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Authors

Upson, Kristen

Shearston, Jenni

Kioumourtzoglou, Marianthi-Anna

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Menstrual products as a source of environmental chemical exposure: A review from the epidemiologic perspective

Kristen Upson, PhD, MPH[1,*], **Jenni A. Shearston, MPH**[2], **Marianthi-Anna Kioumourtzoglou, DSc, MSPH**[2]

[1]Department of Epidemiology and Biostatistics, College of Human Medicine, Michigan State University, East Lansing, Michigan, USA

[2]Department of Environmental Health Sciences, Columbia University Mailman School of Public Health

Abstract

Purpose of review: Menstrual bleeding is a regular, common occurrence in a substantial portion of the population. Menstruators may use more than 10,000 menstrual products over the lifetime. Given the potential for environmental chemicals in menstrual products to be absorbed by the vulvar and vaginal epithelium into systemic circulation, we reviewed the available data on menstrual products as a source of environmental chemical exposure.

Recent findings: Nearly two dozen studies have been conducted measuring environmental contaminants in menstrual products; all have detected environmental chemicals but had discrepant conclusions on exposure risks. Only three human studies have investigated menstrual product use and environmental chemical concentrations and all observed associations.

Summary: Detection of environmental chemicals in menstrual products, in combination with challenges of exposure assessment, scarcity of human studies, and the exceedingly common occurrence of menstrual bleeding, motivate the need for further research. We provide recommendations to move this field forward.

Keywords

menstrual products; environmental chemicals; menses; tampon; menstrual pad

Introduction

Half of the world's population have or will experience menstrual bleeding, a physiologic process that occurs on average every 24-38 days over several decades, from menarche to menopause [1]. Menstrual products are critical to managing menstrual bleeding. The range of commercially-available menstrual products includes disposable absorbent tampons,

*Corresponding Author: Kristen Upson, PhD, MPH, Department of Epidemiology and Biostatistics, College of Human Medicine, Michigan State University, 909 Wilson Road, Room 601, East Lansing, Michigan, 48824, Phone: 517-353-5502, upsonkri@msu.edu.

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menstrual pads (also referred to as sanitary napkins and sanitary towels), and pantiliners (same as panty shields) [2] as well as reusable menstrual pads, menstrual cups and discs, and menstrual underwear. For this review, we also considered products used vaginally or applied externally to the vulva or external genitalia during or after menses to clean or control odor, including vaginal douching, and vulvar sprays, powders, and wipes.

The use of menstrual products is ubiquitous in menstruators. Considering the average age at menarche (12 years) [3] and menopause (52 years) [4], and assuming 13 cycles per year (28 days in length), 5 days of menstrual bleeding per cycle, and an average of 4 menstrual products used each day, menstruators, on average, could use more than 10,000 menstrual products over the lifetime. The use of menstrual products could be substantially higher for those with heavy menstrual bleeding, which has been estimated in community surveys to be prevalent in over one-third of reproductive-age women [5, 6]. In the United States, sales of tampons and menstrual pads, the most commonly used menstrual products, exceeded $2.8 billion [7] in the year 2018 alone, with nearly 600 million units sold [8].

The first commercially successful menstrual product in the United States, a disposable menstrual pad, dates back to 1921 [9]. Despite this long history and the common, regular use of menstrual products in a large portion of the population, the investigation into menstrual products as a source of environmental chemical exposure is relatively new. In this context, environmental chemical exposure includes both chemicals used in the manufacture of menstrual products and constituents in menstrual products contaminated by environmental chemicals. We aim to summarize this emerging research area with this review. We first set the stage for environmental chemical exposure from menstrual product use by describing product design, increased permeability of the vulvar and vaginal epithelium allowing for environmental chemical absorption, and a case example of a menstrual product interacting with the vaginal environment and menstrual fluid, in the context of vaginal epithelial permeability, to contribute to adverse health. This is followed by our review of studies that have measured environmental chemicals in menstrual products, as well as epidemiologic studies that have investigated menstrual product use and environmental chemical concentrations measured in women. We conclude by providing recommendations for future research to move the investigation of menstrual product use in the context of environmental health forward.

In this review, we use the term “menstrual bleeding” broadly to include bleeding from menstruation, bleeding between menstrual periods, and spotting, as well as withdrawal bleeding and breakthrough bleeding and spotting with hormonal contraceptive use [10]. Similarly, we use the term “menstruators” to refer to anyone who has ever experienced menstrual bleeding (using our broad definition), acknowledging that not all individuals who have ever menstruated identify as a woman and not all those who identify as a woman have ever menstruated [11, 12]. In alignment with the use of “menstruator”, we use the inclusive term “menstrual products” as opposed to the terms “feminine hygiene products” or “feminine care products” used by product manufacturers [13].

Setting the stage for environmental chemical exposure from menstrual product use

Brief overview of menstrual product design—Menstrual pads are typically constructed with three layers [9, 14, 15]: (1) a topsheet generally comprised of perforated, non-woven polypropylene/polyethylene fibers. The topsheet acquires menstrual fluid and is covered in emollient for soft contact with the vulva; (2) an absorbent polymeric core which stores menstrual fluid; and (3) a backsheet that prevents menstrual fluid leakage from the pad. The backsheet has adhesive to fasten the menstrual pad to underwear. Between the undersurface of the absorbent core and the backsheet, perfume may also be added [14]. Pantiliners are similar to menstrual pads in overall construction, with a topsheet, absorbent core, and backsheet [16, 17]. Pantiliners tend to be smaller in size and thinner than menstrual pads [16].

Whereas menstrual pads are constructed to store menstrual fluid away from the body [9], tampons are designed to absorb and retain menstrual fluid inside the vagina [16]. Tampons are made of a cellulose absorbent material comprising either rayon, cotton, or mixture of the two; the proportion of cotton to rayon varies with the cost of cotton [11]. The absorbent core is covered by a thin layer of non-woven or perforated film to facilitate both smooth insertion and minimize fiber loss, with a withdrawal cord attached [16]. Tampons may have fragrances added for aesthetic or deodorizing purposes [18].

Menstrual cups are designed to collect and hold menstrual fluid within the vagina [19]. The device is composed of medical-grade silicone, rubber, latex, or elastomer [20]. Although most menstrual cups are re-usable, some single-use disposable cups exist [20].

As for products used during or after menses to clean or control odor, the constituents of aerosol and pump vulvar sprays may include antimicrobial agents, astringents, fragrances, and propellents [2]. The typical formulation of vulvar wipes consists of water with a mild cleaning agent, preservatives, antimicrobials, and fragrance [2]. Vulvar powders typically contain cornstarch for odor control [2]. Vaginal douches are composed of a bag apparatus with a nozzle that contains or is used with a solution. The solution can be homemade, such as water with vinegar or baking soda or water alone; commercially-available products contain fragrances, acetic acid, water, and surfactant detergents [21, 22]. Gynecologic professional organizations and governmental entities in the U.S. generally do not recommend the use of vaginal cleaning or odor-control products [23, 24] as product use may disrupt the vaginal microbiome, promoting the microorganism overgrowth and increasing the risk of vaginitis [25].

Related to product design, the regulation of menstrual products differs worldwide. In the United States, the U.S. Food and Drug Administration (FDA) regulates tampons, menstrual pads, menstrual cups, and douching bag apparatus and nozzle as medical devices [26] whereas products “intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body or any part thereof for cleansing, beautifying, promoting attractiveness, or altering the appearance” such as douching solutions, vulvar sprays, wipes and powders, are regulated as cosmetics [27]. A review of existing regulations and policy-related implications were considered beyond the scope of this review and are not further discussed.

Potential for environmental chemical absorption via vulvar and vaginal epithelium—It is biologically plausible that environmental contaminants in contact with vaginal and vulvar epithelium can be absorbed and pass into systemic circulation. The vaginal epithelium is comprised of a mucosal membrane that is permeable to a range of compounds [28] with numerous folds that increase the surface area [29]. Furthermore, the vagina is well-vascularized and chemicals absorbed by the vagina bypass first-pass metabolism by the liver and directly enter systemic circulation [29]. Efficiency of vaginal absorption was demonstrated in a study comparing the pharmacokinetics of vaginal and oral administration of 80 mg of propranolol; the mean maximal plasma concentration using the vaginal route was twice that of the oral route (112.0 μg/l vs 52.2 μg/l, respectively) [30]. As such, vaginal medication administration can provide prolonged, continuous drug delivery, using a lower dose [28]. Given the efficient systemic drug delivery, the list of medications administered vaginally is growing, including vaginal rings for hormonal contraception and hormone therapy [29], with HIV PrEP vaginal rings being tested in clinical trials [31].

The permeability of the vulvar epithelium varies by the degree of its keratinization and thickness, with thin areas of lower or no keratinization allowing for greater permeability [32, 33]. The mons pubis and labia majora exhibit keratinized, stratified squamous epithelium similar to skin at other sites, although it is more hydrated which increases permeability [33]. Keratinization and epithelial thickness decrease over the clitoris and labia minor, and the inner third of the labia minora is non-keratinized and thin. This portion of the vulvar mucosa is morphologically similar to the vagina. Consistent with the vulva having higher permeability than skin at other body sites [32], greater absorption of the steroid medication hydrocortisone was observed when applied on the vulva versus the arm [34].

Menstrual product interaction with vaginal environment and menstrual fluid to contribute to adverse health: Tampon use and menstrual toxic shock syndrome—An adverse health consequence related to the permeability of the vaginal mucosa and menstrual product use was borne out in the late 1970s and early 1980s with the menstrual toxic shock syndrome epidemic. In the late 1970s, a new superabsorbent tampon product, called Rely, was introduced into the market [35]. The use of synthetic material constituents provided increased absorbency over other commercially available tampons. However, the Rely tampon interacted with the vaginal environment and microorganisms in the vaginal microbiota to promote the bacterial growth of *Staphylococcus aureus* and its expression of toxins [36]; the toxins passed through the vaginal mucosa into systemic circulation to produce fever, vomiting, and diarrhea, progressing to hypotensive shock, which had a 10-15% case fatality ratio [37]. Although uncertainty remains as to the exact mechanism of Rely tampon use in the development of menstrual toxic shock syndrome, contributing factors include: (1) the introduction of oxygen by the superabsorbent materials in the tampon, changing the vagina from an anaerobic to aerobic environment [38], (2) the menses-related shift in vaginal pH from acidic to neutral, (3) the rise in *S. aureus* numbers in the vaginal microbiome during menstruation [38], (4) the interaction between *S. aureus* colonizing the tampon, menses entering the tampon, and menses providing a source of oxygen to bacteria [39], and (5) the lack of antibodies to the toxin in some women [36]. Hence, the menstrual toxic shock syndrome epidemic 40 years ago challenged the paradigm

that the constituents within menstrual products are inert [11]. Instead, it provided critical proof-of-principle that a menstrual product could interact with the vaginal environment and menstrual fluid, in the context of vaginal epithelial permeability, to contribute to adverse health.

Environmental chemicals measured in menstrual products

In the last decade, the investigation into environmental chemicals in menstrual products has substantially increased, with results being reported in a wide range of venues, from peer-reviewed academic journals and government reports to online websites of consumer associations and environmental magazines. We restricted our review to studies in which enough information was provided to understand the scientific methods and results (Table 1). Studies that did not meet this requirement are listed in Supplemental Table 1. We also excluded studies that conducted a risk assessment but did not measure chemicals in menstrual products [40] or that described a novel method to measure environmental chemicals in menstrual products but did not provide the chemical concentrations quantified in products [41]. Given the involvement of non-academic, non-governmental entities involved in the conduct of this research, it is possible that some studies reported online were missed in this review.

Dioxins and furans—The first studies measuring environmental chemicals in menstrual products focused on dioxins [42-47]. Interest in dioxins in menstrual products appears to stem from concerns about the formation and release of dioxins during the chlorine bleaching process used to separate and remove lignin and other impurities from cellulose fibers in cotton and rayon [45, 48] used in tampons and menstrual pads. Dioxins are a chemical class of hydrocarbons that are not intentionally produced but are a by-product of industrial processes [49]. These chemicals are highly persistent and bioaccumulate, and the most potent dioxin, 2,3,7,8-tetrachlorodibenzo-p-dioxin, is a well-established carcinogen [49]. Hence, the use of elemental chlorine gas in the bleaching process was discontinued in the late 1980s in favor of an elemental chlorine-free method using chlorine dioxide that reduces dioxin by-product formation [49, 45]. An environmental organization, Mothers and Others for a Livable Planet, was involved in menstrual product collection and funding for two of the early studies of menstrual products and dioxins [43, 44]. Of the studies conducted [42-47, 50-52], all but one [46] suggested potential exposure to dioxins from menstrual products would be negligible.

Interestingly, one study compared the concentrations of dioxins by the absorbency of tampon products and reported higher octachlorodibenzo-p-dioxin (OCDD) concentrations in regular absorbency tampons compared to those with “SuperPlus” absorbency [45]. Another study observed that the concentrations of dioxins in menstrual pads varied by the country from which they were purchased [46].

Volatile organic compounds—Volatile organic compounds (VOCs) are chemicals that evaporate easily and contain carbon atoms. The most well-known VOC is benzene, a human carcinogen that also exhibits reproductive effects [53]. Relevant to menstrual products, VOCs can be used in fragrances, absorbents, adhesives, binders, and moisture barriers

[54]. The first study of VOCs in menstrual products was commissioned by a non-profit environmental organization, Women's Voices for the Earth, in which four menstrual products sold in the US were measured for VOCs; all 19 measured VOCs were detected in the products [55]. Subsequent studies have quantified VOCs in menstrual pads [56-58, 54], liners [56], tampons [58, 54], and wipes, sprays, and washes [54]. Two of the three studies that conducted risk characterization raised concerns about daily absorption of toluene from pads [57] as well as risks that approached or exceeded guidelines with inhalation of 1,4-dioxane in washes, dermal exposure to benzene in sprays and powders, and exposure to n-heptane from pads, sprays, and powders [54].

Of note, one study evaluated menstrual product labelling such as "organic", "all natural", and "for sensitive skin" in relation to VOC concentrations; no differences in VOC concentrations were observed for these products compared to conventional products [54]. In the same study, scented products had higher VOC concentrations than unscented products [54]. This pattern was not observed in another study that evaluated scented and unscented menstrual pads [55].

Related to VOCs, a study of allergenic fragrances measured in menstrual pads and liners reported that several fragrances were present at above 10 μg/g, the actionable level for labelling on products if the cosmetic legislation in Europe applied to menstrual products [18].

Phthalates—Phthalates are synthetic chemicals used in the production of a wide variety of consumer products, including as plasticizers, solvents, and fragrance fixatives in personal care products and cosmetics [59-61]. Hence, dermal application of these products is an important route for human exposure, with increased phthalate metabolite concentrations being measured in urine with a greater frequency and number of products used [62]. Phthalates exhibit endocrine disrupting properties and have been associated with a range of reproductive outcomes [63, 64]. Phthalates may be present in menstrual products from use in fragrances, menstrual pad or liner adhesive, or in the processing of raw materials and manufacture of menstrual products [65]. Most studies evaluating menstrual products have detected phthalate concentrations [66, 51, 57, 65, 67, 68, 52] with several studies reporting that menstrual products could substantially contribute to phthalate exposure [66, 57, 65, 67, 68]. Two studies observed concentrations of di(2-ethylhexyl) phthalate (DEHP) in menstrual pads exceeding acceptable levels for carcinogenic risk [66, 65]. Two other studies reported that menstrual products had higher phthalate concentrations than other consumer plastic products [57] and indoor dust [68]. Scented menstrual pads had higher phthalate concentrations than unscented pads [66, 65, 68].

Broad investigation of chemicals—We found government reports investigating a range of environmental chemicals in menstrual products from five European countries [69, 70, 50, 51, 17, 52]. Denmark was the first to examine menstrual products as part of an initiative since 2001 to investigate consumer products that may contain problematic chemicals or to which consumers are highly exposed [71]. Menstrual products were selected given both the duration of use and use close to the skin and mucous membrane (pads and liner) or direct contact with mucous membrane (tampons) [69, 70]. Similarly, an investigation in Sweden

was motivated by the government directive to evaluate products for hazardous chemical substances to promote the phaseout of these substances in products available to the general public [17]. Menstrual products were selected given their direct contact with the body and regular use by a large proportion of the population. Other investigations were motivated by mounting media reports [50, 51] and consumer associations reporting the presence of contaminants in tampons and pads that may have endocrine disruptive or carcinogenic properties [52]. All the reports generally concluded that menstrual products likely contribute little to exposure [50, 52], or exhibit low health risk from exposure [69, 51, 17].

Comments on studies measuring chemicals in menstrual products—The evaluation of menstrual products as a source of environmental chemical exposure has had a unique history, with environmental organizations and consumer associations in combination with media reports motivating the conduct of research. All the reviewed studies detected environmental chemical concentrations in menstrual products, albeit for some chemicals the concentrations were low. Across studies we also noted an interesting pattern: regardless of the environmental chemical studied, concentrations of environmental chemicals varied within menstrual product type (e.g., menstrual pad, tampon, etc.) [43, 69, 70, 45, 46, 55, 50, 72, 57, 18, 52].

Of the 23 studies we reviewed, 13 conducted exposure assessment and risk characterization. Those studies yielded discrepant conclusions and varied in the approach to exposure assessment (Supplemental Table 2). Over half the studies estimated average daily exposure considering a timeframe of an average month (30 days) or over lifetime, instead of exposure on days when using products. Although a few studies considered exposure in adolescence by using an average body weight near the age of menarche, most studies used an average adult weight. The common data gap cited by most studies was the lack of information on vulvar and vaginal mucosal absorption of chemicals. To address this gap, many studies made assumptions about transmucosal absorption by extrapolating from limited available data on dermal absorption. This data gap is critical given the increased permeability of the vulvar and vaginal mucosa as well as the ability of chemicals to bypass first-pass metabolism and enter systemic circulation.

In addition, all studies considered the menstrual products or its constituents in isolation from menstrual fluid and the vulvar or vaginal environment. In the case of menstrual pads, chemicals in pads could be transferred to the absorbed menstrual fluid, with a portion of the menstrual fluid resurfacing back to the topsheet with changes in surface pressure such as body weight when sitting (described as “rewet” or “reflux” by menstrual product manufacturers [14]). The resurfaced menstrual fluid could then come in contact with the vulva and chemicals could be absorbed. Although menstrual pads are designed to promote dryness of the topsheet, it is possible that heavy menstrual flow or thicker menstrual fluid does not pass through the topsheet and remains on the pad surface. This would provide another mechanism for chemicals in emollients covering the topsheet to be dissolved into menstrual fluid that is in contact with the vulva. As for tampons, use of a product with absorbency exceeding the amount of menstrual flow could also result in vaginal tears and increase the absorption of environmental chemicals in the product. Applicable to both menstrual pads and tampons, the dissolution of chemicals in menstrual fluid and vulvar/

vaginal absorption could be affected by the number of hours a menstrual pad is worn or a tampon is retained in the vagina and the conditions within the vulvar or vaginal environment, drawing from the case of tampons and menstrual toxic shock syndrome. To accurately characterize exposure, it has been proposed that exposure assessment should simulate the actual wearing environment of the menstrual product [15], which could include the use of multiple products at the same time.

Menstrual product use and environmental chemical concentrations in women

To date, only three epidemiologic studies have been conducted on menstrual product use and concentrations of environmental chemicals measured in women [73-75], with the first study only published in the past 6 years (Table 2).

Phthalates—In 2015, Branch et al published a study which extended the research inquiry into the use of personal care products as a source of exposure to phthalate metabolites to menstrual products [73]. At the time the study was conducted, menstrual products had not yet been evaluated for the presence of phthalates. Using publicly available data from the National Health and Nutrition Examination Survey (NHANES) 2001-2004, the authors conducted a cross-sectional study that examined tampon, sanitary napkin, vaginal douche, feminine spray, feminine powder, wipe/towelette, and other product use in the past month in relation to urinary concentrations of phthalate metabolites, mono-ethyl phthalate (MEP) and mono-*n*-butyl phthalate (MnBP) in women ages 20-49 years [73]. The parent phthalate diesters from which these metabolites derive, diethyl phthalate (DEP) and di-*n*-butyl phthalate (DnBP), respectively, are frequently used in fragrances. The authors observed that those who self-reported vaginal douche use in the past month had MEP concentrations that were 52% higher than non-users (95% CI: 19%, 94%). Furthermore, MEP concentrations increased with frequency of use, suggesting a dose-response relationship. The data also suggested increased MEP concentrations with feminine spray and powder use. No associations were observed with tampon and sanitary napkin use nor with MnBP.

VOCs—Another study using NHANES 2001-2004 data evaluated tampon, menstrual pad, wipe, spray, and douche use in relation to whole blood VOCs concentrations measured in women ages 20-49 years [75]. Although the chemical class of VOCs can include a range of substances, the study focused on VOCs that could be detected in 50% or more of study participants: bromodichloromethane, chloroform, dibromochloromethane, 1,4-dichlorobenzene (DCB), ethylbenzene, toluene, and m-/p-xylene [75]. The authors reported that those who used feminine powder in the past month had 36% higher whole blood concentrations of ethylbenzene (95% CI: 0% to 83%) compared to non-users and that women who vaginally douched two or more times in the past six months had 1,4-DCB concentrations that were 81% higher than those who did not douche (95% CI: 2% to 221%). The data also suggested that use of feminine powder in the past month was associated with higher concentrations of 1,4-DCB (108% higher, 95% CI: −9%, 377%) compared to non-users.

Metals—Singh et al (2019) investigated the association between tampon use and whole blood concentrations of toxic metals cadmium, lead, and mercury [74]. The authors focused

on tampons as a potential source of metal exposure given that the main constituent of tampons is cotton, rayon, or their blend; these constituents derive from cotton plants and wood pulp, which can bioaccumulate metals present in soil and water from industrial processes or metal-containing fertilizers. Toxic metals cadmium, lead, and mercury have well-established adverse impacts on health [76-78] and no prior studies have evaluated the presence of metals in tampons. That study was conducted among premenopausal women ages 18-44 years in Western New York who participated in the BioCycle Study. The BioCycle Study had extensive study inclusion criteria pertaining to menstrual cycle length, hormonal contraceptive use, body mass index, and disease history [79, 74]. Any tampon use during the study period (up to two menstrual cycles) was associated with a 25% higher geometric mean mercury concentration (adjusted ratio of the expected geometric mean 1.25, 95% CI: 0.93-1.68); no associations were observed with cadmium and lead concentrations [74]. Interestingly, the data also suggested associations between tampon use and biomarkers of oxidative stress, including isoprostanes, thiobarbituric acid reactive substances, and human serum paraoxonase 1 paraoxonase; the authors postulated that other contaminants in tampons such as pesticides that induce oxidative stress and inflammation may have contributed to the observed associations.

Comments on epidemiologic studies—All three epidemiologic studies observed associations between menstrual products directly applied to the vagina (douching) or vulva (powder) or with continued contact with the vagina (tampons) and increased concentrations of select environmental chemicals. However, the studies employed a cross-sectional design; it is not possible to determine the temporal sequence between product use with menstrual bleeding and environmental chemical exposure. Interestingly, despite multiple studies investigating dioxin concentrations in menstrual products, no epidemiologic human studies to our knowledge have investigated the association between menstrual product use and the concentration of dioxins in menstruating individuals.

With the exception of douching frequency in two studies, none of the studies evaluated the frequency or duration of product use or multiple product use in relation to chemical concentrations. Some products, such as pantiliners are used daily by 10-30% of users [80]. Multiple products may be used for heavy menstrual bleeding, or products may be used together, such as powder on menstrual pads [2]. In addition, the collection of biologic samples for the measurement of environmental chemicals was not timed in relation to exposure to menstrual products during menses. Furthermore, the studies using NHANES data were not exclusively conducted among menstruators and included menopausal and pregnant women. Despite these limitations, the three studies have revealed intriguing findings that warrant replication and further investigation.

Recommendations for future research

Over two dozen studies have quantified chemicals within menstrual products, with only three epidemiologic studies examining menstrual product use and environmental chemical concentrations in women. Based on the research to date, we propose the following recommendations to move the field forward from the epidemiologic perspective:

Recommendation #1. Generate empirical data on vaginal and vulvar absorption of chemicals in menstrual products and interaction between menstrual product, menstrual fluid, and vaginal/vulvar environment.—Empirical data are needed to address the critical gap mentioned in most studies measuring environmental chemicals in menstrual products and conducting exposure assessment and risk characterization – the lack of information on vulvar and vaginal mucosal absorption of chemicals. Building on the case of tampons and menstrual toxic shock syndrome, empirical data are also needed on the interaction between menstrual product use and factors such as vaginal pH, oxygenation, microbiome, menstrual fluid dynamics, composition, and volume.

Recommendation #2. Expand epidemiologic research of menstrual product use and environmental chemicals measured in menstruators.—We recommend expanding epidemiologic research to investigate (i) the range of environmental chemicals that have been detected in studies of menstrual products, (ii) menstrual products that have recently come to market and/or increased in popularity, such as menstrual underwear, menstrual cups and discs, and reusable menstrual pads, (iii) behavioral patterns of menstrual product use, including duration and frequency of product use and use of multiple products, and (iv) environmental chemicals previously studied to understand if the results are replicable. Epidemiologic studies using a prospective study design among menstruators with exposure measurement timed with menses would allow for a better understanding of the temporal sequence between product use and environmental chemical exposure. Evaluation of behavioral patterns of menstrual product use particularly as they relate to underlying social and economic drivers of menstrual product use would inform environmental justice efforts to promote health equity [81].

Recommendation #3. Consider menstrual products as a source of environmental chemicals in the design of epidemiologic studies of gynecologic conditions.—If the results in human studies are replicated, menstrual product use will need to be considered in the epidemiologic investigation of gynecologic conditions. Several gynecologic conditions, including uterine fibroids, endometriosis, and adenomyosis, are associated with heavy menstrual bleeding [82], requiring greater menstrual product use. Hence, if the biologic sample collection is near the time of disease diagnosis, exposure to environmental chemicals during the etiologically relevant time period could be overestimated as a result of the greater menstrual product use after disease development. In addition, depending on the research question, environmental chemical exposure from menstrual product use could be a source of confounding.

Recommendation #4. Collaboration between academic and non-governmental organizations for the dissemination and publication of scientific research.—Consumer and environmental organizations have commissioned the measurement of environmental chemicals in menstrual products at accredited laboratories or academic institutions with results reported on websites and in the media. To facilitate the identification and evaluation of this research by the scientific community, scientific publication of these studies in academic journals retrievable using established, searchable biomedical databases

(e.g., PubMed, Scopus, Web of Science, etc.) is needed. Similarly, efforts should be made to communicate results from academic-derived studies to the public.

Conclusions

Menstrual bleeding and its importance for environmental health has long been overlooked in environmental epidemiologic research, despite being a common, regular occurrence in the population. In this review, we found that nearly two dozen studies have been conducted measuring environmental contaminants in menstrual products; all detected environmental chemicals but had discrepant conclusions on exposure risks. Only three human studies have investigated menstrual product use and environmental chemical concentrations and all observed associations. Given the detection of environmental chemicals in menstrual products, challenges in exposure assessment due to the lack of data on transmucosal absorption of environmental chemicals, the scarcity of human studies of menstrual product use and environmental chemical exposure, and the exceedingly common event of menstrual bleeding in a substantial portion of the population, further research is warranted. We have provided recommendations to move the field forward.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Papers of particular interest have been highlighted as:

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●● Of major importance

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Table 1.

Measurement of environmental chemical in menstrual products.

Author, year [ref], *Country*	**Menstrual products[a] (portion)**	**Chemical groups investigated (n)[b]**	**Chemicals detected (n)**	**Risk characterization**	**Author's conclusion on risk**
Wiberg 1989 [42] *Sweden*	Tampons (number of products NR)	Dioxin and furan congeners (17)	2 dioxin and furan congeners	No	PCDDs and PCDFs in blood adsorbed by tampon greater than PCDDs and PCDFs in tampon; low exposure as PCDDs and PCDFs unlikely to move in direction against flow
Schecter 1998 [43] *USA*	2 pad and 5 tampon products	Dioxin and furan congeners (NR)	*Pads and tampons:* Concentrations reported for PCDDs and PCDFs, and not for specific congeners	No	NR
DeVito 2002 [44] *USA*	5 tampon products	Dioxin and furan congeners (17)[c]	At least 8 dioxin and furan congeners	Yes	Trace amounts of dioxin in tampons do not significantly contribute to dioxin exposure
Pors 2002 [69] *Denmark*	5 tampon products (cut)	GC/MS screening (6) Acrylates (10) Pesticides (27) Colophony optical brightener	GC/MS screening (6)	No	6 components detected, including glycerol tricaprylate and oleyl alcohol
Pors 2002 [70] *Denmark*	7 pad and 1 liner products	Colophony Organic tin compounds (8) Ethanolamines (3) Optical brightener Bleach (2) Acrylates (10) Phenols (13) GC/MS screening (11)	*Pads:* Colophony Ethanolamines (2) GC/MS screening (11) *Liner:* Colophony GC/MS screening (6)	No	*Pads:* 2 ethanolamines detected; GC/MS screening detected 11 components/groups *Liners:* Colophony and 6 components/ groups detected by GC/MS screening
Archer 2005 [45] *USA*	14 tampon products (cut into strips)	Dioxin and furan congeners (17)[c]	4 dioxin and furan congeners	Yes	Most dioxins and furans <LOD
Shin 2007 [46] *Korea, Japan, USA, Germany, China*	13 pad and 6 tampon products	Dioxin and furan congeners (17)[c]	*Pads:* 8 dioxin and furan congeners *Tampons:* 10 dioxin and furan congeners	No	Concerns about exposure to dioxin in women's sanitary products is warranted
Ishii 2014 [47] *Japan*	7 pad product samples (absorbent core fluff pulp)	Dioxin and furan congener groups (10)[d] Dioxin-like PCB groups (2)[d]	4 dioxin and furan congener groups 2 dioxin-like PCB groups	Yes	Dioxin exposure risk through pads negligible
Women's Voices for the Earth 2014 [55] *USA*	4 pad products	VOCs (19)	VOCs (19)	No	Although low concentrations, presence of chemicals warrants concern for users.

Author, year [ref], *Country*	Menstrual products[a] (portion)	Chemical groups investigated (n)[b]	Chemicals detected (n)		Risk characterization	Author's conclusion on risk
OSAV 2016 [50] *Switzerland*	8 pad and 8 tampon products	Dioxins (17) PAHs (16) Formaldehyde Phthalates (8) Glyphosate (3) GC/MS Pesticide screening LC-MS/MS Pesticide screening	*Pads:* Dioxins (1) PAHs (14) *Tampons:* Dioxins (5) PAHs (5)		Yes	Pads and tampons do not significantly contribute to exposure
Chai 2017 [66] *China*	16 pad brands (cut)	Phthalates (16)	All detected		Yes	Carcinogenic risks from exposure to DEHP in pads exceeded acceptable level
ANSES 2018 [51] *France*	Pad, liner, and 10 tampon products (shredded) (number of pads and liners NR)	Authors refer to Directorate General for Competition Policy, Consumer Affairs and Fraud Control (DGCCRF) commissioned tests by Joint Laboratory Service; chemicals tested NR	*Pads:* PAHs (10) Pesticides (3) Phthalate (1) *Liners:* Fragrance (1) PAHs (5) Pesticides (3)	*Tampons:* PAHs (1) Dioxins and furans (5) Phthalate (1)	Yes	No health risk in tampons, pads, and/or liners; recommends eliminating or reducing substances with carcinogenic, endocrine-disrupting or skin-sensitizing effects in products; lack of information on materials in tampons and menstrual cups
Swedish Chemicals Agency 2018 [17] *Sweden*	7 pad, 10 liner, 10 tampon, and 8 menstrual cup products (ground)	Pads (48) Liners (47) Tampons (52) Cups (8)	Pads (10) Liners (13) Tampons (5) Cups (7)		Yes	Low risk of negative health effects from exposure to chemical substances in menstrual products
Kim 2019 [56] *Korea*	504 pad and 162 liner products (ground)	VOCs (74)	VOCs (50) *Note:* Concentrations not reported separately for pads and liners		Yes	Pads pose no adverse risk to health
Kuki 2019 [72] *EU, Hungary*[e]	2 pad, 1 liner, 2 tampon (EU), and 1 wipe (Hungary) products	Untargeted screening by DART-MS	Pads (18) Liner (13) Tampon (13) Wipe (5)		No	Wide variety of compounds detected
Park 2019 [57] *Korea, Japan, Finland, France, Greece, USA*	11 pad products (cut from 4 locations on pad or sampled air from pack center)	Phthalates (4) VOCs (5)	Phthalates (3) VOCs (5)		Yes	Daily absorption of toluene from pad reached 38.4% of RfD (maximum); finding raises concern for safety
Tang 2019 [65] *Japan, Korea, USA, UK, Australia, Germany*	36 pad products (6 products from each country) (cut)	Phthalates (15)	All detected		Yes	Carcinogenic risks exceeded acceptable levels for DEHP
Desmedt 2020 [18] *Belgium*	3 pad, 3 liner (top layer analyzed separately from absorbent layer for one product), and 4 tampon products	Fragrances (24)	*Liners:* Fragrances (3) *Tampons:* Fragrances (3)		No	Several allergenic fragrances present above 10 μg/g

Author, year [ref], *Country*	Menstrual products[a] (portion)	Chemical groups investigated (n)[b]	Chemicals detected (n)		Risk characterization	Author's conclusion on risk
Gao 2020 [67] *USA*	18 pad, 13 liner (surface layer), 12 tampon, 12 wipe, 4 spray, and 4 powder (entire product) products	Phthalates (9) Parabens (6) Bisphenols (8) triclocarban	*Pads:* Phthalates (5) Parabens (4) Bisphenols (2) triclocarban *Liners:* Phthalates (5) Parabens (5) Bisphenols (3) Triclocarban *Tampons:* Phthalates (5) Parabens (4) Bisphenols (3) triclocarban	*Wipes:* Phthalates (5) Parabens (5) Bisphenols (4) triclocarban *Sprays:* Parabens (5) Bisphenols (2) triclocarban *Powders:* Phthalates (6) Parabens (4) triclocarban	Yes	Presence of phthalates, parabens, bisphenols, and triclocarbans in menstrual products; depending on absorption rate, menstrual products could substantially contribute to exposure
Gao 2020 [68] *China*	64 pad (top layer and whole), 36 vulvar cleaning, and 20 douche products	Phthalates (8)	*Pads:* Phthalates (7) *Vulvar cleaning products:* Phthalates (6) *Douches:* Phthalates (6)		Yes	Phthalates in >98% of top layers of pads in contact with skin; phthalates in 86% of products analyzed; exposure dose for several phthalates with pads higher than ingestion of indoor dust, but lower than dietary intake
Griet 2020 [52] *Belgium*	13 pad (top layer) and 11 tampon (cut) brands	Glyphosate (2) PAH (18) Phthalates, TCPP, isosorbide (24) Phenols (10) Biocides and caprolactam (12) BTEX (6) Dioxins (17)	*Pads:* Glyphosate (2) Phthalates, TCPP, isosorbide (16) Phenols (1) Biocides and caprolactam (4) Dioxins (13) *Tampons:* Glyphosate (2) Phthalates, TCPP, isosorbide (10) Biocides and caprolactam (1) Dioxins (2)		No	Tampons and pads sold in Belgium are free or only contain negligible amounts of chemicals.
Kim 2020 [58] *Korea*	10 pad and 3 tampon products (cut and pulverized)	VOCs (12)	*Pads:* VOCs (8) *Tampons:* VOCs (4)		No	Not provided
Lin 2020 [54] *USA*	22 pad, 22 tampon, 12 wipe, 5 spray, 5 powder, and 13 wash products (purge and trap methods)	VOCs (98) (divided into chemical groups: aldehydes (6), alkanes (12), aromatics (19), halohydrocarbons (40), terpenes (2), ketones (4), esters (7), others(8))	All products had detectable concentrations of chemicals in each group (individual concentrations NR); authors identified 11 to 45 target VOCs in various products; washes, sprays, and powders had highest total target VOC concentrations		Yes	Most products associated with calculated cancer and non-cancer risk below guidelines, although several products had higher VOC concentrations that approach or exceed guidelines.

Abbreviations: ANSES, Agence Nationale de Securite Sanitaire de l'alimentation, de l'environment, et du travail (French Agency for Food, Environmental and Occupational Health & Safety) BTEX, benzene, toluene, ethylbenzene, and xylenes; EU, European Union, DART-MS, direct analysis in real time mass spectrometry; DEHP, di(2-ethylhexyl) phthalate; GC/MS, gas chromatography/mass spectrometry; LC-MS/MS, liquid chromatography tandem mass spectrometry; LOD, limit of detection; NR, not reported; OSAV, Office Fédéral de la Sécurité Alimentaire et des Affaires Vétérinaires; PAHs, polyaromatic hydrocarbons; PCDDs, Polychlorinated dibenzo-p-dioxins, PCDFs, polychlorinated dibenzofurans; PCB, polychlorinated biphenyls; RfD, reference dose; TCPP, trichloropropyl phosphate; USA, United States of America; UK, United Kingdom; VOCs, volatile organic compounds,

[a] Some studies evaluated additional products such as diapers and incontinence pads. Only menstrual products listed in table. Studies varied in terminology for menstrual pads, including sanitary napkins and sanitary towels. Term pad used for consistency.

[b] Number of chemicals by chemical class listed.

[c] 17 compounds with 2,3,7,8-chloro-substituted dibenzo-p-dioxins and dibenzofurans

[d] Concentrations of PCDDs (TeCDDs, PeCDDs, HxCDDs, HpCDDs, OCDD), PCDFs (TCDFs, PeCDFs, HxCDFs, HpCDFs, OCDF) and dioxin-like PCBs (non-ortho, mono-ortho) were measured.

[e] Study included a broader range of products from China, Germany, EU, Turkey, and Philippines.

Table 2.

Epidemiologic investigation of menstrual product use and environmental chemical concentrations measured in women.

Author, year [ref]	Location	Study design	Study population	Inclusion/exclusion criteria	Menstrual product(s)	Chemicals investigated	Results
Phthalates							
Branch 2015 [73]	USA	Cross-sectional	NHANES 2001-2004 n=739 (unweighted)	Women ages 20-49 with self-reported data on menstrual product use and urinary measurements of MEP and MnBP.	Tampons, pads, vaginal douche, vulvar spray, powder, wipes/ towelettes, other products[a]	Urinary MEP, MnBP	Vaginal douche and ↑MEP; suggested association vulvar spray, powder and ↑MEP
Volatile organic compounds (VOCs)							
Ding 2020 [75]	USA	Cross-sectional	NHANES 2001-2004 n=2432[b] (unweighted)	Women ages 20-49 with self-reported data on menstrual product use.	Tampons, pads, vaginal douche, vulvar spray, powder, wipes/ towelettes, other products[b]	Whole blood bromodichloromethane, chloroform, dibromochloromethane, 1,4-DCB, ethylbenzene, toluene, m-/p-xylene	Vulvar powder and ↑ethylbenzene; vaginal douching and ↑1,4-DCB; suggested association between vulvar powder and ↑1,4-DCB
Metals							
Singh 2019 [74]	USA	Cross-sectional	BioCycle Study, n=259	Women ages 18-44 21-35 day cycle length in past 6 months; no hormonal contraceptive use in past 3 months; BMI 18-35 kg/m^2; no history of gynecologic or other chronic diseases; not planning to become pregnant; willing to not take supplements	Tampons	Whole blood Cd, Pb, Hg	Tampons and ↑Hg

Abbreviations: BMI, body mass index; Cd, cadmium; DCB, dichlorobenzene; Hg, mercury; MEP, mono-ethyl phthalate; MnBP, mono-n-butyl phthalate; NHANES, National Health and Nutrition Examination Survey; Pb, lead.

[a]Data collected by self-report on tampon, sanitary napkin, vaginal douche, feminine spray, feminine powder, wipes/towelettes and other products in the past month. In the table, we used term pad instead of sanitary napkin for consistency; we also used terms vulvar spray, powder, wipes/towelettes, and other products to be explicit as to the site of product application.

[b]Unweighted sample size of 2432 for women ages 20-49 with self-reported menstrual product data. In analyses of individual VOCs, reported unweighted sample size ranged from 704 to 827 women.