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Electrochemical sensing and bio-sensing of bisphenol A and detection of its damage to DNA: A comprehensive review

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ABSTRACT

This review is aimed at providing comprehensive information on the applications of electrochemical sensors and biosensors to the determination of bisphenol A (BPA) and detection of its damage to DNA as one of the most important endocrine disrupting chemicals (EDCs). The BPA exhibits endocrine disruption in binding to estrogen receptors, such as alterations in endogenous hormone synthesis, hormone metabolism and hormone concentrations in blood which can cause cancerous tumors, birth defects and other developmental disorders. Therefore, sensitive and selective determination of BPA and its damage to DNA is needed and interesting. Electrochemical sensors and biosensors are very suitable for monitoring because of their excellent selectivity and sensitivity, automation, fast response and good repeatability and reproducibility. In this review, we have provided valuable information about electrochemical sensors and biosensors applied for determination of BPA and detection of its damage to DNA.

1. Introduction

During the current century, a lot of synthetic chemicals were produced to provide scientific, medical, industrial and agricultural needs. Although these chemicals provided social and economic benefits, their disposal cause release of a lot of pollutants into the environment [1–14]. When endocrine active chemicals are present in the environment, they can affect an organism, a population and even a community. Some of these chemicals are called xeno-estrogens which have estrogenic activity. The endocrine system, which controls the release of hormones and therefore a body system, plays a major role in the health of mammals [15–18]. Endocrine disrupting chemicals (EDCs) are exogenous substances which can interfere with the endocrine system. These disruptions cause birth defects, tumors, and other developmental disorders and therefore, any system in the body which is controlled by hormones can be affected by EDCs [19–27]. Bisphenol A, abbreviated as BPA, is an EDC and its structure is shown in Fig. 1. BPA is known for its use in the production of epoxy coatings and polycarbonate. BPA is used as an antioxidant or stabilizer in polyvinyl chloride [28] and as an intermediate in plastics used in industry and household. Some of these materials are used in food containers or water bottles from which BPA migrates [29–31].

There are different analytical methods for the determination of BPA including high-performance liquid chromatography, liquid chromatography-mass spectrometry, gas chromatography–mass spectrometry, fluorimetry, chemiluminescence, molecularly imprinted polymers

Abbreviations: BPA, bisphenol A; EDCs, endocrine disrupting chemicals; MIP, molecularly imprinted polymers; GCE, glassy carbon electrode; CNT, carbon nanotubes; SF, silk fibroin; MWCNTs, multiwalled carbon nanotubes; CoPc, cobalt phthalocyanine; CV, cyclic voltammetry; NiTPPS, Ni(II)tetrakis(4-sulfonatophenyl) porphyrin; PGA, polyglutamate acid; CS, chitosan; N-GS, nitrogen-doped graphene sheets; CMEs, chemically modified electrodes; HQ, hydroquinone; NP, 4-nonylphenol; OP, 4-*t*-octylphenol; MB, methylene blue; TTIP, titanium isopropoxide; NPGF, nanoporous gold film; BDD, boron-doped diamond; DPV, differential pulse voltammetry; SWCNTs, single walled carbon nanotubes; IL, ionic liquid; CTAB, hexadecyltrimethylammonium bromide; GS, graphene nanosheets; CB, carbon black; CC, catechol; BDD, boron-doped diamond; CPE, carbon paste electrode; CoPc, cobalt phthalocyanine; MNPs, magnetic nanoparticles; rGO, reduced graphene oxide; TA/N-G, tannic acid functionalized N-doped graphene; PEDOT, poly(3,4-ethylenedioxythiophene); BMIMBr, 1-butyl-3-methylimidazolium bromide; SPCE, screen-printed carbon electrodes; LSV, linear sweep voltammetry; CMK-3/nano-CILPE, ordered mesoporous carbon CMK-3 modified nano-carbon ionic liquid paste electrode; Fc, ferrocene; ds-DNA, double-stranded DNA; CoTe QDs, CoTe quantum dots; PBS, phosphate buffered solution; QCM, quartz crystal microbalance; BHPVA, 4,4-bis(4-hydroxyphenyl) valeric acid; BSA, bovine serum albumin; EIS, electrochemical impedance spectroscopy; FET, field effect transistor; NGP, nanographene; GNPs, gold nanoparticles; ABPE, acetylene black paste electrode; Bi_2WO_6-CPE, modified carbon paste electrode; DES, diethylstilbestrol; Pβ-CD/EG, poly-β-cyclodextrin/electroreduced graphene; 3Au-1Pd alloy NPs/GN, 3Au-1Pd alloy nanoparticles/graphene composite; DAPPT, propane tetrafluoroborate ionic liquid; PEC, photoelectrochemical; SSB, single-strand break; DSB, double-strand break; HMDE, hanging mercury drop electrode; AgSAE, silver solid amalgam electrodes; ssDNA, single-stranded DNA; ROS, reactive oxygen species; ACV, alternating current voltammetry; PSS, poly(styrene sulfonate); CTAB, cetyltrimethylammonium bromide; RSD, relative standard deviation; GCP, graphite carbon powder; NOP, nonylphenol; EST, ethynylestradiol; β-CD, β-cyclodextrin; CYP2C9, cytochrome P450 2C9; PAM, polyacrylamide; CNTFET, carbon nanotube field-effect transistor; MMIN, magnetic molecularly imprinted nanoparticles; AB, acetylene black; DHP, dihexadecyl hydrogen phosphate; SWV, square wave voltammetry; JugBPA, 5-hydroxy-1,4-naphthoquinone-BPA

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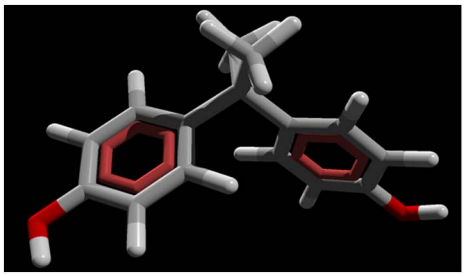

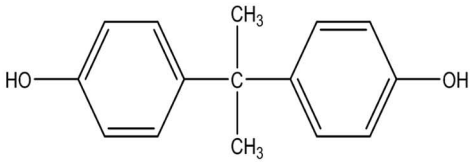

Fig. 1. Molecular structure of BPA.

(MIP), and enzyme linked immunosorbent assay [32–36] and the most frequently used of them are chromatography and MS techniques [37]. These techniques are able to the analysis of BPA with high sensitivity but skilled operators, large capital investment, and sample preparation and pretreatment are required and these requirements reduce their applicability [38]. Other recently developed approaches for determination of BPA include enzyme-linked immunosorbent assay [39], fluorescent method [40–44], surface-enhanced Raman scattering [45,46], ultraviolet [47], mass detectors [48,49], colorimetric methods [50], and electrochemical sensors [41–63]. Among the mentioned methods, electrochemical sensors are the widely accepted and employed group because of selectivity, simple real-life sample analysis, and feasibility of BPA analysis in human internal fluid. BPA is electrochemically active, but direct electrochemical oxidation of BPA at an unmodified electrochemical sensor is irreversible and requires overpotentials, which decreases the sensitivity of detection. Moreover, oxidation of BPA at unmodified electrodes causes formation of oxidation products which foul the electrode. To overcome these challenges, novel sensing materials with high stability, good catalytic activity and excellent conductivity must be developed. A lot of electrochemical sensors have been constructed involving metal nanoparticles [52], quantum dots [53], carbon nanotubes [54,55], graphene [51,56–58], the composite of nanomaterials [59–61] carbon nanotubes [64], CoTe quantum dots [65], mesoporous silica [66], gold nanoparticles [67] or other functional materials including cobalt phthalocyanine [68], high aspect-ratio ZnO nano tetrapods [69], Mg-Al layered double hydroxide [70], thionine-tyrosinase [71,72] and Ni(II) tetraaminometallophthalocyanine polymer [73] for the detection of BPA.

In this review, we will provide an extensive overview on efforts for the design and applications of electrochemical sensors and biosensors for determination of BPA in various types of real-life samples. Some discussion on applications of electrochemical sensors for detection of DNA damage induced by BPA will be presented as well. In the first section, some information about EDCs, BPA and electrochemical sensors are introduced. In the second section, selected examples of developed electrochemical BPA sensors and biosensors reported in literature will be discussed. In the third and fourth sections, we will review applications of electrochemical sensors, and finally the results of the review will be discussed and concluded.

2. Development of electrochemical BPA sensors

In this section, introduce examples of developed electrochemical BPA sensors.

Electrochemical sensors are the most rapidly growing group of chemical sensors among presently available systems for practical applications. Chemically modified electrodes (CMEs) comprise a relatively modem approach to electrode systems that finds utility in (1) a wide spectrum of basic electrochemical investigations, including the relationship of heterogeneous electron transfer and chemical reactivity to electrode surface chemistry, electrostatic phenomena at electrode surfaces, and electron and ionic transport phenomena in polymers, and (2) the design of electrochemical devices and systems for applications in chemical sensing, energy conversion and storage, molecular electronics, electrochromic displays, corrosion protection, and electro-organic syntheses. Compared with other electrode concepts in electrochemistry, the distinguishing feature of a CME is that a generally quite thin film (from a molecular monolayer to perhaps a few micrometer-thick multilayer) of a selected reagent is bonded to or coated on the electrode surface to endow the electrode with the chemical, electrochemical, optical, electrical, transport, and other desirable properties of the film in a rational, chemically designed manner. Biosensor is a special type of CME in which a biochemical recognition process is coupled to an appropriate electrochemical transducer. The electrode surface is modified by the attachment of a biocomponent (e.g., enzyme, antigen/antibody, plant or animal tissue) which functions as the biological recognition element or biochemical receptor.

Understanding the redox behaviour of BPA is critical for designing and successful application of electrochemical BPA sensors. In Liu et al.'s work [74], the electrochemical behaviour of BPA was studied at a bare glassy carbon electrode (GCE) and Ni(II)tetrakis(4-sulfonatophenyl) porphyrin (NiTPPS)/carbon nanotube modified GCE (NiTPPS/CNT/GCE) in PBS (0.1 M, pH 7.2) containing 10% (v/v) acetonitrile by cyclic voltammetry (CV) [74]. This electrode was fabricated by electropolymerizing NiTPPS monomers on the CNT/GCE. They observed an irreversible oxidation peak between 0.5 V and 0.9 V and no reduction peak in the reverse scan. In addition, the oxidation peak decreased rapidly in successive scans, resulting in featureless voltammograms after three scans at bare GCE. This was attributed to strong passivation on the bare GCE surface by an insulating dimer or quinine product layer formed during the oxidation of BPA [75,76]. The CNTs have previously been demonstrated to enhance the detection sensitivity and stability of phenolic estrogenic compounds [77–80]. This study confirmed that the NiTPPS/CNT/GCE with limits of detection ranging from 15 nM to 260 nM shows strong electrochemical catalytic effect and anti-fouling ability towards the detection of phenolic estrogenic compounds. In another study, Yin et al. constructed … tyrosinase on a multiwalled carbon nanotube (MWCNT)-cobalt phthalocyanine (CoPc)-silk fibroin (SF) composite modified GCE [81]. The cyclic voltammogram of BPA at this biosensor exhibited a well-defined anodic peak at 0.625 V and the BPA oxidation signal has significantly increased compared to that obtained at a bare GCE. A mesoporous silica-based electrochemical sensor was constructed by Wang et al. for sensitive determination of BPA [82], so that the large active surface area and high accumulation efficiency were exploited to enhance the response signal of BPA. A work by Lin et al. reported the application of polyglutamate acid (PGA) and an amino-functionalised carbon nanotube (MWCNT-NH_2) nanocomposite modified GCE for the electrochemical determination of BPA [83]. The PGA/MWCNT-NH_2 nanocomposite exhibits excellent electrocatalytic activity for the oxidation of BPA by substantially enhancing the current response and decreasing the BPA oxidation overpotential. Fan et al. used nitrogen-doped graphene sheets (N-GS) and chitosan (CS) to prepare an electrochemical BPA sensor [84]. Compared with graphene, N-GS exhibited favorable electron transfer capability and electrocatalytic property which enhanced the response signal towards BPA. CS also exhibited excellent film forming ability and improved the electrochemical behaviour of N-GS modified electrode.

Yang et al. have reported the fabrication of a highly sensitive