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Direct Electrode Modification of Paper-based Microfluidic Electrochemical Sensors Through Electrodeposition and Electropolymerization for Clozapine Sensing

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Summary:

Here we demonstrate the superior performance of microfluidic electrochemical sensors (µCS) over screen-printed carbon-based electrodes (SPCE). Additionally, electrodeposition of gold nanoparticles (ED (AuNPs)) and electropolymerization of L-cysteine (EP (L-cys)) are introduced for the first time for modifying the working electrode through a paper-based microfluidic sensor. Also, the sensor was employed for clozapine (CLZ) sensing in human blood plasma, which depicted the excellent applicability of the device which making it a promising platform for point-of-care diagnostics.

Keywords: Microfluidic electrochemical sensor, Paper-based sensor, Electrodeposition, Electropolymerization.

Introduction

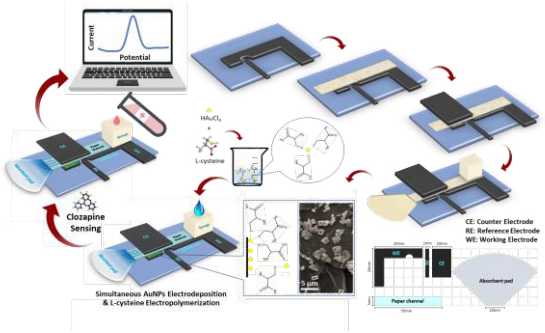
Schizophrenia is a debilitating mental disorder characterized by disruptions in perceiving reality which clozapine (CLZ) stands out as the most promising drug for treating that.

Using catalytic active modifiers and additives e.g. to improve electron or ion transport in electrochemical sensors usually offers significant benefits by improving sensitivity and selectivity. An elegant way to introduce both is electrodeposition (ED) and electropolymerization (EP). Despite classical static devices with glassy carbon electrodes or SPCE electrodes paper-based microfluidic electrochemical sensors have gained significant attention [1]. Advantages are simplicity, portability, cost-effectiveness, and potential for point-of-care applications. Although ED of AuNPs and EP of (L-cys) improved the sensing in classical static devices, electrodes for microfluidic systems have up to now not been functionalized by these approaches. Furthermore, despite an external functionalization a direct ED and EP onto the electrode within the final paper-based microfluidic device could be possible, but was not reported up to now.

Scope of this study is to find proper conditions for the ED of AuNPs and EP of (L-cys) onto the electrodes of paper-based microfluidic electrochemical sensor, while using the microfluidic channel also for transport of the electrodeposition solution [2]. Furthermore, the study compares the performance of widely employed SPCE electrodes to µCS based systems. Ultimately, the µCS/S (ED & EP) employed for CLZ sensing in real blood serum successfully.

Experimental

The alignment of the component for the µCS device is sketched in Scheme 1. After providing the $HAuCl_4$ and L-cysteine solution through the sponge the electrochemical fabrication and detection are carried out through cyclic voltammetry (CV). AuNPs were electrodeposited and L-cys were electropolymerized simultaneously through the µCS by handling a potential window of −1.5 to +2.2 V at a scan rate of 100 mV s^{-1} via CV run for 10 cycles in a solution of 0.1 M PBS at pH = 6.0 consists of 1.0 mM $HAuCl_4$ and 1.0 mM L-cys. As a result, the prepared simultaneous ED of AuNPs and EP of L-cys through a paper-based microfluidic sensor (µCS/S (ED & EP)) was used after 3 CV runs in 0.1 M PBS at pH = 6.0 and employed as the sensor. Electrochemical measurements were performed using an Ivium Potentiostat (Vertex) controlled with IviumSoft software. Scanning electron microscope (SEM), CV, and electrochemical impedance spectroscopy (EIS) were employed to certify that the AuNPs and poly (L-cys) were attached successfully to the working electrode surface.



Scheme. 1. μCS/S (ED & EP) sensor assembling process.

Results and discussion

To confirm the immobilization of each substrate onto the working electrode, CVs and EIS of the platforms were recorded in a solution consisting of 5.0 mM of $[Fe(CN)6]^{3-/4-}$. By modifying the platforms by simultaneous ED of AuNPs and EP of (L-cys) not only did peak currents increase dramatically but also ΔE_p were decreased to 17 mV and 13 mV for SPCE/S (ED & EP) and μCS/S (ED & EP), respectively. By comparing the EIS curves related to the bare SPCE and μCS it is clear that the R_{ct} value for μCS (46 Ω) is much lower than SPCE (690 Ω). It may be attributed to the 3D and sandwich-like structure of μCS devices. SPCE/S (ED & EP) and μCS/S (ED & EP) present very smaller semicircles with R_{ct} values of 225 Ω and 13 Ω, respectively. The herein-reported EIS data corroborate the preceding results related to the CV data and both confirm that the electrode for sensing is successfully obtained.

Square wave voltammetry (SWV) was applied for CLZ analysis under the optimized protocols (Fig. 1A) and calibration plot for that were constructed under optimal conditions in which the peak currents of CLZ increase linearly with concentration from 0.5 to 10.0 μM in 0.1 M ABS in pH = 8.0 (Fig. 1B). The limit of detection (LOD) and quantitation (LOQ) were calculated to be 70 nM and 0.23 μM, respectively.

For the stability study, the SWV signal employed in the presence of 3.0 μM of CLZ in 0.1 M PBS with pH = 8.0 for 6 consecutive SWVs and the peak current response is depicted against the replicate (Fig. 1C). The anodic stripping current exhibits only a marginal decrease (11%) after 6 repetitions. This slight reduction is likely attributed to the depletion of the analyte within the sampling sponge or/and the filling or removal of the modifier layer from the WE surface. This investigation also shows the great robustness of μCS/S (ED & EP) for drug sensing applications.

To determine the sensor's ability to CLZ sensing in the presence of possible potentially interfering substances, selectivity studies were carried out (Fig. 1D). Results show that with 30.0 μM ascorbic acid, 30.0 μM uric acid did not significant interfere with 10.0 μM CLZ and the sensor was able to detect CLZ even in the presence of these common interfering substances. However, in the presence of 30.0 μM glucose, the CLZ signal drops by 20%, in the presence of 30.0 μM ascorbic acid, 30.0 μM uric acid and 30.0 μM glucose as a same time did not significant interfere with 10.0 μM CLZ. The sensor exhibited a negligible altering current and gave notable selectivity in CLZ sensing in the presence of ascorbic acid, glucose and uric acid as common interfering biomolecules.

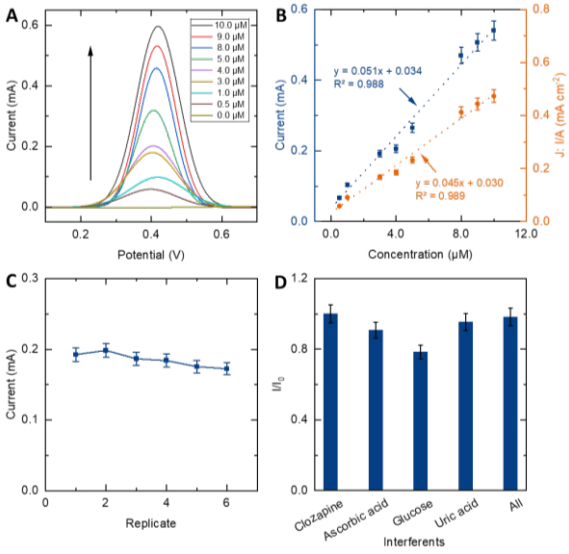


Fig. 1. (A) SWVs of the μCS/S (ED & EP) for different concentrations of CLZ, (B) the calibration plot of Ipa vs. CLZ concentration, (C) Stability study, and (D) selectivity study.

Conclusion

The μCS offers several advantages over SPCE in terms of cost, simplicity, and sensitivity. These advantages are due to the combined microfluidic configuration, 3D electrode layout, and a unique electrochemical modifier. The μCS/S (ED & EP) is capable of detecting CLZ with a wide linear range, low LOD, and high sensitivity. We believe our findings have significant implications in developing other portable, fast, and cost-effective electrochemical sensors, such as clinical diagnosis and security inspection.

References

[1] L.-L Shen, et al., Paper-based microfluidics for electrochemical applications, *ChemElectroChem* 7.1, 10-30 (2020); doi: 10.1002/celc.201901495

[2] MH Ghanbari, et al., Superior performance of N-doped carbon Nanoonions/Nafion based microfluidic electrochemical Cd2+ sensor when compared to Screen-Printed Carbon-Based electrode devices, *Microchemical Journal* 110506 (2024); doi: 10.1016/j.microc.2024.110506