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RESEARCH PAPER

Erythromycin Nanoparticles: Electrochemical Evaluation of a Nano-Antibiotic System

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ABSTRACT

Erythromycin (ERY) is one of the macrolid antibiotics used for the treatment of various infections caused by bacteria. Nanoparticles (NPs) can enhance the delivery and efficacy of erythromycin in the blood stream. Investigating the electrochemical characteristics of erythromycin nanoparticles (ERY NPs) in blood medium can provide insights into their interactions, stability, and overall efficacy. This study aimed to characterize the electrochemical behavior of ERY NPs in simulated blood medium at varying concentrations and pH levels, and to evaluate their stability, release kinetics, and interactions with blood components. The micro form of erythromycin was converted to nano form by lyophilization (freeze-dried) technique. The characteristics of new formed ERY NPs were detected by several microscopic and spectroscopic techniques, including atomic force microscopy (AFM), field emission scanning electron microscopy (FESEM), X-ray diffraction (XRD), Fourier transform infrared (FTIR) and Ultraviolet–visible (UV-Visible). Fresh human blood was used and different PH levels were adjusted (normal, acidic and basic levels) for the blood medium. All electrochemical investigations in blood medium were done by cyclic voltammetry instrument. Microscopical examination of the ERY-NPs by FESEM and AFM reveal the bars-like shape with an average diameter of about 40 - 46 ηm. FTIR, UV-visible, and XRD spectroscopy showed that the nanoparticles were crystalline in nature, which is what erythromycin looks like in bulk. The cyclic voltammetry profiles of ERY-NPs in blood medium at different concentrations and pH levels showed significant shifts in the anodal and cathodic highest currents. Significant variations were demonstrated in the electrochemical properties of ERY NPs, which are affected by the blood medium composition, different pH levels, and nanoparticle concentration, providing insights into their performance as antibacterial reagents.

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INTRODUCTION

The increased spread of antibiotic resistance results in multidrug-resistant (MDR) bacterial isolates, which threaten public health around the world. As a result, it is important to create new antibacterial agents to eradicate MDR

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pathogens. Nowadays, nanotechnology is used as an advanced, effective antibacterial agent that eliminates the (MDR) bacterial isolates [1]. Erythromycin is an antibiotic widely used to treat the bacterial infections, particularly infections caused by Gram-positive organisms. In the form of nanoparticles, erythromycin has shown improved bioavailability and antibacterial properties compared to its conventional form. However, the behavior of these nanoparticles in biological media such as blood is not fully understood [2-6]. The electrochemical properties of erythromycin nanoparticles (ERY-NPs) can provide valuable insights into their stability, interaction with biological components, and overall efficacy as antibacterial agents. Electrochemical techniques are effective in analyzing the surface properties and charge interactions of nanoparticles in biological fluids. Understanding these interactions is crucial to improve the design of antibiotic-loaded nanoparticles and predict their behavior in real biological environments [7-11].

The erythromycin nanocrystalline formulation introduced in this study shows potential as a novel method to improve the solubility, dissolution rate, and antibacterial efficacy of erythromycin for efficient pulmonary administration [12].

To assess the impact of erythromycin, both independently and in conjunction with gold nanoparticles (AuNPs), on clinical GBS isolated from pregnant women, the findings indicated that the combination of erythromycin and gold nanoparticles augmented the antibacterial efficacy of erythromycin against GBS isolates [13].

Sepsis is commonly caused by bacterial infections, which can kill a lot of people. Bacterial resistance to many medications makes it hard to treat certain kinds of infections. The erythromycin (Ery) antibiotic is a macrolide antibiotic used to treat many infections caused by bacteria; however certain bacteria have become resistant to it. Recently, polymer nanoparticles made from polylactide-co-glycolic acid (PLGA) have been found to be better at delivering drugs and being compatible with living things. This research illustrates that polymer nanoparticles derived from polylactide-co-glycolic acid (PLGA) can augment the effectiveness of erythromycin, and can inhibit proliferation and formation of biofilm by *P. aeruginosa*. These polymer nanoparticles with drug-delivering nano formulation could be used as antimicrobials and surface coatings for medical devices [14].

Polymeric micelles with a size of 87.14 nm were made using erythromycin and had an encapsulation effectiveness of 86.94%. To reduce the polymer micelle-like bursting impact of these NPs, the formulation was mixed into a Carbopol 934P gel base. This made the drug's release duration and penetration profile of the erythromycin last longer. After effective inclusion, the gel formed quickly and easily changed from a solution to a gel, which was clear. The optimised formulation showed a strong mucoadhesive capacity, which is very important for keeping the product in place for a longer duration. With first rupture, the release of the drug was flooded, and over 75% of the drug discharged into the simulated tear fluid. Studies on the permeability of the cornea showed that the gel formulation has further benefits of polymeric micelles, such as being able to easily pass over the cornea's aqueous humour. This formulation may be a new ocular formulation that treat bacterial infections of the eye while still having antibacterial properties [15].

Erythromycin (ERY) has demonstrated significant efficacy in bovine mastitis. Nonetheless, it encounters issues related to its treatment, including resistant bacteria, pharmacokinetics, and limitations in efficacy. Methicillin-resistant Staphylococcus aureus (MRSA) has emerged. The administration of ERY which was encapsulated in biodegradable chitosan nanoparticles (CS NPs) used to treat mastitis can enhance its therapeutic efficacy. The findings demonstrated enhanced antibacterial activity of ERY-CSNPs. It may be concluded that ERY-CSNPs and CSNPs demonstrated satisfactory physicochemical features and potent antibacterial efficacy against MRSA. These formulations can serve as drug delivery vehicles which enhance their antibacterial action, pharmacokinetics, and effectiveness for the treatment of mastitis caused by MRSA [16].

This research involved the fabrication of antibacterial nanofibrous mats made from cellulose acetate (CA) nanofibers infused with erythromycin-chitosan nanoparticles (Ery-CS NPs) to be used as wound dressings. Relevant investigations confirmed that the nanoparticles integrated into the nanofibers exhibited substantial water retention capacity alongside elevated porosity. The Ery-CS NPs/CA mats effectively inhibited the proliferation of both Gram-positive and Gram-negative bacteria without exhibiting

cytotoxicity towards human dermal fibroblasts. In summary, our findings indicate that the suggested method is applicable as antibacterial mats for wound dressing purposes [17].

MATERIALS AND METHODS

Materials

Erythromycin powder from HyperChem (China), HCl and NaOH from Fluka Company (Germany), ascorbic acid from SER (China), healthy blood sample from center medical city /Baghdad, double-deionized water was used in all preparations.

Methods

The Synthesis of Erythromycin Nanoparticles

The lyophilization technique was employed to transform micro erythromycin (ERY) into nanoparticles (NPs) utilizing the lyophilizer seen in Fig. 1. Field emission scanning electron microscopy (FESEM) and atomic force microscopy (AFM) were used to study the change from micro erythromycin to NPs. The FESEM analysis results that show the shape and size of the ERY NPs at 46 nm. ERY NPs were synthesized using a precipitation method. ERY (purity >99%) was dissolved in a suitable solvent, and a stabilizing agent was added to form the nanoparticles. The mixture was centrifuged and washed to get rid of excess solvents and stabilizers. Transmission electron microscopy (TEM) and X-ray diffraction (XRD) were used to confirm the nanoparticles' size, shape, and structure.

Blood Medium Preparation

A simulated blood medium was prepared by mixing a blood sample with deionized water (DW) in ratio of (1 ml blood: 9 ml DW). The pH of the medium was adjusted to 7.4 for normal conditions, and additional tests were directed at acidic pH (5.5) and basic pH (9.0) circumstances to assess the impact of pH on nanoparticle behavior.

Preparation of ERY NPs

The lyophilization technique was employed to transform the ERY into nanoparticles (ERY NPs) utilizing the lyophilizer apparatus [18].

Microscopic and Spectroscopic Characterization of ERY NPs

Different microscopic techniques, including atomic force microscopy (AFM) and field emission scanning electron microscopy (FESEM) were utilized to characterize ERY NPs. Spectroscopic analyses, including X-ray diffraction (XRD), Fourier transform infrared (FTIR) and Ultraviolet–visible (UV-Visible) were employed to characterize the structure of ERY NPs and validate the nano compound.

Field Emission Scanning Electron Microscopy (FESEM)

Field Emission Scanning Electron Microscopy (FESEM) is a powerful imaging technique used to analyze the morphology and size of nanoparticles, such as (ERY NPs). Fig. 1 describes the shape

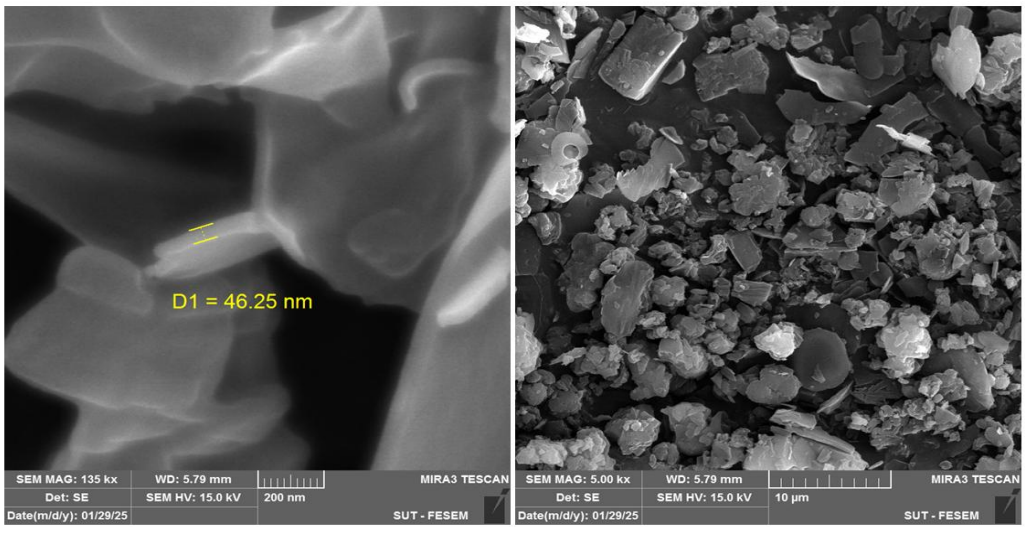

Fig. 1. FESEM of ERY NPs.

and surface characteristics of the nanoparticles. Common shapes have rod-like forms with 46 nm dimension of the nanoparticles.

Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM) is a valuable technique used to analyze the superficial characteristics of nanoparticles, including ERY NPs. AFM provides detailed topographical maps of the nanoparticle surface. Fig. 2 describes the roughness, texture, and any features observed.

Fourier Transform Infrared Spectroscopy (FTIR) Study

Fourier transforms infrared (FTIR) spectroscopy study used to confirm that erythromycin is present in the nanoparticle formulation. The sample (pure erythromycin, blank nanoparticles, and erythromycin-loaded nanoparticles) is scanned from 4000 to 400 cm^{-1}.as shown in Table 1 and Fig. 3. The spectrum shows peaks corresponding to specific bonds:

OH, NH, CH stretches (~3300-2800 cm^{-1})

C=O stretch (around 1700 cm^{-1} — this one is the diva peak, very revealing)

C–O, C–N, and others that point to esters, amines, and alcohols.

UV-Visible Spectroscopy

Erythromycin isn't particularly flashy in the UV-Vis region. It doesn't have big conjugated systems or aromatic rings strutting down the runway at 300 nm. But it does absorb weakly in the UV region (around 200–230 nm) as shown in Fig. 4.

XRD Spectroscopy

X-Ray Diffraction (XRD) Spectroscopy of erythromycin nanoparticles is where things get really judgmental. This technique doesn't just look at the sample; it scrutinizes its soul. XRD was used for the determination of crystal-like structure of the materials. And in the context of erythromycin nanoparticles Table 2 illustrated with Fig.5 all band of ERY NPs structure.

Electrochemical Measurements

Electrochemical characterization was carried out using a potentiostat with three-electrodes setup, including a glassy carbon working electrode (GCE), a platinum wire as counter electrode, and Ag/AgCL as reference electrode (RE). Cyclic voltammetry (CV) was employed to study the redox behavior, charge transfer resistance, and stability of ERY-NPs in the blood medium at different concentrations (0.02, 0.04, 0.06, 0.08, 0.1, 0.12, 0.14, 0.16, 0.18, 0.2, 0.22, 0.24, 0.26, 0.28, and 0.3 mM) and pH levels (4, 5, 6, 7, 8, 9, and 10).

Cyclic Voltametric Instrument

The EZstat (potentiostat/galvanostat, NuVant Systems Inc., US) has been the basis for wholly investigations. There is a working electrode (glassy carbon electrode (GCE)), reference electrode (Ag/AgCl (3M of the KCl)), and a counter electrode (platinum wire (1mm in diameter)) in all CV

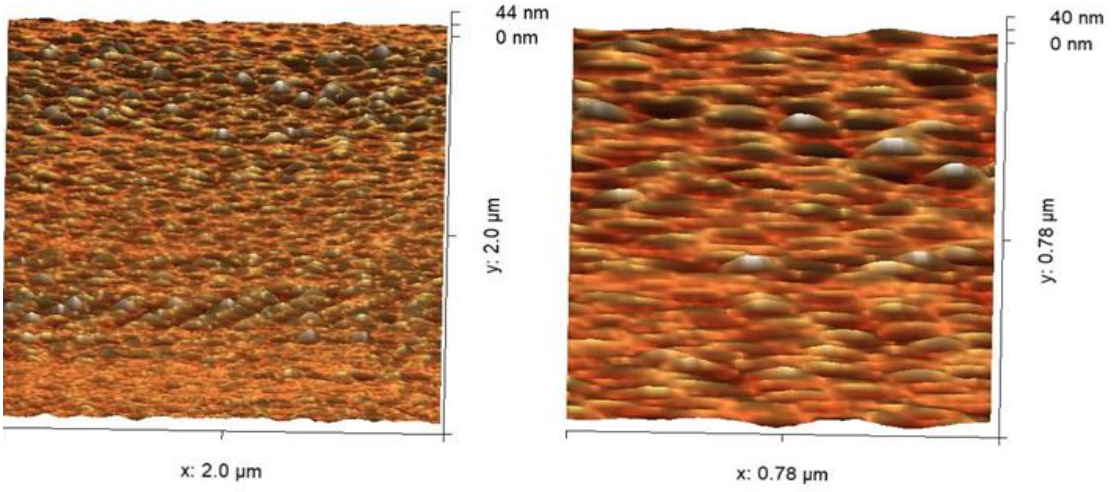

Fig. 2. AFM of ERY NPs.

voltmeter sections. This program on the personal computer that does the electro analytical measurement has set all three electrodes to a potential state. To get rid of any dirt before using the GCE in the CV cell, it was polished with an alumina solution and put in a water sonic path for around 10 minutes. Fig. 6 shows how to set up a cyclic voltammetric system.

Method

In a voltammetric quartz cell with a volume of 15ml, three electrodes (working, reference, and counter) have been inserted into a 10ml blood sample. The three electrodes are linked to potentiometers to obtain findings via a personal computer through a periodic voltammogram [19,20].

RESULTS AND DISCUSSION

Spectroscopic and Microscopic Characterization of ERY NPs

The ERY-NPs were shaped like bars and had an average diameter of about 40 - 46 ηm, as observed from FESEM, and AFM microscopy. FTIR, UV-visible, and XRD spectroscopy also showed that

Table 1. FTIR band of ERY NPs.

Peak Number	X (cm-1)	Y (%T)
1	3436.20	55.17
2	2958.30	62.05
3	2925.32	58.15
4	2853.78	62.74
5	2047.62	64.43
6	1732.99	64.49
7	1632.45	63.70
8	1465.44	63.35
9	1384.51	63.19
10	1272.07	65.43
11	1169.22	61.57
12	1109.79	61.44
13	1080.83	59.90
14	1055.17	60.57
15	1013.90	61.18
16	908.46	66.88
17	491.02	66.89
18	478.14	66.89

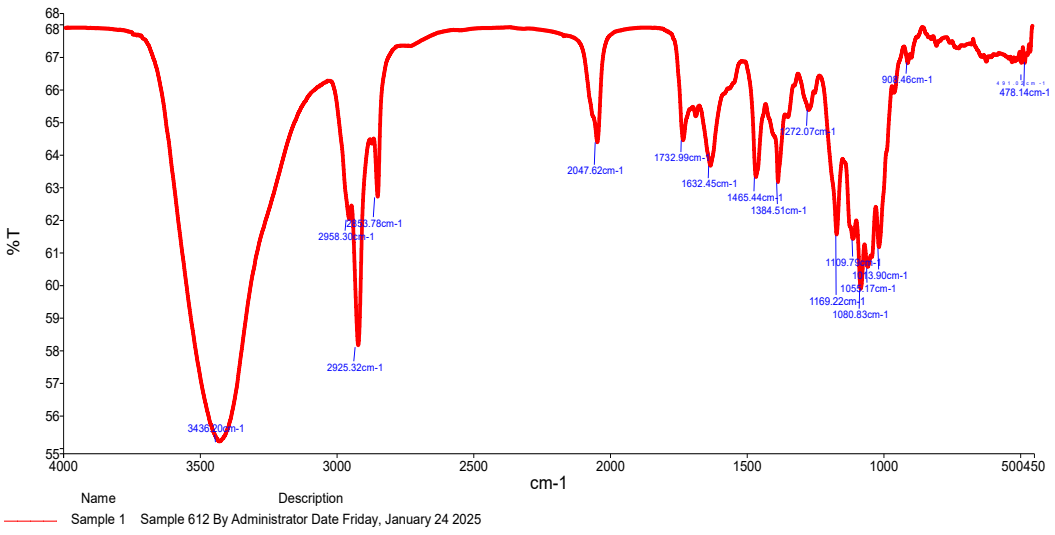

Fig. 3. FTIR spectroscopy of ERY NPs.

the nanoparticles were crystalline in nature, which is what erythromycin looks like in bulk.

Electrochemical Behavior of ERY NPs in Blood Medium by Cyclic Voltammetry (CV)

The cyclic voltammetry profiles of ERY-NPs in blood medium at different concentrations and pH conditions showed significant shifts in the anodal and cathodic topmost currents. At pH 7.4, the ERY-NPs exhibited well-defined redox peaks, indicative of stable electron transfer processes. However, at lower pH (5.5), the redox peaks shifted toward

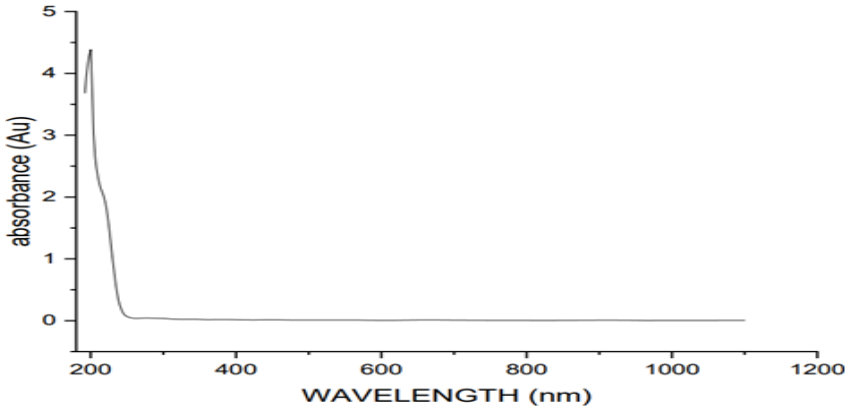

Fig. 4. UV-Visible spectroscopy of ERY NPs.

Table 2. Anchor Scan Parameters.

Raw Data Origin	Rigaku-binary (.RAW)
Scan Axis	Gonio
Start Position [°2Th.]	8.0000
End Position [°2Th.]	80.0000
Step Size [°2Th.]	0.0400
Scan Step Time [s]	1.0000
Scan Type	Pre-set time
Offset [°2Th.]	0.0000
Divergence Slit Type	Fixed
Divergence Slit Size [°]	1.0000
Specimen Length [mm]	10.00
Receiving Slit Size [mm]	0.1000
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [?]	1.54060
K-Alpha2 [?]	1.54443
K-Beta [?]	1.39225
K-A2 / K-A1 Ratio	0.50000
Generator Settings	0 mA, 0 kV
Diffractometer Number	0 Raw Data Origin
Scan Axis	Gonio
Start Position [°2Th.]	8.0000
End Position [°2Th.]	80.0000
Step Size [°2Th.]	0.0400
Scan Step Time [s]	1.0000
Scan Type	Pre-set time
Offset [°2Th.]	0.0000
Divergence Slit Type	Fixed
Divergence Slit Size [°]	1.0000
Specimen Length [mm]	10.00
Receiving Slit Size [mm]	0.1000
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [?]	1.54060
K-Alpha2 [?]	1.54443
K-Beta [?]	1.39225
K-A2 / K-A1 Ratio	0.50000
Generator Settings	0 mA, 0 kV
Diffractometer Number	0
Goniometer Radius [mm]	240.00
Dist. Focus-Diverg. Slit [mm]	91.00
Incident Beam Monochromator	No
Spinning	No

more negative potentials, suggesting a change in the interaction between the nanoparticles and the blood medium. At higher concentrations (100 µM), the current intensities increased, reflecting higher nanoparticle concentrations and enhanced electrochemical activity.

Effect ERY NPs in Blood Medium

As illustrated in Fig. 7, the ERY NPs in blood medium has been affected on the oxidation current peak that reduced by the nanoparticles of ERY, and the increasing of the concentration causes enhance the oxidation peak as shown in Fig. 8.

Effect ERY NPs in Different pH of Blood Medium

The electrochemical behavior of erythromycin nanoparticles is significantly affected by the pH of the blood medium. Acidic conditions limit electrochemical activity due to reduced solubility and hindered electron transfer, while alkaline conditions enhance activity by increasing solubility and favorable ionization states as shown in Fig. 9.

The Effect of Ascorbic Acid on ERY NPs in Blood Medium

In electrochemical studies, the redox activity of ascorbic acid can influence the behavior of concomitant molecules, such as erythromycin

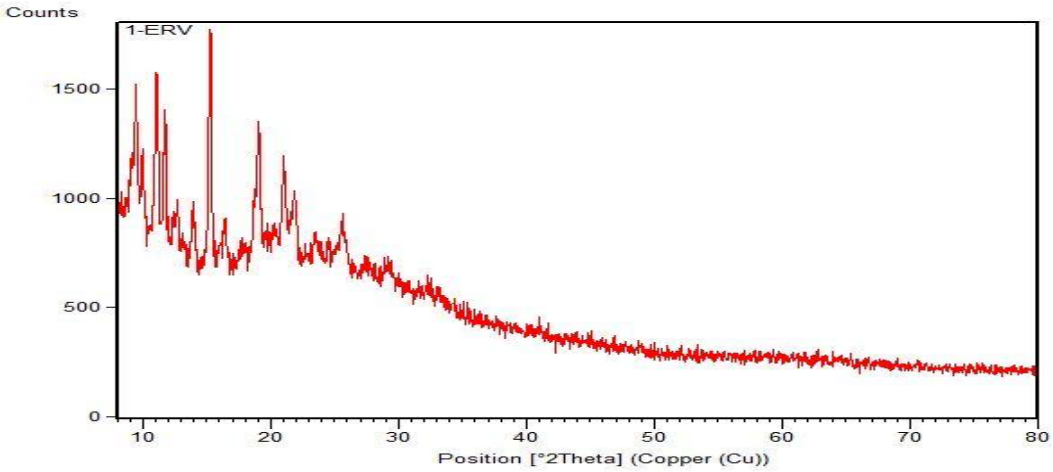

Fig. 5. XRD spectroscopy of ERY NPs.

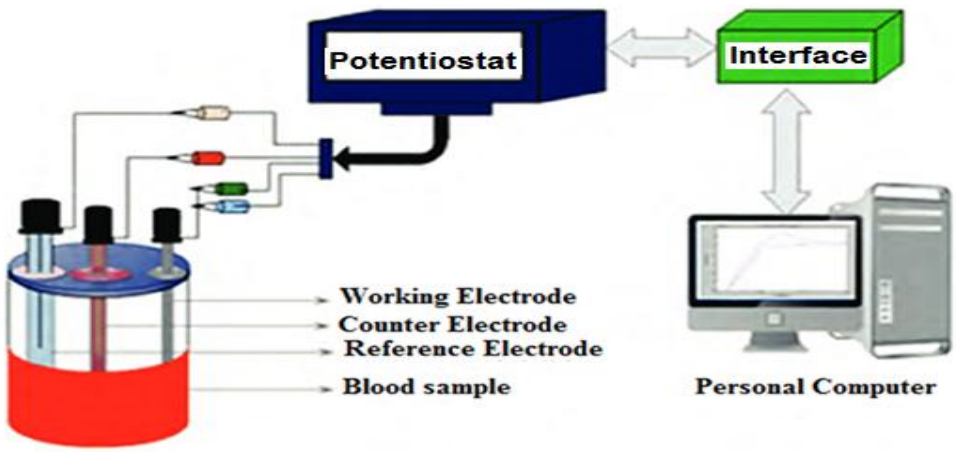

Fig. 6. Setup of cyclic voltametric technique.

nanoparticles (ERY NPs), especially in complex matrices such as blood as shown in Fig. 10.

Reliability and Stability Study

The method that used to confirm the potential of electrochemical and nanotechnology-based strategies to enhance the reliability and stability of erythromycin, this was achieved by repeating the scanning for ten times and observing the cyclic voltammtamogram conformation, as shown in Fig. 11.

Biological Effect of ERY NPs in Blood Medium

Electrochemical systems, like cyclic voltammetry, have been utilized in evaluate the behavior of antibiotic nanoparticles in biological fluids. Studies have shown that nano antibiotics exhibit distinct electrochemical patterns compared to their counterparts in biological fluids, often exhibiting a reduced oxidation peak.

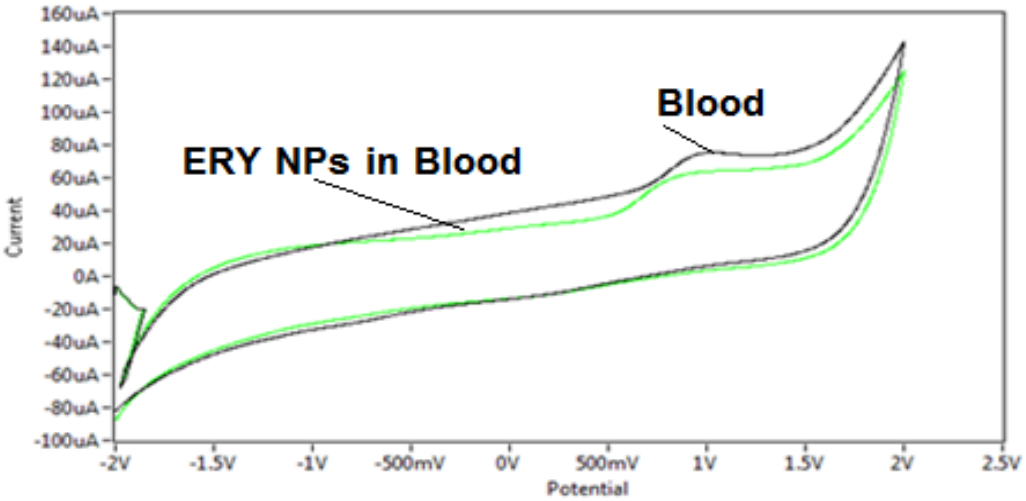

Fig. 7. Cyclic voltammogram of ERY NPs in blood medium (green line), blood medium only (black line) on working electrode (GCE) contrary to reference electrode (Ag/AgCl) with image degree of 0.1 Vsec-1. The oxidation current peak of the blood decreased effected by the ERY NPs.

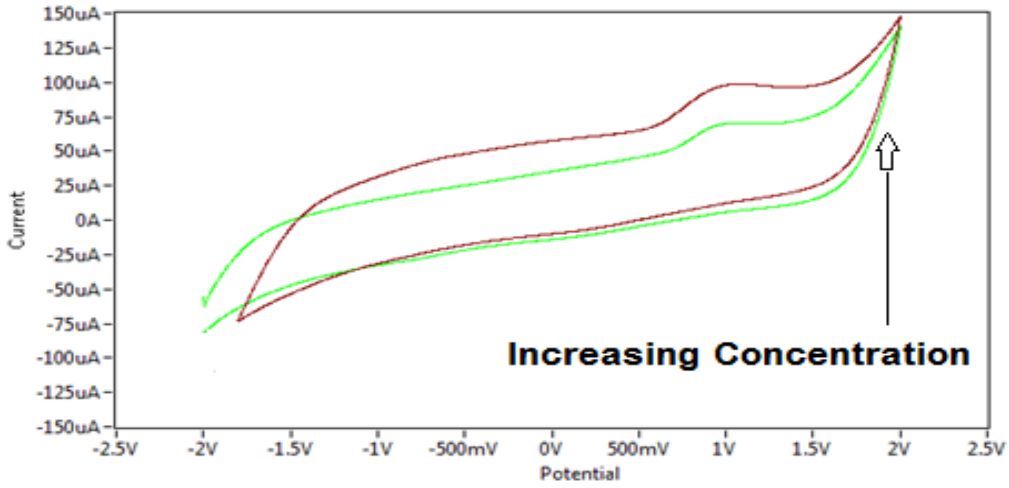

Fig. 8. Cyclic voltammogram of ERY NPs in blood medium at diverse concentrations on working electrode (GCE) contrary to reference electrode (Ag/AgCl) with image degree of 0.1 Vsec-1. The oxidation current peak of the blood was enhanced by increasing the concentration of nanoparticles.

This suggests improved stability and a potential antioxidant effect in blood serum, which may be useful in mitigating the oxidative stress associated with infections.

Erythromycin, a macrolide antibiotic, has been extensively studied for its electrochemical properties, particularly when formulated as nanoparticles (NPs). Nano formulation of erythromycin improves its surface area, potentially enhancing its interaction with electrochemical sensors and biological matrices such as blood. In the blood medium, the electrochemical behavior of erythromycin nanoparticles is affected by several influences which include the presence of proteins, electrolytes, and other biomolecules. These components can interact with the nanoparticles, affecting their redox properties and, consequently, their electrochemical signals. For example, the adsorption of plasma proteins to the surface of erythromycin nanoparticles can cause the creation of a protein corona, which may alter electron transfer kinetics. Electrochemical sensors, particularly those modified with nanomaterial, have shown promising results in

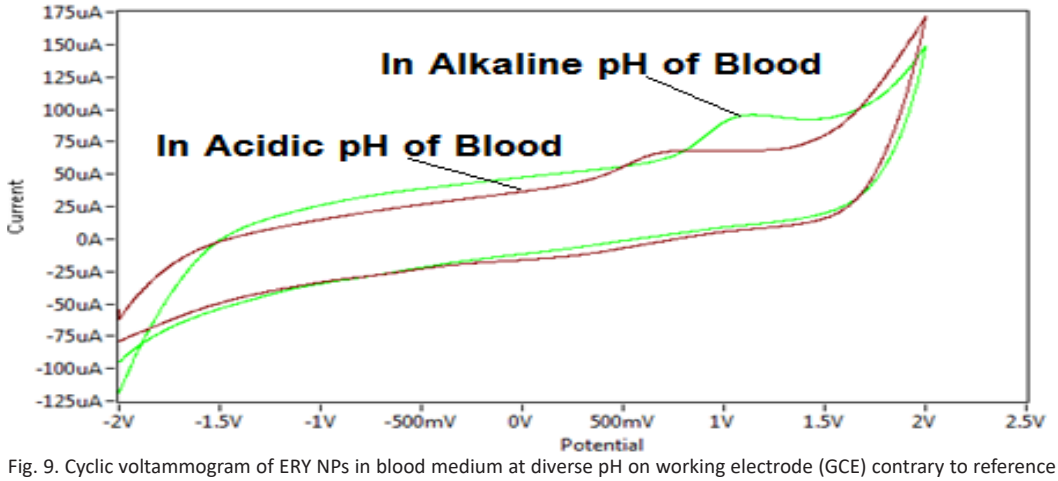

Fig. 9. Cyclic voltammogram of ERY NPs in blood medium at diverse pH on working electrode (GCE) contrary to reference electrode (Ag/AgCl) with image degree of 0.1 Vsec-1. The oxidation current peak of the ERY NPs in blood was enhanced by alkaline blood medium.

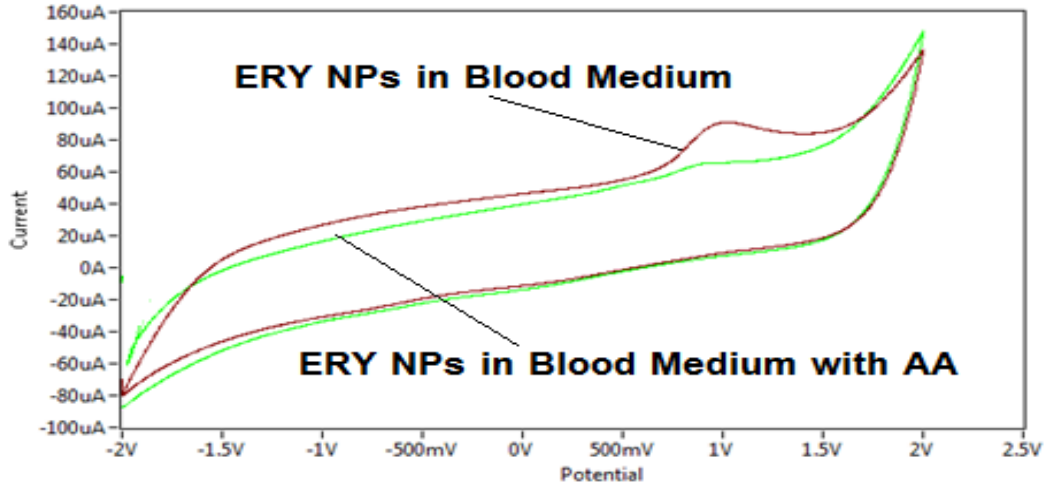

Fig. 10. Cyclic voltammogram of ERY NPs in blood medium with and without AA on working electrode (GCE) contrary to reference electrode (Ag/AgCl) with image degree of 0.1 Vsec-1. The oxidation current peak of the ERY NPs in blood with AA was acted as antioxidant in blood medium.

detecting erythromycin in complex matrices. For example, one study used the glassy carbon electrode which is altered by acetylene black nanoparticles to enhance erythromycin detection, achieving a detection limit of 8×10^{-8} M. These modifications improve the sensor's sensitivity by increasing its surface area and facilitating electron transfer [21].

Furthermore, molecularly imprinted polymers (MIPs) have been utilized to increase selectivity of electrochemical sensors for erythromycin detection. To manufacture MIPs, functional monomers are polymerized in the occurrence of a target fragment, creating specific binding sites. When incorporated into electrochemical sensors, molecularly imprinted polymers can selectively rebind to the target fragment, even when there is structurally similar compounds [22]. In the context of blood media, the application of MIP-based sensors can be challenging due to the complexity of their matrix. However, advances in sensor design, such as the incorporation of nanomaterial like gold nanoparticles and graphene, have upgraded the performance of these sensors in biological samples [21].

The electrochemical behavior of erythromycin nanoparticles (NPs) is pointedly affected by the pH of the surrounding medium, specifically in complex biological matrices such as blood. Changes in pH can alter the ionization state of erythromycin molecules, affecting their redox properties and interactions with electrochemical sensors. Under acidic conditions, erythromycin exhibits limited solubility and stability, resulting in reduced electrochemical activity. This is because of the protonation of purposeful collections, which can hinder electron transfer processes. Conversely, in alkaline environments, deprotonation enhances the molecule's ability to donate electrons, facilitating redox reactions at the electrode surface. This pH-dependent behavior has been observed in studies evaluating the antimicrobial efficacy of erythromycin, where increased activity was observed in alkaline media [23].

The design of pH-sensitive polymeric nanoparticles has been explored to improve erythromycin release patterns. For example, nanoparticles composed of Eudragit polymers remain intact in acidic environments, reducing drug release. However, under alkaline conditions, the polymer dissolves, leading to a significant increase in drug release. This controlled release mechanism is consistent with the enhanced electrochemical activity observed under alkaline conditions.

Electrochemical sensors have been developed to detect erythromycin of high sensitivity and selectivity. Modifications using nanomaterials, such as multi-walled carbon nanotubes and polyaniline compounds, have improved sensor

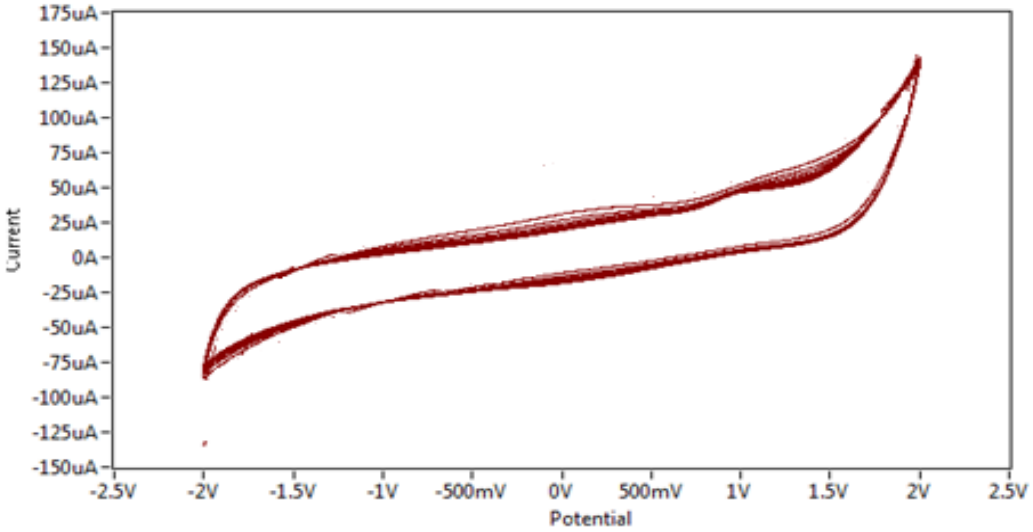

Fig. 11. Cyclic voltammogram of ERY NPs in blood medium for ten times scanning on working electrode (GCE) contrary to reference electrode (Ag/AgCl) with image degree of 0.1 Vsec-1.

performance. These improvements are particularly beneficial in alkaline environments, where increased solubility and ionization of erythromycin facilitate better interaction with the sensor surface. Understanding these pH-dependent behaviors is critical for improving sensor designs and drug delivery systems to ensure effective therapeutic monitoring [24].

Ascorbic acid (vitamin C) is a powerful antioxidant common in biological systems, known for its ability to donate electrons and neutralize reactive oxygen species. The presence of ascorbic acid in blood can lead to competitive interactions on the electrode surface during electrochemical measurements. Due to its strong reducing properties, ascorbic acid can be oxidized at voltages similar to or overlapping those of erythromycin, potentially causing interference in the electrochemical signals. This interference can complicate the interpretation of voltammetric data, making it difficult to distinguish between the oxidation peaks of ascorbic acid and erythromycin [25].

Furthermore, ascorbic acid can interact with the surface of erythromycin nanoparticles, potentially affecting their stability and aggregation behavior. These interactions may alter the surface charge and hydrodynamic size of the nanoparticles, affecting their diffusion coefficients and, consequently, their electrochemical responses [26]. To mitigate the interference caused by ascorbic acid in the electrochemical detection of erythromycin, several strategies can be employed: Selective electrode modification: Using electrode materials or surface modifications that selectively enhance erythromycin oxidation signals compared to ascorbic acid. For example, selectivity can be improved by incorporating molecularly imprinted polymers (MIPs) with specific binding sites for erythromycin.

Using advanced electrochemical techniques such as differential pulse voltammetry (DPV) can help identify closely spaced oxidation peaks, allowing for better discrimination between erythromycin and ascorbic acid signals. Enzymatic Degradation: Enzymes such as ascorbate oxidase in the system can selectively oxidize ascorbic acid, reducing its interference with erythromycin detection. Understanding the interactions between ascorbic acid and erythromycin nanoparticles is critical for accurate electrochemical detection of erythromycin in blood. By implementing strategies to reduce interference, the reliability and sensitivity of erythromycin electrochemical sensors can be significantly improved.

The reliability and stability of erythromycin in nano antibiotic systems have been the focus of recent electrochemical evaluations, especially in the development of innovative sensing platforms. These results are useful for nano antibiotic systems, paving the way for more effective antibacterial therapeutics and monitoring tools [27].

The unique electrochemical properties of erythromycin nanoparticles in blood emphasize their potential as effective therapeutic agents. Their stability, enhanced detection capabilities, and synergistic antibacterial effects make them promising candidates for the development of advanced antibiotic nano systems for clinical applications [28]. In summary, the electrochemical evaluation of erythromycin nanoparticles in blood reveals their positive biological effects, highlighting their potential to enhance antibiotic therapy through improved stability, detection, and efficacy.

CONCLUSION

Electrochemical evaluation of erythromycin nanoparticles (NPs) in blood confirms their great potential in modern antibiotic therapy. Erythromycin nanoparticles exhibit enhanced electrochemical stability, reduced oxidative degradation, and improved detection sensitivity. These properties support superior bioavailability and sustained activity in biological fluids. Overall, the study highlights that erythromycin nanoparticles not only maintain their pharmacological efficacy in complex biological environments but also offer promising prospects for the development of next-generation nanoantibiotic systems with improved therapeutic outcomes and resistance mitigation. Furthermore, the electrochemical analysis of erythromycin nanoparticles (NPs) in blood holds great potential for enhancing antibiotic delivery and efficacy. The results indicate that these nanoparticles facilitate enhanced interaction with bacterial cells, potentially leading to increased antibacterial activity. The stability and biocompatibility of the nanoparticles in biological environments support their potential for use as an antibiotic nano system. This research underscores the significance of nanotechnology in the developing of advanced therapeutic policies, paving the way to future

studies aimed at improving the formulation of erythromycin nanoparticles and their application in clinical settings. Further investigation into their mechanisms of action and long-term effects will be crucial to harnessing their full potential in combating antibiotic-resistant infections.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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