SWEAT BIOSENSORS FOR SPORTS MONITORING

BIOSSENSORES DE SUOR PARA MONITORAMENTO ESPORTIVO

BIOSENSORES DE SUDOR PARA LA MONITORIZACIÓN DEPORTIVA

ORIGINAL ARTICLE
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Liang Duan[1]
(Physical Education Professional)
Xuanfei Yan[2]
(Physical Education Professional)

1. College of Shandong sport University, Rizhao 276826, Shandong, China.
2. The physical education department, Guangdong Polytechnic College; Zhaoqing 526100,Guangdong, China.

Correspondence:
Xuanfei Yan
Rizhao, Shandong, China. 276826.
1353231381@qq.com

ABSTRACT

Introduction: Biometric sweat monitoring is an important tool for optimizing sports training. The possibility of developing a wearable amperometric lactate biosensor using a screen-printed carbon electrode (SPCE) impregnated by Ag nanoparticles (Ag NPs) for sweat determination in sports monitoring is questioned. Objective: To develop a sensor with GCE substrate coated on Ag NPs/SPCE. Methods: FESEM and XRD analysis were used for the morphological and structural characterizations of Ag and SPCE NPs, respectively. Results: FESEM, EDS, and XRD revealed that Ag NPs were uniformly dispersed in SPCE. The electrochemical biosensor responded linearly to lactate in phosphate buffer solutions, with detection and sensitivity limits of 1.2 µM and 14.2 mAcm-2 mM-1, respectively. Conclusion: The results suggest that Ag NPs/SPCE can be used to continuously monitor lactate levels in sweat as a practical and reliable biosensor for use. ***Level of evidence II; Therapeutic studies - investigation of treatment outcomes.***

Keywords: Biosensing Techniques; Sweat; Athletic Performance; Biological Monitoring.

RESUMO

Introdução: O monitoramento biométrico do suor é uma ferramenta importante para otimização do treino esportivo. Questiona-se a possibilidade do desenvolvimento de um biossensor amperométrico de lactato vestível utilizando eletrodo de carbono impresso em tela (SPCE) impregnado por nanopartículas Ag (Ag NPs) para determinação do suor no monitoramento esportivo. Objetivos: Desenvolver um sensor com substrato GCE revestido em Ag NPs/SPCE. Métodos: A análise FESEM e XRD foi utilizada para as caracterizações morfológicas e estruturais dos NPs de Ag e SPCE, respectivamente. Resultados: Os resultados da FESEM, EDS, XRD revelaram que os NPs de Ag estavam uniformemente dispersos em SPCE. O biossensor eletroquímico respondeu linearmente ao lactato em soluções tampão fosfato, com limites de detecção e sensibilidade de 1,2 µM e 14,2 mAcm-2 mM-1, respectivamente. Conclusão: Os resultados sugerem que o Ag NPs/SPCE pode ser utilizado para monitorar continuamente os níveis de ácido láctico no suor como um biossensor prático e confiável para o uso. ***Nível de evidência II; Estudos terapêuticos - investigação dos resultados do tratamento.***

***Descritores*:** *Técnicas Biossensoriais; Suor; Desempenho Atlético; Monitoramento Biológico.*

RESUMEN

Introducción: La monitorización biométrica del sudor es una herramienta importante para la optimización del entrenamiento deportivo. Se cuestiona la posibilidad de desarrollar un biosensor de lactato amperométrico vestible utilizando un electrodo de carbono serigrafiado (SPCE) impregnado por nanopartículas de Ag (Ag NPs) para la determinación del sudor en la monitorización deportiva. Objetivos: Desarrollar un sensor con sustrato GCE recubierto de Ag NPs/SPCE. Métodos: Se utilizó el análisis FESEM y XRD para las caracterizaciones morfológicas y estructurales de las NPs de Ag y SPCE, respectivamente. Resultados: Los resultados de FESEM, EDS y XRD revelaron que las NPs de Ag estaban uniformemente dispersas en el SPCE. El biosensor electroquímico respondió linealmente al lactato en soluciones de tampón fosfato, con límites de detección y sensibilidad de 1,2 µM y 14,2 mAcm-2 mM-1, respectivamente. Conclusión: Los resultados sugieren que Ag NPs/SPCE puede utilizarse para monitorizar de forma continua los niveles de lactato en el sudor como un biosensor práctico y fiable para su uso. ***Nivel de evidencia II; Estudios terapéuticos - investigación de los resultados del tratamiento.***

***Descriptores*:** *Técnicas Biosensibles; Sudor; Rendimiento Atlético; Monitoreo Biológico.*

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INTRODUCTION

The clinical diagnostic of a regularly examined relevant parameter, Lactate content, is utilized in sports medicine, surgery, severe mental/physical discomfort, and the food industry to assess a person's health procedure, pathology, and normal health inspection.[1] Depending on the intensity of the activity, the level can reach 25 mmol/L.[2] Lactate monitoring is important in diseases such as respiratory failure, tissue destruction, hemorrhage, infection, and liver illness, in addition to being widely utilized in health management and food industry.[3,4] Traditional methods for determining lactate levels are imprecise and time-consuming, necessitating the development of a biosensor with excellent precision and high input for lactate screening in a variety of samples.[5] As a result, there has been a lot of focus on developing low-cost transportable device, notably electrochemical biosensors, for quick, real-time lactate monitoring.

Chemical and electrochemical data is translated into analytical signals by wearable chemicals and electrochemical sensors.[6,7] Wearable epidermal electrochemical sensors have also been shown in studies to help evaluate glucose, lactate, potassium, cortisol, ammonia, alcohol, and urea contents in human urine for sport and healthcare monitoring.[8] Lactate, an important element of intermediate metabolism, is linked to sports motivation and performance regimens.[9,10] Lactate ($C_3H_6O_3$) is a result of glucose metabolism by muscle cells. Because of their antibacterial capabilities, Ag nanoparticles have lately acquired favor in biosensor applications.[11,12] In endurance and high-intensity activities, lactate monitoring can assist prevent blood clot and hemorrhagic shock. As a result, the focus of this research was on the development of wearable amperometric biosensing using Ag NPs/SPCE as a lactate sensor for sweat monitoring in sport and healthcare management.

MATERIALS AND METHOD

0.4g pyrrole monomer, 4.5g $AgNO_3$ (99%), and 0.5g $FeCl_3$ (99%) were dissolved in 100 mL of ethylene glycol (98%) to make Ag NPs.[13,14] This mix was stirred for 2 hours at 120°C. After cooling to room temperature, 5mL glycerol (99.5%), 10 mL N-methyl pyrrolidone (99.8%), 10mL poly (vinylpyrrolidone) (99.8%), and 25 mL ethylene glycol have been added to the resulting product under mechanical stirring for 5 hours at room temperature. After that, the Ag NPs were centrifuged for 10 minutes at 2000 rpm. To attain the 15 mg/mL of distributed Ag NPs mix, Ag NPs were soaked in distilled water and ultrasonic assisted dispersed in ethanol (99%), respectively. The scattered Ag NPs were then stored in the dark at room temperature for using. The substrate was built on a flexible terephthalate (PET) substrate with a screen-printed carbon electrode (SPCE).

An Eco-Chemie Autolab method was used for electrochemical investigations, which included a cell with three compartments, a functioning Ag NPs/SPCE electrode, and a platinum wire as counter electrode. The Ag/AgCl reference electrode's potentials were measured and recorded. Lactate solution was produced by combining 5.0mg Lactate with 1.0 mL phosphate-buffered saline (PBS). 20 liters of the solution were poured onto the electrodes' surfaces and allowed to dry in the open air. A field-emission scanning electron microscope was used to examine the Ag NPs/SPCE electrode. Using an X-ray diffractometer, the structural characteristics of Ag NPs/SPCE were investigated (XRD). EIS also looked studied the charge transfer process at different frequencies ranging from 0.1 Hz to 100 kHz with 10mV potential amplitudes. Real sweat samples were gathered from numerous athletes and analysed immediately after their responses. To perform a sensor regaining analysis, a tiny fraction of the 950L total sample was combined with 50L of lactate solution (0.1M).

The study was conducted in accordance with the Declaration of Helsinki. The participants signed the Free and Informed Consent Form (EHIC) for this work.

RESULTS AND DISCUSSION

Figure 1a displays SEM image of AgNPs spin-coated SPCE, which show that Ag nanoparticles with just a diameter of 100 nm formed uniformly onto porous surface of the SPCE. The XRD pattern of SPCE and AgNPs/SPCE were indicated in Figure 1b. As can be seen, all samples' XRD patterns show a diffraction peak in 26.19°, which corresponds to the (002) plane of the graphitic structures of SPCE (JCPDS card No. 12-0212).[15] Figure 2b displays diffraction peaks at 38.1°, 44.3°, and 64.5°, which correspond to the (111), (220), (200), and (311) plane of the fcc phase of Ag^+ ions (JCPDS card No.04-0783).

Figure 2a shows the EDS of AgNPs/SPCE. Ag elements can be seen in the EDS spectra, as can be seen. Furthermore, the signals of O and C elements that are connected to the SPCE layer are noticed.[16]

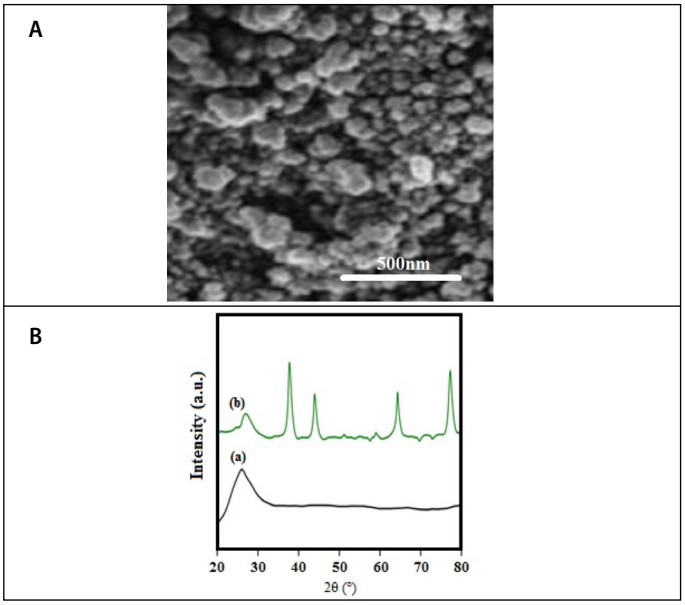

Figure 1. (A) SEM image of Ag NPs/SPCE, (B) XRD pattern of (A) SPCE, (B) Ag NPs/SPCE.

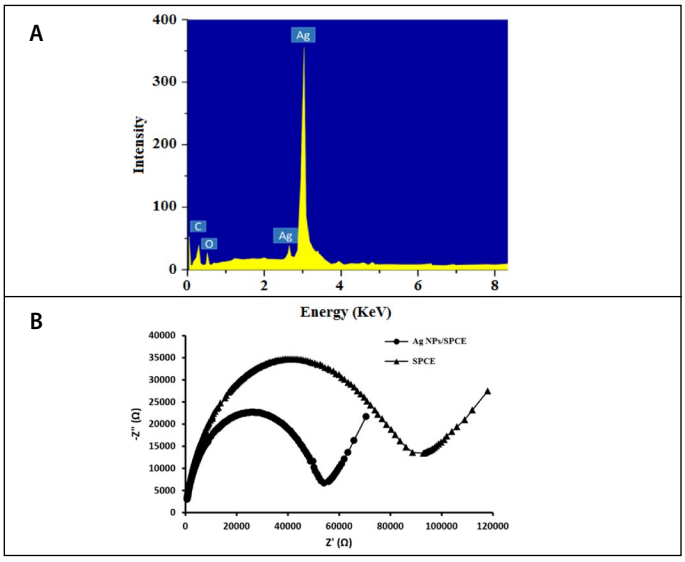

Figure 2. (A) EDS spectum of AgNPs/SPCE, (B) EIS Nyquist curves of SPCE and Ag NPs/SPCE.

SEM, XRD, and EDS investigations show that bimetallic Ag NPs were successfully formed on SPCE.

EIS is a famous and effective tool for detecting charge-separation and -transfer in sensing applications.[17] EIS characterized the effect of AgNPs onto the charge-separation process in SPCE in greater detail. The arc radius visible in EIS spectra indicates the electron transport resistance in the surface of the electrode. Figure 2b shows that arc radius for AgNPs/SPCE is smaller than that of SPCE, indicating that the earlier has superior charge parting and faster interfacial charge transfer than the latter. The EIS findings demonstrate that using AgNPs in SPCE structures can effectively development charge-transfer. This gives us a new, better substance to fabricate biosensors.

Because the sensor is quite stable, it might be used to determine the true lactate content in sweat specimens. Lactate concentration was evaluated in sweat to explore the AgNPs/SPCE electrodes for measuring lactate in biological fluids.[18] Lactate with in sweat sample was determined using a conventional lactate injection. Figure 3 displays the observed amperometrogram of a sweet Ag NPs/SPCE produced sample after 0.1 µM lactate liquid injections. The calibration curve in Figure 3 has a coefficient

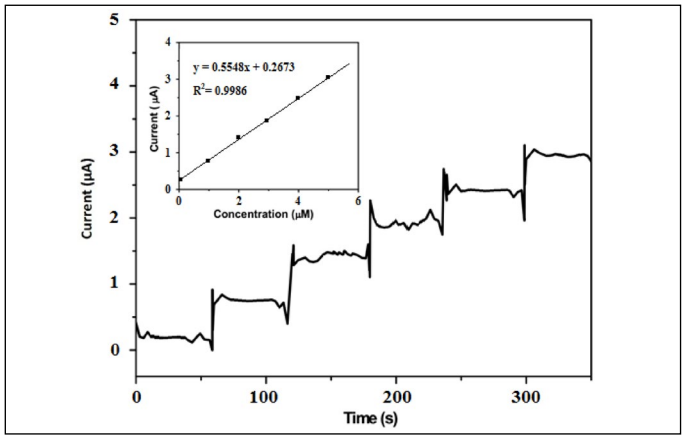

Figure 3. The observed amperometrogram of AgNPs/SPCE in 0.1M PBS as well as varied lactate concentrations in a genuine sample; inset of Fig. 5 shows the calibration curve plot.

of correlation of 0.9986. As a result, lactate concentrations in 0.1M PBS and pure sweat were estimated to be 0.42 μM and 0.26 μM, respectively.

The detection limit (LOD) was 0.44M. As indicated in Table 1, the LOD is comparable with those found from other lactate determination methods generally, which may be related to their greater aspect ratio as well as a longer carrier lifespan compared to the other. The repeatability was determined by calculating the relative-standard-deviation (RSD) from 9 different readings of 5mM lactate concentration using a constant biosensor. RSD was given a percentage value of 5%. The storage stability was evaluated, and it was determined that 15 days later, it retains 50% of its previous responses. Based on these findings, it may be determined that using AgNPs/SPCE to manufacture lactate biosensors allows for the acquisition of analytical responses comparable to those obtained using other nanostructures. Furthermore, the biosensor developed in this work has benefits for example a simple production procedure and the utilization of cost-effective nanomaterial [19-21].

Table 1. Comparison of the performance of the AgNPs/SPCE sensor with that of other lactate sensors.

Technique	Electrodes	Sensitivity ($\mu Acm^{-2}\ \mu M^{-1}$)	LOD(μM)	Ref.
Amperometric	Ag NPs/SPCE	0.55	0.44	This work
Amperometric	Au nanostructures	37.10	11.52	19
Amperometric	GNWs/LOx/PET	18.43	1.02	20
Amperometric	PtNp-CNF-PDDA/SPCE	36.81	11.14	21

CONCLUSIONS

When evaluating an athlete's performance, sweat lactate level is among the most crucial factors to be considered. A sensitive electrochemical sensor was built in this study to discover lactate using a simple approach. The sensor was created using a GCE substrate that had been coated with Ag NPs/SPCE. FESEM and XRD analyses were used to characterize the structural and morphological properties of AgNPs/SPCE. The FESEM results revealed that the Ag NPs in SPCE were uniformly distributed. Amperometry was used to test the device's sensor performance. The lactate in phosphate buffer solution electrochemical biosensor had a linear response with a low detection limit and sensitivity of 0.44 μM and 0.55 $mAcm^{-2}\ mM^{-1}$, respectively. This sensor calculated the level of lactate in genuine sweat samples to be extremely near towards the amount of injection, making it a biosensor in lactate detection in sweat samples.

All authors declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: The work is conceived and executed by Liang Duan. The analysis and manuscript writing is by Xuanfei Yan. The authors are equally contributed in execution and writing of this manuscript. .

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