10{-}7$, respectively.

Karim-Nezhad, Ghasem et al., (2018) This work described a simple, repeatable two-step carbon paste electrode (CPE) approach for recognizing and classifying Acyclovir (ACV). Doping electrode tissue with 5% TiO2 nanoparticles was the first step in creating the TiO2 NPs-CPE structure. Step two involves electropolymerizing β-Cyclodextrin (β-CD) onto TiO2 NPs-CPE, creating a β-CD/TiO2 NPs-CPE composite. Electrodes were tested for topography, characteristics, and electrochemical response using FESEM, CC, CV, and DPV. XRD was used to study discarded TiO2 NP particles. The sensor design enhanced the composite electrode's surface area, which improved ACV oxidation performance. The recommended analytical technique worked in two linear calibration ranges (0.09-2.98 μM and 2.98-47.61 μM) under ideal conditions. The predicted detection limit for low-concentration ACV was 21 nM (S/N=3). Finally, the synthetic composite electrode detected narcotic ACV in blood serum samples.

Shetti, Nagaraj et al., (2017) Using CV and SWV in a pH5.0 environment, a nano clay modified carbon paste sensor can measure acyclovir. Modifying the sensor doubled ACV electro-oxidation current. Analyzing the nano clay modifier with a SEM and XRD. The study

studied how scan rate, pH, accumulation time, modifier quantity, and concentration affected the drug's peak current. Researchers evaluated ACV concentrations using SWV and achieved the lowest detection limit compared to previous approaches. The produced sensor measured pharmaceutical and biological acyclovir concentrations.

Sadıkoğlu, Murat et al., (2011) Electroanalytical methods can directly and quantitatively assess acyclovir (Acy) in spiked human urine using its oxidation characteristic. Using various voltammetric methods, glassy carbon electrodes (GCE) and ultra trace graphite electrodes (UTGE) easily oxidized and identified Acy. These electrodes were electrochemically studied utilizing CV and DPV in buffer solutions with pH values between 3.66 and 9.08. The DPV technique plus 0.2 M acetate buffer (pH=4.66) gave the most accurate quantitative Acy measurements. One irreversible anodic peak was discovered in acidic medium. ANODIC peak current and potential were examined in response to pH and scan rate. Nature was governed by peak diffusion. Acy was found for UTGE at 4x10-6 to 7x10-5 molL-1 and for GCE at 2.0x10-6 to 1.0x10-4 molL-1 using the electroanalytical technique. On UTGE, LOD and LOQ were 1.0x10-6 and 3.3x10-6 molL-1. GCE values were 3.5x10-7 and 1.2x10-6 molL-1. Recovery experiments with spiked urine assessed the new method's repeatability, precision, and accuracy.

Wang, Fang et al., (2006) CV, LSV, EIS, and chronocoulometry were used to study the electrochemical behavior of acyclovir on the glassy carbon electrode (GCE) coated with a film of multi-wall carbon nanotubes (MWNTs) and dihexadecyl hydrogen phosphate (DHP). Acyclovir oxidation peak current and potential increased significantly at a GCE with a MWNTs-DHP layer. Acyclovir electrochemical oxidation was greatly improved by this nano-structured film electrode. Thus, a sensitive and simple electroanalytical method determined acyclovir. Acyclovir concentrations from 8.0 x 10(-8) to 1.0 x 10(-5) mol/L correlated with oxidation peak current. The detection limit for 60 seconds of accumulation at 0.00 V was 3.0 x 10(-8) mol/L. Acyclovir pills demonstrated the intended method, which worked.

3. MATERIALS AND METHODS

Instrumentation

An Ag/AgCl reference electrode, an auxiliary electrode made of platinum wire, and a working electrode that was modified from CPE were used to produce voltammetric readings. Using NOVA software and a µ-Autolab type III/FRA2 potentiostat/galvanostat, the impedance measurements were taken. Discovering the look and feel of magnetic nanoparticles is the objective. Using Cu Ka radiation that had been filtered with Ni, an XRD pattern was obtained by a Philips-X'pertpro diffractometer. The voltammograms were acquired by PSTrace, and the data was analyzed by Excel.

Chemicals and Reagents

All chemicals were made to analytical purity by an Indian manufacturer. Indian Company supplied us ACV standard powder. Dissolving the appropriate amounts in enough water formed ACV stock solutions for analysis. We created other standard solutions by adding phosphate buffer solution to stock solutions.

Procurement of Fe3O4 Nanoparticles

An Indian business made all chemicals analytically pure. The Indian Company supplied our ACV standard powder. The prescribed volumes of ACV stock solutions were dissolved in enough water before analysis. Phosphate buffer solution was added to stock solutions to create other standard solutions.

Production of Composite Nanoparticles from CdO and Fe3O4

Diluted with 50 mL of deionized water, the Fe3O4 nanoparticles were dispersed. The mixture was homogenized by gently stirring it for 10 minutes. In a 50 mL NaOH solution with a concentration of 2.5 mol L−1, combine one millimole of cadmium nitrate with a Fe3O4 dispersion. Stir for 15 minutes at 70◦C. Last but not least, distilled water was used to rinse the CdO/Fe3O4 precipitate. They calcined it at 450◦C for 70 minutes after it dried.

Preparation of Magnetic Nanoparticle-Modified Carbon Paste Electrode

A uniform paste was made by combining 0.14 g of graphite, 0.01 g of magnetic nanoparticles, and a small amount of oil. The next step was to transfer the paste to a 2 mm plastic pipe. Electrical impulses were conveyed via copper cables. The surface of the electrode was smoothed out using a sheet of paper until it was consistent. With just 0.15 g of graphite and oil, the original CPE was made.

Sample Preparation and Pretreatment

Make tablet sample Weighing and crushing 10 ACV-200 mg tablets. The powder was diluted in 100 mL pH 4 0.1 M phosphate buffer for 225 mg. Diluted 500-fold and agitated for 10 minutes, the solution was filtered before use. After collection, urine and plasma were refrigerated. Next, 5 ml of the solutions were centrifuged at 5,000 rpm for 5 minutes to remove suspended particles. These particles might adsorb on the electrode, lowering efficiency. Dilution with 0.1 phosphate buffer (pH = 4) diminished matrix impact. ACV content was measured with samples as normal.

4. RESULTS AND DISCUSSION

EDS and XRD Characterization of Synthesized Magnetic CdO/Fe3O4 Nanoparticles

Our findings show a biphasic, pure CdO/Fe3O4 nanostructure. In the first phase of the Fe3O4 sample, the diffraction peaks at 35.45°, 43.08°, 57.16°, and 62.72° match the JCPDS file for the cubic phase (space group Fd-3m, JCPDS No. 75-0449). In contrast, the CdO sample displays diffraction peaks at 33.35°, 38.78°, 55.52°, 65.92°, and 69.33°, which match the space group of Fd-3m in JCPDS 75-0592, the standard JCPDS for the tetragonal crystal structure. CdO-Fe3O4 nanoparticles are 23 nm. Figure 1 demonstrates that EDS analysis revealed pure Cd, Fe, and oxygen components.

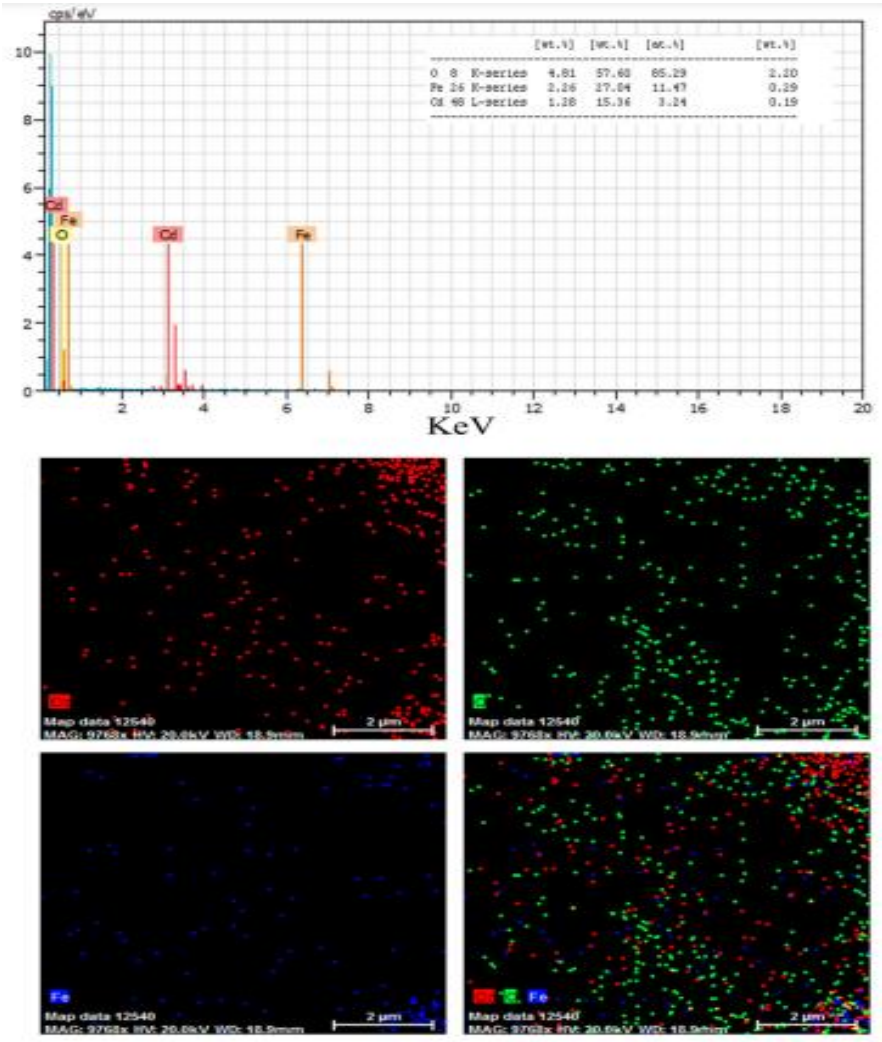

Figure 1: Nuclear Desorption Spectroscopy Findings for Manufactured CdO/Fe3O4 Nanoparticles

Evaluating the Suggested Approach Against Existing Electrosensors and Its Analytical Performance

The sensor's functioning range was determined using differential pulse voltammetry (DPV) of varied acyclovir (ACV) doses in ideal conditions (0.1 M phosphate buffer at pH 4.0, 50 mV s−1), with three duplicates. Figure 3 shows that the method's linear range is 1 to 100 µM, with a detection limit of 0.3 µM (current vs concentration graph). Other analytical performance parameters like repeatability and stability were studied.

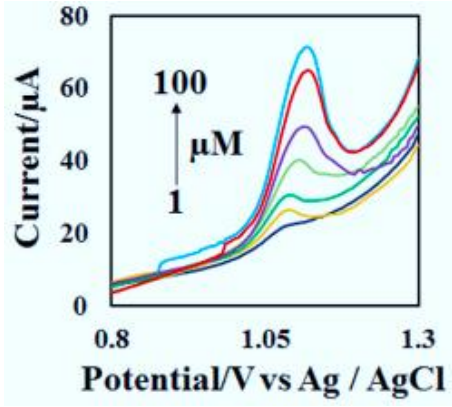

Figure 2: DPE DPVs of the CdO/Fe3O4 mix

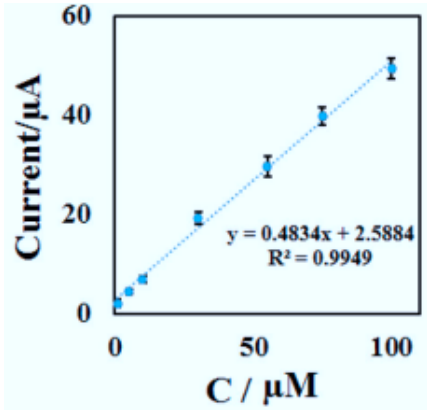

Figure 3: A standard curve

ACV-related voltammograms were plotted five times at three concentrations to assess the electrode response's RSD. The modified electrode response's repeatability was examined. <4.3% of electrode response RSD values were negative. We confirmed the enhanced CPE's stability by recording ACV voltammograms weekly for 8 weeks. Signal strength dropped 5% from the first week after eight weeks, showing long-term stability of the CdO/Fe3O4/CPE surface.

The created method appears to have advantages over conventional ACV measurement methods (Table 1). The electrode is cheaper than glassy carbon electrodes (GCEs) or scattered nanoparticle modifiers. Two further analytical parameters, detection limits and linear ranges, sometimes match or exceed the proposed methodologies.

Table 1: Evaluate the suggested procedure in light of existing electrochemical protocols

Electrode	Linear range (µM)	LOD (µM)
GCE/MWCNT/ZnO	0.009–1	0.005
CPE/Nnao clay	0.05–1	0.0003
GCE/MWCNT- DHP[a]	0.79–130	0.18

GCE/C60	0.8–6	0.12
CPE/PVP[b]	0.01–75	0.05
CPE/CuNPs	27–521	2.7
CdO/Fe3O4/CPE	1–100	0.2

PVP/dihexadecyl hydrogen phosphate.

The redesigned electrode was tested for electrochemical ACV determination utilizing tablet, urine, and plasma samples. This study's results are in Table 2. When tested on real samples, the modified electrode measures ACV well. Each sample was given three ACV concentrations within the calibration range, and the exact amount was calculated using the traditional addition procedure. The ACV analytical signal in phosphate buffer was compared to actual samples to assess the technique's relative recovery (RR). Actual sample recovery rates of 94.5% to 103.9% demonstrate the procedure's accuracy.

Table 2: Finding the ACV Concentration in Actual Samples and Evaluating the Relative Recovery

Sample	Added (µM)	Found (µM)	RR (%)	RSD (%)
Tablet (200 mg)	0	20.2	99.8	2.3
	5	24.7	99.1	1.9
	10	30.2	100.3	1.9
	20	40.1	100.1	2.1
Urine	0	0	Not detected	–
	10.0	9.4	94.5	1.9
	15.0	15.1	101.1	2.3
	30.0	31.1	103.8	1.7
Plasma	0	0	Not detected	–
	25.0	26.1	103.9	1.5
	35.0	34.4	98.1	2.1
	50.0	50.0	100.0	2.1

5. CONCLUSION

This study uses a reliable and efficient CdO/Fe3O4-modified carbon paste electrode (CPE) to electrochemically detect acyclovir (ACV). The nanoparticles were pure and well-defined using EDS and XRD. These features improved the modified CPE. The electrode showed great repeatability (RSD < 4.3%) and stability over eight weeks, with a low detection limit of 0.3 µM and a linear detection range of 1-100 µM. The method was accurate, with relative recovery rates of 94.5% to 103.9% for pharmaceutical tablets and biological materials including plasma and urine. Due to its cost-effectiveness and comparable analytical performance, the CdO/Fe3O4-modified CPE is an appealing approach for ACV analysis in clinical and pharmaceutical settings.

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