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Assessment of human exposure to triclocarban, triclosan and five parabens in U.S. indoor dust using dispersive solid phase extraction followed by liquid chromatography tandem mass spectrometry

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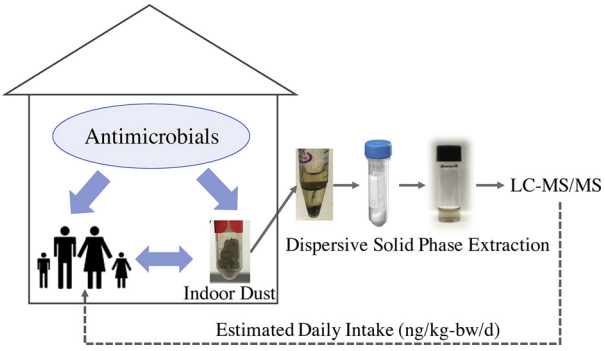
GRAPHICAL ABSTRACT



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ABSTRACT

Antimicrobials in indoor dust pose concerns due to their endocrine disrupting activities and potential promotion of antibiotic resistance. We adopted dispersive solid phase extraction (d-SPE) and liquid chromatography-tandem mass spectrometry (LC–MS/MS) to quantify antimicrobials in dust. The method showed favorable linearity ($R^2 > 0.99$), recovery (83–115%), and method detection limits (1.2–5.6 ng/g, dry weight). All seven analytes were found at median concentrations in ng/g in each of the 80 U.S. dust samples collected from athletic facilities and residential homes: methyl paraben (1920) > propyl paraben (965) > triclosan (390) > triclocarban (270) > ethyl paraben (195) > butyl paraben (80) > benzyl paraben (6). Triclosan levels in dust from athletic facilities were significantly higher than those in private homes ($p < 0.05$). Median estimated daily intake (EDI) of antimicrobials in ng/kg-body weight/d from dust ingestion was lowest for adults (1.9) and higher for more sensitive subpopulations, including infants (19.8), toddlers (23.6), children (11.8) and teenagers (4.6). This first application of d-SPE to the analysis of dust produced U.S. baseline data for triclosan and triclocarban levels in indoor dust just prior to the 2017 Federal ban on use of these trichlorinated aromatics in antiseptic soaps and related personal care products.

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1. Introduction

Triclocarban (3,4,4′-trichlorocarbanilide; TCC) and triclosan (5-chloro-2-(2,4-dichlorophenoxy) phenol; TCS) are antimicrobial agents widely used in various personal care products such as liquid and bar soap, dish detergent, toothpaste, and medical disinfectants at levels of up to 2% and 0.3% (w/w), respectively [1,2]. They are also formulated into carpets, toys, paints and building materials [3]. Parabens exhibit antimicrobial activity, are stable over wide pH and temperature ranges, and are moderately soluble in water. These properties make them ideal to use as preservatives in a spectrum of products including lotions, face washes, facial creams, food stuffs, beverages, and industrial products [4]. Parabens are found in more than 22,000 cosmetic products with levels up to 0.4% (by weight) for any individual paraben and 0.8% in combination. In pharmaceuticals, maximum paraben content may exceed 1% [5]. Use of antimicrobial chemicals has resulted in widespread environmental occurrence and human exposure, with detections in diverse environmental matrices, including indoor dust, wastewater influent and effluent, surface water, and sewage sludge [6–8], and in biological matrices such as breast milk, serum, urine, cord blood and amniotic fluid [9–14].

Concerns over the potential risks of the above mentioned antimicrobial agents on human and animal health have been raised in the past decades [3,15]. These compounds are considered as a group of emerging endocrine disruptors that cause immune dysfunction and affect human reproductive outcomes [2,16–19]. Studies have shown their toxicities to aquatic organisms, such as algae, fish and invertebrates [20–24]. Potential links have been suggested between human exposure to parabens and the etiology of breast cancer [25,26]. There are also studies showing positive associations between the occurrence of antimicrobials and the detection frequency of antibiotic-resistance genes [8,27]. In September 2016, the U.S. Food and Drug Administration (FDA) issued a final rule banning 19 antimicrobial ingredients including TCS and TCC, in over-the-counter (OTC) consumer antiseptic wash products, and the rule took effect starting from September 2017 [28]. With inadequate evaluation of the impact of these emerging contaminants on ecosystems and human health, it is necessary to keep monitoring their occurrence in the environment and levels of human exposure. In addition, continuous monitoring of the occurrence of these antimicrobials in the environment will assist in evaluating the effectiveness of certain regulatory practices.

In developed countries, people spend over 90% of their time in indoor environments, and the quality of the indoor environment has received increasing attention because of its implications for public health [29,30]. Indoor dust is known to be a sink for semi-volatile organic compounds (SVOC) and particle-bound organic matter and thus has frequently been used as a matrix to assess indoor contamination and human indoor exposure [31–33]. Exposure to contaminants in dust can occur via ingestion through direct contact with indoor dust and hand-to-mouth movements, as well as indirect contact as dust deposits on food or consumer products, which are later ingested. Inhalation and dermal absorption are also possible routes of exposure to contaminants deposited in dust [29]. Children are the most susceptible population to contaminants in indoor dust, due to their rapidly developing organs and neurological system, greater intake of dust relative to body size and weight, and their activities on and in proximity to the floor, which leads to potentially elevated contact with contaminants [34].

So far, only a limited number of studies have reported the presence of parabens and TCS in indoor dust [35–42], and only one prior study worldwide has quantified TCC in dust [8]. Due to their complex compositions, challenges exist for sensitive and accurate measurement of trace level contaminants in dust. In these studies, sample preparation often involves extraction followed by further cleanup, such as pressurized liquid extraction (PLE) with in-cell cleanup [35] or accelerated solvent extraction (ASE) followed by solid phase extraction (SPE) [41], matrix solid phase extraction (MSPD) [36], pressurized hot water extraction (PHWE) [43], and solvent extraction by mechanical shaking or sonication followed by SPE [8,37,39,40]. Instrument analysis involves liquid chromatography-tandem mass spectrometry (LC–MS/MS) [8,37,39,40], gas chromatography-mass spectrometry (GC–MS) [38,42] and gas chromatography-tandem mass spectrometry (GC–MS/MS) [35,36,41]. Although GC–MS or GC–MS/MS may have advantages on selectivity and sensitivity, they often require a pre-column derivatization step to make certain compounds suitable for GC analysis [41], which adds time and labor to an already cumbersome sample pretreatment.

In the past decades, modern sample preparation techniques such as QuEChERS (quick, easy, cheap, effective, rugged and safe) have been developed [44] that require less organic solvent and are less time-consuming compared to the above mentioned sample preparation methods. The QuEChERS method is based on solvent extraction (normally utilizing acetonitrile) with an addition of salts to induce liquid-liquid partitioning, followed by a dispersive solid-phase extraction (d-SPE) for cleanup. The method was originally developed for extracting pesticides from fruits and vegetables, and later was modified and expanded to target a larger variety of chemicals in different matrices such as liver [45], urine and whole blood [46], sewage sludge [47], sediment [48], and drinking water treatment sludge [49]. To the best of our knowledge, this method has not been used for the extraction of chemicals from indoor dust.

The aim of this study was to: 1) adopt the QuEChERS method for the extraction of antimicrobial compounds from indoor dust; 2) assess the occurrence in two different indoor dust environments of seven antimicrobials used widely in personal care products prior to the 2017 U.S. ban on 19 antimicrobials; and 3) establish a benchmark risk assessment for daily intake of antimicrobials from dust ingestion.

2. Experimental

2.1. Chemicals and reagents

Methylparaben (MePB), triclosan (TCS) and triclocarban (TCC) were purchased from Aldrich (Sigma-Aldrich, St. Louis, MO); ethylparaben (EtPB), propylparaben (PrPB), butylparaben (BuPB), and benzylparaben (BePB) were purchased from RT Corp (Laramie, WY). Isotopically labeled standards $^{13}C_6$-MePB (99%), $^{13}C_6$-TCC (> 99%) and $^{13}C_{12}$-TCS (> 99%) were obtained from Cambridge Isotope Laboratories (Andover, MA). d_5-EtPB, d_4-PrPB, and d_4-BuPB were purchased from C/D/N Isotopes (Quebec, Canada). LC–MS-grade (99%) methanol, water, and acetic acid were obtained from Fluka (NJ, USA). LC–MS-grade acetone (99%) was obtained from Sigma-Aldrich (St. Louis, MO, USA). Individual stock solutions of all compounds were prepared in methanol. Working standards were prepared in methanol by serial dilution of stock solutions prior to use. All stock solutions were stored in glass vials at −20 °C. Anhydrous magnesium sulfate ($MgSO_4$, 97%) was obtained from ACROS (New Jersey, USA) and anhydrous sodium acetate ($NaCH_3COO$, > 99%) was obtained from Dionex (Sunnyvale, CA, USA). 2 mL DiSQuE QuEChERS tubes (150 mg $MgSO_4$, 50 mg PSA, and 50 mg C18) were purchased from Waters Corporation (Milford, MA, USA).

2.2. Dust sample collection

During July and August of 2016, a total of 53 dust samples from 19 athletic facilities and 27 dust samples from 27 single family detached homes located in Oregon were collected using a vacuum apparatus fitted with Dustream collectors with 40 µm nylon mesh filter (Indoor Biotechnologies, Charlottesville, VA). In the athletic facilities dust was collected separately from each of 3 spaces (typically a workout space, hallway, and office) until at least two collectors had been filled or no further apparent dust was available. For the homes study, dust was vacuumed for five minutes in the primary living space using a single

dust collector. Samples were stored in a sterile plastic bag at −20 °C until processing. In some cases (n = 10), when two samples were collected in the same house and space (a living or family room) at separate time points, average concentrations are reported. Dust was aliquoted into duplicate or triplicate (each at about 0.1 g) by mixing the collected sample and distributing the desired mass using sterile forceps and spatulas in a sterile hood. Aliquots were then shipped on dry ice to Arizona State University and stored in −20 °C prior to extraction.

2.3. Sample preparation

Approximately 0.1 *g* of dust was spiked with 30 µL of isotopically-labeled standards (100 ng/mL of $^{13}C_6$-MePB, d_5-EtPB, d_4-PrPB, d_4-BuPB, $^{13}C_6$-TCC, and 1 µg/mL of $^{13}C_{12}$-TCS), and then 1 mL of MS-grade water was added. After vortexing for 30 s, 1.5 mL of acetonitrile with 0.1% acetic acid was added, the slurry was vortexed again for 30 s, and put into a sonication bath for 60 min. After sonication, 0.4 *g* of anhydrous magnesium sulfate and 0.1 *g* of anhydrous sodium acetate were added. The slurry was then vortexed immediately for 1 min, and centrifuged at 4000 *g* for 10 min. The upper organic layer was transferred into a 2-mL DiSQuE QuEChERS tube, vortexed for 1 min and centrifuged at 25,000 rpm for 10 min. Finally, the supernatant was transferred into a 4-mL amber vial and stored at −20 °C prior to analysis. 100 µL of the final extract was diluted with 100 µL of MS grade water for LC–MS/MS analysis.

2.4. Chemical detection and quantitation

Instrument detection parameters were the same as those previously used [50]. Briefly, a Shimadzu Prominence HPLC (Shimadzu Scientific, Kyoto, Japan) was coupled to an ABsciex API 4000 triple quadrupole mass spectrometer (Applied Biosystems, Framingham, MA) equipped with electrospray ionization (ESI) for chemical analysis. 10 µL of sample was injected on to a Waters X-Bridge C_8 column (4.6 × 150 mm, 3.5 µm particle size, Waters Corporation, Milford, MA) with a Waters X-Bridge C_8 Sentry Guard column (3 × 20 mm, 3.5 µm particle size, Waters Corporation, Milford, MA) was employed for analyte separation. Water was used as mobile phase A and methanol as mobile phase B with the following gradient program: initial conditions were 60% B followed by a linear gradient to 95% B over 4 min. The conditions were held for 6 min, returned to initial starting conditions over 1 min, and allowed to re-equilibrate for 2 min. The MS was operated in negative mode and the MS parameters were as follows: curtain gas (CUR) = 25 psi, ion source gas 1 (GS1) = 70 psi, ion source gas 2 (GS2) = 50 psi, ion spray voltage (IS) = −4500 eV, source temperature = 500 °C, entrance potential (EP) = −10 eV, and collision activated dissociation (CAD) gas = 12 psi. Retention time and MS/MS parameters for target analytes and labeled standards are included in Supplementary Information (SI, Table S1).

2.5. Quality assurance/control

Analytes of interest and isotopically labeled analytes were identified by collecting the multiple reaction monitoring (MRM) transitions for each analyte and matching the specific retention time of analyte peaks in samples with those of standards. As a known issue, background levels of these antimicrobials could be detected owing to the high prevalance of these compounds [9,50], all extractions were performed along side method blanks (procedural controls). A double blank consisting of water and acetonitrile (50/50, v/v) with 0.1% acetic acid was injected once per 10 samples to determine if there was any carryover from sample to sample. None of the analytes were detected in solvent blanks or method blanks.

Method detection limits (MDLs) were determined for individual analytes following the United States Geological Survey (USGS) [51] and the United States Environmental Protection Agency (USEPA) guidelines [52]. The limits of quantitation (LOQ) for each compound were determined according to the USEPA guidelines [52]. Compound MDLs and LOQs can be found in Table 1.

Table 1
Recovery, precision, method detection limit (MDL) and limit of quantification (LOQ) for individual analyte.

Compounds	Recovery (%)[a]		Precision (RSD, %)[a]		MDL (ng/g)	LOQ (ng/g)
	300 ng/g	600 ng/g	300 ng/g	600 ng/g		
MePB	109	105	7	4	2.3	7.9
EtPB	108	103	9	5	1.7	5.8
PrPB	101	104	16	13	1.6	5.6
BuPB	93	95	3	7	1.5	5.3
BePB	83	100	9	7	1.6	5.4
TCS	107	91	6	14	3.7	17.5
TCC	88	115	9	30	2.6	8.6

[a] Number of replicates (n = 3).

2.6. Data analysis

LC–MS/MS data were acquired with Analyst software (version 1.5, Applied Biosystems, Foster City, CA). Concentrations of analytes in dust were obtained using the isotope-dilution method and reported as ng/g. For BePB, d_4-BuPB was used as the surrogate internal standard for quantification. Analyte peak concentrations were quantified when the analyte peak height was greater than 3 times the background noise (signal-to-noise ratio > 3), extracted analyte responses fell within the linear dynamic range of the calibration curve, and the calculated analyte concentrations within the samples were above the MDL. Statistical analyses were performed using Excel 2007 (Microsoft Corporation, Redmond, WA), IBM SPSS Statistics (version 24, Armonk, NY), and R (version 3.3.2, R Foundation for Statistical Computing, Vienna, Austria). A non-parametric Spearman's rank correlation test (2-tailed) was utilized to determine if correlations existed between individual parabens and total paraben concentration. A principal component analysis (PCA) with Kaiser normalization was further performed on the concentrations of individual parabens, TCC, and TCS concentrations.

Estimated daily intake (EDI, ng/kg) of ΣPBs (total parabens), TCS and TCC through dust ingestion were calculated using the following equation:

$$EDI_i = \frac{C_i * IR}{BW}$$

where IR is the daily dust ingestion rate (g/d), C_i is the measured concentration of a specific analyte (ng/g) in dust, and BW is average body weight (kg). Based on the USEPA exposure factors handbook (2011) [53], daily dust ingestion rate for infants, toddlers, children, teenagers and adults were 30, 60, 60, 60, and 30 mg, respectively, with average body weight for each group at 7.5, 12.6, 25.2, 64.2 and 80 kg, respectively.

3. Results and discussions

3.1. Method performance

In this study, the versatile QuEChERS dispersive solid phase extraction method [44] was modified and applied to the analysis of parabens, TCS, and TCC in indoor dust followed by compound identification and quantification by LC–MS/MS. Compared with previous studies (SI, Table S2) using SPE, MSPD, PLE/ASE or PHWE [8,35–37,39–41,43], which use about 15–40 mL of organic solvents, this method only required 1.5 mL of acetonitrile with 0.1% acetic acid, without further drying, concentrating or solvent changing, and thus was more cost-effective, environmentally friendly and less labor intensive. The method performance parameters are presented in Table 1. Isotope-

corrected recoveries at two spiking levels varied from 83 to 115%, and precisions, expressed as relative standard deviations (RSDs) from triplicate analyses at two spiking levels, ranged from 3 to 30%. MDLs varied from 1.5 to 3.7 ng/g, which were comparable to the MDLs or LOQs reported in previous studies (0.1 to 10 ng/g) [8,35–37,39–41,43].

These performance characteristics were in the range of those of other studies that reported average RSDs of < 18% [38] and average percentage differences of < 20% [42] using sieved dust samples analyzed in duplicate only. It is difficult to judge whether the modest differences in reproducibility observed here were caused by the type of dust analyzed, the method used for extraction, or the pretreatment of samples. Some studies employed pre-fractionation of dust by sieving [39,40,43] (SI, Table S2), noting that organic contaminant concentrations in indoor dust can increase with decreasing particle size [33]. However, at present there is no consensus or prescribed standard methodology on whether and how to fractionate dust prior to analysis and what particle cutoff size to use. Overall, application of d-SPE resulted in a fast, robust and efficient method for dust analysis with other performance characteristics similar to those of previously used methods that require more time and larger amounts of organic solvents.

Previous studies have reported heterogeneous distribution of a variety of organic contaminants in indoor dust and relatively higher concentrations in smaller particle fractions [33], but consensus on the need for and type of sample fractionation by sieving is currently lacking. Therefore, selection of the dust fraction for analysis should depend on the aims of the study (characterization of the source, assessment of contamination or exposure) [34]. We chose not to sieve our dust samples because the aims of the present study were to demonstrate the applicability of d-SPE approach for the determination of antimicrobials in indoor dust and to assess the occurrence of antimicrobials in U.S. indoor dust.

3.2. Occurrence of parabens, TCS and TCC in indoor dust

A total of 80 dust samples were analyzed in this study, and 100% detection frequency was obtained for each analyte, indicating widespread occurrence of these antimicrobials in indoor environments. Concentrations of individual compounds (median, range; ng/g) are listed in decreasing order (also shown in Fig. 1, detailed summary statistics in SI Table S3): MePB (1920, 50–26200) > PrPB (960, 70–11150) > TCS (390, 20–3270) > TCC (270, 20–9760) > EtPB (195, 9–1060) > BuPB (80, 6–860) > BePB (6, 2–27). The sum of five parabens (ΣPBs) ranged from 140 to 39,090 ng/g, with a median at 3490 ng/g.

Median paraben concentrations found in this study were similar to the levels found in South Korea, Japan, Canada and the U.S. (Table 2), but higher than those in Vietnam, China, Spain and Belgium. Since a major source of parabens in indoor environment is from the use of cosmetics and personal care products, Wang et al. indicated that significantly lower levels of parabens in indoor dust from China may be related to lower per-capita consumption of cosmetics and personal care products than in Japan, Korea and the U.S. [39]. Guo et al. had analyzed paraben concentrations in 52 personal care products (PCPs) from Tianjing, China [54], and 170 PCPs from Albany, NY, U.S. [55], showing that levels of parabens (SI, Table S4) in Chinese PCPs were similar to those from the U. S., supporting the previous postulated hypothesis that the differences of parabens in dust observed between China and U.S. were likely related to different usage patterns and amounts of PCPs, given similar product formulations. Indoor abundances of antimicrobial compounds may also be influenced by different rates of use of building materials that incorporate the compounds, along with construction and operation practices that would affect removal by ventilation or cleaning.

Consistent with all the other studies, MePB and PrPB were the most abundant parabens found in indoor dust, with average contributions to ΣPBs of 58% and 32%, respectively. Furthermore, individual paraben concentrations were positively correlated (Spearman's *rho* = 0.22 – 0.89, SI, Table S5), particularly for MePB and PrPB (Spearman's *rho* = 0.89, $p < 0.01$), indicating similar sources of parabens in the dust, which could be explained by the fact that parabens are often used in combination to improve antimicrobial activities [54]. Similar positive correlations have been observed in various matrices such as urine, blood, sewage sludge, and sediment [7,56,57].

TCS levels found in this study also were similar to those reported elsewhere [35–38,41]. Together with a previous study of only a single athletic facility in Oregon [8], this report constitutes the first simultaneous monitoring of TCS and TCC in indoor dust from the U.S. and it was conducted just prior to implementation of the recent Federal ban on use of 19 antimicrobials (including TCS and TCC) in antiseptic hand washes [28].

A PCA was applied to individual antimicrobial concentrations, where two factors with Eigenvalue > 1.000 accounting for 62.7% of the variance were retained. The results are shown in Figure S1, where MePB, EtPB, PrPB, and BuPB are clustered together, and BePB, TCS and TCC are clustered together, which again reflects the combined use of multiple parabens in commercial products [58], and co-occurrence of TCS and TCC in the environment due to their similar chemical structures, usage and disposal mode [1,59,60].

3.3. Levels of antimicrobials as a function of sampling location

The 80 dust samples analyzed in this study originated from private homes ($n = 27$) and athletic facilities ($n = 53$). A statistical comparison (two-tailed t-test) of the two data sets obtained for the various analytes indicated no statistical differences ($p > 0.05$) in levels of parabens and TCC between these two sampling location types, whereas TCS levels in private homes (mean ± SD: 311 ± 239 ng/g) were significantly lower ($p < 0.05$) than those found in athletic facilities (684 ± 585 ng/g), which could be due to less frequent use of TCS-containing antiseptic wash products in private homes than in athletic facilities.

3.4. Estimated daily intake from dust ingestion and comparison with other exposure routes

Estimated daily intake of total parabens, TCS and TCC were calculated with the same approach used in previous studies [39,40]. A summary of maximum, median and mean EDIs are listed in Table 3. Median EDIs (ng/kg-bw/d) varied from 1.3 (adults) to 16.6 (toddlers), 0.1–1.9, and 0.1–1.3 for total parabens, TCS and TCC, respectively. Generally, infants and toddlers had about 10-fold higher EDIs than the ones for adults.

Exposure to parabens through dust ingestion calculated in this study (median EDI, ng/kg-bw/d) were slightly higher than those reported for Koreans (1.11–5.42) and Japanese (1.18–5.38), and much higher than those for Chinese (0.2–0.98) [39] and Vietnamese (0.11–0.53) [40]. Two studies have estimated daily intake of TCS from dust ingestion for Belgians [37] and Chinese [41]; EDIs for TCS were similar between this study and the Chinese study, but slightly higher than the Belgian one. No other studies to date have estimated TCC intakes from dust ingestion.

Intakes of these antimicrobials through other exposure routes have been reported earlier (Fig. 2) [55,61–64]. Liao et al. have estimated mean daily dietary intakes of parabens for U.S. children and adults to be 470 and 307 ng/kg-bw/d, respectively, which were 40- and 170-times higher than the mean intakes of parabens estimated for children and adults in this study. Intakes of total parabens for children and adults from biomonitoring data were estimated to be 60,300 and 53,800 ng/kg-bw/d, respectively [62]. Intakes of dust ingestion calculated in this study would thus contribute < 0.15% and < 0.03% of the total paraben exposure for children and adults, respectively, indicating that dust ingestion is a minor route of paraben exposure for U.S. children and adults. While total exposure of parabens for infants and toddlers were

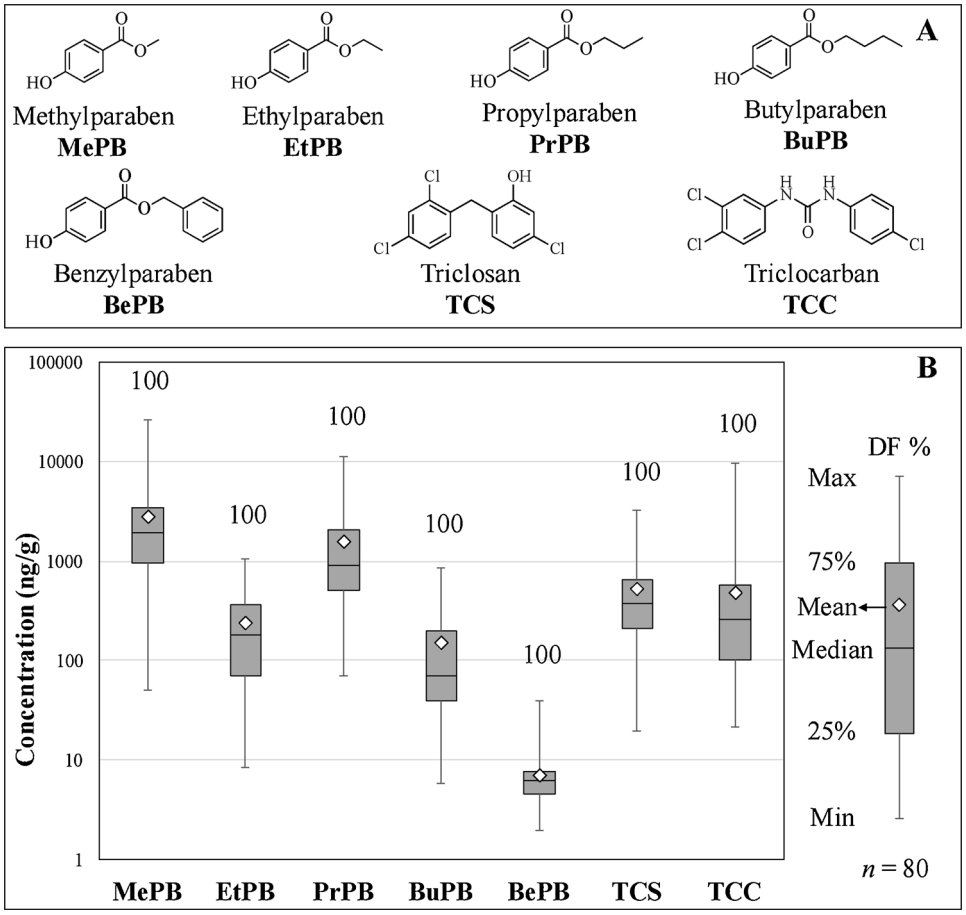

Fig. 1. Chemical structures, names and abbreviations of target antimicrobials (Panel A); Box-and-whisker plot of individual antimicrobial concentrations found in 80 indoor dust samples (Panel B). DF: detection frequency.

not available, use of PCPs has been considered as the major route to parabens exposure. Median dermal intakes of six parabens for U.S. infants and toddlers from use of PCPs have been estimated to be 200 and 120 ng/kg-bw/d, [55], median paraben intakes from dust ingestion account for 7% and 14% of the exposure from PCPs for infants and toddlers, respectively. Thus, dust ingestion may contribute more to the intake of total parabens for infants and toddlers than it does for children and adults.

Rodricks et al. had estimated TCS daily intake based on median urinary concentrations of TCS reported in the NHANES 2003–2004 survey, to be 200 and 100 ng/kg-bw/d for adults and children, respectively [63], whereas median intakes of TCS through dust ingestion in this study were 0.1 and 0.9 ng/kg-bw/d for adults and children, respectively, contributing less than 0.1% towards total exposure to TCS. It is anticipated that children under 6 would use fewer products containing TCS than children and adults, therefore similar to paraben exposure, dust ingestion may contribute more to total TCS intake for infants and toddlers than for children and adults.

Table 2
Comparison of median concentrations (ng/g) found in this study with the ones from other dust studies.

Country	Sample Size	Median Concentration (ng/g)						Ref
		MePB	EtPB	PrPB	BuPB	BePB	TCS	
Belgium	20	\	\	\	\	\	220	Geens et al. [37]
Spain	6	912[a]	276[a]	425[a]	212[a]	\	\	Ramírez et al. [43]
	10	455	58	415	43	\	525	Canosa et al. [35]
	10	451	135	226	106	\	880	Canosa et al. [36]
Canada	63	1080	25	463	59	< 8	378	Fan et al. [38]
Vietnam	41	58.2	12.7	15	14.9	0.92	\	Tran et al. [40]
China	110	\	\	\	\	\	260	Ao et al. [41]
	55	320	11	182	2	0.8	\	Wang et al. [50]
South Korea	41	1310	46	800	40	1.85	\	
Japan	22	1470	127	228	45	\	\	
U.S.	40	760	33	706	24	0.7	\	
	118	978	< 200	\	< 200	\	\	Rudel et al. [42]
	23	1020	60	380	60	< MDL	200	Hartmann et al. [8]
	80	1920	180	965	80	6	390	This study

[a]Mean concentration; \ indicates that the analyte was not included in the study.

Table 3
Estimated daily intake (EDI, ng/kg-bw/d) of ΣPBs, TCS and TCC via dust ingestion for different age groups.

EDI (ng/kg-bw/d)	Parabens			TCS		TCC			
	Max	Median	Mean	Max	Median	Mean	Max	Median	Mean
Infants	156.4	14.0	19.3	13.1	1.6	2.2	39.0	1.1	2.0
Toddlers	186.1	16.6	23.0	15.6	1.9	2.7	46.5	1.3	2.4
Children	93.1	8.3	11.5	7.8	0.9	1.3	23.2	0.6	1.2
Teenagers	36.5	3.3	4.5	3.1	0.4	0.5	9.1	0.3	0.5
Adults	14.7	1.3	1.8	1.2	0.1	0.2	3.7	0.1	0.2

Migration of parabens, TCS and TCC from baby teethers collected from the U.S. market has been reported earlier [64]. Median daily intakes of six parabens were 0.59 and 0.63 ng/kg-bw/d for male and female infants, respectively, which were over 20-times lower than the intakes from dust ingestion. Median intakes for TCS and TCC from teethers were 0.004 ng/kg-bw/d, about three orders of magnitude lower than the intake from dust ingestion.

Although use of TCS and TCC in hand washes and soaps was banned effective September 2017 in the U.S., these compounds can still be used in other PCPs (e.g., toothpaste, body lotion and deodorant), building materials, household products and textiles. The system exposure doses (SED) of TCS from toothpaste, hand soap and body soap were calculated as 23.4, 6.6 and 26.8 μg/kg-bw/d [65] for adults, accounting for 40%, 11% and 46% of total intakes from common-use PCPs, respectively. After the ban, the use of TCS-containing toothpaste may constitute the bulk of total TCS exposure. Similarly, SEDs for dermal exposure to bar soap, liquid soap and body wash containing TCC for a 60-kg adult were 7.4, 19.5 and 5.2 μg/kg-bw/d, respectively, and total aggregate exposure was 32.1 μg/kg-bw/d [66]. After the ban, use of other consumer products containing TCC may contribute more to total TCC intake. The data presented in this study can serve as a baseline of pre-ban antimicrobial concentrations in U.S. dust and, as such, may help to discern the impact of the 2017 U.S. restrictions on antimicrobial use in consumer products on inhalation hazards from indoor dust in public and private spaces.

3.5. Limitations

Differences of antimicrobials levels observed among different studies could be the result of different usage patterns and volumes of consumer products containing these compounds, but it could also be influenced by different sampling methods, sieved fractions, sample preparation techniques and analytical methods. For future studies aimed at comparing antimicrobial levels in indoor dust before and after the 2017 FDA ban on antimicrobials in antiseptic washes, similar sample treatments and analytical approaches should be taken to deliver the most comparable results. For the assessment of human exposure to contaminants via dust ingestion, selection of different dust fractions may hinder a comparison of results from different studies. Current studies are limited by the lack of data on the daily exposure to different size fractions of dust, the distribution of contaminant concentrations with different particle sizes, and the bioavailability of contaminants as a function of particle size. More studies are needed to tackle these issues to better assess human exposure to organic contaminants via dust ingestion.

4. Conclusions

This work demonstrates the first use of d-SPE to measure antimicrobial compounds in indoor dust. The method employed here reduces sample preparation time and the amount of solvent used compared to previously established extraction methods. Using d-SPE dust samples from residential homes and athletic facilities were shown to contain measurable amounts of MePB, EtPB, PrPB, BuPb, BePb, TCS, and TCC. Daily intake of total parabens, TCC, and TCS from indoor dust was estimated to be approximately 10 times higher in infants and toddlers compared to adults. Although dust intake is a minor source of antimicrobial exposure for all age groups, assessing the content of these compounds in dust can lead to a better understanding of their environmental distribution. Future studies should examine the effect of the 2017 FDA ban on TCC and TCS levels in indoor dust to determine if the ban resulted in a significant decrease of detectable levels of these antimicrobial compounds.

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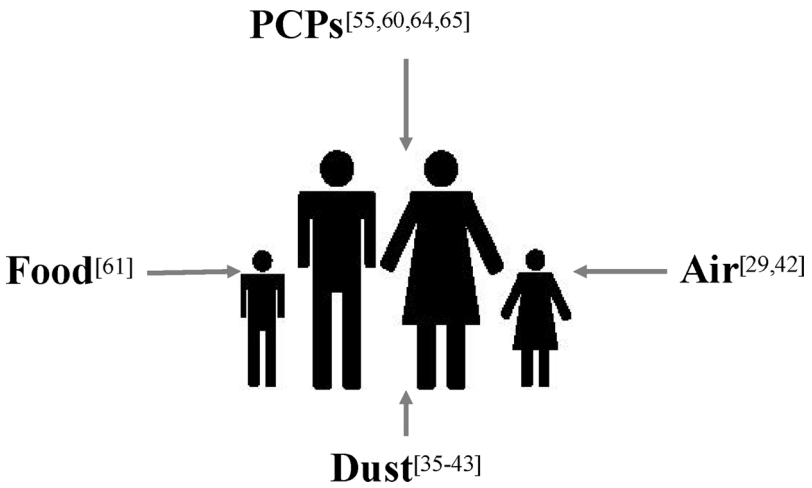

Fig. 2. Routes of human exposure to target antimicrobials. Corresponding references were included in brackets.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jhazmat.2018.08.014.

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