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Employment of nanostructured conducting polymer for the preparation of electrochemical biosensors

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Abstract
The twenty first century has gained great attention regarding nanostructured conducting polymers and their number of application in the field of biosensors, microelectronics, polymer batteries, actuators, energy conversion, and biological applications. In the field of bioengineering application, the conducting polymers have been exploited as excellent matrixes for the functionalization of various biological molecules and thus enhanced their performances as biosensors. Moreover, combinations of metals or metal oxides nanostructures with conducting polymers result in improving the stability and sensitivity as the bio sensing platform. This article explains the fabrications of various conducting polymers nanostructures and their composites with different shapes.

Keywords: Conducting polymers, molecularly imprinted polymer, cell-based chip, nanotechnology, biosensors, electrochemical sensor

1. Introduction

Conducting polymers (CPs) are considered as one of the most explored materials in the field of biosensors and tissue engineering applications [1-3]. The biocompatibility as well as the unique electrical properties enhance the broad acceptability of the CPs. CPs have potential to convert the biochemical information into electrical signals. Additionally, CPs possess many functional groups, which are responsible for maximum enzyme loading through the interaction between the enzyme molecules and the polymers' functional groups, and this phenomenon results in the preparation of a well-organized scaffold biosensors [4]. Recently, nanostructured CPs represented an excellent building block for developing highly sensitive biosensors [5] due to their unique properties that combine with those of the CPs (Biocompatibility, direct electrochemical synthesis) and the nanomaterials (e.g., large surface area, flexibility for the immobilization of biomolecules and quantum effect) [6-8].

2. NSCP-Integrated Electrochemical Biosensors

2.1 NSCPs for Cell-Based Chip Applications: It is challenging to understand cell behavior based on the measurement of only nucleic acid or protein expression levels because the cells are much more complicated than the sum of its components [9]. Several electrically conductive scaffolds have been used for making a cell-based chip for enhancing the adhesion, proliferation, and differentiation of several cell types such as neurons [9-10]. Here, we will address the uses of CPs modified electrodes for developing cell-based chips and their applications. Lee *et al.* developed an electrochemical conducting scaffold composed of pyrrole N-hydroxyl succinimidyl ester and pyrrole (PPy-NSE) copolymer, then modified this copolymer with nerve growth factor (NGF) and it used for PC12 cells immobilizations [11]. They have claimed that cells have extended neurites similarly to that for cells cultured in medium containing NGF. El-Said *et al.* reported on uses of a thin layer of polyaniline emeraldine base (EB) coated indium–tin oxide (ITO) electrode as a cell-based chip [10].

2.2 NSCPs for Electrochemical Detection of Glucose and H_2O_2: Nowadays, diabetes mellitus represents a severe health problem worldwide due to its complications that are more harmful than diabetes itself [12]. Therefore, developing an accurate and fast assay for early diagnosis of diabetes disease is an urgently needed issue. Several analytical assays were reported for monitoring diabetes based on the measurement of glucose level in blood [13-14].

The glucose sensors could be classified into enzymatic and enzyme-free sensors [13-15]. Here, we will discuss the uses of CPs for developing highly sensitive glucose sensors. Deepshikha *et al*. report on the preparation of PANI NSs by using sodium dodecylsulphate (NSPANI-SDS) as glucose and H_2O_2 biosensor [16]. SDS acts as an ideal structure-directing agent for the synthesis of ordered nanostructured polymer composed of framework protonated amine such as PANI NSs. The uses of these NSs polymer with large specific surface area could enhance the conductivity of PANI and results in easily immobilization with high loading of horseradish peroxidase (HRP) and glucose oxidase (GOx). In addition, these NSs enhance the rate of electron transfer and the current response. These modified PANI NSs were used as optical and electrical biosensors with good performances, fast response time, wide linear range, and good selectivity, stability and reproducibility.

2.3 Nscps for Different Biosensor Applications: Conducting polymers have been widely used for preparing of sensor platforms and imparts many advantages due to the incorporation of their functional groups into their fabrication. Here, we will discuss the fabrication and uses of different NSCPs and their composites, as well as their electrochemical biosensor applications for the various biological targets such as nucleic acid, ATP, neurotransmitter, etc. Guanine (G) and adenine (A) and are two of the purine bases, which participate in the building of nucleic acids and are fundamental compounds in different biological systems. The abnormal concentration of A and G in body fluid is related to the deficiency of the immunity system. Hence, monitoring of the A and G concentration in living organisms is a great demand issue. El-Said *et al*. have fabricated poly (4–aminothiophenol) (PATP) nanostructures layered on gold nanodots patterned indium tin oxide (ITO) electrode based on a simple method. The modified gold nanodots ITO electrode was fabricated based on thermal evaporation of pure Au metal onto the ITO surface through polystyrene monolayer. Then, use of these Au nanodots as a template for self–assembly immobilization of ATP molecules followed by electrochemical polymerization of ATP into PATP. The modified electrode was applied to monitor the concentration of the mixture of adenine and guanine with LOD of 500 and 250 nM, respectively. Furthermore, the modified electrode was extensively applied for detecting adenine and guanine in human serum.

3. Molecularly Imprinted Polymers as Selective Biosensors: Molecularly imprinted polymers (MIPs) were reported as one of the most sensitive and selective materials for biosensor applications [17]. The fabrication process of the MIPs involved the uses of three components (i) the template molecules (imprinted molecules), (ii) the functional monomers (FM) and (iii) the cross-linker molecules. The polymerization process was performed in the presence of a cross-linker. The template molecules were removed from the resultant polymers to form imprinted cavities that could rebind with the template molecules during the recognition process. The selectivity mechanism of the MIPs is based on the fact that these MIPs offered structurally adapted recognition sites for the rebinding of target molecules such as drugs in complex mixtures. The selectivity of the MIPs to molecules is related to their matching in chemical groups and the interactions between template molecules and imprinted groups that depend on the shape and rigidity of the template molecules. Therefore, these cavities could be used for enantiomeric resolution (i.e., differentiate between the S-type and R-type analogs (optical enantiomers)).

4. Conclusion
Here we have discussed the synthesis and uses of conducting polymers nanostructured as well as their biosensors and biological applications. Uses of the conducting polymers nanostructures in the biosensors field related to their excellent conductivity, stability, and ease of preparation. One of the important inherent specificity of enzyme-based electrochemical biosensors is that the uses of biorecognition elements are to choose suitable matrixes for immobilization of the biorecognition elements. The conducting polymers could provide excellent matrixes for immobilization of different biorecognition elements molecules (e.g., enzymes) with keeping their redox centers in excellent electrical communication with the transducing electrode and hence enhance their biosensors efficiency. Furthermore, combinations of metals nanostructures with conducting polymers result in enhancing the stability of the nanostructures composites. Here we have shown the synthesis and application of several metals/conducting polymer nanostructures. Especially the electrochemical biosensor applications of the conducting polymers nanostructures for monitoring different important biological target species such as DNA bases, proteins, peptides, glucose, viruses, and cell-based chips. Moreover, we have discussed the fabrication of the molecularly imprinted polymer-based biosensors.

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