

Sources of pharmaceuticals and personal care products in swimming pools

Laura M. Suppes, Ching-Hua Huang, Wan-Ning Lee and Kyle J. Brockman

ABSTRACT

Pharmaceuticals and personal care products (PPCPs) in swimming pool water are hypothesized to originate from fill water and anthropogenic sources like urine, sweat, swimwear and body surfaces. However, research exploring PPCP origins in pools is lacking. This research investigates PPCP sources at 31 swimming pools. Pool water was analyzed for 24 representative PPCPs using advanced liquid chromatography-mass spectrometry techniques. Fill water was analyzed as a contamination source and to determine if swimmers introduce PPCPs to pools. Results show every PPCP in fill water was present in pools except one, suggesting fill water is a PPCP source at pools. The presence of the antidepressant fluoxetine in 26% of pools and 0% of fill water indicates swimmers introduce pharmaceuticals. The flame retardant (tris(2-carboxyethyl)phosphine (TCEP)) was present 48% more frequently in pool than fill water, suggesting TCEP is introduced by body surfaces or swimwear. Enforcing showering and bathroom breaks is recommended to reduce PPCP contamination from swimmers.

Key words | anthropogenic, personal care product, pharmaceuticals, pool water, swimming pool

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INTRODUCTION

Pharmaceuticals and personal care products (PPCPs) have been found recently in swimming pool water and are thought to be introduced by urination, sweat, body surfaces and swimwear from swimmers (Weng *et al.* 2014; Ekowati *et al.* 2016; Teo *et al.* 2016a, 2016b). Tap water used to fill swimming pools (referred to as 'fill water' in this article) may also be a source of contamination, since PPCPs are found in finished drinking water (Benotti *et al.* 2009; Padhye *et al.* 2014). Chronic exposure to PPCPs from drinking water is a concern, because human health effects from low-dose exposures to PPCPs are unknown (Naidu *et al.* 2016). Swimmers consume 13.7 mL/h of pool water and visit pools 72.6 times/year on average (Suppes *et al.* 2014; Suppes *et al.* 2016), suggesting there is PPCP exposure at swimming pools and therefore risk of disease. It is necessary to identify sources of PPCP contamination to design controls and reduce disease risk from chronic PPCP exposures

at swimming pools. Potential risk factors associated with PPCP contamination are venue type (outdoor, indoor, hotel, school, apartment/condominium/homeowners association, water park, therapy and fitness facilities) and shower and toilet use. Pre-swim showering has been shown to remove organic waste from swimmers that would otherwise contaminate pool water (Keuten *et al.* 2012). Keuten and colleagues recommend showering for at least 60 seconds before swimming to remove organic waste and presumably other contaminants, like personal care products, from body surfaces before swimming. Providing showers at swimming pools is necessary for meeting pre-swim shower recommendations and is required in the Centers for Disease Control and Prevention Model Aquatic Health Code (MAHC) (CDC 2016). The MAHC is the US model swimming pool code available for state and local health departments to adopt. Toilets are also required at

swimming pools in the MAHC. Bathers release on average 30 mL of urine during swimming (Gunkel & Jessen 1986), which could contain pharmaceuticals. Accessible toilets are necessary for reducing intentional or accidental urination in pool water. This research explores PPCP contamination risk factors and identifies contamination sources in a larger range of pool types than previous studies to identify controls for reducing PPCPs in pool water.

METHODS

Pool water and fill water samples were collected from 31 swimming pools in eastern Minnesota and western Wisconsin, from March to July in 2015 and analyzed for 24 PPCPs. A variety of pool types were recruited (outdoor, indoor, hotel, school, apartment/condominium/homeowners association, water park, therapy and fitness facilities) to identify contamination sources in a larger range of pool types than previous studies. A questionnaire was issued at each site to collect information about the venue type and shower and toilet accessibility. The 24 PPCPs included analgesics (acetaminophen, diclofenac and ibuprofen), antimicrobials (clarithromycin, erythromycin anhydrate, roxithromycin, sulfamethoxazole, triclosan and trimethoprim), antidepressants (fluoxetine and paroxetine), one antiepileptic (carbamazepine), β -blockers (atenolol and metoprolol), lipid regulators (atorvastatin and gemfibrozil), stimulants (caffeine and cotinine), one fragrance (tonalide), one UV filter (benzophenone-3), one insect repellent (*N,N*-diethyl-meta-toluamide [DEET]), one flame retardant (tris(2-carboxyethyl)phosphine [TCEP]), one detergent degradate (nonylphenol) and one herbicide (atrazine). These PPCPs were selected based on the likelihood of use by swimmers (Weng *et al.* 2014) and frequent occurrence in finished drinking water (Padhye *et al.* 2014). Table S1 in the Supporting Information (available with the online version of this paper) lists the 24 PPCPs and their chemical classes and primary health effects. The PPCPs' reactivity to chlorine and probability from swimmers were also estimated and ranked in Table S1.

Samples were processed at the University of Wisconsin-Eau Claire Environmental Public Health laboratory and analyzed at the Georgia Institute of Technology School of Civil and Environmental Engineering. Sampling, processing and analysis methods were adopted from Weng *et al.* (2014)

and Padhye *et al.* (2014). Samples were processed and analyzed using advanced solid phase extraction and liquid chromatography-mass spectrometry techniques. Sample processing and analysis procedures are detailed in the Supporting Information. Analysis of the analytical results focused on confirmed detection of PPCPs in the samples (i.e., frequency of detection) instead of exact concentrations, due to extraction problems sometimes encountered.

RESULTS

The pool sample sizes by venue type are shown in Table 1. Table 1 also illustrates the frequency of TCEP, ibuprofen and DEET in the pool water samples by venue type. Notably, the insect repellent DEET was present in 100% of pool and fill water samples regardless of season, location and venue type.

Figure 1 illustrates the frequency of PPCPs detected in the 31 swimming pool water samples. DEET, ibuprofen, caffeine and TCEP were detected most frequently. Of the 24 PPCPs in this study, 20 were present in pool water at least once. The four PPCPs not present in any pool water samples were atenolol, clarithromycin, roxithromycin and triclosan. PPCPs were also present in fill water. Like pool water, atenolol, clarithromycin and roxithromycin were not present in fill water. With the exception of triclosan, which was detected at 4% frequency in fill water, every PPCP present in fill water was also present in pool water (Figure 2). The only PPCP present in pool but not in fill water was fluoxetine (Figure 2). Fluoxetine was present in 26% of pools

Table 1 | Frequency of TCEP, ibuprofen and DEET in pool water by venue type

Venue type (n)	TCEP (%)	Ibuprofen (%)	DEET (%)
Therapy pool (1)	100	100	100
Water park (1)	100	0	100
Fitness facility (1)	100	100	100
Apartment/condo/HOA ^a (9)	33	56	100
School (6)	67	100	100
Hotel (13)	85	69	100
Indoor (22)	89	56	100
Outdoor (9)	38	69	100

^aHome Owners' Association.

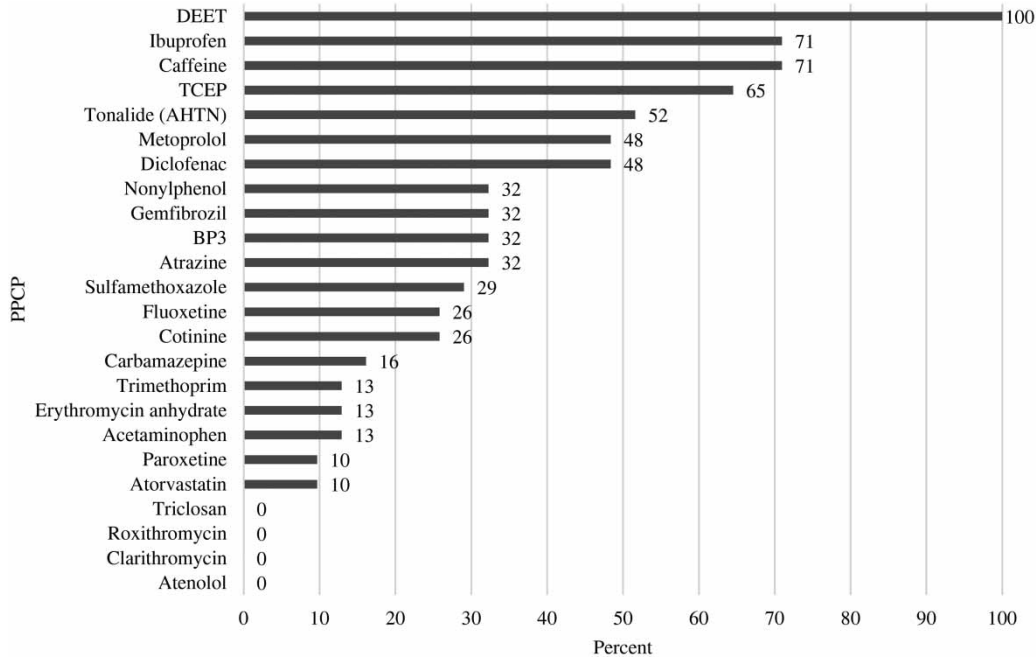


Figure 1 | Frequency of PPCP presence at the 31 swimming pool sites. The PPCPs that occurred most frequently were DEET (100%), ibuprofen (71%), caffeine (71%) and TCEP (65%).

and 0% of fill water. The TCEP frequency in pool water was approximately four times that in fill water.

Results from the questionnaire indicate 51% (16/31) of pools do not have a shower facility available to

swimmers, 88% (27/31) of pool operators report swimmers do not shower before swimming and 48% (15/31) of pools do not have a toilet available to swimmers.

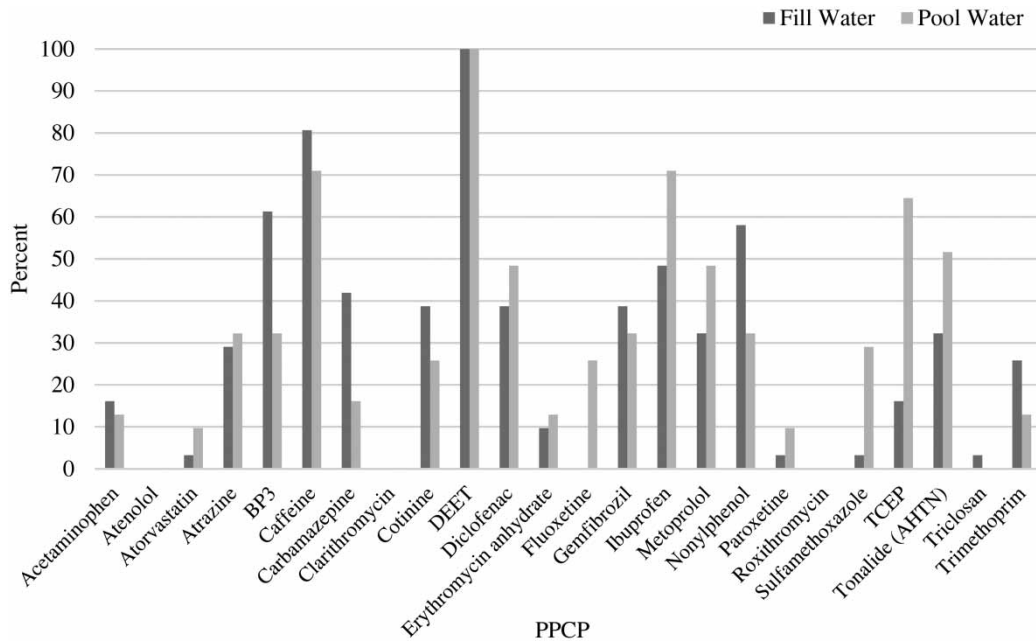


Figure 2 | Comparison of PPCP frequency in fill and pool water. DEET was present in 100% of pool and fill water samples.

DISCUSSION

The presence of DEET in 100% of pool and fill water samples regardless of season, location and venue type was unexpected since insect repellants or sunscreen containing insect repellants are not likely to be applied by swimmers during winter months in the Midwestern USA where this study took place. These results suggest DEET is either persisting in pool water after being introduced by swimmers during times of insect repellant use, DEET is entering pool water from fill water sources, or residual DEET on swimwear is being introduced during winter months. The high detection frequency of DEET is consistent with the previous study by *Weng et al. (2014)* which also found DEET in all three studied pools in the Midwestern and Southeastern USA. Investigating DEET residues on swimmer body surfaces and swimwear is recommended for future research to identify the exact origin(s) of DEET in pool water.

The frequency of detecting DEET, ibuprofen, caffeine and TCEP in this study is consistent with *Weng et al. (2014)* who reported that DEET, caffeine and TCEP were the most detectable compounds among 32 PPCPs examined in pools. The frequency of PPCPs detected in the pools in this study also generally agrees with the expectation based on reactivity to aqueous free chlorine. PPCPs that are more resistant to reaction with chlorine will likely be more persistent and easily detected in the pool water. Among the most frequently detected PPCPs, DEET, ibuprofen, and caffeine were shown previously to react very slowly with chlorine (*Weng et al. 2014; Sun et al. 2016*). TCEP and tonalide do not contain structural functional groups that are known to readily react with chlorine. Metoprolol has been shown to react weakly with chlorine (Table S1) and diclofenac's structure also suggests weak chlorine reactivity. On the other hand, PPCPs that are shown to have fast reaction rates with chlorine, such as sulfamethoxazole, triclosan and trimethoprim (Table S1), were detected much less frequently in pool water.

The presence of the antidepressant fluoxetine in 26% of pools and 0% of fill water indicates swimmers introduce this pharmaceutical into pools, likely through urination. Every PPCP present in fill water was also present in pool water with the exception of triclosan. This suggests fill water is a

source of PPCP contamination in pools. The presence of the flame retardant TCEP four times more frequently in pool than fill water suggests swimmers introduce TCEP through body surfaces or swimwear. This finding supports results reported by *Teo et al. (2016b)* demonstrating organophosphate flame retardants, including TCEP, have been found to leach from swimwear.

Results from the questionnaire indicate swimmers do not have shower access at over 50% of pools. To meet the pre-swim shower length recommendation of 60 sec (*Keuten et al. 2012*), pool operators need to have showers available to swimmers and enforce showering before swimming. Results from the questionnaire also indicate swimmers do not have toilet access at over 45% of pools. Toilets should be available at swimming pools to reduce the potential for pharmaceutical contamination by swimmer urination. Hygiene facilities with toilets and showers should be required at swimming pools by health departments, under a state or local pool code, to reduce PPCP loading by swimmers. Jurisdictions that do not require toilets and showers can adopt all or part of the CDC MAHC, which requires toilets and showers be available to swimmers. Mandatory toilet breaks for swim teams or open swim groups are also recommended to reduce pharmaceutical loading from swimmer urination. Signage at pool venues should emphasize the need for toilet use and pre-swim showering to reduce PPCP loading in pool water.

CONCLUSION

This research explores PPCP contamination risk factors and identifies contamination sources to identify controls for reducing PPCPs in pool water. A total of 83% (20/24) of PPCPs studied were found in pool water and 100% (31/31) of pools contained DEET, with likely main sources from fill water, swimmers and swimwear. Swimmers did not have access to toilets at 48% (15/31) of the pools studied and showers were not available at 51% (16/30) of the pools. Future research should further investigate residues of PPCPs on swimmers/swimwear and in fill water over a wider range of conditions and time, to identify the exact origin(s) and levels of PPCPs in pool water.

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