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SHORT RESEARCH AND DISCUSSION ARTICLE

Do estrogenic compounds in drinking water migrating from plastic pipe distribution system pose adverse effects to human? An analysis of scientific literature

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Abstract With the widespread application of plastic pipes in drinking water distribution system, the effects of various leachable organic chemicals have been investigated and their occurrence in drinking water supplies is monitored. Most studies focus on the odor problems these substances may cause. This study investigates the potential endocrine disrupting effects of the migrating compound 2,4-di-tert-butylphenol (2,4-d-t-BP). The summarized results show that the migration of 2,4-d-t-BP from plastic pipes could result in chronic exposure and the migration levels varied greatly among different plastic pipe materials and manufacturing brands. Based on estrogen equivalent (EEQ), the migrating levels of the leachable compound 2,4-d-t-BP in most plastic pipes were relative low. However, the EEQ levels in drinking water migrating from four out of 15 pipes may pose significant adverse effects. With the increasingly strict requirements on regulation of drinking water quality, these results indicate that some drinking water transported with plastic pipes may not be safe for human consumption due to the occurrence of 2,4-d-t-BP. Moreover, 2,4-d-t-BP is not the only plastic pipe-migrating estrogenic compound, other compounds such as 2-tert-butylphenol (2-t-BP), 4-tert-butylphenol (4-t-BP), and others may also be leachable from plastic pipes.

Keywords Drinking water · Plastic pipe distribution system · Polyethylene pipe · Polypropylene pipe · Polybutylene pipe · Estrogenic compounds · Migration · Adverse effects

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Introduction

Since the 1980s, plastic piping has been increasingly utilized in drinking water distribution systems, in preference to other pipe materials such as cast iron, concrete, and copper. In Denmark, nearly all new drinking water pipes are made of polyethylene (PE), which comprised approximately 16% of the pipeline system in 2002. Meanwhile, 0.8–1.5% of the old pipeline system was replaced with PE pipes per year (Ryssel et al. 2015). According to the DK-VAND list of certified companies and products approved for drinking water in Denmark, pipes made of un-plasticized polyvinyl chloride (PVC) are also permitted for potable water system (DHI 2016).

According to Lucintel (2015), the global plastic pipe market has been forecast to expand further, with an annual growth rate of 6.8% from 2015 to 2020. The major drivers for this growing market are infrastructure development, rise in construction activities, replacement of aging pipelines made of traditional materials, and increasing population and urbanization. Potable water supply is expected to remain the largest market for plastic piping after wastewater supply application, as compared to alternative materials they are less expensive, lighter, and easier to install (Kelley et al. 2014; Lucintel 2015).

With the widespread application of plastic pipes in drinking water distribution systems, many substances which are potentially leachable from plastic pipes have been investigated (Brocca et al. 2002; Skjevrak et al. 2003; Loschner et al.

2011; Ryssel et al. 2015). To date, as many as 158 chemicals have been found to leach from plastic piping into drinking water (Whelton and Nguyen 2013). The migrating of chemicals from plastic pipes can result in a wide range of consequences, with the three main issues, increased total organic carbon (TOC) levels, increased odor problems in potable water, and potential public health risks, as outlined below.

TOC concentrations in drinking water are regulated in some countries as an indicator of drinking water quality. The maximum permitted TOC concentrations in Japanese and Chinese drinking water quality standards are 3 and 5 mg/L, respectively (Liu et al. 2016). Limits on TOC levels are mainly in place to minimize microbial growth in drinking water supplies, as the released TOC can be utilized by microorganisms as a source of energy and carbon, causing increased biofilm production in comparison to copper or stainless steel pipes (Van der Kooij et al. 2005).

Research by Kelley et al. (2014) revealed that the released TOC from cross-linked polyethylene (PEX) pipe was up to 6 mg/L in a simulated drinking water system, which exceeds the TOC limits for both Japanese and Chinese drinking water quality standards. There is though, some disagreement between studies as while Lund et al. (2011) found similar results to Kelley et al. (2014), other research has shown a much smaller effect on TOC levels by plastic piping (Heim and Dietrich 2007; Zhang et al. 2014).

The second main issue, increased odor problem in drinking water, is the result of plastics such as PEX piping producing a chemical/solvent odor in drinking water. A study by Durand and Dietrich (2007), identified 2-ethyoxy-2-methylpropane (ETBE) as an important contributor to the odor. Kelley et al. (2014) monitored ETBE concentrations in a migration test and found ETBE to leach in a range of 3 to 179 μg/L during 1-year operation. As the odor threshold of ETBE is only 2 μg/L (Van Wezel et al., 2009), the abovementioned research in Kelly et al. (2014) indicates that drinking water odor issue due to ETBE migrating from plastic pipes may be a long-term problem.

In addition to ETBE, odorant migrating substances from plastics include methyl tert-butyl ether (MTBE), 1,3-dibutadiene and cyclohexadiene among others, may also exist in drinking water (Heim and Dietrich 2007; Lund et al. 2011; Kelley et al. 2014). In addition to the migrating compounds, the presence of their degradation byproducts as a result of biodegradation by biofilm microbes, may also be responsible for inducing strong odors over time (Skjevrak et al. 2005; Lund et al. 2011).

The third main problem with substances leaching from plastic pipelines is the potential human health risks these migrating compounds may cause. Compared to TOC and odor issues, there is less available research on the human health risk associated with migrating leachable chemicals. In one study, concentrations of ten migrating compounds were monitored, and their potential health risks were evaluated based on their known toxicities, with the conclusion that the health risk from those migrating substances from new plastic piping, was low (Lund et al. 2011). The toxicity of two migrating compounds 2-t-BP and 2,4-d-t-BP to newborn rats, was studied by Hirata-Koizumi et al. (2005), establishing a no-observed-adverse-effect level (NOAEL) of 20 and 5 mg/kg/day, respectively. The high NOAELs of 2,4-d-t-BP appears to support the evidence that migrating compounds from plastic drinking water pipes have low potential health risks to humans. However, it should be noted that some migrating compounds such as 2-t-BP, 4-t-BP, and 2,4-d-t-BP are also reported to have estrogenic effects (Akahori et al. 2008; Tollefsen and Nilsen, 2008) and are reported to be endocrine disrupting compounds (EDCs).

In the last few decades, EDCs have been heavily researched due to their potential adverse effects on both wildlife and humans (Hu et al. 2009; Kidd et al. 2007; Liu et al. 2009a). A wide range of different substances belongs to the group of EDCs, including estrogens, androgens, phytoestrogens, progestins, as well as a number of industrial chemicals (Liu et al. 2011a, 2015a, 2015b). Due to the significant progress in EDC research, some of them have now been regulated within some drinking water quality standards.

Bisphenol A, diethyl phthalate, and di-butyl phthalate are three EDCs which are at present regulated in the Chinese drinking water quality standard, while 17β-estradiol (E2) and other four EDCs have been regulated in the latest Japanese drinking water quality standard (Liu et al. 2016). Despite this, little is known on their estrogenic potential, or the adverse effects of these estrogenic migrating compounds on human. Therefore, the main objective of this work was to evaluate the potential health risk of 2,4-d-t-BP from the viewpoint of endocrine disruption based on current existing literature, to further understand the effects of known and unknown estrogenic compounds, which are leachable from plastic drinking water pipes.

Materials and methods

Some basic information of 2,4-d-t-BP

2,4-d-t-BP is the most widely detected estrogenic compound leaching into drinking water from plastic pipes (Kelley et al. 2014; Loschner et al. 2011; Lund et al. 2011). The main source of 2,4-d-t-BP is from the degradation of phosphonite-based antioxidants such as antioxidant type 168 (Loschner et al. 2011), therefore, the presence of the antioxidants within plastic pipelines results in continual production of 2,4-d-t-BP, both within the pipe material or when antioxidant additives are released into

Table 1 Basic physicochemical properties of 2,4-d-t-BP

Name	CAS	Molecular formula	Water solubility (mg/L)	LogKow	Boil point (°C)	Saturated pressure (mmHg)	Odor threshold (μg/L)	Estrogenic potencies	
								rtER	hER (α)
2,4-d-t-BP	96-76-4	$C_{14}H_{22}O$	120	4.97	263.5	0.00557	200 [1]	1.6e-5[2]	1.5e-5[3]

Information of the physicochemical properties is drawn from Scifinder, rtER: rainbow trout estrogen receptor; hER (α) in Table 1: human estrogen receptor α; [1] Tao and Zhang, 2010; [2] Tollefsen and Nilsen, 2008; [3] Akahori et al., 2008

drinking water. The basic physiochemical properties of 2,4-d-t-BP are outlined in Table 1.

Potential health risk evaluation

In order to evaluate the potential health risks of 2,4-d-t-BP, firstly, we identified the existing levels of the target chemical in drinking water based on simulated migration test data available within scientific literature. The second step was to evaluate its potential risks, which was hindered significantly by the lack of direct investigation of the potential health risks associated with 2,4-d-t-BP as an estrogenic compound. Therefore, we evaluated comparable extensively studied estrogenic compounds, such as studies on potential health risks of 17α-ethynyl estradiol (EE2) and others at environmental relevant concentrations. However, the estrogenic activities of chemical compounds vary greatly, so for direct comparison the concentrations of the estrogenic compounds were all expressed as estrogen equivalence (EEQ) as shown in the equation below (Liu et al. 2009b,2011b, Yuan et al., 2016).

$$EEQ = \sum EP_i \times c_i \quad (1)$$

Where EP and c denote the estrogenic potency of an individual estrogenic compound and the corresponding existing concentration, respectively. EP of estrogenic compound is often determined by different in vitro bioassays such as yeast estrogen screen (YES) and estrogen receptor (ER) competitive ligand binding assay, in which E_2 with the strongest estrogenic activity among natural estrogens is often selected as the standard estrogenic compound, i.e., the EP of E_2 is set as 1. When the estrogenic activity of one compound is stronger than that of E_2, its EP would above 1, otherwise, the corresponding EP

Table 2 Standard procedure studies assessing the migration levels of 2,4-d-t-BP concentration from plastic pipes into drinking water

No	Pipe type[a]	Pipe age[b] (d)	Detected concentration (μg/L)	EEQ (ngE2/L)	Oral exposure level (ngE2/d/P)[d]	Ref
1	PE	30	3.7 (23)[c]	0.06	0.12	[1]
2	PE-RT	30	2.8 (60)	0.04	0.08	[1]
3	PEXb	30	26 (23)	0.39	0.78	[1]
4	PEXc	30	10 (23); 31 (60)	0.15; 0.47	0.3; 0.94	[1]
5	PEXd	30	4.6 (60)	0.07	0.14	[1]
6	PP	30	6.1 (23); 13 (60)	0.09;0.2	0.18;0.4	[1]
7	PB	30	113 (23); >368 (60)	1.7; >5.5	3.4;>11	[1]
8	PEXd	3	0.5 (37)	0.01	0.02	[2]
9	HDPE	3	~5 (room)	~0.08	~0.16	[3]
10	PEXb	9	~0.68 (room)	~0.01	~0.02	[4]
11	PEXc	9	~2.2 (room)	~0.03	~0.06	[4]
12	PEXd	9	~2.9 (room)	~0.04	~0.08	[4]
13	PB	9	344.9 (room)	5.2	10.4	[4]
14	PEXd	150	0.37 (room)	0.01	0.02	[4]
15	PEXc	150	0.27 (room)	0.004	0.008	[4]

[a] PE-RT: polyethylene; PEXa: polyethylene cross-linked by peroxides; PEXb: polyethylene cross-linked by silanes; PEXc: polyethylene cross-linked by electron beam processing; PP: polypropylene; PB: polybutylene; HDPE: high density polyethylene

[b] Under simulated migration test

[c] Data in the parenthesis is the centigrade temperature

[d] Taken 2 L of drinking water is consumed every day, the EP value was based on hER (α); [1] Loschner et al. 2011; [2] Ryssel et al. 2015; [3] Skjevrak et al. 2003; [4] Lund et al. 2011

Table 3 Adverse effects of different EDCs on different kinds of model animals

No	Subject	Target chemical	Exposure level		Exposure time (*d*)	Main conclusions	Ref
			Concentration (ng/L)	EEQ[a] (ngE2/L)			
1	Juvenile turbot (*Psetta maxima*)	EE_2	3.5	4.9	15	Reduction of both androgen production and plasma level in males was observed, which indicated that juvenile male turbots were susceptible to hormonal imbalance as a consequence of short-term exposure to environmentally relevant concentrations of EE_2.	[a]
2	Japanese Medaka (*Oryzias latipes*)	EE_2	0.2–10	0.28–14	120–180 (posthatch to sexually mature)	1) At exposure level of 0.2–2 ng/L, mixed secondary sex characteristics in male fishes were observed, but mating behavior and reproductive success were normal; 2) when the exposure level increased to 10 ng/L, 16 among 19 males did not copulate, and reproductive success was very low; 3) female fish showed normal development and oogenesis even at exposure level of 10 ng/L, but they had poor reproductive success; 4) presence of oocytes in testicular tissue may not directly impact the reproductive capability of the male fish, but exposure of EDCs causing gonadal intersex was sufficient to reduce reproductive performance.	[b]
3	Adult zebrafish	EE_2	10	14	17	1) Reduction in both male paternity and female maternity was observed; 2) reproductive success in male zebrafish was associated with the plasma concentration of 11-ketotestosterone and the corresponding concentration was suppressed in EE_2-exposed males.	[c]
4	Embryonic zebrafish (*Danio rerio*)	EE_2	0.19–1	0.27–1.4	~240	1) No significant differences in transcription of vtg1 gene in zebrafish were observed in male fish at the exposure concentrations of 0.19 and 0.24 ng/L, while significantly elevated vtg1 gene transcription were observed at the exposure level of 1 ng/L; 2) a significant concentration-dependent increase in egg mortality between 8 and 24 h post-fertilization was observed at all the exposure concentrations of 0.19, 0.24, and 1 ng/L; 3) at two lowest exposure concentrations of 0.19 and 0.24 ng/L, EE_2 impacted late gastrulation and/or early organogenesis, whereas exposure to 1 ng/L disrupted development in the blastula phase.	[d]
5	Japanese medaka (*Oryzias latipes*)	E_2	29.3	29.3	25	At exposure concentration of 29.3 ng/L, 62.5% of male fishes had testis-ova gonad.	[e]
6	Adult zebrafish (*Danio rerio*)	EE_2, E_2, E_1, and other 8 EDCs	3–1608	20.7 (in total)	21	Vitellogenin mRNA and HIS in males confirmed both exposure regimes as physiological active. Meanwhile, potential candidates for estrogenic disturbance of steroidogenesis were identified (StAR, 17Bhsd1, CYP19A1), which suggested that “non-classical effects” of estrogenic EDC in fish were mediated via transcription factor.	[f]
7	Frog (*Xenopus tropicalis*)	EE_2	1.8–180	2.52-252	32	EE_2 caused a concentration-dependent increase in the proportion of phenotypic females, and the percentages of females in control, 1.8, 18, and 180 ng/L of EE_2 were 32, 63, 90, and 100%, respectively.	[g]
8	Sydney rock oyster (*Saccostrea glomerata*)	EE_2	6.25–50	8.75–70	49	1) Vitellogenin was found to increase in a dose dependent manner with EE_2 exposure for males;	[h]

Table 3 (continued)

No	Subject	Target chemical	Exposure level		Exposure time (*d*)	Main conclusions	Ref
			Concentration (ng/L)	EEQ[a] (ngE2/L)			
						2) histological examination of gonads revealed a number of individuals exhibited intersex (ovotestis) at exposure level of 6.25 ng/L or more for 49 days.	
9	Zebrafish (*Danio rerio*)	E_2	25	25	21	1) Vitellogenin induction was observed in adult male fish under the E2 exposure concentrations between 5 and 25 ng/L; 2) a modification of the secondary sexual characteristics in adult male fish at exposure concentration of 25 ng/L was observed.	[i]
10	Male fathead minnows	4-nonylphenol	6100	1.84	14	1) Exposure resulted in an induction of plasma vitellogenin in males within 14 days; 2) reproductive competence of the exposed males was decreased when compared to the controlled males.	[j]
11	Salmon smolts	4-nonylphenol	2000	0.60	21	1) Exposure of 4-nonylphenol would result in delayed mortality rates; 2) One year after exposure, yolk-sac larvae decreased gill sodium-potassium-activated adenosine triphosphatase activity and seawater tolerance during smolt development; 3) exposed fish had 20% lower plasma insulin-like growth factor I levels and 35% lower plasma triiodothyronine.	[k]
12	Zebrafish (*Danio rerio*)	EE_2	5	7	Life-long exposure	1) Life-long exposure caused a 56% reduction in fecundity and complete population failure with no fertilization; 2) infertility was due to disturbed sexual differentiation, with males having no functional testes and either undifferentiated or intersex gonads.	[l]
13	Mussel (*Mytilus edilus*)	Bispenol A	50,000	6.3	21	1) It induced the expression of phospho-proteins in females and spawning in both sexes; 2) Severe damaging effects on ovarian follicles and ovocytes were observed in female mussels.	[m]
14	Zebrafish	Zearalenone	100–1000	2.83–28.3	21	1) At exposure concentration of 1000 ng/L, the relative spawning frequency was reduced to 38.9%; 2) relatively fecundity at 100 and 1000 ng/L was reduced to 74.2 43.8%, respectively; 3) a 4.4-fold induction of plasma vitellogenins was observed in male zebrafish at 1000 ng/L.	[n]

[a] EP values of EE2, 4-nonylphenol, bisphenol A and zearlenone were 1.4, 3.01×10^{-4}, 1.26×10^{-4}, and 2.83×10^{-2}, respectively, which were derived from Liu et al. (2009c, 2010); [a] Labadie and Budzinski, 2006; [b] Balch et al. 2004; [c] Coe et al. 2008; [d] Soares et al. 2009; [e] Kang et al. 2002; [f] Urbatzka et al. 2012; [g] Pettersson and Berg, 2007; [h] Andrew et al. 2010; [i] Brion et al. 2004; [j] Schoenfuss et al. 2008; [k] Lerner et al. 2007; [l] Nash et al. 2004; [m] Arab et al., 2006; [n] Schwartz et al., 2010

would below 1. Therefore, the unit of EEQ is normally represented as ngE_2/L.

Results and discussions

Migration levels

Polymer plastic materials may include numerous residual monomers, oligomers, or other substances and additives (such as antioxidants) for protection of pipe material during its production and use. Many of these substances, as well as their degradation products and impurities have the potential to migrate into the drinking water (Loschner et al. 2011). In order to check potential migrating chemicals, some standard procedures such as EN-1420-1, prEN-15768, and NSF1 standard 61 have been applied, to simulate the migration levels of substances from plastic pipes into drinking water (Loschner et al. 2011; Lund et al. 2011; Kelley et al. 2014). In these tests, a pre-flushed new plastic pipe is filled with ultrapure water, allowed to stagnate for 72 h and then emptied, with the effluent collected and prepared for the analysis of the migrating compounds. To evaluate the long-term period migration, the above migration test is continued with repeated ultrapure water testing every 72 h. The results of these studies are summarized in Table 2.

As shown in Table 2, several kinds of plastic pipes have been utilized in drinking water distribution systems. PB pipe has been shown to release the highest concentrations of 2,4-d-t-BP into drinking water among all plastic pipe materials. Studies have shown that the release of 2,4-d-t-BP from PEX pipes is more complex. Loschner et al. (2011), found three kinds of PEX pipes to release between 4.6–26 μg/L of 2,4-d-t-BP into drinking water after 1 month of pipe usage.

One potential reason for the long-term release of 2,4-d-t-BP at relatively high levels from PEX pipes, might be that the compound is non-biodegradable to the microbial communities that form the biofilms within PEX plastic pipes (Ryssel et al. 2015). However, another study found that the same three kinds of new PEX pipes, after 9 days of usage released no more than 2.9 μg/L of 2,4-d-t-BP (Lund et al. 2011). As the temperature between the two above simulated tests were similar, these results seem to suggest that PEX pipes made of the same material but by different manufacturing brands, may leach varying amounts of 2,4-d-t-BP into drinking water. This variation should be investigated further as it may also apply to other plastic pipes.

Potential health risk evaluation

It is of some concern that 2,4-d-t-BP is widely used in food-related plastic products as an antioxidant. Since 1967, the US Food and Drug Administration have permitted its usage in packaging for irradiated foods (Paquette 2004) and since the 2011 ban on the production of polycarbonate baby bottles within the EU, due to the toxic effect of bisphenol A, 2,4-d-t-BP has been detected in baby bottles made of the alternative approved materials, despite the fact that it has not been safety assessed under the European Union Regulations (10/2011) (Onghena et al. 2014). Due to the lack of direct investigations, the potential health risks of 2,4-d-t-BP are evaluated based on the EEQ value.

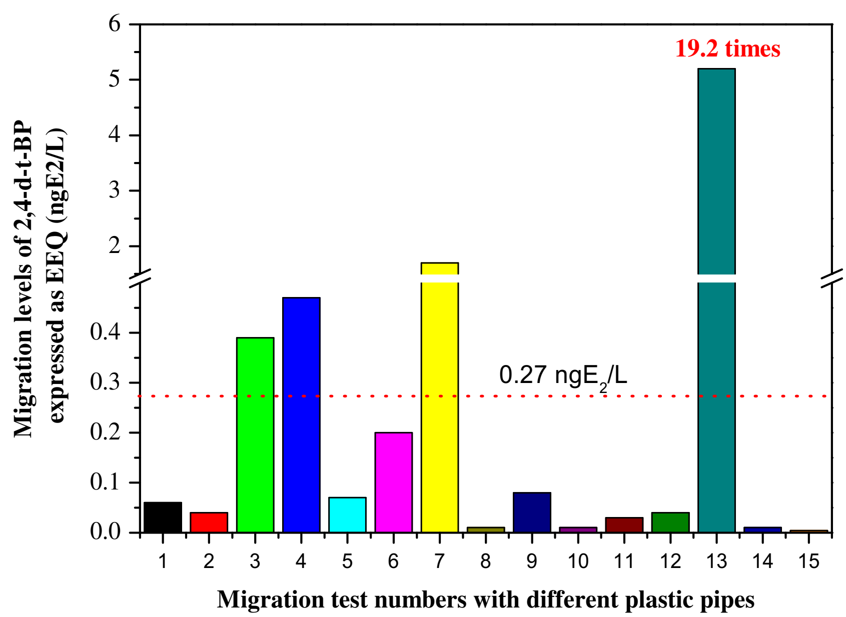

Fig. 1 The migration levels of 2,4-d-t-BP from different plastic pipes expressed as EEQ under simulated migration test (numbers in the horizontal axis agree with the numbers of the migration tests in Table 2)

There have been various studies on the adverse effects of EDCs on fish and other animal model species, at environmentally relevant concentrations. These studies have been summarized, as shown in Table 3. EE_2 is at present the most widely studied EDC and the adverse effects mainly include vitellogenin induction, intersex induction (the development of ovotestis), infertility, and disruption to mating behaviors, in addition to mortality and other effects. It is also significant that different animal models or different developmental stages show significant variation in their responses to EDC exposure. However, trace EEQ concentrations of less than 10 ngE_2/L, resulted in adverse effects in ten out of 14 (71.4%) of the summarized studies in Table 3, including effects on seven different animal models and developmental stages, including juvenile turbot, Japanese medaka, zebrafish, frog; Sydney rock oysters, fathead minnows, and salmon smolts. Soares et al. (2009) reported that at EEQ exposure levels as low as 0.27 ngE_2/L, egg mortality and other adverse effects could be seen in late gastrulation and/or early organogenesis in zebrafish. Therefore, the EEQ levels of 2,4-d-t-BP leached from the plastic pipes in four out of the 15 simulated drinking water tests (Fig.1), would comparatively result in a higher level of adverse effects than seen in the study by Soares et al. (2009). This is especially the case for PB pipes where the maximal migrating EEQ level of 2,4-d-t-BP at room temperature was 5.2 ng E_2/L, over 19 times the EEQ level that caused adverse effects on the zebrafish model in the study by Soares et al. (2009). Although PB pipes are not as widely used as PEX pipes in drinking water distribution system, in some applications PB pipes are suggested as replacement for PEXs (Lund et al. 2011). This is of concern as the human consumption of 2 L drinking water per day could result in a daily 2,4-d-t-BP oral exposure of up to 10.4 $ngE_2/d/P$.

It is generally assumed that potable drinking water, such as those simulated in Table 2, are safe for human consumption. However, the EEQ level of 2,4-d-t-BP in some drinking water supplies, raise serious questions about the potential health effects of long-term consumption of such drinking water transported with plastic pipes.

It must be considered that EDCs with the same EEQ levels may still induce very different adverse effects on animal models, thus the reported results of the adverse effects summarized in Table 3 may not necessarily reflect the same adverse effects caused by 2,4-d-t-BP in drinking water. In most cases, the migrating levels of 2,4-d-t-BP in PE and PEX pipes are relative low, and only 15.3% of the tested pipes leached levels of 2,4-d-t-BP that may cause adverse health effects. However, due to the tight regulations for drinking water, further investigation of this contaminant should be undertaken and under the current strict requirements on drinking water quality; the latent risks of 2,4-d-t-BP as an estrogenic compound must be better understood and regulated. Moreover, 2,4-d-t-BP is not the only estrogenic compound leachable from the plastic pipes, other migrating compounds such as 2-t-BP and 4-t-BP also showed estrogenic activities (Akahori et al. 2008), suggesting that this problem is more complex than removing one harmful substance from our water supplies. Given our limited knowledge on the migrating compounds, more attentions should be paid to the safety of drinking water from the viewpoint of its estrogenicity.

Conclusions

The migrating levels of 2,4-d-t-BP into drinking water from different kinds of plastic pipes under simulated migration tests were summarized. Generally, the PB pipes released much higher levels of 2,4-d-t-BP than PE and PP pipes, and plastic pipes made of the same materials but by different manufacturing brands may release different amounts of 2,4-d-t-BP. To evaluate the latent risk effects of 2,4-d-t-BP, the migrating levels from different plastic pipes were converted into EEQ levels. Although the EEQ levels of 2,4-d-t-BP migrating from pipes in most occasions were relative low. However, in a few cases, the released levels of 2,4-d-t-BP may cause potential adverse health effects on humans as the maximal migrating levels were over 19 times higher than the level that could pose adverse effects to different model animals. In addition, it should be pointed out that the continual release of 2,4-d-t-BP from plastic pipes may last for 1 year or longer, which suggest that the potential adverse influence may not be a short-term problem. To the best of our knowledge, this is the first report of estrogenic levels of 2,4-d-t-BP in drinking water, a readily leachable compound from plastic pipes that widely used in drinking water distribution systems.

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