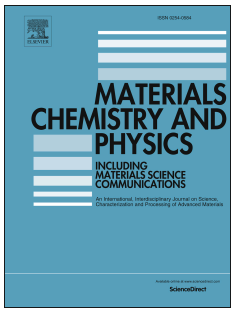

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Credit Author Statement

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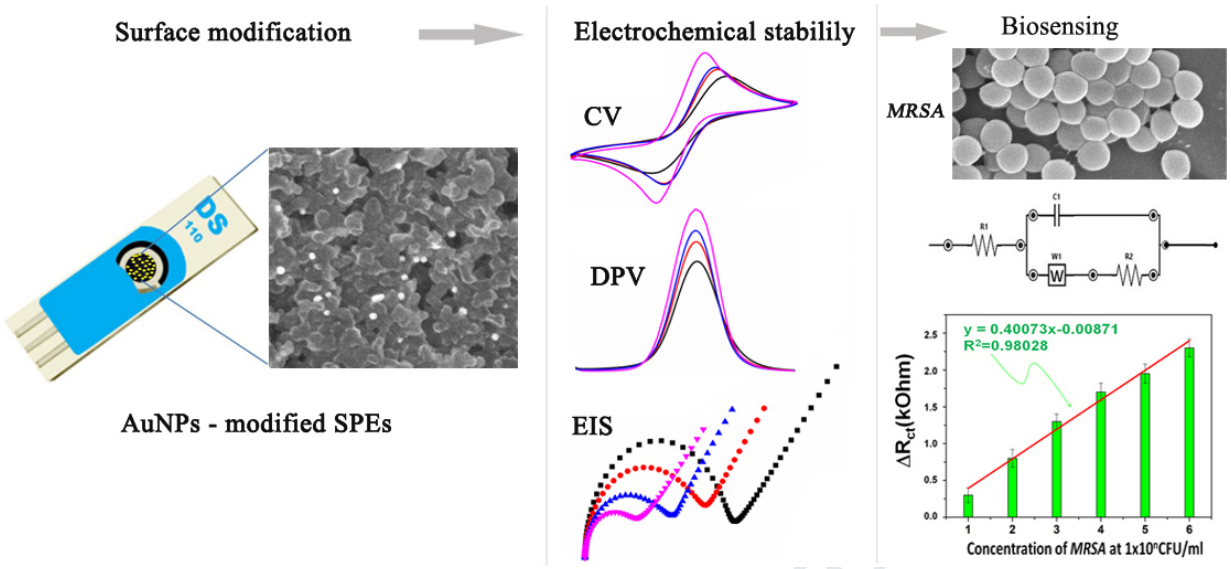

Electrochemical stability of screen-printed electrodes modified with Au nanoparticles for detection of methicillin-resistant *Staphylococcus aureus*

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Abstract

In this study, the surface of carbon screen-printed electrodes (SPEs) was modified with Au nanoparticles (AuNPs) of different sizes to investigate their electrochemical stability for detection of methicillin-resistant *Staphylococcus aureus* (*MRSA*). AuNPs were electrochemically synthesised and used to modify the working electrode of SPEs via drop-casting method. Electron microscopic techniques were conducted to investigate the change in the morphology of AuNP-modified SPEs. The electrochemical behaviour of the AuNP-modified SPEs was studied by cyclic voltammetry (CV), differential pulse voltammetry, and electrochemical impedance spectroscopy in 5.0 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$ solution added with 0.1 M KCl. The AuNP-modified SPEs were also functionalised and prepared for the electrochemical detection of *MRSA*. Results showed that spherical AuNPs were successfully synthesised, the mean sizes were 25, and 15 nm. The electrochemical behaviour of modified SPEs strongly depended on the size of AuNPs. The AuNP-modified SPEs were stable after 25 CV cycles and can detect *MRSA* in the range of 10–10^6 CFU/ml, with a limit of detection (LoD) of 13 CFU/ml. The study revealed that carbon SPEs modified with AuNPs of suitable sizes can provide high-stability in the electrochemical behaviour for biosensing devices, especially for the rapid detection of highly pathogenic microorganisms.

Keywords: carbon screen-printed electrode; AuNPs; electrochemical detection; *MRSA*

1. Introduction

Biosensing technologies have been widely considered by scientists worldwide, and various types of biosensors have been developed for the rapid determination of pathogenic agents [1]. Thanks to their compactness, portability, quick response time, high sensitivity, and high specificity, biosensors are expected to be alternative diagnostics for the rapid screening of dangerous pathogens on-site. However, there are few commercial biosensors available in the market. The major problems concerning the potential development of biosensors are stable over time and production cost [2,3]. Carbon screen-printed electrodes (SPEs) are a great solution for sensing technologies due to their ease of use, low-cost, and availability [4], [5], [6]. SPEs have been modified and widely applied for the electrochemical determination of glucose [7], thiamphenicol residue in milk [8], vitamin C [9], acetylcholine [10], and bentazone [11]. SPEs have also been developed to detect highly pathogenic agents, such as carcinoembryonic antigen [12], *Staphylococcus aureus* [13], *Salmonella* [14], and *Escherichia coli* O157:H7 [15]. Several nanostructured materials, including Au nanoparticles (AuNPs) [16], [17], AuNPs-MoS_2 [18], Ag nanoparticles [19], [20], Pt nanowires [21], magnetic beads [22], Prussian blue [23], [24], carbon nanotubes [25], [26], [27], graphene oxide [28], [29], [30], and zinc oxide nanorods [31], are used to modify the surface of SPEs for biosensing. Among these nanostructured materials, AuNPs are preferably used to improve the biosensing performance because of their unique properties, such as high surface free energy, excellent conductivity, and biocompatibility [32]. Biomolecules can easily bound to the surface of AuNPs and retain their bioactivity and stability of the latter during storage and measurement [33], [34]. In electrochemical detection, the surface stability and sensitivity of electrodes are keys to ensure the successful development of biosensors, and AuNPs can act as electron wires to enhance the electron transfer rate between the electrolytic solution and electrode [32], [35].

Although scientific papers have described the use of nanostructured materials to modify carbon SPEs for enhancing the sensitivity of such devices, the surface stability of these modified SPEs has not been clearly reported [5,6]. Active nanomaterials and functionalisation processes are selected depending on the type of specific interactions between the target analyte and probe. Specifically, bio-functionalisation and electrochemical measurement may change the surface properties of the modified SPEs and the quality of the developed biosensors.

Methicillin-resistant *S. aureus* (*MRSA*) is a Gram-positive, one of the leading causes of hospital-acquired infections, and a major problem in the global public health [36]. At present, there are a few diagnostics available to detect *MRSA* except the traditional culture-based method, and molecular techniques in clinical laboratories such as quantitative PCR or loop-mediated isothermal amplification (LAMP) [37], [38]. Hence, the development of biosensing devices for rapid detection of *MRSA* has become crucial for screening and identifying outbreaks caused by this bacterial strain. In 2015, Hiremath *et al.* [39] developed a magnetoelastic biosensor based on a lytic phage for detection of *MRSA*, and its LoD was found at 3.0 log CFU/ml. The selectivity and binding kinetics of a lytic phage to *MRSA* were also demonstrated by testing the biosensor in individual cultures of *MRSA* mixed with other foodborne pathogens [40]. Recently, Maldonado *et al.* [41] have been developed a nanophotonic interferometric biosensor for label-free detection of nosocomial bacteria. Results showed that the biosensor could detect MRSA at a concentration of 800 CFU/ml, and LoD was found at 29 CFU/ml.

In our strategy for the development of electrochemical biosensors for direct detection of bacterial pathogens, carbon SPEs were modified with AuNPs of different sizes to investigate their electrochemical stability during measurements. The AuNP-modified SPEs were then functionalised and tested to detect *MRSA* directly without any labels. The findings of the work

are expected to provide useful information to develop AuNP-modified carbon SPEs for quick and label-free detection of highly pathogenic bacteria and other microorganisms causing infectious diseases.

2. Materials and methods

2.1. Materials

Carbon SPEs (SPEs-DS110) were purchased from DS Dropsens, Spain. (3-Mercaptopropyl) trimethoxysilane (MTS; 95%), (N-gamma-maleimidobutyrloxy) sulphosuccinimide (GMBS; 98.5%), $K_3[Fe(CN_6)]$ and $K_4[Fe(CN_6)]$ (98.5%), KCl (≥99%), phosphate-buffered saline (PBS, pH 7.4), ethanol absolute, and bovine serum albumin (BSA, 96%) were purchased from Sigma-Aldrich (USA). All chemicals were of analytical grade.

Mouse monoclonal anti-*MRSA* antibody was purchased from Abcam. *MRSA* (10^6 CFU/ml) and *E. coli* O157:H7 (10^6 CFU/ml) were isolated from clinical samples and provided by the Department of Bacteriology, National Institute of Hygiene and Epidemiology (NIHE), Hanoi, Vietnam.

2.2. AuNP preparation

AuNPs were electrochemically synthesised and supplied by NIHE, Hanoi, Vietnam. Briefly, AuNPs were synthesised from bulk gold bars using a modified electrochemical method published previously [42]. Two electrodes were washed by bi-distilled water to remove rough and dirt residues under ultrasonic vibration for 30 min and then connected to the power as an anode and a cathode. The electrodes were dipped in an electrochemical jar containing 50 ml bi-distilled water and added with 0.1% trisodium citrate. Direct current power was supplied to the system, and the electrochemical process was conducted for 2 h under stirring condition. The formation, size, and morphology of AuNPs were checked by transmission electron microscopy (TEM, JEM1010-JEOL).

2.3 Preparation of carbon SPEs modified with AuNPs

The surface of bare SPEs was checked by scanning electron microscopy (SEM, S4800-Hitachi) before modification. Afterwards, bare SPEs were incubated with 50 ppm AuNPs by drop-casting method for 60 min at room temperature. Next, AuNP-modified SPEs were electrochemically cleaned in a 5 mM $Fe_3(CN)_6/Fe_4(CN)_6$ solution with five cyclic voltammetry (CV) cycles to remove all unspecific molecules, including unbound AuNPs and other residues on the SPE surface. Finally, the AuNP-modified SPEs were rinsed thrice with bi-distilled water before use.

Differential pulse voltammetry (DPV, a scan rate of 20 mV s^{-1}, E_{pulse} step of 10 mV, and t_{pulse} of 0.02 s, in the range of −0.3 V to 0.5 V), cyclic voltammetry (CV, a scan rate of 50 mV s^{-1} in the range of −0.4 V to 0.6 V), and electrochemical impedance spectroscopy (EIS, an amplitude of 10 mV, in the frequency range of 0.01 Hz to 50 kHz), were conducted in a 5.0 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$ solution added with 0.1 M KCl.

2.3. Surface functionalisation and antibody immobilisation

The working surface of the AuNP-modified SPEs was immersed in a solution of 2% MTS/ethanol for 1 h at room temperature to create –SH groups. After washing with bi-distilled water, the surface was continuously incubated with 6 µl GMBS (0.04 M) for 30 min at room temperature to create –NHS groups. Finally, the electrodes were washed thrice with PBS (pH 7.4) before immobilisation with antibody (Ab) [31][43].

In the preparation of electrochemical biosensors, a drop of anti-*MRSA* Ab (10 µg/ml, diluted in PBS at pH 7.4) was incubated with the working surface of AuNP-modified SPEs for 1 h at room temperature. The sensors were then thoroughly washed thrice with PBS at pH 7.4 to remove unbound antibodies. Afterwards, a drop of blocking buffer (2% BSA/PBS) was added, and the biosensors were incubated for 30 min at room temperature to block all non-specific binding sites on the biosensor surface [44,45].

To test the biosensing ability, we incubated the biosensors with *MRSA* at different concentrations from 10 to 10^6 CFU/ml for 30 min, and electrochemical measurements were conducted using a portable electrochemical system (Palmsens 3.0, Netherlands; Fig. 1). Interference control tests were tested with *E. coli* O157:H7 at a concentration of 10^6 CFU/ml with the same protocol. For positive control, after functionalisation to create – NHS groups, the electrodes were incubated with *MRSA* at a concentration of 10^3 CFU/ml for 30 min without the presence of anti-*MRSA* antibody, the EIS was then measured to see the change in R_{ct}.

(Figure 1)

3. Results and discussion

3.1 Surface characterisation

In this study, AuNPs were electrochemically synthesised in two different sizes, namely, 15 (Fig. 2A), and 25 nm (Fig. 2B). TEM observation showed the spherical shape and homogeneous status of AuNPs. The homogeneity of AuNPs was expected to help them bind firmly to the SPE surface, reduce its surface impedance, and enhance the conductivity and stability of SPEs during the electrochemical process.

(Figure 2)

SEM observation showed that the SPE surface contained a porous structure with pores that were less than 25 nm in diameter (Fig. 2C), and there are numerous AuNPs firmly adhered to the carbon surface (white dots in Fig. 2C). Different AuNP sizes were tested to observe whether these nanoparticles bind tightly to the SPE surfaces and deeply penetrate the porous structure. The presence of AuNPs can result in the best possible Ab binding and ensure that their contact space with the samples would remain unaffected during electrochemical measurement. Energy-dispersive X-ray spectroscopic (EDX) analysis also revealed that there was only Au element found in the carbon electrode structure (Fig. 2D), and no impurity affected the SPE surface.

3.2 Electrochemical behaviour of AuNP-modified SPEs

The electrochemical behaviour of the modified SPEs was analysed by CV at 50 mV s^{-1}; EIS in the frequency ranging from 0.01 Hz to 50 kHz, DPV at a scan rate of 20 mV s^{-1}, E_{pulse} step of 10 mV, and t_{pulse} of 0.02 s in 5.0 mM $Fe_3(CN)_6/Fe_4(CN)_6$ solution added with 0.1 M KCl.

(Figure 3)

Fig. 3A shows the different CVs of the modified SPEs. After modification, the I_{peak} of the AuNP-modified SPEs can be found at 210.66 (Fig. 3A, curve "b"), and 215.06 (Fig. 3A, curve "c"), corresponding to the 25, and 15 nm AuNPs, respectively. The redox current of the AuNP-modified SPEs was considerably higher than that of bare SPEs (154.01 µÅ, Fig. 3A, curve "a"). The highest redox current obtained corresponded to SPEs that were modified with the small AuNPs (15 nm). The small size of AuNPs ensured their good adherence to the electrode surface, and penetration of the porous structure of the carbon working electrode resulted in the surface stability under the washing steps or electrochemical process. Hence, the small size of AuNPs has also the advantage of stabilising the electron transfer rate on the SPE surface [29]. As shown in Fig. 3B, EIS demonstrated that the charge transfer resistance (R_{ct}) of the bare SPE (Fig. 3B, curve "a") was 1.81 kOhm, and it reduced to 1.48, and 1.13 kOhm for SPEs modified with 25 (Fig. 3B, curve "b"), and 15 nm (Fig. 3B, curve "c"), respectively. As shown in Fig. 3C, the DPV responses of the SPEs before and after modification with AuNPs significantly changed. The experimental data revealed that the anode current of the bare SPE was approximately 146.01 µÅ (Fig. 3C, curve "a"). After modification with AuNPs of two different sizes, the anode current significantly increased to 174.20 (Fig. 3C, curve "b"), and 185.61 µÅ (Fig. 3C, curve "c"), corresponding to AuNP sizes of 25, and 15 nm, respectively. The highest anode current was also obtained from the SPEs modified with 15 nm AuNPs. These techniques confirm that the electrochemical behaviour of SPEs strongly depends on the size of AuNPs used to modify the porous structure of the carbon working electrode. The size of NPs should be

smaller than that of pores in the porous carbon structure. It ensures that small signals that are generated from biochemical or immunological reactions on the SPE surface could be detected. AuNPs should also adhere firmly on the carbon SPEs to provide the necessary stability during the electrochemical process for biosensing applications.

Among the carbon SPEs which were modified with AuNPs of two different sizes, 15 nm AuNP-modified SPEs were selected to investigate their stability during the electrochemical process for biosensing ability because it was also to ensure that the AuNPs in 15 nm firmly adhered on the electrode after different treatments and measurements. As shown in Fig. 4A, the DPV responses of 15 AuNP-modified SPEs for E_{pulse} step values (10 mV) from 0.1 V to 0.35 V were measured in 5 mM $Fe_3(CN)_6/Fe_4(CN)_6$ solution added with 0.1 M KCl at a scan rate of 20 mVs^{-1}, and t_{pulse} of 0.02 s ranging from −0.3 V to 0.5 V. The inset in Fig. 4A indicates that the anode current increased linearly, corresponding to the increase in E_{pulse} (Fig. 4A, inset).

(Figure 4)

Fig. 4B shows the stability of the 15 nm AuNP-modified SPEs in CV cycles. No change was observed in the redox current after 25 CV cycles at a scan rate of 50 mV s^{-1}, which proved that the surface of these modified SPEs remained stable after functionalisation and electrochemical process. Hence, carbon SPEs modified with AuNPs in 15 nm, the size is less than that of pores in the carbon structure, is suitable for the electrochemical detection of small signals generated from biochemical reactions on the electrode surface.

3.3 Electrochemical detection of MRSA

The 15 nm AuNP-modified SPEs were functionalised and prepared for label-free detection of *MRSA* by CV and EIS. Before measurements, the bacterial sample of *MRSA* was checked by SEM. Fig. 5A shows the typical morphology of *MRSA*, that is, a spherical shape, and agglomeration. Electrochemical measurements were conducted in 5.0 mM $Fe_3(CN)_6/Fe_4(CN)_6$ solution added with 0.1 M KCl. Fig 5B. shows the CVs of the SPEs before and after

modification with 15 nm AuNPs, after each step of the surface functionalisation, and the incubation of biological molecules. The changes in the redox current of the modified and bare SPEs were 215.10 and 154.05 μÅ, respectively (Fig. 5B, curves "a" and "b"). After surface functionalisation to form –NHS groups and antibody immobilisation, the redox current decreased significantly from 215.10 μÅ to 150.81 and 96.70 μÅ, respectively (Fig. 5B, curves "c" and "d"). The incubation with the sample of *MRSA* at a concentration of 10^2 CFU/ml also resulted in decreasing the redox current, because it is assumed that these *MRSA* hindered the electron transfer between the electrolytic and electrode surfaces (Fig. 5B, curve "f").

(Figure 5)

These results can be explained considering that the surface modification of carbon SPEs with 15 nm AuNPs could increase the electron transfer rate between the electrolytic solution and modified electrode compared with that of bare SPE. However, the functionalisation of the modified SPE surface with chemical and biological molecules reduced the electron transfer rate significantly. This result is important evidence showing the necessity of the surface modification of carbon SPEs with conductive nanomaterials for capturing small signals generated from biochemical reactions on the electrode for biosensing applications.

To demonstrate such a phenomenon, we conducted the EIS of the 15 nm AuNP-modified SPEs. Fig. 6A shows the Nyquist plots of modified SPEs after functionalisation steps, and it can be seen the increase of R_{ct} of AuNPs-modified SPE from 1.13 kOhm (Fig. 6A, curve "a") to 1.65 kOhm (Fig. 6A, curve "b") after functionalisation to create -NHS groups, and 1.79 kOhm (Fig. 6A, curve "c") after immobilization with anti-*MRSA* Ab. In this study, a positive control of modified SPEs was tested with *MRSA* at 10^3 CFU/ml without the presence of anti-MRSA Ab; the EIS curve showed a slight increase in R_{ct} to 1.83 kOhm (Fig. 6A, curve "d"). It can be explained that the increase may not come from *MRSA*, because the size of *MRSA* is much larger than that of pores of the carbon membrane. Without the specific binding with

antibody, bacteria can be easily detached during the electrochemical process. However, the increase in R_{ct} may result from small molecules in the media, which go deep inside the carbon network during the incubation. This was also demonstrated when the SPEs immobilized with the antibody for *MRSA* detection at different concentrations in the range of 10–10^6 CFU/ml. Fig 6B shows the increase in R_{ct} values, corresponding to the increase in bacterial concentrations. The smallest and highest R_{ct} values are approximately 2.10, and 4.26 kOhm, corresponding to *MRSA* concentrations of 10 (Fig. 6B, curve "a") and 10^6 CFU/ml (Fig. 6B, curve "f"), respectively. In Figure 6 A-B, R_{ct} was calculated by the diameter of the semicircle fitted by the equivalent circuit and analysed by the Z-view software. ΔR_{ct} can be calculated by comparing the R_{ct} obtained from the EIS curves of AuNP-modified SPEs tested as a positive control and after incubation with *MRSA* at different concentrations. The calibration curve was also obtained using the linear equation, $y = 0.40073x + 0.00871$, with a correlation coefficient of 0.98028 (Fig. C).

(Figure 6)

To confirm the selectivity and stability of the electrochemical biosensors, they were also tested with *E. coli* O157:H7 at a concentration of 10^6 CFU/ml for 30 min at room temperature, using the same protocol used when measuring *MRSA*. The EIS results showed that the R_{ct} value was approximately 2.12 kOhm for *E. coli* O157:H7 detection (Fig. 6D, curve "a"), a little increase in R_{ct} compared to that of modified SPEs detected with *MRSA* at a concentration of 10 CFU/ml (Fig. 6B, curve "a"). However, this value was considerably lower than that of *MRSA* at the concentration of 10^2 CFU/ml (Fig. 6D, curve "b"). According to serial dilutions of *MRSA* concentrations from 100 to 10 CFU/ml for testing with the biosensor, the limit of detection (LoD) was found approximately 13 CFU/ml. As shown in Table 1, this biosensor could detect *MRSA* at a low concentration compared to that of SPEs – based biosensors published

previously for the electrochemical detection of other pathogenic bacteria [13], [22], [23], [46], [47], [48].

(Table 1)

4. Conclusions

In this study, we investigated the surface stability and electrochemical behaviour of carbon SPEs modified with AuNPs of different sizes for biosensing applications. The results demonstrated that the electrochemical stability of modified carbon SPEs strongly depended on the size of AuNPs. The size of these NPs should be smaller than that of pores in the carbon structure of the working electrode. The AuNP-modified SPEs were stable after 25 CV cycles. The electrochemical biosensors based on 15 nm AuNP-modified SPEs could detect *MRSA* in the range of 10–10^6 CFU/ml after 30 min of incubation, with the LoD equal to 13 CFU/ml. This work provides evidence for the electrochemical stability of AuNP-modified carbon SPEs. Biosensors based on these modified SPEs may have potential use for the rapid and label-free detection of highly pathogenic bacteria and other agents causing emerging infectious diseases.

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Captions for Figures

Figure 1. Preparation of AuNP-modified carbon SPEs for biosensing applications.

Figure 2. TEM images of AuNPs of different sizes: (A) 15, and (B) 25 nm. SEM images of the SPE modified with AuNPs. (F) EDX spectra of the SPEs modified with AuNPs.

Figure 3. Electrochemical behaviour of SPEs before and after modification with AuNPs of different sizes: (A) CV, (B) EIS, and (C) DPV responses.

Figure 4. Electrochemical stability of 15 nm AuNP-modified SPEs: (A) DPV responses in the range of 0.10–0.35 V (inset: calibration curve of the anode current corresponding to the increase in E_{pulse}) and (B) 25 CV cycles at the scan rate of 50 mV s^{-1} (inset: stable redox current).

Figure 5. (A) SEM image of *MRSA*. (B) CV cycles of SPEs, including (a) bare SPE, (b) SPE/AuNPs-15 nm, (c) SPE/AuNPs/NHS, (d) SPE/AuNPs/NHS/Ab, (e) SPE/AuNPs/NHS/Ab/BSA, and (f) SPE/AuNPs/NHS/Ab/*MRSA*.

Figure 6. (A) Nyquist plots of 15 nm AuNP-modified SPEs before and after functionalization; and (B) for the detection of *MRSA* at different concentrations (inset: equivalent circuit); (C) Calibration curve of ΔR_{ct} vs different *MRSA* concentrations (n=5); and (D) Nyquist plots for the control test with *E. coli* O157:H7.

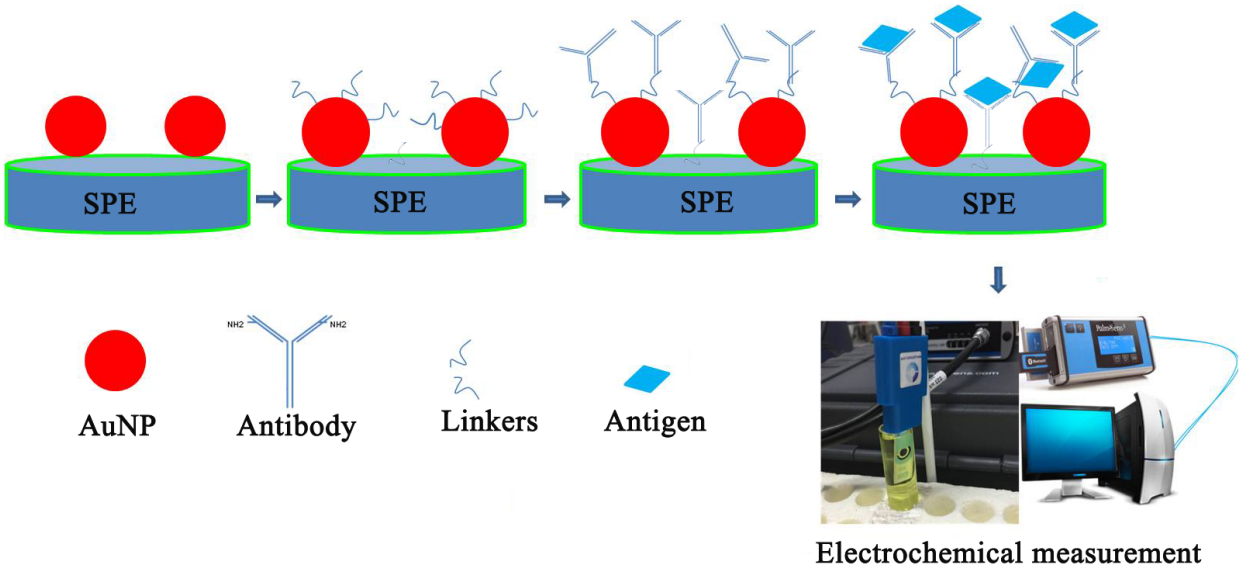
Caption for Tables

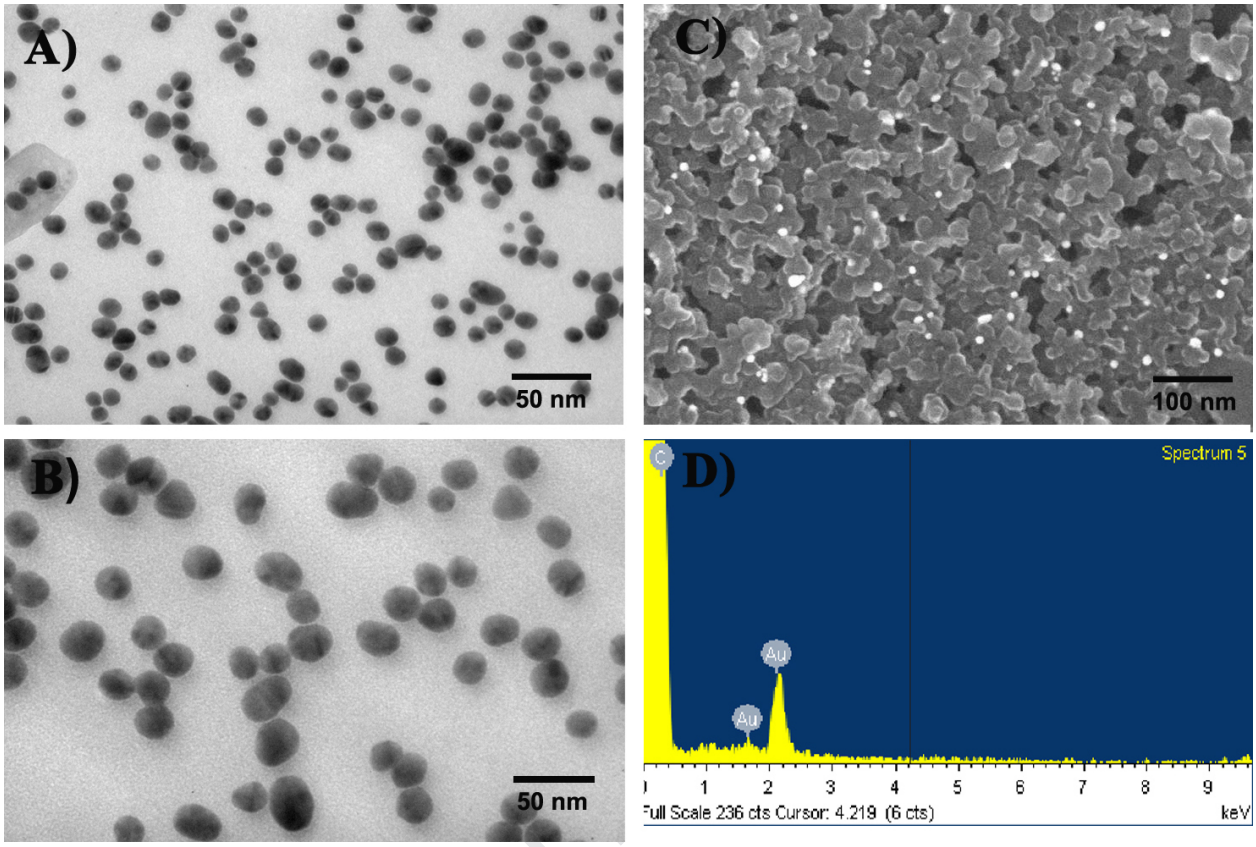
Table 1. Performance comparison of different type of modified SPEs for bacterial detection

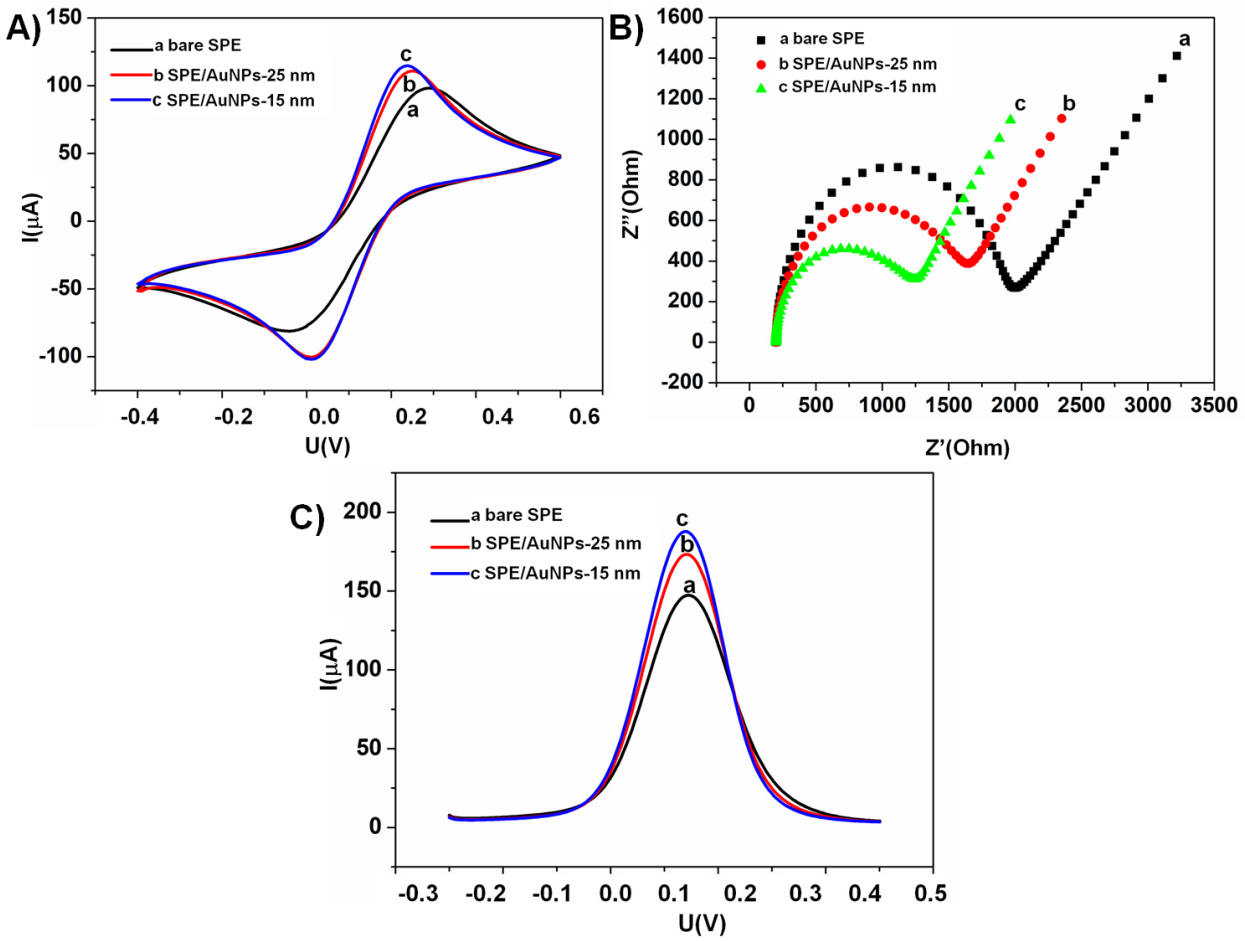
Table 1.

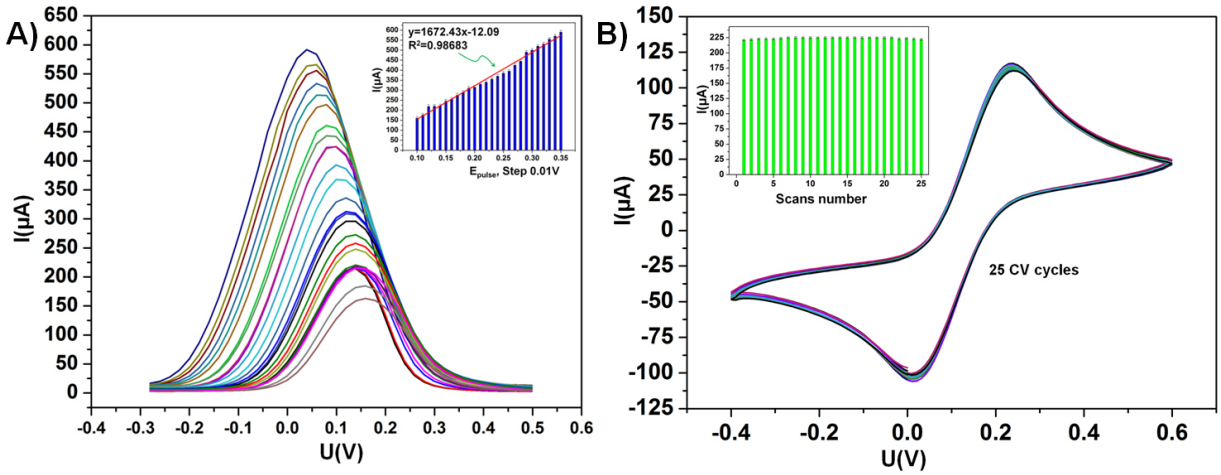
Type of modified SPEs	Pathogenic bacteria	Remarks	Ref.
Carbon SPEs	*Staphylococcus aureus*	- Detection from a starting concentration of 1.8×10^6 CFU/ml within 30 min	[13]
13 nm AuNPs-modified SPEs	*Escherichia coli* O157:H7	-Detection in the range of 10^2 to 10^7 CFU/ml; -LODs were approximately 6 CFU/strip in PBS buffer and 50CFU/strip in milk	[48]
Bi-functional glucose oxidase-polydopamine nanocomposites and Prussian blue modified screen-printed interdigitated electrodes	*Escherichia coli* O157:H7	-Detection in the range from 10^2 to 10^6 CFU/ml in the pure culture within 1 h; -LoD was 10^2 CFU/ml.	[23]
Carbon SPEs	*Bacillus cereus* (as a surrogate for *B. anthracis*) and *Escherichia coli* O157:H7	-The use of magnetic/polyaniline core/shell nano-particle (c/sNP) for sample extraction; - Detection in the range of 1 to 10^2 CFU/ml, with LoDs were 40 CFU/ml and 6 CFU/ml, respectively	[22]
Gold screen-printed interdigitated microelectrodes	*Escherichia coli* O157:H7 and *Salmonella Typhimurium*	- The use of magnetic beads (MBs) for sample separation -Detection in the range of 10^{2}-10^6 CFU/ml in the pure culture samples - LODs were 2.05 10^3 CFU/g (*E.coli*) in ground beef, and 1.04 x10^3 CFU/ml (*Salmonella*) in chicken rinse water	[46]

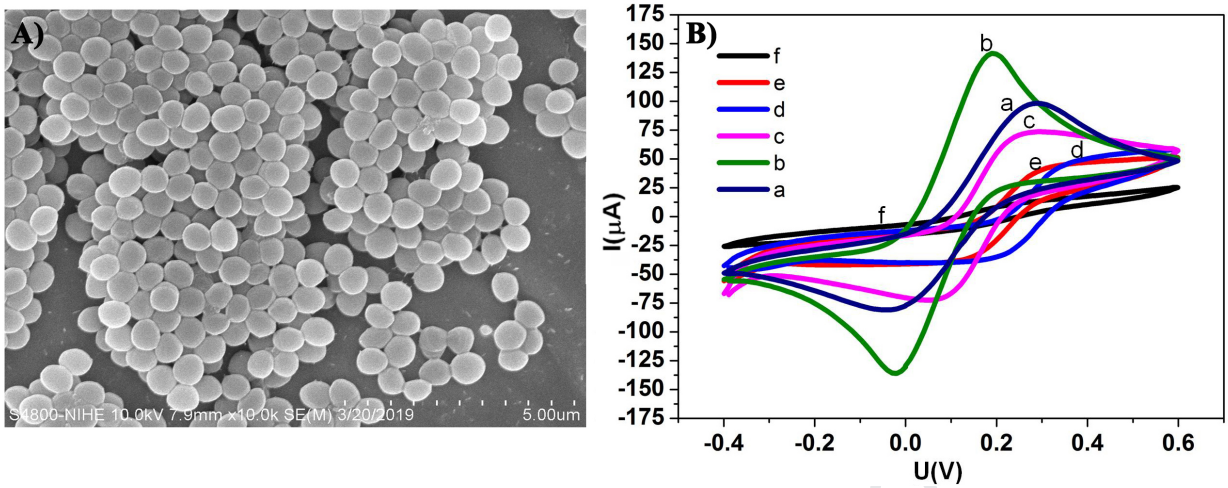
Screen-printed graphene electrodes	*Vibrio parahaemolyticus*	- Combining with loop-mediated isothermal amplification (LAMP) - LoD was 0.3 CFU per 25 g of raw seafood within 45 min	[47]
15 nm AuNPs –modified SPEs	Methicillin-resistant *Staphylococcus aureus*	-Detection the range of $10–10^6$ CFU/ml after 30 min of incubation -LoD was about 13 CFU/ml	**This study**

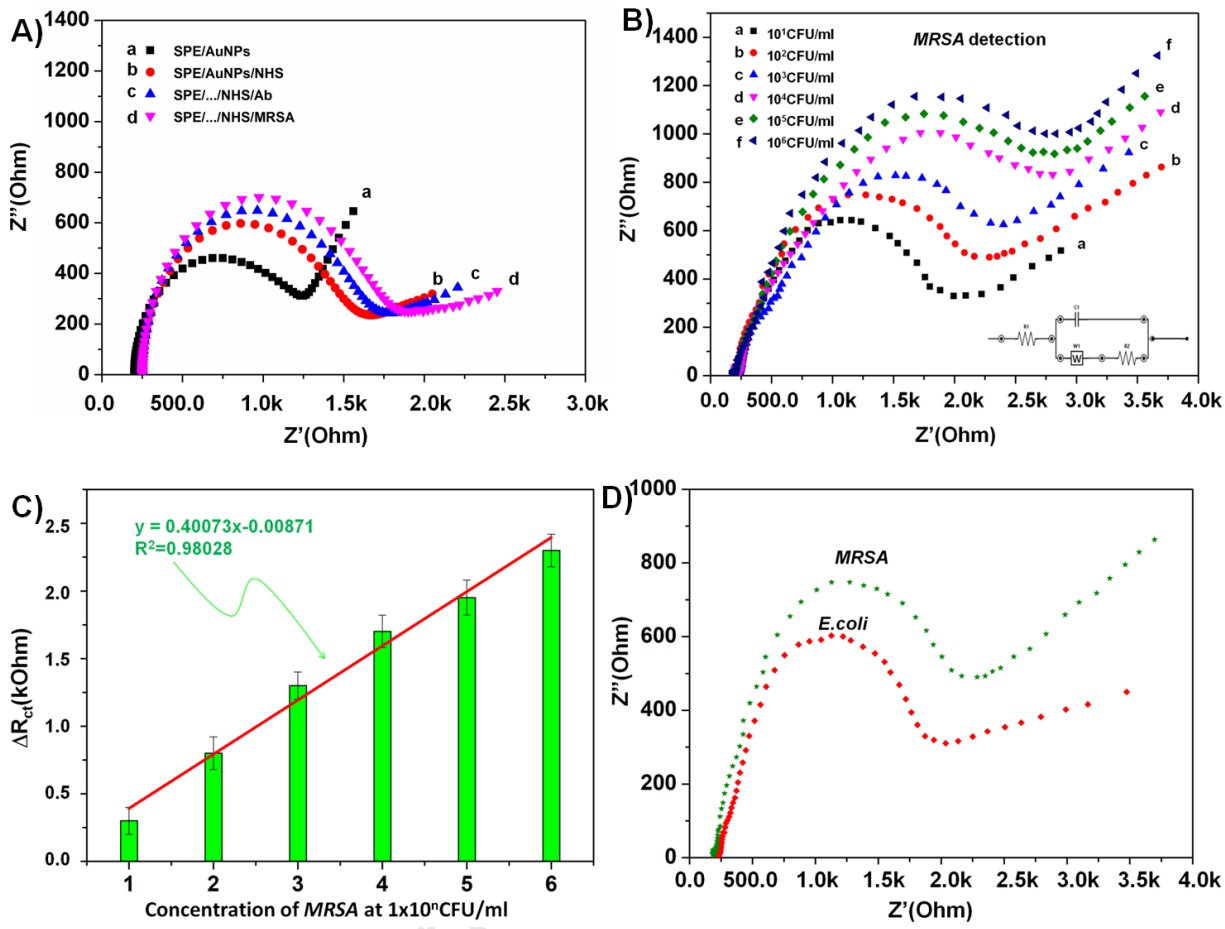



A)
50 nm
C)
100 nm
B)
50 nm
D)
Spectrum 5
C
Au
Au
0
1
2
3
4
5
6
7
8
9
Full Scale 236 cts Cursor: 4.219 (6 cts)
keV


A)
a bare SPE
b SPE/AuNPs-25 nm
c SPE/AuNPs-15 nm
I(μA)
U(V)
B)
a bare SPE
b SPE/AuNPs-25 nm
c SPE/AuNPs-15 nm
Z''(Ohm)
Z'(Ohm)
C)
a bare SPE
b SPE/AuNPs-25 nm
c SPE/AuNPs-15 nm
I(μA)
U(V)






A)
a SPE/AuNPs
b SPE/AuNPs/NHS
c SPE/.../NHS/Ab
d SPE/.../NHS/MRSA
Z''(Ohm)
Z'(Ohm)
B)
a 10¹CFU/ml
b 10²CFU/ml
c 10³CFU/ml
d 10⁴CFU/ml
e 10⁵CFU/ml
f 10⁶CFU/ml
MRSA detection
Z''(Ohm)
Z'(Ohm)
C)
y = 0.40073x-0.00871
R²=0.98028
ΔRct(kOhm)
Concentration of MRSA at 1x10ⁿCFU/ml
D)
MRSA
E.coli
Z''(Ohm)
Z'(Ohm)

- The carbon SPEs are modified with AuNPs of different sizes to investigate their electrochemical stability.
- The electrochemical behaviour of modified SPEs strongly depends on the size of AuNPs and keep stable after 25 CV cycles.
- The AuNPs-modified carbon SPEs can detect Methicillin-resistant *Staphylococcus aureus* with the LoD of 13 CFU/ml.