Research Article

An Electrochemical-Based Point-of-Care Testing Methodology for Uric Acid Measurement

Yuetong Zhao and Xia Song

Department of Rheumatology and Immunology, The First Hospital of China Medical University, No.155 Nnajing Street, Heping District, Shenyang 110000, Liaoning Province, China

Department of Operating Room, The First Hospital of China Medical University, No.155 Nnajing Street, Shenyang 110000, Liaoning Province, China

Correspondence should be addressed to Xia Song; ssong0801@sina.com

Received 14 May 2022; Revised 23 June 2022; Accepted 29 June 2022; Published 23 July 2022

ACM Editor: Li Fu

Copyright © 2022 Yuetong Zhao and Xia Song. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Point-of-care technology (POCT) is an important method in clinical testing in the future, which can achieve the purpose of rapid analysis. In this work, we assembled an electrochemical POC sensor for uric acid (UA) by surface modification of a screen-printed electrode. Copper nanowires were used as electrode modifiers to achieve high-performance electrochemical oxidation of UA. This electrochemical sensor can achieve linear detection of UA in the range of 10 nM to 2 mM. The detection limit of the sensor was calculated to be 2 nM. Although the detection performance of this sensor is not competitive with high-performance electrochemical sensors, it has been able to meet the needs of POC detection. At the same time, the sensor has excellent anti-interference performance. It has also been used successfully to test urine and serum samples from healthy and gout patients.

1. Introduction

The sensitivity, detection speed, and reliability of traditional molecular diagnostic methods have been continuously improved in recent years. However, due to its dependence on the isolation area of environmental control, large biochemical equipment, and the need for strict professional training of operators [1–4], it is still unable to break through barriers and enter scenarios outside the laboratory. POCT, as a new technology, can be directly applied to hospital beds, outpatient clinics, operating rooms, or accident sites [5, 6]. Accompanying diagnosis with just-in-time testing can reduce patient wait times and speed up access to drugs for treatment. At the same time, it is generally automatic analysis from samples to results, so the operator training requirements are low. It can also be performed in hospital laboratory departments, avoiding third-party testing [7–11]. With the rise of connected consumer devices and treatments increasingly tailored to an individual’s precise genetics and biomarkers, POCT diagnostics will increasingly enter the daily lives of individual patients and consumers [12–15].

POCT devices are often equipped with biosensors. A biosensor refers to an analytical device for detecting analytes, usually through a small analytical system in which the biological components are fixed to a solid surface and interact with the analyte [16–18]. Electrochemical or optical methods can detect these interactions. Due to the simplicity of the fabrication process, commercially available printed electrodes are an excellent alternative to conventional disk electrodes for inexpensive, high-throughput biochemical analysis [19–21]. Yamaguchi et al. [22] fabricated arrays of micropore-addressable electrodes on commercially available compact discs recordable (CD-R) substrates, and then assembled with microchannel PDMS chips into arrays of electrochemical sensing chips. It was also used for the sensitive detection of serum marker IL-6, with a detection limit of 10 fg/mL. In addition, the group also used a printed carbon electrode array as the substrate, combined with a...
PDMS microchannel, and inserted a silver reference electrode and platinum wire counter electrode in the channel to form an array electrochemical sensor chip, realizing the simultaneous detection of PSA and IL-6 [23]. Qi et al. [24] combined microfluidic and printed carbon electrode chips to produce an intelligent electrochemical microchip device for rapid and multivariate detection of tumor markers. The device integrates an automated solution delivery unit and a portable electrochemical detection platform, reducing multistep experiments to one-step implementation and interference. At the same time, the sensitive detection of tumor markers AFP and PSA was successfully realized by cyclic voltammetry analysis and the time-current curve method of a multichannel electrochemical instrument.

Uric acid (UA) accounts for about half of the active antioxidant substances in the blood and can change the redox potential or prevent oxidative damage [25, 26]. UA molecules are part of the normal cycle of nucleic acids produced when purines (from DNA or RNA) are oxidized by xanthine oxidase, which is present in peroxidase in most cells. Most mammals deliver uricase in the liver, while humans and other primates deposit uric acid in the kidneys, and most other mammals excrete uric acid in the urine. Uric acid in the body has antioxidant properties, and when its concentration is lower than the average level, it will induce some diseases, such as multiple sclerosis, Parkinson’s disease, and pernicious anemia [31–33]. Therefore, accurate and rapid detection of UA concentration in the human body plays an important role in treating and diagnosing the above diseases [34–36].

In this work, we proposed a simple method for in situ preparation of CuNW/SPCE for UA detection. Firstly, SPCE was placed as the substrate electrode, and the copper film was reduced and deposited on the surface of SPCE by the electrochemical method. Then, copper hydroxide nanowires were grown in situ on the surface of SPCE by a mixed solution of ammonium persulfate and sodium hydroxide. CuOHNW was converted to CuNWs by high-temperature heating and electric reduction, and UA was detected by electrochemistry.

2.2. Preparation of CuNW/SPCE. The preparation of CuNW was adopted from Xu et al. [37] with some modifications. Firstly, SPCE was placed as the working electrode in the electrolyte of 0.1 M NaAc and 0.02 M Cu(OAc)₂. The pH of the electrolyte was adjusted to 5.5 by HAc, and the copper film was deposited on the surface of SPCE for 8 min at the constant potential of ~0.9 V. The electrodes were then removed from the electrolyte, rinsed with water, and blow-dried with nitrogen. The solution was stirred and kept at room temperature during the entire electrodeposition process. Then, Cu(OH)₂NW was grown in situ on the surface of Cu/SPCE by soaking the prepared Cu/SPCE in a mixture of 0.133 M (NH₄)₂S₂O₈ and 2.667 M NaOH for 5 min. SPCE modified with Cu(OH)₂NW was converted into copper oxide nanowire (CuONW) by heating it at 150°C for 12 h. Then, the SPCE modified with CuONW was used as the working electrode. The CuNW grown in situ on the SPCE was obtained by electric reduction at ~0.7 V for 30 min in a 0.1 M KHCO₃ solution (denoted as CuNW/SPCE).

3. Results and Discussion

In this work, CuNWs were prepared in situ on SPCE. CuNW-modified SPCE was characterized by scanning electron microscopy and electrochemistry, and the electrocatalytic activity of the electrode on the UA was discussed. Figure 1 shows the schematic diagram of the preparation of CuNW/SPCE for UA detection.

In this work, we proposed a simple method for in situ preparation of CuNW on the surface of SPCE in the liquid phase and characterized the surface morphology by SEM. The rough surface structure of SPCE can be seen in Figure 2(a). Then, Cu(II) was reduced and deposited on the surface of SPCE by electrochemical deposition to obtain Cu/SPCE. Since Cu(OH)₂ can be converted to CuO as a precursor [38, 39]. It is necessary to prepare Cu(OH)₂NW in situ on Cu/SPCE surface. Cu(OH)₂NW was transformed into CuONW by heat treatment in an air atmosphere. Electrochemical reduction of CuONW was carried out in KHCO₃ electrolyte containing saturated N₂. As shown in Figure 2(b), free-growing CuNW was formed on the surface of SPCE.

In order to evaluate the analytical applicability of the CuNW/SPCE, the electrochemical performance of the sensor for UA oxidation was investigated in buffer solution. The sensors were placed in buffer solutions with and without UA, and cyclic voltammetry (CV) scanning was performed in the potential range of ~1.0 V to 0.8 V, as shown in Figure 3. Bare SPCE has no current response in 0.1 M NaOH solution. This phenomenon indicates that SPCE has no catalytic activity for the electro-oxidation of UA in the applied potential window. The CV curve of CuNW grown on the surface of SPCE is similar to that of Cu/SPCE. These results indicate the formation of CuNW on SPCE [40]. In CuNW/SPCE, the peak at 0.3 V may be due to the formation...
of soluble material by CuNW and OH\(^-\). This peak is usually used to study the electro-oxidation mechanism of UA. Compared with the CV curve without UA, some changes occur in the CV curve of the sensor in the presence of 2mM UA. The peak of the curve disappears at 0.3 V, mainly due to the adsorption of UA onto the surface of CuNW. The peak centered at 0.6 V is the response of the sensor to the electrocatalytic oxidation of UA. A weaker oxidation peak was also observed at 0.6V for Cu/SPCE than CuNW/SPCE. This phenomenon indicates that CuNW indeed causes the electrocatalytic oxidation signal of UA [40–42].

At the same time, the CV curves of the sensor for different concentrations of UA in the potential range of 0.0–0.8 V were also studied. As can be seen from Figure 4, the catalytic current is generated within the potential range of 0.4 V–0.8 V, and the oxidation peak current increases with the increase of UA concentration. This indicates that the oxidation of UA by CuNW has obvious electrocatalytic behavior [43, 44]. The influence of oxygen on the analytical performance of the sensor was also studied. The UA was scanned with the sensor before and after deoxygenation [45]. The experimental results show that the sensor is not affected by oxygen in UA detection.

The current response of the sensor was obtained by adding UA at 0.6 V constant potential. As can be seen from Figure 5, with the continuous dripping of UA, the current response increases step by step and reaches stability within 2s. The linear response range of UA concentration from 10 µM to 2 mM can be obtained. The linear regression
The equation is \( \text{ImA} = 2.1 + 220C(\text{mM}) \), and the correlation coefficient \( r = 0.997 \). The detection limit can be calculated to be 2 \( \mu \text{M} \). Table 1 shows the comparison of the proposed uric acid sensor with previous reports.

The loss of only 5% of the current response of the CuNW/SPCE to UA was observed in an \( \text{N}_2 \) atmosphere for one month, indicating good stability of the sensor. The relative standard deviation of 6 measurements of UA with different sensors was used to evaluate the reproducibility of the measurements. The relative standard deviation of 2 mM UA is 4.3%. The results show that UA detection with sensors has high reproducibility.

Selectivity is one of the important characteristics of electrochemical UA sensors, especially for detecting UA in practical samples. Ascorbic acid, glucose, and acetaminophen commonly coexist with UA in serum samples as general interfering compounds [51]. Because these small molecule compounds are easily electro-oxidized, they will produce a disturbing signal. Therefore, it is very important to study the influence of these compounds on sensor detection performance. To minimize the interference caused by the presence of anions in the biological medium, naphthol was dropped onto the surface of CuNW/SPCE and the resulting electrode was dried at room temperature for 15 min. The current response of 0.1 mM of ascorbic acid, 0.3 mM of glucose, 0.1 mM of acetaminophen, and 1 mM of UA at 0.6 V was measured. Compared with bare SPCE, these interferences have almost no effect on UA detected by the sensor, as shown in Figure 6. This indicates that the sensor used for UA detection is highly selective.

To evaluate the practical application of the sensor, it was used to detect UA in serum and urine samples from gout patients and healthy persons, respectively. The sample was dropped into 0.1 M NaOH solution, the solution was stirred, and the current response at 0.6 V potential was recorded. As can be seen from Figure 7, serum samples of healthy persons

### Table 1: Comparison of CuNW/SPCE with previously reported uric acid sensors.

| Sensor                                      | Linear range | Lod    | Reference |
|---------------------------------------------|--------------|--------|-----------|
| Zn-Al-LDH-QM/MWCNT/CPE                     | 0.1 to 100 \( \mu \text{M} \) | 0.05 \( \mu \text{M} \) | [46]       |
| GNP@CDs/GO/GO/GCE                          | 0.1 to 20 \( \mu \text{M} \)  | 0.0335 | [47]      |
| PANI/GO                                    | 1.5 to 890 \( \mu \text{M} \) | 0.57 \( \mu \text{M} \)  | [48]      |
| CDs/GCE                                    | 3 to 28.5 \( \mu \text{M} \) | 0.011 \( \mu \text{M} \) | [49]      |
| Graphite modified by \( \text{fe}_3\text{O}_4@\text{au-cys/ pani} \) | 20 \( \mu \text{M} \) to 1 mM | 1.8 \( \mu \text{M} \)  | [50]      |
| CuNW/SPCE                                  | 10 \( \mu \text{M} \) to 2 mM | 2.0 \( \mu \text{M} \)  | This work |

**Figure 5:** Amperometric responses of CuNW/SPCE upon the successive addition of UA at 0.6 V (0.1 M NaOH).

**Figure 6:** Amperometric response recorded using CuNW/SPCE towards UA and interference species (0.1 M NaOH).

**Figure 7:** Amperometric response recorded using CuNW/SPCE towards urine samples and serum samples from healthy person and gout patient.
and urine samples of gout patients have an obvious current response. When urine samples from healthy people were used, almost no current response was observed.

4. Conclusion

In conclusion, we proposed an electrochemical-based POC sensor for rapid UA detection. Commercial SPCE modified by CuNW has excellent electrocatalytic oxidation performance towards UA. This disposable sensor can be used for rapid detection of UA. The sensor provides linear detection of UA in the concentration range of 10 μM to 2 mM, with a detection limit of 2 μM. In addition, this POC sensor has been successfully applied for the detection of UA in urine samples and serum samples.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Z. Li, J. Li, Y. Dou, L. Wang, and S. Song, “A carbon-based antifouling nano-biosensing interface for label-free POCT of HbA1c,” Biosensors, vol. 11, no. 4, 2021.
[2] Y. Yi, A. Liang, L. Luo, Y. Zhang, H. Zhao, and A. Luo, “A novel real-time TMAO detection method based on microbial electrochemical technology,” Bioelectrochemistry, vol. 144, Article ID 108038, 2022.
[3] Y. Fan, S. Shi, J. Ma, and Y. Guo, “A paper-based electrochemical immunosensor with reduced graphene oxide/thiophene/gold nanoparticles nanocomposites modification for the detection of cancer antigen 125,” Biosensors and Bioelectronics, vol. 135, pp. 1–7, 2019.
[4] H. Karimi-Maleh, Y. Orooji, F. Karimi et al., “A critical review on the use of potentiometric based biosensors for biomarkers detection,” Biosensors and Bioelectronics, vol. 184, Article ID 113252, 2021.
[5] Y. Li, Z. Li, H. Liu et al., “A portable electrochemical platform integrated with a 3D AuNPs/CNTs sponge for point-of-care testing of neurotransmitters,” Journal of the Electrochemical Society, vol. 166, no. 6, pp. B524–B531, 2019.
[6] S.-E. Kim, Y. J. Kim, S. Song, K.-N. Lee, and W. K. Seong, “A simple electrochemical immunosensor platform for detection of Apolipoprotein A1 (Apo-A1) as a bladder cancer biomarker in urine,” Sensors and Actuators B: Chemical, vol. 278, pp. 103–109, 2019.
[7] W. Iwasaki, C. Kataoka, K. Sawadaishi, K. Suyama, N. Morita, and M. Miyazaki, “A simple, low cost, sensitive, and portable electrochemical immunochromatography sensing device to measure estrone-3-sulfate,” Sensors, vol. 20, no. 17, 2020.
[8] Z. Xu, Z. Liu, M. Xiao, L. Jiang, and C. Yi, “A smartphone-based quantitative point-of-care testing (POCT) system for simultaneous detection of multiple heavy metal ions,” Chemical Engineering Journal, vol. 394, Article ID 124966, 2020.
[9] Y. Kanno, Y. Zhou, T. Fukuma, and Y. Takahashi, “Alkaline phosphatase based electrochemical analysis for point of care testing,” Electroanalysis, vol. 34, no. 2, pp. 161–167, 2022.
[10] H. Karimi-Maleh, A. Khataee, F. Karimi et al., “A green and sensitive guanine-based DNA biosensor for idarubicin anti-cancer monitoring in biological samples: a simple and fast strategy for control of health quality in chemotherapy procedure confirmed by docking investigation,” Chemosphere, vol. 291, Article ID 132928, 2022.
[11] H. Karimi-Maleh, F. Karimi, L. Fu et al., “Cyanazine herbicide monitoring as a hazardous substance by a DNA nanostructure biosensor,” Journal of Hazardous Materials, vol. 423, Article ID 127058, 2022.
[12] B. Zhang, M. Chen, J. Cao et al., “An integrated electrochemical POCT platform for ultrasensitive circRNA detection towards hepatocellular carcinoma diagnosis,” Biosensors and Bioelectronics, vol. 192, Article ID 113500, 2021.
[13] C. Joe, B. H. Lee, S. H. Kim, Y. Ko, and M. B. Gu, “Aptamer duo-based portable electrochemical biosensors for early diagnosis of periodontal disease,” Biosensors and Bioelectronics, vol. 199, Article ID 113884, 2022.
[14] H. Karimi-Maleh, C. Karaman, O. Karaman et al., “Nanochemistry approach for the fabrication of Fe and N co-decorated biomass-derived activated carbon frameworks: a promising oxygen reduction reaction electrocatalyst in neutral media,” Journal of Nanostructure in Chemistry, 2022.
[15] H. Karimi-Maleh, H. Beitollahi, P. S. Kumar et al., “Recent advances in carbon nanomaterials-based electrochemical sensors for food azo dyes detection,” Food and Chemical Toxicology, vol. 164, Article ID 112961, 2022.
[16] Y. Li, R. He, Y. Niu, and F. Li, “Paper-based electrochemical biosensors for point-of-care testing of neurotransmitters,” Journal of Analysis and Testing, vol. 3, no. 1, pp. 19–36, 2019.
[17] L. Fu, X. Zhang, S. Ding et al., “Recent developments in the electrochemical determination of sulfonamides,” Current Pharmaceutical Analysis, vol. 18, no. 1, pp. 4–13, 2022.
[18] H. Shi, L. Fu, F. Chen, S. Zhao, and G. Lai, “Preparation of highly sensitive electrochemical sensor for detection of nitrite in drinking water samples,” Environmental Research, vol. 209, Article ID 112747, 2022.
[19] I.-H. Cho, J. Lee, J. Kim et al., “Current technologies of electrochemical immunosensors: perspective on signal amplification,” Sensors, vol. 18, no. 2, 2018.
[20] J. Lee, Y. Kang, J. Chang, J. Song, and B.-K. Kim, ACS Sensors, vol. 5, no. 7, pp. 1943–1948, 2020.
[21] H. Wang and K. Wang, International Journal of Electrochemical Science, vol. 16, p. 2, 2021.
[22] A. Yamaguchi, P. Jin, H. Tsuchiya et al., “Rapid fabrication of electrochemical enzyme sensor chip using polydimethylsiloxane microfluidic channel,” Analytica Chimica Acta, vol. 468, no. 1, pp. 143–152, 2002.
[23] B. V. Chikkaveeraiah, V. Mani, V. Patel, J. S. Gutkind, and J. F. Rusling, “Microfluidic electrochemical immunoarray for ultrasensitive detection of two cancer biomarker proteins in serum,” Biosensors and Bioelectronics, vol. 26, no. 11, pp. 4477–4483, 2011.
[24] L. Qi, S. Liu, Y. Jiang, J.-M. Lin, L. Yu, and Q. Hu, “Simultaneous detection of multiple tumor markers in blood by functional liquid crystal sensors assisted with target-induced dissociation of aptamer,” Analytical Chemistry, vol. 92, no. 5, pp. 3867–3873, 2020.
[25] M. Khanwal, R. Fujita, J. Lee et al., “Development of a POCT type insulin sensor employing anti-insulin single chain...
variable fragment based on faradaic electrochemical impedance spectroscopy under single frequency measurement," *Biosensors and Bioelectronics*, vol. 200, Article ID 113901, 2022.

[26] S. Dervin, P. Garguly, and R. S. Dahiya, "Disposable electrochemical sensor using graphene oxide–chitosan modified carbon-based electrodes for the detection of tyrosine," *IEEE Sensors Journal*, vol. 21, no. 23, pp. 26226–26233, 2021.

[27] J. F. Hernández-Rodríguez, D. Rojas, and A. Escarpa, "Electrochemical sensing directions for next-generation healthcare: trends, challenges, and frontiers," *Analytical Chemistry*, vol. 93, pp. 167–183, 2020.

[28] X. Wang and L. Hu, "Review—enzymatic strips for detection of serum total cholesterol with point-of-care testing (POCT) devices: current status and future prospect," *Journal of the Electrochemical Society*, vol. 167, no. 3, Article ID 037535, 2020.

[29] H. Karimi-Maleh, A. Ayati, S. Ghanbari et al., "Electrochemical biosensor for the determination of sufentanil in human plasma and urine based on tiO2-graphene composite modified carbon paste electrode," *Journal of Molecular Liquids*, vol. 329, Article ID 115062, 2021.

[30] H. Karimi-Maleh, A. Ayati, R. Davoodi et al., "Recent advances in using of chitosan-based adsorbents for removal of pharmaceutical contaminants," *Journal of Cleaner Production*, vol. 291, Article ID 125880, 2021.

[31] Y. M. Park, Y. S. Choi, H.-R. Lee et al., "Flexible and highly ordered nanopillar electrochemical sensor for sensitive insulin evaluation," *Biosensors and Bioelectronics*, vol. 161, Article ID 112252, 2020.

[32] S. Bunyarataphan, T. Dharakul, S. Fucharoen, K. Paiboonsukwong, and D. Japrung, "Glycated albumin measurement using an electrochemical aptasensor for screening and monitoring of diabetes mellitus," *Electroanalysis*, vol. 31, no. 11, pp. 2254–2261, 2019.

[33] B. D. Mansuriya and Z. Altintas, "Graphene quantum dot-based electrochemical immunosensors for biomedical applications," *Materials*, vol. 13, no. 1, 2019.

[34] Q. Cao, B. Liang, C. Yu et al., "High accuracy determination of multi metabolite by an origami-based coulometric electrochemical biosensor," *Journal of Electroanalytical Chemistry*, vol. 873, Article ID 114358, 2020.

[35] T. Islam, M. M. Hasan, A. Awal, M. Nurunnabi, and A. J. S. Ahmammad, "Metal nanoparticles for electrochemical sensing: progress and challenges in the clinical transition of point-of-care testing," *Molecules*, vol. 25, no. 24, 2020.

[36] J. Liu, W. Lu, L. Zhang et al., "Integrated hand-held electrochemical sensor for multicomponent detection in urine," *Biosensors and Bioelectronics*, vol. 193, Article ID 113534, 2021.

[37] X. Xu, R. Wang, P. Nie et al., "Copper nanowire-based aerogel with tunable pore structure and its application as flexible pressure sensor," *ACS Applied Materials & Interfaces*, vol. 9, no. 16, pp. 14273–14280, 2017.

[38] W. Zhang, R. Wang, F. Luo, P. Wang, and Z. Lin, "Miniaturized electrochemical sensors and their point-of-care applications," *Chinese Chemical Letters*, vol. 31, no. 3, pp. 589–600, 2020.

[39] H. Jiang, J. Yang, K. Wang, D. Jiang, and C. Jin, "Miniaturized paper-supported 3D cell-based electrochemical sensor for bacterial lipopolysaccharide detection," *ACS Sensors*, vol. 5, pp. 1325–1335, 2020.

[40] O. Surucu, E. Öztürk, and F. Kuralay, "Nucleic acid integrated technologies for electrochemical point of care diagnostics: a comprehensive review," *Electroanalysis*, vol. 34, no. 2, pp. 148–160, 2022.

[41] L. Xu, N. Shaw, F. Jahanpeyma, J. Zhao, M. Azimzadeh, and K. T. Al-Jamil, "Optical, electrochemical and electrical (nano)biosensors for detection of exosomes: a comprehensive overview," *Biosensors and Bioelectronics*, vol. 161, Article ID 112222, 2020.

[42] A. D. Luong, A. Buzid, S. K. Vashist, and J. H. Luong, "Perspectives on electrochemical biosensing of COVID-19," *Current Opinion in Electrochemistry*, vol. 30, Article ID 100794, 2021.

[43] H. Kimura, D. Miura, W. Tsugawa, K. Ikebukuro, K. Sode, and R. Asano, "Rapid and homogeneous electrochemical detection by fabricating a high affinity bispecific antibody-enzyme complex using two catcher/tag systems," *Biosensors and Bioelectronics*, vol. 175, Article ID 112885, 2021.

[44] R. Sung and Y. S. Heo, "Sandwich ELISA-based electrochemical biosensor for leptin in control and diet-induced obesity mouse model," *Biosensors*, vol. 11, no. 1, p. 7, 2020.

[45] L. Liu, Y. Gao, J. Liu et al., "Sensitive techniques for POCT sensing on the residues of pesticides and veterinary drugs in food," *Bulletin of Environmental Contamination and Toxicology*, vol. 107, no. 2, pp. 206–214, 2021.

[46] R. Zainul, N. Hashim, S. N. A. M. Yazid et al., *International Journal of Electrochemical Science*, vol. 16, Article ID 210941, 2021.

[47] M. Li, X. Yang, W. Liu, H. Wang, H. Jiang, and X. Liu, "Ultrasensitive determination of dopamine and uric acid based on gold nanoparticles@carbon dots/electrochemical reduced graphene oxide modified glassy carbon electrode," *International Journal of Electrochemical Science*, vol. 16, Article ID 21084, 2021.

[48] L. Shi, N. Wu, W. Liu, G. Yang, and Z. Wang, "Electrochemical determination of ascorbic acid, dopamine and uric acid at polyaniline-graphene nanocomposites modified electrode," *International Journal of Electrochemical Science*, vol. 16, Article ID 210556, 2021.

[49] Z. Wang, R. An, Y. Dai, and H. Luo, "A simple strategy for the simultaneous determination of dopamine, uric acid, l-tryptophan and theophylline based on a carbon dots modified electrode," *International Journal of Electrochemical Science*, vol. 16, Article ID 210450, 2021.

[50] W. T. Wahyuni, B. R. Putra, A. Fauzi, D. Ramadhanti, E. Rohaeti, and R. Heryanto, "A brief review on fabrication of screen-printed carbon electrode: materials and techniques," *International Journal of Electrochemical Science*, vol. 8, no. 3, pp. 210–218, 2021.

[51] J. E. Contreras-Naranjo and O. Aguilar, "Suppressing non-specific binding of proteins onto electrode surfaces in the development of electrochemical immunosensors," *Biosensors*, vol. 9, no. 1, 2019.