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ORIGINAL PAPER

Sensitive detection of sulfanilamide by redox process electroanalysis of oxidation products formed in situ on glassy carbon electrode

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Abstract This paper reported a simple method for sulfanilamide determination by redox process electroanalysis of oxidation products (SFDox) formed in situ on glassy carbon electrode. The CV experiments showed a reversible process after applied E_{acc} = + 1.06 V and t_{acc} = 1 s, in 0.1 mol L^{-1} BRBS (pH = 2.0) at 50 mV s^{-1}. Different voltammetric scan rates (from 10 to 450 mV s^{-1}) suggested that the redox peaks of SFDox on the glassy carbon electrode (GCE) is an adsorption-controlled process. Square-wave voltammetry (SWV) method optimized conditions showed a linear response to SFD from 3.00 to 250.0 μmol L^{-1} (R = 0.998) with a limit of detection of 0.638 μmol L^{-1} and limit of quantification of 2.0 μmol L^{-1}. The developed the SWV method was successfully used in the determination of SFD pharmaceutical formulation and human serum. The SFD quantification results in pharmaceutical obtained by SWV-GCE were comparable to those found by official analytical protocols.

Keywords Square-wave voltammetry · Sulfanilamide · Glassy carbon electrode · Oxidation product detection

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Introduction

Sulfanilamide (SFD), a sulfonamide, is an organic compound consisting of an aniline derivatized with a sulfonamide group and one of the oldest antimicrobial drugs, which have been used for the treatment of humans and animals from the last decades. Sulfonamides act as bacteriostatic agents and possess chemotherapeutic activity against infections caused by gram-positive and gram-negative bacteria and some protozoa [1]. As relatively persistent antibiotics, sulfonamide drugs and their residues can accumulate in soil and may leach to the groundwater or surface water thus pose potential threat to human beings and aquatic organisms [2, 3]. Intensive researches on these drugs have been carried out, which include detection, distribution, transformation, and impact on humans and animals in the surrounding environment, including chromatographic methods [2, 4–7], and fluorescence [8]. However, these methods show some disadvantages such as high cost, long analysis time, and requirement for sample pretreatment and in some cases low sensitivity and selectivity that makes them unsuitable for routine analysis. In other hand, the electrochemical methods present good advantages for drug detection in several matrices, for example, high sensitivity, accuracy, precision, simplicity, low cost, and riddance of laborious sample preparation procedures [9]. Electrochemical methods also have been used for SFD determination in different matrices employed chemically modified electrodes (CME) [10, 11]. Although much research is devoted to chemically modified electrodes, the use of non-modified electrodes is of interest because of their major robustness and repeatability/reproducibility [12–14].

In this sense, the objective of this study was to develop a method for sulfanilamide determination using square-wave voltammetry (SWV), on an unmodified glassy carbon electrode (GCE). This electrode has been used as sensor for

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voltammetric measurements of different organic substances [15] such as herbicides [16], antibiotics drugs [17, 18], and chemotherapy drugs [19, 20]. The analysis of oxidation products and electrochemical oxidation products has been employed to eliminate interfering substances that coexists in the matrix in which it is desired to determine an analyte. Özcan and Şahin [21] proposed a novel method to determine paracetamol in the presence of uric acid in body fluids. The electrochemical performance of the electrochemically treated pencil graphite electrode (ETPGE) was evaluated by adsorptive transfer stripping differential pulse voltammetry. The linear range obtained was from 0.05 to 2.5 μmol L^{-1} with detection limit of 2.5 nmol L^{-1}. In another study, Özcan and Şahin [22] developed a method for simultaneous determination of tryptophan in blood serum human in the presence of tyrosine using ETPGE. In this study, the simultaneous detection is only possible after electrolysis step to form the oxidation product and reduce it to suitable potential value. The linear range obtained was from 0.5 to 50.0 μmol L^{-1} with a detection limit of 0.05 μmol L^{-1}. It is known that electrochemical degradation of sulfonamide drugs forms electroactive products [23]. Thus, we used this approach for the first time in this study for detection sulfanilamide.

Experimental

Chemicals

Sulfanilamide (99%) was obtained from Sigma. Other chemicals were of analytical reagent grade and used without further purification. Aqueous solutions were prepared with ultra-pure deionized water (Milli-Q). The voltammetric measurements were performed in 0.1 Britton-Robinson buffer solution in which was prepared by mixing equimolar amounts of phosphoric acid, acetic acid, and boric acid.

Apparatus

Electrochemical experiments were carried out by a conventional three-electrode system. The GCE (A = 0.07 cm^2) was used as working electrodes. Pt wire and Ag/AgCl 3.0 mol L^{-1} KCl were used as an auxiliary and reference electrode, respectively. The voltammetric measurements were carried out on an Autolab PGSTAT 128 N (Metrohm Autolab B.V., Utrecht, and the Netherlands) potentiostat/galvanostat controlled by NOVA 1.10.4 electrochemical software. The pH measurements were done with a calibrated standard buffers at room temperature. The methodology used for comparison with the electrochemical method proposed in this study was performed according to the European pharmacopeia.

Electrode preparations procedure

The GCE (∅ = 3.0 mm) was polished on a mirror finish using alumina 0.05 μm and then rinsed with plenty of water. The electrode was then conditioned in 0.1 mol L^{-1} sulphuric acid by 10 successive CV scans (from 0 to + 1.4 V) at a scan rate of 0.5 V s^{-1}. In the CV and SWV experiments, the electrode was always polished between measurements.

Square-wave voltammetry measurements

The voltammetric determination of SFD was performed by the SWV using the GCE. In order to form SFDox on the electrode surface, the GCE waited at + 1.1 V for 250 s in the measurement solution containing appropriate amount of SFD. Then, the electrode waited for 3 s in the same medium. Finally, the anodic scan of SFDox was performed by potential scanning from + 0.25 to + 0.60 V. Each measurement was performed with a fresh electrode and repeated three times.

UV-Vis absorption spectroscopy procedure

The SFD contend in pharmaceutical was also determined by UV analysis. The analysis was carried out at using the spectrophotometer. The otologic solution was diluted 100 times using deionized water. An aliquot of 175 μL of the diluted solution was placed on quartz cuvete, and the volume was complete to 2.0 mL with deionized water. The UV detections were performed at 260 nm.

Preparation of samples for quantification of SFD by the SWV

Otologic solution

The developed voltammetric method was tested for determination of SFD in pharmaceutical formulations. Otologic solution of SFD was purchased from a local drugstore. According to the manufacturer's information, each flask of 10 mL contains 0.1 g of SFD. In order to determine the amount of SFD in flask, 10 μL of pharmaceutical sample solution was transferred to 1.0 mL volumetric flask, and the final volume was completed with 0.1 mol L^{-1} BRBS, pH = 2.0 (this solution was named solution A). A volume equal to 1000 μL of solution A was diluted in 10 mL volumetric flask, and the final volume was completed with 0.1 mol L^{-1} BRBS, pH = 2.0 (this solution was named test solution). The test solution was placed in an electrochemical cell, and SFD concentration was determined by the standard addition method.

Human serum spiked

Three drug-free human blood samples (10 mL) obtained from healthy voluntaries were allowed to rest for 20 min to complete blood clotting and then centrifuged (1500*g* for 15 min at 20 °C) to separate the serum (supernatant) from the solid portion. An aliquot of 50 μL of serum and 500 μL of 0.01 mmol L^{-1} SFD standard solution were transferred to 10 mL volumetric flask, and the final volume was completed with 0.1 mol L^{-1} BRBS, pH = 2.0. This final solution was placed in an electrochemical cell, and SFD concentration was determined by the standard addition method.

Results and discussion

Electrochemical behavior of SFD and SFDox at glassy carbon electrode

Initially, the electrochemical behavior of SFD and SFDox in 0.1 mol L^{-1} BRBS (pH = 2.0) was investigated by CV at 50 mV s^{-1} over the potential range of + 0.20 to + 1.40 V. Figure 1 shows the influence of initial potential and scan direction on the electrochemical behavior of SFD and SFDox. On the first cycle of anodic scan (Fig. 1a) displayed one irreversible oxidation peak at + 1.06 V and a reduction peak at + 0.40 V. In the second cycle, an oxidation peak at + 0.43 V was observed followed by decreasing on current intensity of peak at + 1.06 V. In Fig. 1b, a reduction process at + 0.40 V occurs on the first cycle of cathodic scan, which is oxidized in the reverse scan at + 0.43 V. Figure 1c, when the potential started from + 0.60 to + 0.20 V, it was not observed redox process at + 0.40 and + 0.43 V before SFD oxidation at + 1.06 V (reverse scan). In the second cycle, afterward, the oxidation of SFD occurs a reduction peak at + 0.40 V followed by an oxidation peak at + 0.43 V. These results indicate that the oxidation peak at + 0.43 V is dependent on the reduction peak at + 0.40 V in a couple redox (SFDox), which in turn is dependent on the oxidation of the SFD. The observed decrease in current of peaks oxidation at + 1.06 V (Fig. 1a, b, c) may be due to the formation of oxidations products in follow-up reactions resulting in the depletion of the concentration of the SFD in successive potential cycles. This phenomenon will later be approached. It is known that the analysis of substances at high potentials often implies in the decrease of selectivity, interference in the electrochemical signal due to the oxidation of the solvent, and mainly of interfering substances. In this sense, an accumulation potential (E_{acc}) at oxidation peak of SFD and accumulation time (t_{acc}) of 1 s was applied, in order to form the species to be detected on surface electrode, thus detected SFD in low potential, as shown in Fig. 1d.

Effect of pH on electrochemical behavior of SFDox

The pH influence on electrochemical behavior of SFDox was carried out by cyclic voltammetry starting from − 0.10 to + 0.60 V at 50 mV s^{-1}. The pH values were from 2.0 to 9.0 after applied E_{acc} = + 1.06 V and t_{acc} = 1 s in the 0.8 mmol L^{-1} SFD solution. The E_{acc} values were changed in each pH

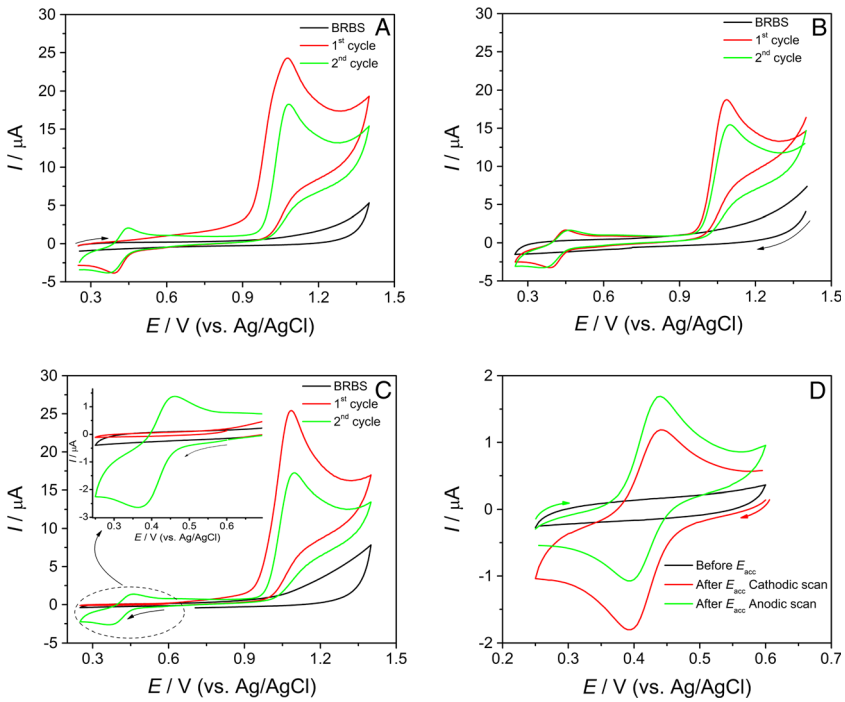

Fig. 1 Cyclic voltammograms of 0.1 mol L^{-1} Britton-Robinson buffer solution (pH = 2.0) in the absence (black line) and the presence of 1.0 mmol L^{-1} SFD on first cycle (red line) and second cycle (green line) in anodic scan (**a**) and wide cathodic scan (**b**) short cathodic window (**c**). **d** Electrochemical behavior of oxidation product (SFDox) at glassy carbon electrode before and after of applied E_{acc} = + 1.06 V, t_{acc} = 1 s, ν = 50 mV s^{-1} in cathodic scan and anodic scan

Table 1 Values of E_{acc}, E_{Pa}, and E_{Pc} in each pH value

Potential (V)	pH values							
	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
E_{acc}	1.065	1.060	1.050	1.020	0.980	0.930	0.880	0.815
E_{Pa}	0.430	0.385	0.325	0.280	0.225	0.170	0.115	0.050
E_{Pc}	0.400	0.345	0.290	0.245	0.190	0.130	0.075	0.010

values investigated due to the oxidation peak of SFD shifts for more negative values with the pH increasing (data not showed). The E_{acc} values used in each pH value, E_{Pa} and E_{Pc}, is shown in Table 1.

Figure 2a, b shows a displacement of peaks potentials of SFDox for negative values with an increasing pH values, and the regression equations (Fig. 2c) can be expressed as E_{Pa} (V) = − 0.05 (± 0.02) pH + 0.50 (± 0.10) (R = 0.999) and E_{Pc} (V) = − 0.05 (± 0.02) pH + 0.50 (± 0.20) (R = 0.9992), indicating that the proton is directly involved in the redox process. According to the following formula: $\Delta E_P/\Delta pH = 2.303mRT/nF$, in which, $\Delta E_P/\Delta pH$ is the slope of E_P vs pH curve, R is the gas constant equal to 8.3145 J mol^{-1} K^{-1}, T is the temperature equal to 298 K, F is the Faraday constant equal to 96,485 C mol^{-1}, m is the number of proton, and n is the number of electron [24], m/n was calculated to be 0.92 for the redox process. It indicates that the number of proton and electron involved in the redox process is the electron number obtained by the following equations: $E_{Pa} - E_{Pa/2}$ = 59.1 mV/n and $E_{Pc} - E_{Pc/2}$ = 59.1 mV/n [25], where E_{Pa}, $E_{Pa/2}$, E_{Pc}, and $E_{Pc/2}$ are equal to + 0.43, + 0.40, + 0.40, and + 0.43 V at pH = 2, respectively. The number of electrons transferred in the process is then found to be 1.9. Thus, two electrons and two protons were involved in redox process. The oxidation peak of SFD also shifted negatively with increasing pH (data not showed), and the regression equations can be expressed as E_{Pa} (V) = − 0.05 (± 0.01) pH + 1.30 (± 0.20) (R = 0.997). Similarly, the number of protons and electrons was obtained using the formula $E_{Pa} - E_{Pa/2}$ = 47.7 mV/$\alpha \times n$, where E_{Pa}, $E_{Pa/2}$, α, and n are the potential peak, potential peak a half-height, electronic transfer coefficient of electron and electronic transfer number of electron, respectively. The calculate values of E_{Pa} equal to + 1.05 V, $E_{Pa/2}$ equal to + 0.96 V, α equal to 0.5 (for most irreversible system α can usually be approximated as 0.5), the number of electron transferred (n) in the oxidation of SFD is calculated to be 1.06.

Mechanism of sulfanilamide's reaction on glassy carbon electrode

The mechanism of reaction was studied by cyclic voltammetry in 0.1 mol L^{-1} BRBS (pH 2.0) at 50 mV s^{-1}. The cycle positive-going voltammograms scan (Fig. 1a) was recorded with start potential of + 0.20 V to upper vertex potential of + 1.40 V, and return to lower vertex potential of + 0.20 V. The cycle negative-going voltammograms scan was recorded with start potential of + 0.60 V to lower vertex potential of + 0.20 V, and upper vertex potential of + 1.40 V. In the first cycle on positive-going voltammograms scan, an only peak current was observed in forward scan at + 1.06 V; this peak may be due to oxidation phenylamine group. In reverse scan, peak next to potential oxidation of phenylamine group is not observed, indicating that this oxidation is irreversible. However, a reduction peak was observed at + 0.40 V which was oxidized at + 0.43 V in a reversible process (I_{Pc}/I_{Pa} = 0.95; ΔE_p = 30 mV). This reversible process is dependent of oxidation at + 1.06 V, as seen in Fig. 1c (second cycle). This fact may be confirmed by the absence of peaks on negative-going scan (1st cycle). When this scan was reversed, no peak was also observed next to + 0.40 V. According to Msagati and Ngila (2002), the oxidation of primary amino group (R − NH_2) accounts for the anodic property, while reduction of sulfonamide group (R − SO_2 − R) accounts for the cathodic property [26]. These peaks only were observed in second

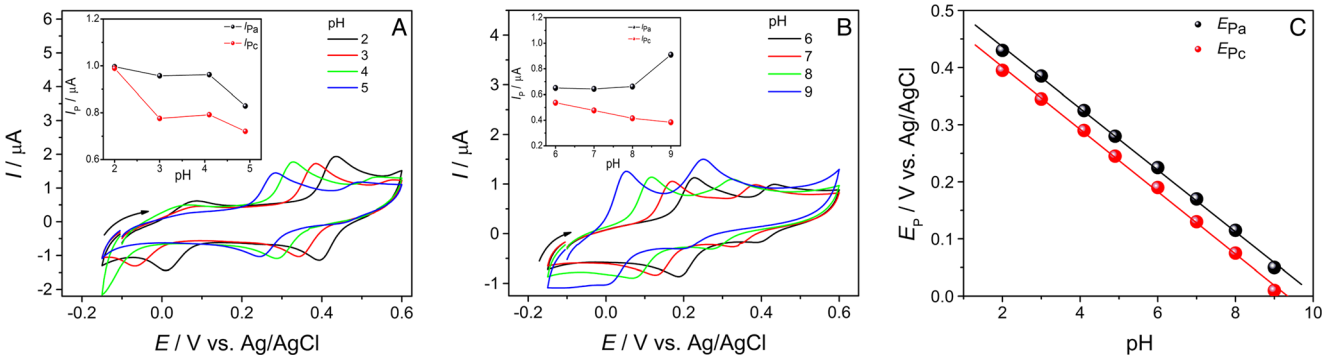

Fig. 2 Cyclic voltammograms of SFDox obtained in 0.8 mmol L^{-1} SFD in 0.1 mol L^{-1} BRBS at pH values from 2.0 to 5.0 (**a**), 6.0 to 9.0 (**b**), and E_P vs pH plot (**c**) obtained with the glassy carbon electrode. E_{acc} = + 1.06 V, t_{acc} = 1 s, ν = 50 mV s^{-1}. Insert: I_P vs pH plot

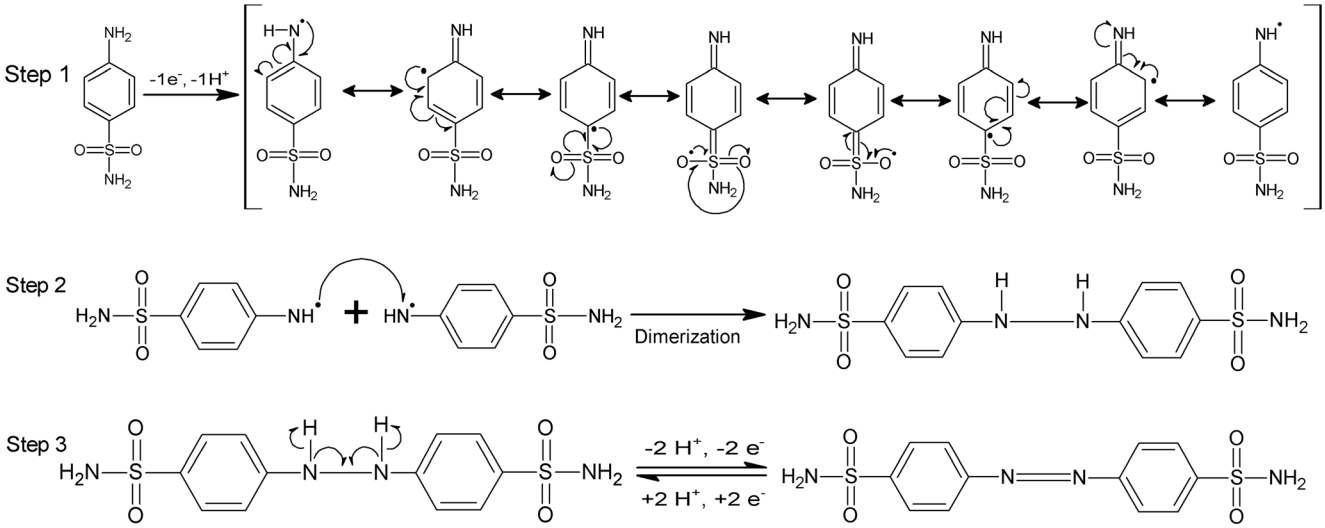

Fig. 3 Mechanism suggested for the SFD electrochemical reaction at glassy carbon electrode in 0.1 mol L^{-1} BRBS, pH 2.0

cycle, after oxidation of phenylamine group at + 1.06 V occurred on the first cycle. The behavior observed is similar to oxidation of *p*-aminobenzene sulfonic acid [27] and a monosubstituted aniline [28]. Thus, the possible reaction pathway (Fig. 3) may be described by the formation of free radical from sulfanilamide oxidation with transferring of one electron and one proton, when applied E_{acc} = + 1.06 V and t_{acc} = 1 s (step 1). On the second step, the species prior formed combines each other through of dimerization reaction (step 2). Finally, the redox process of dimer occurs in a reversible system with E_{Pa} and E_{Pc} at + 0.43 and + 0.40 V, respectively as shown in step 3. Differently from the voltammetric behavior observed for p-aminobenzene sulfonic acid and PABA [27, 28], under such experimental conditions, polymerization of sulfanilamide does not occur. This fact can be justified due to the no increase of the redox process currents on redox region with the increase of the number of cycles [Fig. S1].

Effect of scan rates on cyclic voltammetry

To further investigate the system reversibility of the electrochemical oxidation of SFDox, the effect of scan rate (ν) on the voltammetric response of SFDox at the GCE was studied in detail.

As showed in Fig. 4A and B, a linear correlation was obtained, the regression equations were log (I_{Pa}/μA) = 0.84 (± 0.20) log (ν/mV s^{-1}) − 7.30 (± 0.30) μA (R = 0.997) and log (I_{Pc}/μA) = 0.87 (± 0.01) log (ν/mV s^{-1}) − 7.40 (± 0.10) μA (R = 0.998). These slopes (0.84 and 0.87) are very close to the

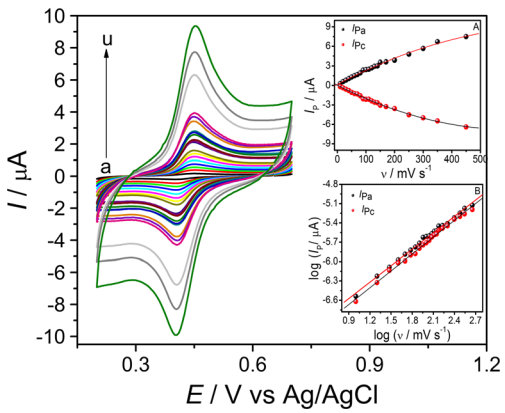

Fig. 4 Cyclic voltammograms of 0.1 mmol L^{-1} SFD in 0.1 mol L^{-1} BRBS, pH = 2.0, obtained at the GCE in different scan rates = 10 (**a**), 20 (**b**), 30 (**c**), 40 (**d**), 50 (**e**), 60 (**f**), 70 (**g**) 80 (**h**), 90 (**i**), 100 (**j**), 110 (**k**), 120 (**l**), 130 (**m**), 140 (**n**), 150 (**o**), 170 (**p**), 200 (**q**), 250 (**r**), 300 (**s**), 350 (**t**), and 450 mV s^{-1} (**u**). E_{acc} = + 1.06 V, t_{acc} = 1 s. Insert: **a** I_P vs. ν plot. **b** log I_P vs. log ν plot

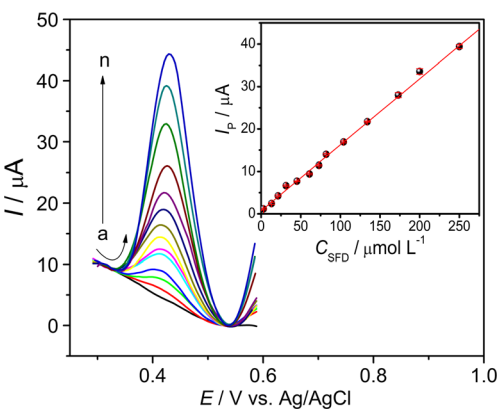

Fig. 5 Square-wave voltammograms of SFD obtained using the GCE under optimized conditions. SFD concentrations: 0.00 (**a**), 3.00 (**b**), 13.2 (**c**), 21.4 (**d**), 31.4 (**e**), 45.2 (**f**), 61.0 (**g**), 73.5 (**h**), 82.6 (**i**), 104.3 (**j**), 134.2 (**k**), 173.4 (**l**), 200.0 (**m**), and 250.0 μmol L^{-1} (**n**). Optimized parameters: a = 50 mV, f = 70 s^{-1} and ΔE_S = 4.0 mV, t_{acc} = 250 s and E_{acc} = + 1.10 V. Insert: calibration plot

Table 2 Parameters investigated and their optimum values for the determination of SFD by SWV at GCE

Parameter	Studied range	Optimum value
Frequency (s^{-1})	10–80	70
Step potential (mV s^{-1})	1–8	4
Amplitude (mV s^{-1})	10–80	50
t_{acc} (s)	50–400	250
E_{acc} (V)	+ 0.95–1.20	+ 1.10

theoretical values reported in literature, which indicates the reaction is limited by adsorption and/or diffusion processes [25, 29].

Optimization of potential and time in electrolysis step

In electrolysis step, the time (t_{acc}) and potential (E_{acc}) may strongly influence the peak current in the SWV measurements, because the voltammetric response of SFDox depends on oxidized amount of SFD on the electrode surface. Thus, the potential and time in electrolysis of SFD on the GCE are critical factor that allow the detection system.

As can be seen in Fig. S2, the redox peak current value of SFDox increased when E_{acc} was increased up to + 1.10 V. After that value, the further increase has led to a gradual decrease. Therefore, the optimal value was determined as + 1.10 V, because at high potentials, there is the possibility of oxidizing other interfering substances and blocking the surface of the electrode. The effect of t_{acc} on the electrochemical redox process of SFDox was examined by waiting the GCE at + 1.10 V for different time periods in 100.0 μM SFD solution (pH = 2). The redox peak current intensity of SFDox gradually increased with the increasing t_{acc} values up to 250 s. The longer time periods has led to no significant increment (Fig. S3). This may be due to saturation of the electrode surface and blocking by other products formed on the surface. Therefore, 250 s was chosen as the optimal accumulation time and used in the rest of the study.

Analytical determination of SFD by square-wave voltammetry

Square-wave voltammetry was performed to investigate the relationship between the peak current and concentration of SFD due to its higher sensitivity. As can be seen in Fig. 5 under the optimal conditions (Table 2), the redox peak current was proportional to SFD concentration in the range from 3.0 to 250 μmol L^{-1} with the regression equation of I_P (μA) = − 0.70 (± 0.10) + 0.20 (± 0.03) (C_{SFD} (μmol L^{-1}) (R = 0.998)). The detection and quantification limits calculated were 0.64 and 2.0 μmol L^{-1}, respectively. The linear range and limit of detection of the proposed electroanalytical method were similar or better than those reported in earlier reports on electrochemical or other analytical techniques (Table 3).

Inter-day and intra-day repeatability

The intra-day precision of the current peak magnitude was determined by successive measurements (n = 7) in 100.0 μmol L^{-1} SFD solution in 0.1 mol L^{-1} BRBS (pH 2.0). When these repeated current peak values were compared with the initial values, relative standard deviation was of 2.5%, indicating a good intra-day precision of the proposed voltammetric method. The inter-day precision for the current peak magnitude of the 100.0 μmol L^{-1} SFD solution was evaluated over a period of 6 days.

A good RSD value was also obtained, 4.28%. Hence, it is possible to conclude that the SWV-GCE approach for SFD determination provides results with adequate precision.

Interference study

The selectivity of the proposed method for SFD determination was tested by the assessment of the effect of possible interferents (magnesium stearate, microcrystalline cellulose, glycine, L-cysteine, glucose, uric acid, and ascorbic acid). Solutions of these compounds were freshly prepared at a SFD solution/interferent compound concentration ratio of

Table 3 Comparison of different electrochemical methods proposed for determination of sulfanilamide

Electrode	Potential detection (V)	Linear range[a]	LOD[a]	Sample	Ref
Ppy-MIP/PGE	+ 0.44	5.8–48.6	0.02	Spiked human serum and ground water	10
MIP/GO/GCE	+ 0.99	0.058–5.8	–	Milk	11
GCE	+ 1.06	5.0–74.7	0.92	Pharmaceutical, spiked human serum, and urine	data not showed
GCE	+ 0.42	3.00–250.0	0.64	Pharmaceutical and spiked human serum	This paper

[a] μmol L^{-1}

Ppy poly pyrrole, *MIP* molecularly imprinted polymers, *PGE* graphite pencil electrode, *GO* graphene oxide, *GCE* glassy carbon electrode

Table 4 SFD determination results for pharmaceutical samples according to the proposed electroanalytical SWV-GCE method and the official spectrophotometric protocol [31]

Sample	Label value (mg/mL)	By proposed method (mg/mL)	By official method (mg/mL)
Solution	0.010	0.098	0.096

1:10 under the same conditions used for 50 μM SFD in 0.1 mol L^{-1} BRBS at pH 2.0. The analytical response was monitored and compared with the signal obtained for the pure SFD solution (Table S4). The results revealed that the proposed method is selective for SFD, once the interferents did not affect the anodic current of the antibiotic under the tested concentration.

Determination of SFD and recovery tests

The GCE was applied to determine SFD in pharmaceutical and human serum, each experiment was conducted in triplicate and using the standard addition method. For comparison purposes, the concentration of SFD in the pharmaceuticals was also determined by the official protocol [31]. The linear range obtained was from 3.00 to 250.0 μmol L^{-1} (Fig. S5). The data were statistically compared through the paired *t* test and *F* test [30], and the results are summarized in Table 4. It was possible to observe that there was no statistical difference between these two methods at a confidence level of 95%, indicating that the GCE can be successfully used for determinations of SFD in pharmaceutical formulations.

Table 5 Results of addiction-recovery experiments using the GCE for determination of SFD in otologic solution and spiked human serum sample ($n = 3$)

Otologic solution			
C_{SFD} added (μM)	C_{SFD} expected (μM)	C_{SFD} found (μM)	Recovery (%)
0.0	–	60.1 (± 1.6)	–
20.0	80.1	80.6 (± 0.3)	100.9 (± 4.2)
40.0	100.1	90.8 (± 0.1)	97.6 (± 1.2)
60.0	120.1	120.4 (± 0.4)	102.8 (± 3.3)
Human serum			
C_{SFD} added (μM)	C_{SFD} expected (μM)	C_{SFD} found (μM)	Recovery (%)
0.0	–	50.0 (± 0.4)	–
50.0	100.0	100.2 (± 0.4)	101.9 (± 4.2)
100.0	150.0	140.8 (± 0.5)	98.3 (± 3.6)
200.0	250.0	250.5 (± 0.3)	102.1 (± 1.1)

The accuracy of the SWV-GCE method and the possibility of matrix interferences were further checked by performing analytical recovery experiments. Precise amounts of SFD were added into otologic solution, and human serum samples and the recovery percentage values were calculated from the actual and added SFD concentrations (Table 5). It can be clearly observed that there was no influence of the matrix on the response obtained by the SWV-GCE.

Conclusions

A novel approach was proposed for the determination of SFD in body fluids and pharmaceutical based on the electrochemical detection of oxidation products formed by the electrochemical oxidation of SFD on the GCE. The method allows the direct determination of SFD in spiked serum samples and pharmaceutical samples without any separation and time consuming pretreatments. The SWV-GCE method provided a wide linear concentration range of 3.0–250.0 μmol L^{-1} and low limits of detection of 0.64 μmol L^{-1}. Additionally, the concentrations of SFD found in pharmaceutical tables by the SWV were equivalent to those attained by UV-Vis spectrophotometry at a confidence level of 95%. The proposed method can be a novel alternative for SFD determination in these samples.

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