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## **Modification of Multi-walled Carbon Nanotubes Composite Paste Electrode with Nanonickel Pentacyanonitrosylferrate and Nickel Oxide Nanoparticles for Non-enzymatic Glucose Determination**

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A novel non-enzymatic electrochemical sensor with high sensitivity for glucose determination was introduced herein with nickel pentacyanonitrosylferrate (NiPCNF)-modified multi-walled carbon nanotubes (MWCNTs) paste electrode and deposited nickel hydroxide onto paste electrode using NiSO<sub>4</sub> solution and H<sub>2</sub>SO<sub>4</sub> as the soft template. The NiO-modified electrode was scanned with the cyclic voltammetry (CV) method in alkaline media to obtain Ni(OH)<sub>2</sub>/NiOOH particles as glucose electrocatalyst. The prepared nickel oxide was then mixed with the paste inside the tube. It was observed that introducing both NiPCNF and NiO could synergistically improve the activity toward electrocatalytic oxidation of glucose with an increase in the accessible active sites and promotion of the electron transport capability. Therefore, the modified electrode did not only exhibit outstanding electrochemical behavior but also decreased the potential for electrochemical oxidation and enhanced the affinity of the electrode to glucose. Field emission scanning electron microscopy (FESEM) was applied to study the surface morphology of the electrode and prepared NiPCNF powder. After optimizing the condition, the chronoamperometry (CA) technique was applied for glucose determination. Porous-modified electrode, containing both nanomaterials of NiPCNF and NiO, exhibited a vast linear range from 5 μM to 1.95 mM (2.6 orders of magnitude) with a low limit of detection (LOD) of  $2.35 \times 10^{-7} \pm 1.52 \times 10^{-8}$  M (S/N = 3) and high sensitivity ( $2.83 \pm 0.17$  mA mM<sup>-1</sup> cm<sup>2</sup>). Finally, the prepared sensor was utilized for glucose determination in the real samples successfully.

**Keywords:** Nickel pentacyanonitrosylferrate, MWCNTs, Nickel oxide, Glucose, Electrochemical, Sensor

### **INTRODUCTION**

Diabetes is believed to be a major health issue causing 4 million deaths annually. On a global scale, 171 million people are currently suffering from diabetes. Even though no cure has been found to date for diabetes, the level of blood glucose of diabetic patients needs to be closely controlled to prevent further issues. On account of the inevitable need for blood glucose monitoring, advanced devices for blood sugar detection have been produced with high accuracy and sensitivity, which

are used for clinical diagnosis as well as personal care. The acute need for these devices in ecology and food-related monitoring courses of action and clinical diagnostics, as well as the improvement in the use of renewable and sustainable energy sources, necessitated ample academic research and considerable commercial efforts for developing glucose sensors with a high level of sensitivity and selectivity, reasonable price, perfect reliability, and quick response [1]. To date, great efforts have been devoted to exploring cost-effective reliable glucose sensing techniques that are of a high level of sensitivity and selectivity, including chemiluminescence, colorimetric, conductometric, optical, fluorescent, and electrochemical methods along with surface plasmon resonance technique [2-

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9]. Among these methods, electrochemical ones are very popular glucose-sensing applications based on industry standards owing to scarce detection limits, and short time of response, and is far more cost-effective in comparison with those designed on the basis of other detection mechanisms [10]. Numerous approaches have been applied for the fabrication of glucose biosensors based on glucose oxidase enzyme. Nonetheless, immobilizing an enzyme on an electrode surface involves a lot of challenges, and is under the significant effect of different environmental factors, such as temperature, pH, and humidity, leading to poor stability [11-12]. Therefore, it is necessary to develop non-enzymatic glucose sensors as well. To this end, the synthesis of efficient catalysts for direct electro-oxidation of glucose is believed to be a pivotal step [13]. Moreover, several research works have focused on nanostructured materials owing to their extensive applications in different fields of science and technology over the recent years [14]. Metal oxides possess excellent properties for use in electrochemical biosensors, including controllable size, chemical stability, functional biocompatibility, enhanced electron transfer kinetics, catalytic activity, strong adsorption capabilities, along with modification capacity with various other materials [15]. Metal oxides that are widely utilized in the fabrication of non-enzymatic glucose sensors include NiO [16,17], ZnO [18,19], Co<sub>3</sub>O<sub>4</sub> [20,21], Fe<sub>2</sub>O<sub>3</sub> [22,23], MnO<sub>2</sub> [24,25], Mn<sub>3</sub>O<sub>4</sub> [26], CuO [13,27,28], and Cu<sub>2</sub>O [29-31]. In comparison with other materials, Ni is relatively cost-effective, making it a good choice for fabricating sensors in batches [32]. Moreover, nickel compounds are far more abundant and biocompatible (low toxicity), and present high stability in alkaline medium [33].

MWCNTs, as one of the most well-known types of carbon nanotubes, are the nanostructured materials applied in the preparation of glucose electrochemical sensors. Their unique qualities have attracted a great deal of attention in the field of the development of MWCNT-based chemical (bio)sensors, particularly for general and electrochemical detections. These sensors have demonstrated an extensive application for the detection of certain compounds, such as glucose [34].

It is important to obtain higher current densities in electrochemical sensors, which could be possible by the existence of the two metals with synergistic effects [35]. There is a great body of literature on these synergistic effects,

one of which reported that a higher current density associated with cobalt-nickel an alloy was attributed to a synergistic effect for the electro-catalytic activity [36]. The synergistic effect of silver nanoparticles, carbon nanotubes, and copper was reported by Naikoo *et al.* who found it to be an efficient electrochemical sensor for the trace recognition of amlodipine besylate drug [37]. To determine the anticonvulsant drug valproic acid, Casero *et al.* investigated the synergistic effect of diamond nanoparticles and MoS<sub>2</sub> in electrochemical sensors [38]. Yu and Ding *et al.* indicated the Co/Ni synergistic effect in ultrathin metal-organic framework nanosheets for the prominent optimization of non-enzymatic electrochemical glucose detection [39]. Synergistic effects should thus be further considered in electrochemical detections in order to prepare more sensitive sensors. For this purpose, NiPCNF and nickel oxide were utilized in this work for creating an operative synergistic effect, thereby an outstanding level of glucose sensing.

Finally, the present work aimed to fabricate a novel non-enzymatic glucose sensor according to MWCNTs paste electrode modified with NiPCNF/NiO nanoparticles with a low cost, outstanding stability, and high sensitivity. NiO particles were prepared *via* a simple electro-deposition method on MWCNTs paste electrode associated with hydrogen bubble evolution. The current work, for the first time, investigated the electro-catalytic behavior of NiPCNF-modified MWCNTs paste electrode/NiO nanoparticles film with synergistic effects towards glucose direct oxidation through the use of electrochemical methods. Eventually, the proposed electrochemical sensor was utilized for monitoring glucose in human blood serum.

## EXPERIMENTAL

### General

The electrochemical measurements herein were done with a potentiostat/galvanostat ( $\mu$ Autolab type III, The Netherlands). A handmade carbon paste electrode with a radius of 1.5 mm was adopted as the working electrode, a slice of Pt wire functioned as a counter electrode (Azar electrode, Iran), and an Ag/AgCl electrode saturated with KCl acted as a reference electrode (Azar electrode, Iran). Centrifuge Model MIKRO 220 classic was purchased from Hettich Co., Germany. FESEM images were obtained at Razi

Metallurgical Research Center (RMRC), Iran, a MIRA3 TESCAN SEM system. All the experiments were conducted in stationary media, but the solutions in CA method for determination were stirred at the fixed rotation speed of 150 RPM (Revolutions Per Minute). All the parameters affecting the experiments were optimized, including the concentration of solutions, the percentage of the NiPCNF and MWCNTs used for preparing carbon paste electrode, applied step potentials, as well as time. The examinations were all repeated three times or more at room temperature (25 °C).

### Materials and Solvents

All the chemical materials, namely NiSO<sub>4</sub>·5H<sub>2</sub>O, NaOH, H<sub>2</sub>SO<sub>4</sub>, KH<sub>2</sub>PO<sub>4</sub>, K<sub>2</sub>HPO<sub>4</sub>, KNO<sub>3</sub> paraffin oil, D-(+)-glucose, graphite powder, sodium nitroprusside, HCl, ethanol, ascorbic acid (AA), uric acid (UA), dopamine (DA), and nickel chloride, were bought from Merck Co. (Darmstadt, Germany). MWCNTs were purchased from Carbon Nano-Material Technology Co. (South Korea). Human blood serum samples were obtained from Urmia Blood Transition Center, Iran. Polyethylene tube was purchased from a local store. 0.1 M phosphate buffer (pH 7.2) and 0.1 M KNO<sub>3</sub> solution were used as an electrolyte for glucose electro-catalysis. Double-distilled (DD) water was utilized for preparing all the experimental solutions. All the glucose stock solutions were refrigerated (4 °C) for a day before being used to achieve adequate maturation.

### Synthesis of NiPCNF

Through dropwise mixing, NiPCNF particles were prepared. In a beaker, after balancing the temperature in a thermostat at 5-10 °C under vigorous stirring, 10 ml of the aqueous solution of nickel chloride (0.02 M) was taken. Afterward, 10 ml of the aqueous solution of sodium nitroprusside (0.01 M) was added to the aqueous solution of nickel chloride dropwise. Through the use of 1 N HCl, the pH of the obtained mixture was adjusted to 3 in order to avoid metal hydroxides formation; the precipitate remained in the same situation overnight. The residue was centrifuged after rejecting the supernatant liquid. NiPCNF residue was primarily washed with a high quantity of DD water and ultimately, using alcohol. The residue was collected in a petri dish and dried at room temperature. The obtained NiPCNF particles were utilized as a modifier for making carbon paste

electrodes [40].

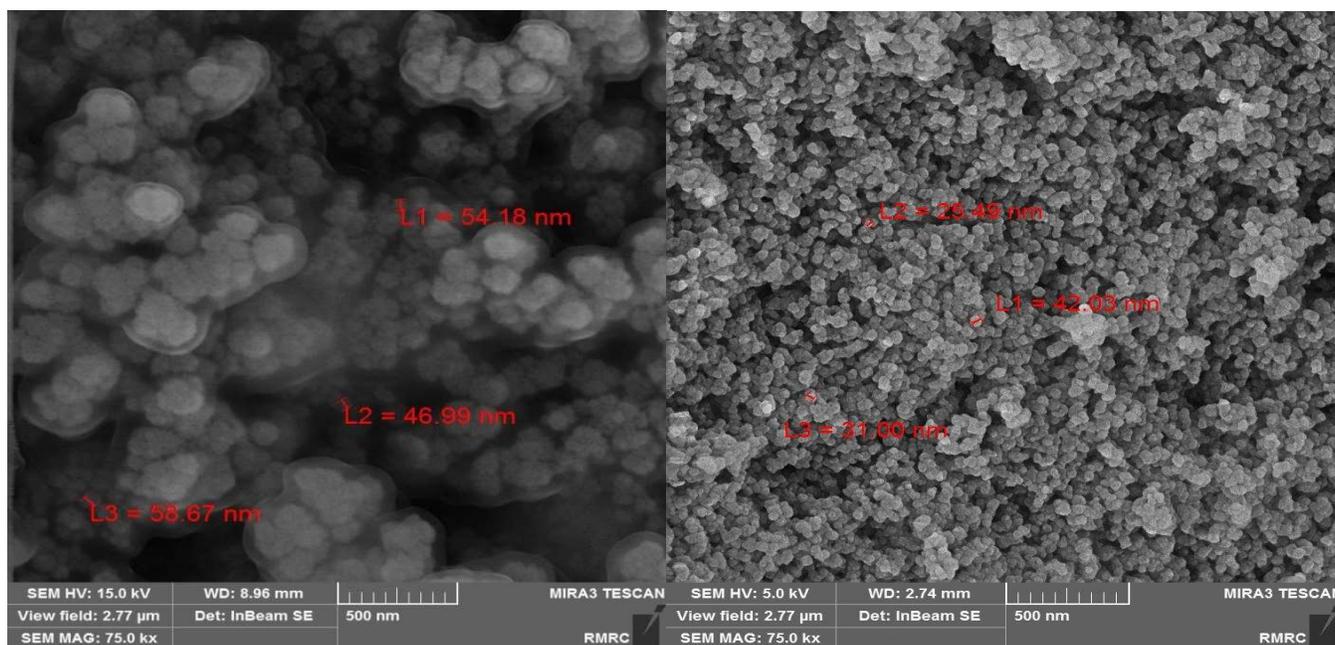
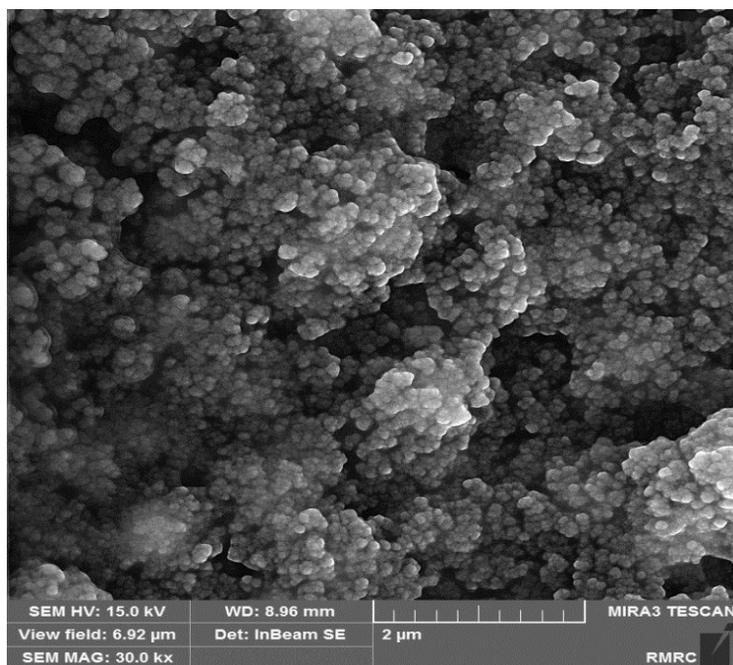
### Procedures of NiPCNF-Modified Carbon Paste Electrode/Nickel Oxide Fabrication

First, a mixture of 80% graphite powder, 10% MWCNTs, and 10% NiPCNF was prepared and pulverized for 15 min. In the next step, paraffin oil (20 μl) was added gradually to the above-mentioned mixture. The new combination was then stirred for 15 min until a homogeneous carbon paste was obtained. Subsequently, a portion of the resulting nanocomposite was packed into a polyethylene tube and a copper rod was pushed into the tube in the opposite direction of the paste in order to make contact with the carbon paste. The electrode surface was then wiped with clean paper to obtain a smooth surface. The fabricated paste electrode was immersed into a mixture solution containing NiSO<sub>4</sub> (0.14 M) and H<sub>2</sub>SO<sub>4</sub> (0.14 M). Afterwards, the electrodeposition of Ni particles was accomplished by applying a -1 V potential for 900 s *via* the CA technique. The surface of the electro-modified electrode was then washed with DD water and placed in NaOH (0.1 M) solution. It was scanned with the CV method in the range of 0-1.0 V potential until a constant voltammogram was obtained. Through this procedure, the deposited Ni particles were converted into nickel oxide particles. The electrode was then washed and left to dry. Thereafter, 3 mm of the contents of the polyethylene tube was expelled from the tube by pressing the copper rod. The desired amount was weighed and packed into the tip of the tube by pulling back the copper wire. Under optimized conditions, a potential of +0.5 V was observed using the CA method for glucose determination in 0.1 M phosphate buffer solution with a pH of 7.2 and 0.1 M KNO<sub>3</sub>.

## RESULTS AND DISCUSSION

### Characterization of the Electro-modified Surface

The surface examination of the electrode is of particular importance since this surface reacts as an electro-catalyst in analyte detection. One of the best techniques for studying surface morphology is the FESEM method. Figure 1 represents the FESEM image of NiPCNF powder, in which the nanoparticle size of NiPCNF is clearly seen. NiPCNF nanoparticles increased the specific surface area of MWCNTs and improved the headstock of the electrode



**Fig. 1.** FESEM images of NiPCNF powder (upper image) and NiPCNF modified MWCNTs nanocomposite paste electrode/nanonickel oxide by different magnifications that electrodeposited at -1 V for 900 s in the solution consisting of 0.1 M NiSO<sub>4</sub> and 0.1 M H<sub>2</sub>SO<sub>4</sub> (down images).

surface for subsequent modification with nickel nanoparticles. Moreover, the images at the bottom of Fig. 1 were taken under different magnifications. As seen, nickel

oxide particles were placed alongside each other, forming a nanostructure. Additionally, the surface resembled a porous film, which was due to the generation of H<sub>2</sub> gas as a soft

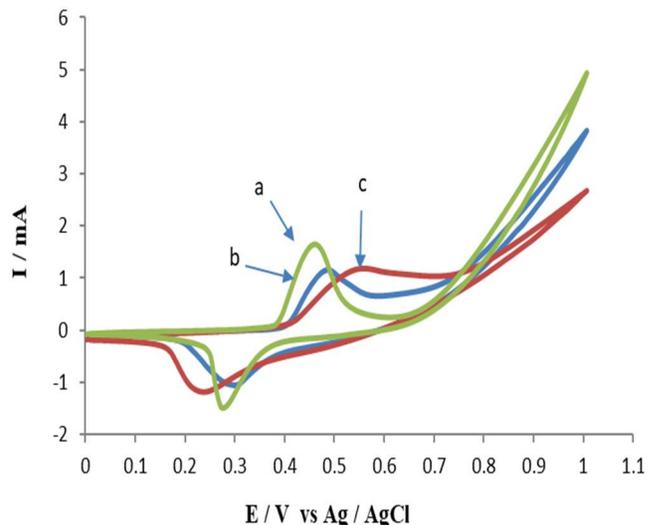
template for gaining a porous surface. The presence of sulfuric acid obviously led to the generation of H<sub>2</sub>. The application of a porous nickel oxide nanoparticle film rather than a traditional one increased the specific surface area, resulting in more NiO nanoparticles for higher electro-catalysis of glucose. Furthermore, the use of MWCNTs and NiPCNF nanopowder for the paste preparation provided a larger surface area for the preparation of nickel oxide particles. The surface area of the electrode was measured *via* Randles-Sevcik equation; the area was studied utilizing the cyclic voltammetric method, 1.0 mM K<sub>3</sub>Fe(CN)<sub>6</sub> as a test solution along with 0.1 M KCl as the supporting electrolyte, at different sweep scan rates, at T = 298 K. For a reversible process, the following equation was applied:

$$I_p = 2.69 \times 10^5 n^{3/2} A D^{1/2} \nu^{1/2} C_0$$

A denotes the area of the electrode surface, D shows the diffusion coefficient,  $\nu$  is the sweep rate, and C<sub>0</sub> is the concentration of K<sub>3</sub>Fe(CN)<sub>6</sub>. The electroactive surface area of 33.78 mm<sup>2</sup> and 13.51 mm<sup>2</sup> were respectively obtained using Randles-Sevcik equation for modified and unmodified electrodes. Furthermore, the surface area of the modified electrode increased by 60% compared with that of the unmodified one.

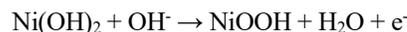
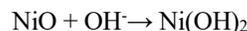
### Electro-catalytic Behavior of NiPCNF/Nickel Oxide Nanoparticles/MWCNTs-Modified Paste Electrode towards Glucose Oxidation

The electro-catalytic behavior of NiPCNF/NiO/MWCNTs nanocomposite paste electrode towards glucose determination was studied through the CV technique. Of note, the potential scanning of nano NiO-modified carbon paste electrode ranged from 0 to 1.0 V in the alkaline solution, which raised the amount of redox couple Ni(OH)<sub>2</sub>/NiOOH resulting from NiO, thereby improving their electrochemical properties and electro-catalytic performance toward the oxidation of glucose. This improvement could be attributed to the synergistic effect between NiPCNF-MWCNTs and NiO, both indicating unique electronic and catalytic properties. The addition of NiPCNF nanoparticles to the MWCNTs paste electrode can cause a significant growth in NiO film by increasing the specific surface area and improving the electro-deposition capacity of NiO. It also exerts a synergistic effect enhancing conductivity.



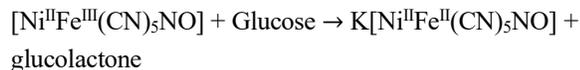
**Fig. 2.** Cyclic voltammograms of a) NiPCNF/NiO modified MWCNTs paste electrode, b) NiO modified MWCNTs paste electrode and c) NiPCNF modified MWCNTs paste electrode in 0.1 M phosphate buffer solution (pH 7.2) and 0.1 M KNO<sub>3</sub> at the scan rate of 50 mV s<sup>-1</sup>.

Therefore, NiPCNF/MWCNTs/NiO-modified electrode demonstrated a high electrode surface area and a faster electron-transfer rate in comparison with the other electrodes. According to Fig. 2, anodic and cathodic peaks were the redox pairs of Ni<sup>2+</sup>/Ni<sup>3+</sup> (16) and Ni<sup>II</sup>Fe<sup>II</sup>(CN)<sub>5</sub>NO/ Ni<sup>II</sup>Fe<sup>III</sup>(CN)<sub>5</sub>NO [41]. The redox peaks of nickel appeared in the following reactions [42]:



It can be deduced that the transition of Ni<sup>2+</sup>/Ni<sup>3+</sup> must have occurred with the help of OH<sup>-</sup> ion. Firstly, NiO could be oxidized in the alkaline electrolyte in the presence of OH<sup>-</sup> ion to form Ni(III) species (NiOOH), acting as strong oxidants. Glucose was then electrocatalytically oxidized to glucolactone by Ni(III) species.

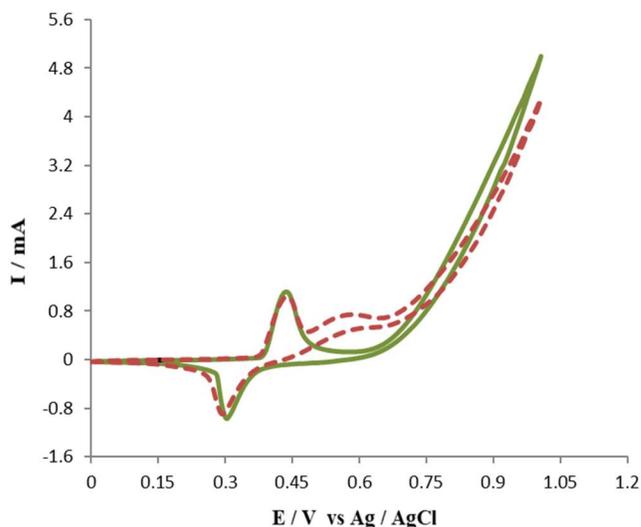
Redox peaks for NiPCNF simultaneously appeared in the following reactions [41]:



Finally, the result was consistent with the commonly reported mechanism of glucose oxidation at NiPCNF/NiO-based modified electrodes in alkaline electrolytes.

For evaluation of the synergistic effect of NiPCNF and NiO cyclic voltammograms of nickel oxide-modified MWCNTs paste electrode (without NiPCNF), NiPCNF-MWCNTs paste electrode surface modified with nanonickel oxide and NiPCNF/NiO/MWCNTs-modified electrode are compared in Fig. 2. As seen, the synergistic effect of NiPCNF and NiO-modified electrodes causes high currents and decreases the demand potential for oxidation in comparison with NiO-modified and NiPCNF-modified electrodes. Thus, the synergistic effect of NiPCNF-MWCNTs/nanonickel oxide provides a great electrocatalytic effect. This phenomenon additionally provides good electrical transfer all over the modified electrode. Figure 3 depicts the cyclic voltammograms of NiPCNF-MWCNTs and NiO-modified electrodes in the potential range of 0 to 1.0 V in the absence (solid-line cyclic voltammogram) and presence (dash-line cyclic voltammogram) of glucose (1.62 mM) in a 0.1 M phosphate buffer solution (pH 7.2) and 0.1 M KNO<sub>3</sub> solution with a scan rate of 50 mV s<sup>-1</sup>. It can be seen in Figure 3 that once glucose is present, there is a rise in the anodic peak charge and reversely, a slight reduction in the cathodic peak current, showing an irreversible reaction on the electrode surface, all of which revealed high electro-oxidation behavior of the suggested non-enzymatic sensor. Furthermore, with the increase in glucose concentration, more glucose was electrochemically oxidized and more NiOOH and [Ni<sup>II</sup>Fe<sup>III</sup>(CN)<sub>5</sub>NO] were at the same time consumed, raising the oxidation peak current of glucose while decreasing the reduction peak current. Moreover, an oxidation peak started at +0.5 V, which was related to glucose oxidation. For the modified electrodes, ΔE<sub>p</sub> increases slightly with the addition of glucose. This is likely due to restricted glucose diffusion processes on the electrode surface during the electrocatalytic reaction.

Figure 4 shows chronoamperogram of NiPCNF/nanonickel oxide/MWCNTs paste electrode to the succeeding additions of glucose into 0.1 M phosphate buffer solution (pH 7.2) and



**Fig. 3.** Cyclic voltammograms of NiPCNF/NiO modified MWCNTs paste electrode in the absence (solid-line) and presence (dash-line) of 1.62 mM glucose in 0.1 M phosphate buffer solution (pH 7.2) and 0.1 M KNO<sub>3</sub> at the scan rate of 50 mV s<sup>-1</sup>.

0.1 M KNO<sub>3</sub> at +0.5 V (a), amperometric response *versus* glucose concentration (b), and corresponding calibration curve (c). In Fig. 4a, the current steps are drawn over time and the glucose concentration in each step increases compared to the previous one. The glucose concentrations of this chronoamperogram are plotted versus the current in Fig. 4b. As shown, the electrode surface is probably poisoned with glucose and does not show linear behavior at high glucose concentrations. Figure 4c illustrates the calibration curve for measuring glucose, which includes a linear range and line equation.

The proposed non-enzymatic glucose sensor of NiPCNF/nanonickel oxide/MWCNTs offers a platform that appeared in a vast linear range from 5 μM to 1.95 mM (2.6 orders of magnitude) with LOD  $2.35 \times 10^{-7} \pm 1.52 \times 10^{-8}$  M (S/N = 3) and high sensitivity ( $2.83 \pm 0.17$  mA mM<sup>-1</sup> cm<sup>-2</sup>) for glucose recognition in addition to a high level of stability (6.8% current loss in a period of one month), acceptable reproducibility with 8% RSD (Relative Standard Deviation) for 10 equal experiments, and great selectivity against common interfering species, such as AA, UA, and DA. Given glucose concentration in human blood being about 30 times DA or AA

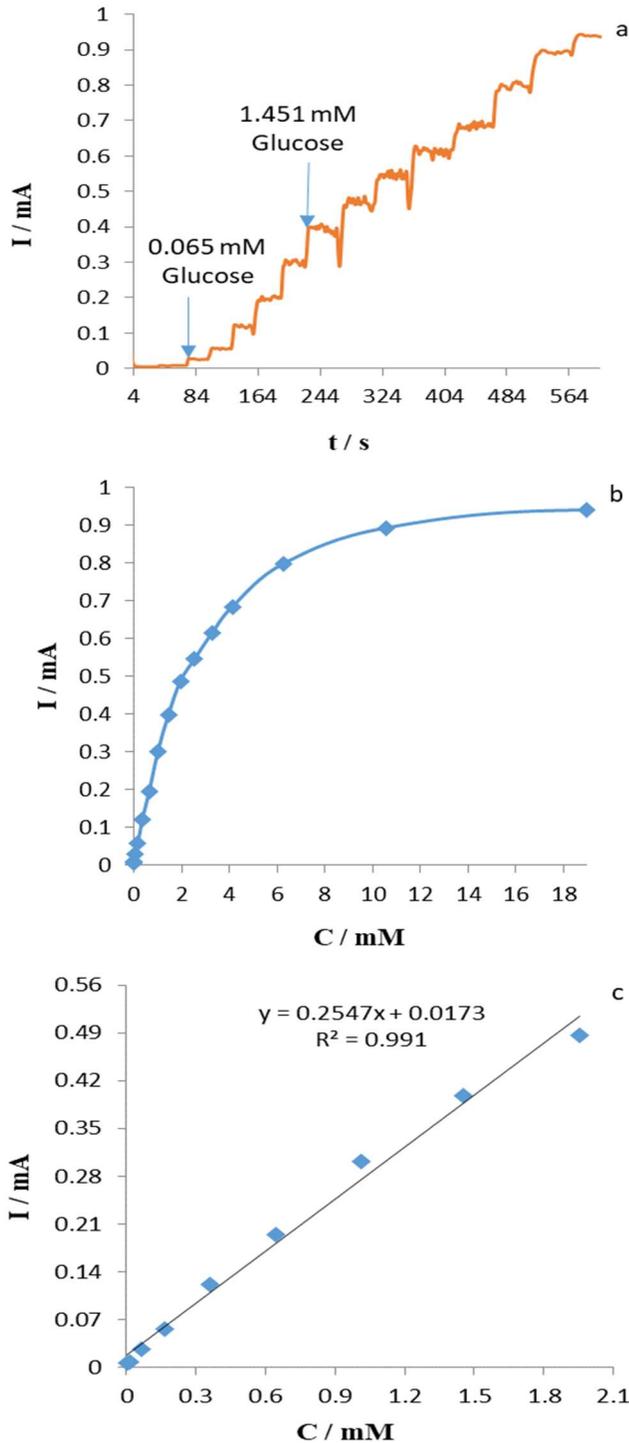


Figure 4. NiPCNF/NiO modified MWCNTs paste electrode, a) chronoamperogram of modified electrode to succeeding additions of glucose into 0.1 M phosphate buffer solution (pH 7.2) and 0.1 M  $KNO_3$  at +0.5 V, b) amperometric response versus glucose concentration and c) corresponding calibration curve.

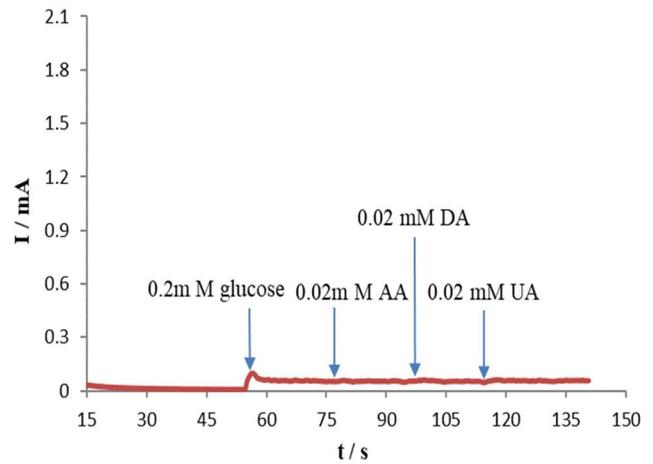


Fig. 5. Chronoamperogram of NiPCNF/NiO modified MWCNTs paste electrode to show selectivity against common foreign materials such as AA, UA, and DA in 0.1 M phosphate buffer solution (pH 7.2) and 0.1 M  $KNO_3$  electrolyte.

[43], the present research examined the modified electrode amperometric responses towards glucose addition at concentrations 10 times higher than the interfering species. As shown in Fig. 5, the impalpable signal decrease was reported for AA, UA, and DA.

For real sample analysis, after centrifuging the real human blood serum samples, 20  $\mu l$  of them was added into 5 ml 0.1 M phosphate buffer solution (pH 7.2), and 0.1 M  $KNO_3$ , and the corresponding current was measured. The results are shown in Table 2. This table also represents the comparative analysis of the blood samples gotten from the clinical blood sugar analyzer as well as the obtained results of the proposed glucose sensor. It is obvious that the two results of each sample were consistent with a relative error of below  $\pm 4.42\%$ , suggesting the possibility of using the proposed glucose sensor in real blood samples.

Some of the characteristics of the proposed glucose sensor are summarized in Table 1. Based on this table, the sensitivity of this work for glucose determination ( $2.83 \pm 0.17 \text{ mA mM}^{-1} \text{ cm}^{-2}$ ) is higher than the values reported with modified electrodes [44-47,55]. Furthermore, the LOD of the proposed electrode for glucose determination is much better than that reported in other articles [16,44-46,49,55-56]. In this case, the impact of using NiPCNF should be noted. As demonstrated in Table 1, this work had some advantages over previous works. That said, it indicated that the fabricated sensor

**Table 1.** Comparison of some Characteristics of Proposed Non-enzymatic Glucose Sensor with Earlier Reports

Electro-catalyst	Linear range (mM)	Sensitivity (mA mM <sup>-1</sup> cm <sup>-2</sup> )	LOD (μM)	Ref.
NiO	0.01-2.14	4.02	1.6	[16]
Pt-Ni	0-15	0.940	0.3	[44]
Ni	0.015-6.45	0.207	4.8	[45]
NiO/nitrogen doped carbon spheres	0.001-0.008	0.398	0.25	[46]
	4-9	0.018	50	
MWCNT-Au@NiO@CuO	$1.00 \times 10^{-6}$ - $5.6 \times 10^{-6}$	1.636	0.15	[47]
NiO-SWCNTs	$0.5 \times 10^{-3}$ - $1.3 \times 10^{-3}$	2.980	0.056	[48]
Ni(OH) <sub>2</sub> /MoS <sub>x</sub>	0.01-1.6	-	5.4	[49]
Reduced graphene oxide/nickel submicrorods composite	$40 \times 10^{-6}$ -0.72	7.121	0.5	[50]
NiO nanosheets/gold	0.25-3.75	1.618	2.5	[51]
NiO based glucose sensor	$0.1 \times 10^{-6}$ -8	0.050	1	[52]
Nickel hexacyanoferrate/polyaniline hybrids on graphene	0.001-0.765	0.487	0.5	[53]
Ni nanoporous thin film	0.002-1.4	2.050	0.34	[54]
NiO-glassy carbon	$50 \times 10^{-6}$ - $600 \times 10^{-6}$	0.987	3.2	[55]
	1-10			
NiO	$10 \times 10^{-6}$ - $100 \times 10^{-6}$	2.942	2	[56]
	$100 \times 10^{-6}$ - $2000 \times 10^{-6}$	0.754		
NiPCNF/NiO MWCNTs	0.005-1.95	$2.83 \pm 0.17$	$0.235 \pm 0.015$	This work

**Table 2.** Determination of Glucose in Human Blood Serum Samples Using the Proposed Non-enzymatic Glucose Sensor

Sample	Clinical analyzer (mmol dm <sup>-3</sup> )	Proposed sensor (mmol dm <sup>-3</sup> )	Relative error (%)
1	5.2	$5.43 \pm 0.31$	4.42
2	4.9	$4.81 \pm 0.29$	-1.84
3	4.6	$4.69 \pm 0.34$	1.95
4	4.9	$5.11 \pm 0.41$	4.28
5	4.0	$3.83 \pm 0.28$	-4.25
6	4.8	$4.90 \pm 0.37$	2.08
7	4.9	$5.00 \pm 0.40$	2.04
8	4.3	$4.22 \pm 0.21$	-2.32

had a proper linear range with a high level of sensitivity and a low level of LOD. This modified electrode for measuring glucose resulted in much more favorable outcomes compared

to that reported in many previous works. This might be owing to the synergistic effect between NiPCNF and NiO, which had been exposed. Ultimately, glucose sensing in practical samples

of human blood serum exhibited excellent consistency with records collected from a local medical laboratory.

## CONCLUSIONS

The present work carried out the electrodeposition of porous nanonickel oxide particles on high-surface electrode NiPCNF-modified MWCNTs nanocomposite paste electrode using hydrogen gas as a soft template. We then utilized NiO nanoparticles inside NiPCNF and MWCNTs paste electrodes for fabricating a glucose non-enzymatic sensor. The excellent electro-catalytic performance of the fabricated electrode originates in NiPCNF and NiO synergistic effects. The proposed glucose electrochemical sensor is believed to be superior to the others owing to its low level of LOD, vast linear range, high selectivity, and sensitivity, along with adequate reproducibility and high stability. The simple and novel method of fabrication of modified electrode with reasonable results showed that developed electrodes could be directly applied for accurate and precise glucose monitoring since they improve the electron transfer rate of the glucose. Furthermore, they could be combined with a hand-made screen-printed electrode and are applicable for practical blood glucose determination.

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