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Water contamination by endocrine disruptors: Impacts, microbiological aspects and trends for environmental protection☆

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ABSTRACT

Hormone active agents constitute a dangerous class of pollutants. Among them, those agents that mimic the action of estrogens on target cells and are part of the group of endocrine-disruptor compounds (EDCs) are termed estrogenic EDCs, the main focus of this review. Exposure to these compounds causes a number of negative effects, including breast cancer, infertility and animal hermaphroditism. However, especially in underdeveloped countries, limited efforts have been made to warn people about this serious issue, explain the methods of minimizing exposure, and develop feasible and efficient mitigation strategies at different levels and in various environments. For instance, the use of bioremediation processes capable of transforming EDCs into environmentally friendly compounds has been little explored. A wide diversity of estrogen-degrading microorganisms could be used to develop such technologies, which include bioremediation processes for EDCs that could be implemented in biological filters for the post-treatment of wastewater effluent. This review describes problems associated with EDCs, primarily estrogenic EDCs, including exposure as well as the present status of understanding and the effects of natural and synthetic hormones and estrogenic EDCs on living organisms. We also describe potential biotechnological strategies for EDC biodegradation, and suggest novel treatment approaches for minimizing the persistence of EDCs in the environment.

1. Introduction

Endocrine-disrupting compounds (EDCs) are widely dispersed in water and other environments. EDCs have the ability to negatively affect the functioning of endocrine systems of humans and animals, because of their structural resemblance to natural hormones (Bar-El and Reifen, 2010; Gibson and Saunders, 2014; Giulivo et al., 2016). An increasing number of reports have described the adverse effects of these compounds, such as disturbances to the reproductive functions of human and animals (Sweeney et al., 2016; Gallo et al., 2016; Sheikh et al., 2017; Sheikh et al., 2016), and increases in metabolic disorders, such as metabolic syndrome (MetS) (reviewed by Heindel et al., 2016) and cancer (reviewed by Giulivo et al., 2016). EDCs may impact the mechanisms of production, metabolism and transport of natural hormones, thus impacting an organism's functioning (Kavlock et al., 1996; Moraes et al., 2008; Vandenberg et al., 2012). Androgens and estrogens (natural and synthetic), synthetically produced medicines, drugs and pharmaceuticals, pesticides, detergents and industrial chemicals are among the main classes of EDCs (Liu et al., 2010).

Multiple hormonal systems are involved in the adjustment of metabolism, growth, reproduction and behavior, and these systems are responsible for maintaining homeostasis (Hall and Guyton, 2006). Hormones, such as estrogens, can affect various types of cells and may have specific actions that impact female sex organs (Nelson and Cox, 2005). Many pathological conditions (breast, testicular and prostate cancer, reproductive dysfunction, and infertility) are affected by hormones (Sharpe and Skakkebaek, 1993; Daston et al., 1997; Lopes et al., 2010; Gibson and Saunders, 2014; Bloom et al., 2016). Several studies have reported on the contamination of water bodies by estrogenic EDCs (Heberer et al., 2002; Barel-Cohen et al., 2006; Balest et al., 2008; Liu et al., 2010;

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Chapman et al., 2011; Rocha et al., 2011a; Nie et al., 2014; Ribeiro et al., 2015; Wu et al., 2015). The major estrogens found in water bodies are the natural estrogens estrone (E1), 17β-estradiol (E2) and estriol (E3); and the synthetic estrogen 17α-ethinylestradiol (EE2). Estrogens are liposoluble and consist of three cyclo-hexyl rings and a cyclopentyl ring that form a single structure (Liu et al., 2015). Reported adverse consequences of the effects of estrogens on the human body and offspring are presented in Fig. 1.

One of the main challenges in mitigating the effects of EDCs is their potential to be toxic at very low concentrations, although the precise thresholds have not been established, especially because the toxicity depends on the affected organism. The LOEL (lowest observable effect level) of EDCs can vary based on the nature of the contaminant. For instance, natural steroids such as E1 and E2 can show LOELs of 10 ng L^{-1} for fish and plants (Barel-Cohen et al., 2006), whereas synthetic compounds can have physiological effects at lower concentrations (Segner et al., 2003; Vandenberg et al., 2012).

Water bodies become contaminated with estrogens and other EDCs because these hormones are not completely removed from sewage in traditional wastewater-treatment plants, and the contaminated effluents from such plants are dispersed widely in the environment (Combalbert and Hernandez-Raquet, 2010; Muller et al., 2010). Sun et al. (2016) reported significant estrogen-disruptor effects (EDEs), even when the secondary effluent was treated. The authors compared five different advanced-treatment systems (coagulation sedimentation, magnetic polyacrylic anion-exchange resin (NDMP) adsorption, activated carbon adsorption, ozonation, and electro-adsorption) and observed toxic effects following all treatment processes.

2. Endocrine disruptors and impacts of contamination on wildlife

Alterations in the endocrine reproductive system of wildlife and humans have been reported for over 50 years (Soto and Sonnenschein, 2015; Carlsen et al., 1992; Burlington and Lindeman, 1950; Daston et al., 1997; Nohynek et al., 2013; Gibson and Saunders, 2014; Kabir et al., 2015; Gallo et al., 2016; Hampl et al., 2016; Heindel et al., 2016; Lauritzen et al., 2016). Specific issues related to the presence of EDCs in the environment include the feminization of secondary sex characteristics in roosters, caused by high doses of dichlorodiphenyltrichloroethane (DDT) (Burlington and Lindeman, 1950), vaginal adenocarcinoma development in children associated with intrauterine exposure to the synthetic estrogen diethylstilbestrol (Rehme et al., 1998), breast growth, lactation, and predisposal to uterine diseases such as endometriosis and fibrosis (McLachlan et al., 2006). Bisphenol A (BPA) and E2 can impact the transcription of the sex genes *Icam5*, *Lhb* and *Fshb* during the neonatal period (Eckstrum et al., 2016). BPA can modify the size of the anteroventral periventricular nucleus (APV), which results in male and female APVs of identical size (Patisaul et al., 2006; Rubin et al., 2006). Disrupted thyroid functions caused by BPA, PCBs (polychlorinated biphenyls) and other disruptors (Kabir et al., 2015) and reproductive failure in birds caused by the bioaccumulation of persistent organochlorine pesticides have been reported (Colborn et al., 1993; Fry, 1995; Vandenberg et al., 2012; Chaiyarat et al., 2014).

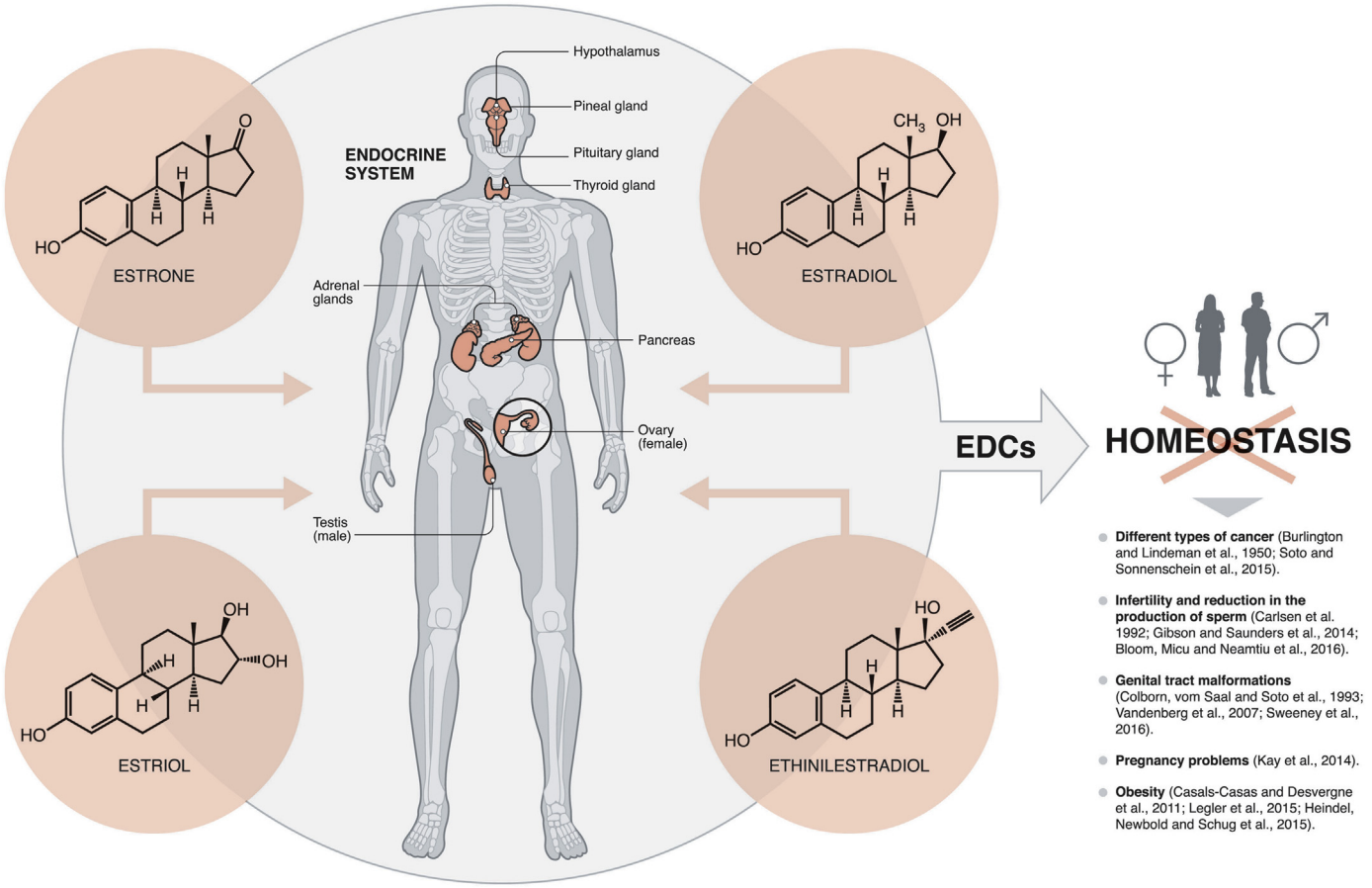

Fig. 1. Schematic representation of estrogens estrone (E1), estradiol (E2), estriol (E3) and ethinylestradiol (EE2) activities in the endocrine system affecting the body's homeostasis.