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TRANSFER OF PHTHALATES FROM C-POLYVINYL CHLORIDE AND CROSS-LINKED POLYETHYLENE PIPE (PEX-B) INTO DRINKING WATER

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Transfer of phthalates from c-polyvinyl chloride and cross-linked polyethylene pipe (PEX-b) into drinking water

Derek R. Faust, Kimberly J. Wooten and Philip N. Smith

ABSTRACT

Several different materials have been used for production of domestic water pipes throughout history. In recent years, the use of cross-linked polyethylene (PEX) pipe has increased dramatically, yet the potential for leaching of phthalates, which are endocrine disrupting compounds associated with adverse reproductive effects in humans, has not been examined. In this study, the potential of chlorinated polyvinyl chloride (cPVC) and red, blue, and heat PEX piping to leach phthalates into static hot and cold water after 2, 8, and 48 hours was evaluated. Concentrations of six phthalates, dimethyl phthalate (DMP), diethyl phthalate (DEP), dibutyl phthalate (DBP), benzyl-butyl phthalate (BBP), di(2-ethylhexyl) phthalate (DEHP), and di(n-octyl) phthalate (DNOP), were determined by gas chromatography-mass spectrometry. Pipe type ($F_{3,71} = 15.6$, $P = 0.001$) contributed significantly to phthalate concentrations in water, while temperature ($F_{4,71} = 1.74$, $P = 0.106$) and time ($F_{4,71} = 1.02$, $P = 0.427$) were not significant factors. Significantly higher concentrations of DEP, DBP, and BBP were observed in cPVC pipe (<method detection limits (MDL) to 466 ng L⁻¹, 252–4,219 ng L⁻¹, 473–18,400 ng L⁻¹, respectively) compared to blue PEX ($T^2 = 12.2$, $P < 0.001$; <MDL, <MDL – 140 ng L⁻¹, <MDL – 459 ng L⁻¹, respectively), red PEX ($T^2 = 19.3$, $P < 0.001$; <MDL, <MDL – 188 ng L⁻¹, <MDL – 881 ng L⁻¹, respectively), and heat PEX ($T^2 = 19.9$, $P < 0.001$; <MDL, <MDL – 162 ng L⁻¹, <MDL – 169 ng L⁻¹, respectively). Phthalate exposure from drinking water via cPVC or PEX is low when compared to other dietary sources. Nonetheless, a shift from cPVC to PEX pipes in households would decrease potential exposure to phthalates.

Key words | cross-linked polyethylene, drinking water, leaching, phthalates, pipe

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INTRODUCTION

Materials used for domestic drinking water pipes have changed throughout history. Lead pipes were prominent in early plumbing, which posed a risk of lead poisoning. Today, older homes may still have copper pipes with lead-containing solder, which can be a lead poisoning risk, especially to children (CDC 2006). Other common plumbing pipe materials include chlorinated polyvinyl chloride (cPVC) and iron. Cross-linked polyethylene (PEX) is a pipe material that continues to gain popularity for use as water lines. Cross-linking molecular chains of polyethylene into a three-dimensional network offers many advantages over

other traditional pipe materials, including durability within a wide range of temperatures and pressures, using fewer fittings, being more resistant to corrosive water conditions, and having the ability to expand when water freezes and returning to its original size upon thawing (i.e., it is freeze-resistant) (CDC 2006). Due to these advantages over other traditional piping, PEX has become preferable to copper for home builders and is also gaining acceptance in commercial construction (PPFA 2009).

The Plastic Pipe and Fittings Association (PPFA) has stated that PEX materials are inert and do not contaminate

potable water (PPFA 2009). PEX pipe is evaluated for its potential to leach compounds that the US EPA acknowledges to cause adverse health effects (e.g., volatile organic chemicals (VOCs), metals, phenolics, methanol, and tert-butyl alcohol) under NSF 61 certification from the American National Standards Institute and National Sanitation Foundation International (NSF/ANSI 2013). However, several studies have detected VOCs (e.g., t-butanol, decanal, 1-hexanol) in water after contact with PEX pipe (Brocca *et al.* 2002; Skjevraak *et al.* 2003; Heim & Dietrich, 2007). Although concentrations were not reported, Tomboulian *et al.* (2004) found that Bisphenol A, an endocrine disrupting compound (EDC), leaches from PEX pipe.

Other EDCs have not yet been examined in PEX pipe leachate, including phthalates. Phthalates are fat-soluble, synthetic chemicals with varying length side chains that are used to soften and impart flexibility to PVC and other plastic products (Howdeshell *et al.* 2008; Al-Saleh *et al.* 2011). Phthalates are added to many commonly used products, including children's toys, health and beauty products (e.g., cosmetics and pharmaceuticals), medical equipment (e.g., dialysis tubing and intravenous bags), food packaging, and clothing (Lovekamp-Swan & Davis 2003; Howdeshell *et al.* 2008; Martino-Andrade & Chahoud 2010). Phthalates are not chemically bound to plastic matrices and thus may leach, migrate, or volatilize from plastics (Heudorf *et al.* 2007). Phthalates have attracted the attention of scientists, regulatory agencies, and the public due to considerable production volumes, extensive use, and endocrine disrupting capacity (Talsness *et al.* 2009).

The potential of individual phthalate congeners to induce endocrine disrupting effects varies in relation to side chain structure. Phthalates with a straight side chain of 4–6 carbons (i.e., dibutyl phthalate (DBP), and di-2-ethylhexyl phthalate (DEHP)) induce the greatest endocrine disrupting effects (Fabjan *et al.* 2006). Endocrine and reproductive effects have been observed following phthalate exposure *in vitro* and *in vivo*. Several phthalates act as agonists to estrogen receptor alpha and antagonists of estrogen receptor beta and androgen receptors *in vitro* (Duty *et al.* 2003; Takeuchi *et al.* 2005). Epidemiological studies have associated phthalate exposure with human reproductive and developmental disorders including poor semen quality in adult males (Duty *et al.* 2002; Hauser *et al.* 2006), altered

reproductive hormone levels (follicle stimulating hormone and inhibin B) in adult men (Duty *et al.* 2005), short pregnancy duration, endometriosis, pre-mature breast development in girls, and reduced anogenital distance in male infants (Martino-Andrade & Chahoud 2010). Human exposure to phthalates has been confirmed via measured concentrations of phthalate metabolites in various human bodily fluids, including maternal urine during pregnancy (Swan *et al.* 2005), urine of adults and children (Wittassek *et al.* 2007; Teitelbaum *et al.* 2008), breast milk (Mortensen *et al.* 2005) and amniotic fluid (Latini *et al.* 2003; Silva *et al.* 2004). Four phthalate metabolites were present in more than 75% of US subjects sampled in the National Health and Nutrition Examination Survey III (Duty *et al.* 2002). A potential, yet understudied exposure route is drinking water wherein phthalates have leached from supply pipes.

The purpose of this study was to determine the potential of cPVC and PEX piping to leach phthalates into water at varying temperatures (hot and cold) and to examine the change in water concentrations as water was held static in pipes for 2, 8, or 48 hours. Based on the likelihood that a PVC material would leach phthalates, cPVC was used as a positive control and for comparison to the types of piping that PEX pipe would be replacing. It was hypothesized that phthalate concentrations leaching into water would be greater in water from cPVC compared to PEX piping, with hot water and longer periods of time resulting in higher phthalate concentrations.

MATERIALS AND METHODS

Pipe materials

Piping used for these experiments was purchased from a retail hardware store in Lubbock, TX and are representative of piping used commercially and in residential homes. Blue, red, and heat 160 psi PEX piping (Vanguard Pipe & Fittings, British Columbia, Canada) and 100 psi cPVC piping (Silver-Line Plastics, OK) with an internal diameter of 12.7 mm was used. All types of the PEX pipe used were manufactured by grafting organo-silanes onto a polyethylene base using a catalyst to initiate the cross-linking process before extrusion.

Pipes manufactured using the organo-silane method are commonly referred to as PEX-b (CB Supplies Ltd 2010b). Typical silane agents include vinyltriethoxysilane, vinyltrimethoxyethoxysilane, and 3-methacryloxy-propyltrimethoxysilane (Denberg 2009). The cross-linking is completed during extrusion by exposing the piping to steam (CB Supplies Ltd 2010b). Blue and red PEX are the same, with the exception of the dye added to facilitate the distinction between multiple water lines (i.e., hot and cold) in the same structure. Heat PEX, primarily used in radiant heating applications, contains three layers: (1) cross-linked, high density polyethylene, (2) an ethylene vinyl alcohol barrier layer sandwiched between layers of PEX, and (3) an adhesive between layers 1 and 2. This barrier layer limits the passage of oxygen through the pipe, decreasing the potential for rust in systems containing iron components (CB Supplies Ltd 2010a). While all these pipes are approved for use in drinking water systems, these systems do not often require this additional oxygen barrier, and standard PEX is the most commonly used PEX type due to its lower cost (PPFA 2009).

The cPVC pipe is a polymer of vinyl chloride (>80%) and contains additives ($\leq 20\%$) including heat stabilizer, calcium stearate, paraffin wax, polyethylene wax, titanium dioxide, calcium carbonate, process aid, colorant, and other proprietary ingredients (PPI 2014). PVC and cPVC pipe are different in that cPVC goes through a free radical chlorination reaction that increases chlorine content, which effectively allows cPVC to be used in hot water applications (PPFA 2014). Phthalates and Bisphenol A were not used in the manufacturing of the cPVC pipe used (R. S. Rutledge, personal communication).

Experimental design

Piping was cut into 1.52 m lengths to be assigned to time and temperature treatments. A length of 1.52 m was used to obtain the minimum volume of water needed for effective extraction of phthalates. Time treatments of 2, 8, and 48 hours were chosen to represent times for which water might reside in pipes during periods of non-use. Temperature treatments for hot ($50\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$) and cold ($23\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$) were in the range defined by the Centers for Disease Control and Prevention for residential use of 49–54 °C and 20–25 °C, respectively (CDC 2006). Three replicates per treatment

were used ($n = 72$). Pipe segments were filled with 18 MOhm water, produced in house using a Thermo Barnstead Nanopure system, at treatment temperatures, and sealed at each end with barbed PEX or cPVC caps. Pipes were randomly organized by temperature on laboratory shelves at room temperature for their respective time treatments. Six method blanks for each temperature treatment consisted of 18 MOhm water placed in 1-L Erlenmeyer flasks covered with aluminum foil to prevent potential photo-degradation of phthalate compounds.

Phthalate extraction and analysis

After the appropriate time period for each time treatment, water was removed from the pipe segments, placed in 1 L glass jars, and stored for a maximum of 24 h at 4 °C. The volume of water removed from the pipe segments ranged from 155 to 185 mL. There are two possible causes for the range of water volume removed from the pipes: (1) small air pockets were not filled with water initially, or (2) some water was lost in removing it from the pipes. Regardless of initial temperature treatment, all water was at room temperature (22 to 25 °C) upon removal from the pipe segments. Water underwent liquid-liquid extraction, following EPA Method 606 for phthalate esters (US EPA 1996). Water samples were first spiked with 100 ng of deuterated diethyl phthalate (d_4 -DEP) to allow for calculation of method recovery following instrumental analysis. Water samples were combined with 30 mL of GC-MS grade methylene chloride (GC RESOLV*, Fisher Scientific), shaken for 3 min, and allowed to separate for at least 10 min before methylene chloride was drained into a round bottom flask. This procedure was performed three times, and methylene chloride fractions were combined prior to concentration to 1 mL using rotary evaporation, transfer to amber glass vials, and storage at $-20\text{ }^{\circ}\text{C}$ until analysis. All glassware used in this study was detergent washed, rinsed in triplicate with tap and deionized water, and acetone. Glassware was subsequently placed in an oven at 120 °C for at least 8 h to limit laboratory phthalate contamination.

Phthalate congeners targeted in this study were selected to encompass a range of side chain lengths, as well as enable comparison with previous studies wherein phthalate

congeners in water are reported. These included DEP, DBP, DEHP, dimethyl phthalate (DMP), benzyl butyl phthalate (BBP), and di-n-octyl phthalate (DNOP). Quantitation of target phthalates was performed via gas chromatography-mass spectrometry (GC-MS) using an HP 6890 gas chromatograph and HP 5973 mass spectrometer equipped with a DB-5 column (30 m × 250 μm × 0.25 μm). Analytes were quantified in selected ion monitoring mode, using m/z 149 to quantify DEP, DBP, BBP, DEHP, and DNOP, m/z 163 for DMP, and m/z 153 for d₄-DEP, with two additional qualitative ions per congener used to confirm identity. Solvent blanks and check standards were included in each instrument run. Reporting limits, as determined by the lowest standard in the calibration curve, were set at 1 ng/sample (3.6–13.0 ng/L water, accounting for variability in water volume and recovery); below this limit, samples are reported as below method detection limits (MDL) and assigned a value of zero for statistical analyses. Concentrations of phthalates in individual samples were corrected for method recovery, as determined by d₄-DEP concentration in the same sample, and corrected to ng/L based on the amount of water extracted.

Statistical analysis

A Permutational Multivariate Analysis of Variance (PERMANOVA) of a nested design, using Euclidean distances and 9,999 permutations, was used to analyze differences among phthalate concentrations in water of the 24 treatments of temperature nested in time, and nested in pipe type. PERMANOVA was used because the assumption of normally distributed residuals under the non-permutational MANOVA model was violated and could not be resolved using data transformation (Anderson & Ter Braak 2003). *Post-hoc* differences between pipe types were analyzed using Hotelling's T-squared (T^2) tests, using 9,999 permutations. Treatments were pooled by pipe type for Hotelling's T^2 tests, because there was not a significant effect due to time or temperature. Data were normalized using z-scores prior to PERMANOVA and Hotelling's T-squared tests, because there were up to three orders of magnitude differences in concentration among treatments. An alpha level of 0.05 was set for the PERMANOVA analysis. A False Discovery Rate correction was used to account for

experiment-wise error with multiple comparisons for Hotelling's T^2 tests (Benjamini & Hochberg 1995). All statistical analyses were performed in R version 3.0.2 Statistical Software (R Core Team 2013).

RESULTS AND DISCUSSION

The purpose of determining phthalate concentrations in water held in cPVC and PEX pipes was to evaluate their potential to leach phthalates into hot and cold water for periods of up to 48 hours. Pipe type ($F_{3,71} = 15.6$, $P = 0.001$) was the only variable that significantly affected concentrations of phthalate congeners in the water. Phthalates leached from both cPVC and PEX piping into water (Supplementary Table 1, available with the online version of this paper; Figure 1). The results of this study support the hypothesis that greater phthalate concentrations would occur in water held in cPVC piping compared to PEX piping. Significantly greater concentrations of DEP, DBP, and BBP leached from cPVC into water compared to all other pipe types (blue PEX $T^2 = 12.2$, $P < 0.001$; red PEX $T^2 = 19.3$, $P < 0.001$; heat PEX $T^2 = 19.9$, $P < 0.001$). Significant differences in concentrations of BBP and DEHP ($T^2 = 2.52$, $P = 0.023$) were noted between blue PEX and red PEX pipe, but not DEP or DBP (Figure 1). No significant difference was observed in phthalate concentrations between blue PEX and heat PEX ($T^2 = 1.28$, $P = 0.265$) or between red PEX and heat PEX ($T^2 = 2.65$, $P = 0.0487$) for any phthalate (Figure 1). DEP was detected only in water from cPVC pipe treatments (Figure 1; Supplementary Table 1). Only two samples contained detectable concentrations of DNOP, a single cPVC 2-hour cold water treatment and a red PEX 8-hour hot water treatment. DMP was not detected in any of the samples (Supplementary Table 1).

Concentrations of individual phthalates in blanks, cPVC, and PEX samples were similar to those previously measured in both tap water and bottled water samples (Table 1); however direct comparisons to these studies are not made because the piping material used was not always specified. DBP (cPVC), BBP (cPVC), and DEHP (cPVC and PEX) concentrations in the current study fell at the upper end of the range of previously reported concentrations. Slightly elevated concentrations are not surprising, based on the use of new pipes in this study. In

Table 1 | Concentrations of phthalates (ng L⁻¹) and material type of bottled water and tap water from other studies and cPVC and PEX pipes from the current study

Study	Material type ^a	DEP	DBP	BBP	DEHP
<i>Bottled Water</i>					
Al Saleh <i>et al.</i> (2011) ^b	PET	1,780	1,160	21,100	1,250
Amiridou & Voutsas (2011) ^b	PET, PC	70	^c	^c	580
Casajuana & Lacorte (2003) ^b	PET, PE	990	72	10	332
Criado <i>et al.</i> (2005) ^a	PET	^c	2,400	^c	^c
Guart <i>et al.</i> (2014) ^a	PET, HDPE	^c	220	131	<MDL ^d
Jeddi <i>et al.</i> (2015) ^a	PET	^c	303	63	917
<i>Tap Water</i>					
Casajuana & Lacorte (2003) ^b	Concrete, glass fiber, PE	90	32	17	331
Domínguez-Morueco <i>et al.</i> (2014)	^e	381	633	<MDL	<MDL
Luo <i>et al.</i> (2012)	^e	^c	1.4	<MDL	3.3
Martine <i>et al.</i> (2013) ^b	^e	900	600	30	660
Psillakis & Kalogerakis (2003)	^e	300	104	^c	930
Regueiro <i>et al.</i> (2008)	^e	195	<MDL	^c	^c
Serodio & Nogueira (2006)	^e	190	520	30	60
Shi <i>et al.</i> (2012) ^b	^e	3.1	110	24	280
Tang <i>et al.</i> (2012) ^b	^e	44,000	931	^c	1,250
<i>Current Study</i>					
cPVC	PVC	195	1,850	7,720	1,310
PEX (all types)	PEX	<MDL	78.6	115	3,240
Blank ^f		<MDL	74.2	70.2	866

^aPET, polyethylene terephthalate; PC, polycarbonate; PE, polyethylene; HDPE, high-density polyethylene; PVC, polyvinyl chloride; PEX, cross-linked polyethylene.

^bMaximum concentrations from range of reported values.

^cCongener not evaluated.

^dBelow method detection limit.

^eMaterials used in water distribution system not specified.

^fMedian value.

a study on PEX pipe, Denberg (2009) reported that new pipes released more degradation products (e.g., phenols, ketones, and quinines) than older pipes and that it takes at least a year of use for all degradation products to be eliminated from PEX pipe. Pipes used in the current study were new; therefore, it is likely that phthalate concentrations would decrease with additional use over time. Additionally, phthalate concentrations were measured from water held static (i.e., no flow). Phthalate concentrations in water flowing through pipes may be less than those in water held under static conditions as a result of less contact time between the pipe and flowing water for effective leaching to occur.

While phthalates were not specifically used as an ingredient in the pipes tested in this study, their inclusion in many

plastics as a plasticizer (i.e., DEHP; CPSC 2010) or as a solvent or adhesive (i.e., DEP; CPSC 2011) makes it possible that they were introduced into the pipes as either residual phthalates left in mixing tanks from previously manufactured plastics or via additives mixed with the polymer (color resin has been suggested by Amiridou & Voutsas (2011)). There seems to be some consistency in the trends of phthalate leaching into water held in the different pipe types. In general, DEP, DBP, BBP concentrations followed a trend of cPVC >> red PEX > blue PEX > heat PEX. For cPVC pipe and associated higher phthalate concentrations, it is reasonable to consider that the pipe was manufactured, mixed, and formed using equipment in which other PVC plastics containing phthalates were produced and thus be the source of phthalates leaching

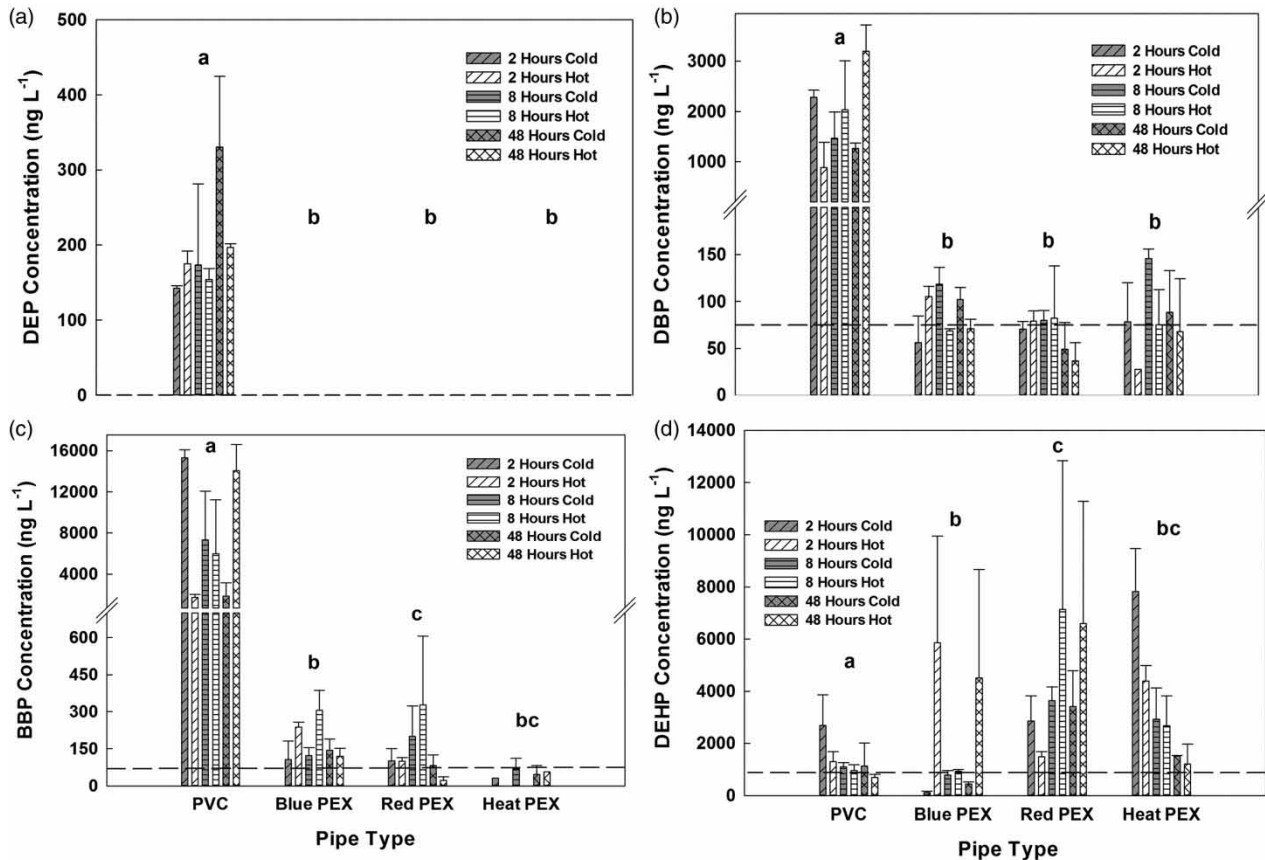


Figure 1 | Mean (\pm standard error) phthalate concentrations in water from cPVC, blue PEX, red PEX, heat PEX piping, and method blanks after time treatments of 2, 8, and 48 hours and cold (23 °C) and hot (50 °C) temperature treatments. Each bar represents $n = 3$; bars without error measurements indicate the phthalate was detected in less than three samples. Dashed lines represent median blank concentrations for each respective phthalate. Phthalates are (a) DEP, (b) DBP, (c) BBP, and (d) DEHP. Different letters represent a statistically significant difference between pipe types using False Discovery Rate corrected alphas.

from cPVC pipe. There are several possible explanations for significant differences in phthalate concentrations in water from cPVC and PEX including differences in: parent materials (PVC-polyvinyl chloride and PEX-polyethylene); manufacturing processes as described in the Materials and methods section; and additives used for a variety of purposes.

The trend for DEHP concentrations was red PEX > blue PEX > heat PEX > cPVC, which is different from the trend observed for DEP, DBP, and BBP. It is possible that different side chains of phthalates impacted leaching from pipes into water. However, despite differences in side chains, trends in phthalate concentrations were generally consistent between pipe types. Given that heat PEX concentrations were lower compared to blue and red PEX, it is possible that the oxygen barrier present in heat PEX impeded phthalate leaching. Concentrations of DEHP were greater in PEX pipes

compared to cPVC, which is counter to the trend observed for all other phthalates, in which cPVC had greater concentrations. In this case, it is possible that 2-ethylhexyl side chains of DEHP were more weakly adsorbed/bonded to the PEX structure and were more likely to leach when compared to the PVC structure.

Initial water temperature ($F_{4,71} = 1.74$, $P = 0.106$) and time held in pipe ($F_{4,71} = 1.02$, $P = 0.427$) did not significantly affect phthalate concentrations in this study. Previous investigations into the impacts of storage time and temperature on phthalate concentration have been conducted in polyethylene terephthalate (PET) bottles. Jeedi *et al.* (2015) observed an increase in phthalate concentration (DBP, BBP, DEHP) with longer storage times and temperatures, but these effects were most pronounced under conditions far more extreme than those examined in the current study (45 days' storage,

40 °C). Casajuana & Lacorte (2003) also observed an increase in concentrations of DEP and DBP in bottled water in both PET and PE bottles following 10 weeks of outdoor storage (up to 30 °C). Other studies of bottled water have yielded less conclusive results on the effects of time (Criado *et al.* 2005; Al-Saleh *et al.* 2011; Amiridou & Voutsas 2011) and temperature (Al-Saleh *et al.* 2011) on phthalate leaching.

The lack of time and temperature effects in phthalate leaching from pipes may be due to rapid desorption of phthalates from new pipes. Over time, breakdown and wear of materials used in manufacturing of cPVC and PEX pipes could potentially result in further release of phthalates. Moreover, hot water temperatures could exacerbate release due to its accelerated wear of pipes. Another possible explanation for the lack of significant time and temperature effects is minimal replication ($n = 3$) per treatment and variability of concentrations within treatments, both of which decrease power to detect statistically significant differences. Although longer storage and higher temperatures may alter phthalate leaching from cPVC and PEX pipes, these conditions are unlikely to represent realistic conditions under which water might reside in pipes during periods of non-use, and were therefore not examined in this study. However, higher temperatures and longer periods of use after installation could impact phthalate leaching into water from cPVC and PEX pipes and such scenarios should be investigated in future studies. Furthermore, it is possible that supplies of raw materials and production procedures used in pipe manufacturing are not constant. As such, results could be different with a different batch or lot number of piping, emphasizing the need for studies to continue investigation into effects of time, temperature, and other variables (e.g., pH, chlorinated versus non-chlorinated) on leaching of phthalates from cPVC and PEX pipes into drinking water.

Previous studies examining human exposure to phthalates suggest that, for some congeners, ingestion is the primary route of exposure (i.e., DEHP; Wormuth *et al.* 2006). Based on the low concentrations of phthalates in water as compared to other food types (i.e., meat and dairy that contribute 53–75% of exposure depending on age; Serrano *et al.* 2014), however, drinking water is not considered to be a major contributor to overall phthalate exposure. Furthermore, DEP and DEHP concentrations in water from cPVC and PEX pipes were below drinking water standards of $5.0 \times 10^6 \text{ ng L}^{-1}$ (six orders of

magnitude lower) and $6.0 \times 10^3 \text{ ng L}^{-1}$ (the same order of magnitude), respectively, established by the US Environmental Protection Agency. Although federal standards are not published, DBP and BBP concentrations in water from pipes were two orders of magnitude below the most conservative state drinking water standard of $1.0 \times 10^5 \text{ ng L}^{-1}$ (HSDB 2016). Based on concentrations below drinking water standards, even for the worst case scenario examined herein (new cPVC pipes), this study supports the notion that exposure via tap water is minimal and unlikely to result in endocrine disrupting or reproductive effects.

CONCLUSIONS

In conclusion, tap water is likely to come in contact with multiple sources of phthalates before delivery, each of which may contribute to total water concentrations. With the exception of DEHP, phthalate leaching from cPVC pipe was greater than leaching from PEX pipe. In this study, time of static contact with pipes and temperature were not significant effects. The results of this study suggest that use of PEX, rather than cPVC pipes in households may help reduce concentrations of phthalates in household drinking water. Future studies should focus on the effects of time of use, temperature, time after installation, water pH, and chlorination on leaching of phthalates from cPVC and PEX used in household drinking water supply lines.

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