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Challenges in the Use of Polyethylene Terephthalate Bottles for the Packaging of Drinking Water

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ABSTRACT

Polyethylene terephthalate (PET) bottles have been marketed for the past four decades, gradually replacing PVC and glass bottles. The main challenges in the production and supply of bottled water are the contamination risk of groundwater and spring sources with agricultural and industrial pollutants, entry of organic compounds from the body of plastic pipes and storage tanks, and the dissolving of the composition of bottles in water due to storage and exposure to light. The present study aimed to investigate the adverse health effects of using PET bottles for the storage and supply of drinking water through reviewing the data in scientific databases such as SID, Springer, and ScienceDirect. According to the literature, the Integrated Risk Information System (IRIS) has introduced bis(2-ethylhexyl) phthalate (DEHP) as a potential pollutant and carcinogenic agent (group B2: probable human carcinogen). DEHP has the maximum concentration in bottled water due to its more frequent application compared to other phthalates. In the assessment of the non-cancer risk of dibutyl phthalate, butyl benzyl phthalate, and DEHP, which are the three main phthalates in bottled water in Iran under the storage conditions of 45°C for 45 days, the hazard quotient index has been calculated by dividing the daily received dose by the reference dose (RFD; μg/kg of body weight/day). The obtained value has been reported to be <1 even in the most vulnerable population (i.e., children). Therefore, it could be concluded the consumption of bottled water in Iran leads to no adverse health effects.

Introduction

Water is vital for living on earth, and the pattern of human settlement has historically been based on the level of access to water. Consumption of high-quality drinking water has no adverse effects on human health since it contains no hazardous impurities, such as bacteria, viruses, and inorganic or organic materials. In addition, there are no undesirable factors in drinking water, such as taste, smell, color or opacity (1).

The most common problems associated with drinking water resources are the hardness, contents of iron, sulfide, and sodium chloride, acidity, and presence of pathogens (e.g., bacteria and viruses). Moreover, water resources may include toxic metals, such as mercury, lead, cadmium, chromium, silver, aluminum, arsenic, and barium. These compounds could cause chronic or acute poisoning and must be removed from drinking water.

More than one billion people do not have access to safe drinking water in different regions of the world, and approximately 80% of the deaths among children occur due to water-related infectious diseases, such as diarrhea (two million deaths per year) (2). Nowadays, water has become an increasingly important economical resource, and markets have emerged for private investors to produce and supply packaged water in many countries, including France, England, Brazil, Austria, Bolivia, and Italy. The origins of packaged waters are mainly natural mineral waters, spring water, and refined waters (3, 4). In many countries, packaged water is used to provide drinking water for several deseeds that are relatively expensive (5).

Polyethylene terephthalate (PET) bottles have been marketed for the past four decades, gradually replacing PVC and glass bottles. In Europe, packaged water accounts for 44% of the market for non-alcoholic beverages with a consumption of 105 liters per year in 2009 (6). PET is the most advantageous substance for the packaging of drinking water. In developing countries, the shortage of safe, accessible drinking water and increased concerns regarding the adverse health effects of harmful compounds in drinking water distribution networks have led to the increased consumption of packaged water, even in the countries with effective water distribution networks (2, 6).

The main challenges in the production and supply of bottled water are the contamination risk of groundwater and spring sources with agricultural and industrial pollutants, entry of organic compounds from the body of plastic pipes and storage tanks, and dissolving of the composition of the bottles in water due to storage and exposure to light (3).

PET is a semi-crystalline polymer belonging to the polystyrene family, which contains water, one or several monomers, and several additives, such as active accelerators, catalytic convertors, stabilizers, antioxidants, bonding agents, and plasticizers (7).

As phthalates do not attach to the polymer chain through chemical bonds, they could easily transfer from packaging materials to water and food. Di-isobutyl phthalate (DIBP), dibutyl phthalate (DBP), butyl benzyl phthalate (BBP), and bis(2-ethylhexyl) phthalate (DEHP) are among the compounds known to disrupt endocrine hormones through interference with the endocrine system (8, 9).

The Integrated Risk Information System (IRIS) has introduced DEHP as a potential pollutant and carcinogenic agent (group B2: probable human carcinogen). DEHP has the maximum concentration in bottled water considering its more frequent application compared to other phthalates. According to the World Health Organization (WHO), the standard level of DEHP is 8 μg/L, and the Environmental Protection Agency (EPA) has recommended the maximum concentration limit (MCL) of 6 μg/L for DEHP (8, 10).

Considering the health hazards associated with phthalates, studies should be focused on the concentrations of phthalates in bottled water and the comparison with the standard limit, as well as their origins, carcinogenicity risk, and strategies to minimize their application in the bottled water industry.

The present study aimed to investigate the health effects of using PET bottles for the storage and supply of drinking water through reviewing the data in scientific databases such as SID, Springer, and ScienceDirect.

Phthalate Sources in Bottled Water

Phthalates in water sources could results from the contamination of water during packaging and transfer of the raw materials used in the preparation of bottles depending on the type of the applied materials and technologies. Furthermore, phthalates may enter water through the stages of water treatment, cross-contamination in the laboratory analysis of water, and due to the resin found in the color of the plastic cap of water bottles (9, 11, 12).

According to the previous studies regarding phthalate sources, there are various concentrations of these compounds in different countries, as well as different brands. In some studies, the concentration of DEHP is above the standard limit (13). For instance, in Portugal, Santana has reported that the concentrations of di-n-butyl phthalate (DnBP) and DIBP are higher in glass water bottles compared to PET water bottles, particularly DnBP, so that the maximum concentration of DIBP in glass and PET water bottles is 2 and 1 μg/L, respectively, while the maximum concentration of DnBP in glass and PET water bottles is 6.5 and 1.5 μg/L, respectively. This could be due to the metal cap with the PVC ring (14). In contrast, the concentrations of phthalates in PET water bottles have been reported to be 20-fold its concentration in glass water bottles (15).

Effects of Temperature and Storage Time on Phthalate Concentrations

In the case of bottled water, the storage conditions and time before use should be considered. Exposure to high temperature and long-term storage increase the transfer rate of phthalates from the bottle into the water. Comparison of DBP concentrations at the temperatures of 10°C and 80°C for 10, 20, and 60 minutes has indicated the highest concentration of DBP at the storage temperature of 80°C for 60 minutes (16).

According to the literature, storage duration of 10 weeks at the temperature of 30°C in glass polyethylene (PE) and PET water bottles changes the concentrations of phthalates from below the detection limit to above the detection limit (13). Among three different temperatures of -18°C, 0°C, and +40°C with the same storage time, the lowest and highest concentrations of DBP, BBP, and DEHP have been observed at -18°C and +40°C, respectively (11). Insignificant changes in the concentrations of phthalates after 15-30 days of storage at the temperature of 40°C have also been reported due to the preparation of samples from supply markets and no effects of storage conditions from production until supply (9). DEHP has been reported to be the most abundant phthalate in various storage conditions (11).

Effects of Physiochemical Parameters of Water on Phthalate Concentrations

Acidic pH of water accelerates the transfer of phthalates from bottles to the water, so that phthalate concentration is higher in acidic water (e.g., soda) compared to water with neutral pH (17, 18). The other physiochemical parameters of bottled water have no effects on phthalate concentrations (15).

Share of Daily Phthalate Intake through Bottled Water and Assessment of Health Effects

Due to the variable water intake in different age groups based on the body weight, the daily intake of phthalates also varies in different age groups. In this regard, the most significant share has been reported in the infants aged 1-6 and 7-12 months, children aged 1-3 and 3-6 years, adolescents, and adults, respectively. According to the investigation of the pathways of phthalate exposure, the daily intake of diethyl phthalate (DEP), DBP, and DEHP through bottled water is less than 0.2% in adults, while the daily intake of DEP, DBP, and DEHP through bottled water in infants has been estimated at 21.4%, 2.9%, and 0.7%, respectively (9, 19).

The tolerable daily intake (TDI) of DEHP and DBP has been reported to be 50 and 10 μg/kg of body weight/day, respectively, and lower levels have been recommended for infants due to the greater vulnerability caused by the lack of the evolution of their defense systems and body detoxification, as well as the differences in their dosage response. In this regard, the rate of exposure to phthalates through bottled water has been estimated at 0.022-1.1% of the total TDI in children (11).

According to the assessment of the non-cancer risk of BBP, DBP, and DEHP in bottled water in Iran under the storage conditions of 45°C for 45 days, the hazard quotient index has been obtained by dividing the daily received dose by the reference dose (RFD) (μg/kg of body weight/day) and estimated at <1 even in the most vulnerable population (i.e., children). Therefore, it could be concluded that bottled water consumption in Iran has no adverse health effects.

Based on the DEHP carcinogenic risk factor of 4×10^{-7} (20) μg/L, the consumption of bottled water in Iran with the maximum DEHP concentration (1.6 μg/L) is not carcinogenic compared to the acceptable risk (one per a million of persons [10^{-6}]) (11).

Effective Strategies

According to the literature, addition of three types of nanoclay particles to PET water bottles could reduce the transfer of phthalates from the bottle to the water through a long, indirect diffusion, decreasing the movement of the polymer chain, and delaying the release of phthalates in water (21).

Conclusion

According to the results of this review, freezing is the optimal condition for the preservation of bottled water, whereas exposure to light and storage at high temperatures are least favorable conditions. Among various water quality parameters, only pH has been reported to affect the transfer of phthalates from the bottle to the water. In the case of non-cancerous complications based on the water use and RFD, the use of bottled water by infants aged less than six months as the most vulnerable age group is associated with adverse health effects if the DEHP concentration (the only phthalate with a guideline concentration) in the water is 17 times higher than the WHO guideline concentration (8 μg/L). In the case of carcinogenesis, if an individual consumes water containing more than 2.5 μg/L of DEHP throughout their life, the risk of cancer will be one per a million people.

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