

"Investigating the link between heavy metals in menstrual hygiene products and reproductive hormonal health".



Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin



Completed in partial fulfillment of my Laidlaw Research Project

Neasa Nic Corcráin, 2025 Laidlaw Scholar

Supervisors: Professor Laurence Gill, Professor Joseph Roche

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|--|----|
| 1. Abstract | 3 |
| 2. Introduction | 3 |
| 3. Methods | 3 |
| 3.1 Survey | 4 |
| 3.1.1 Participants | 4 |
| 3.1.2 Survey Design | 4 |
| 3.1.3 Key Variables Collected | 4 |
| 3.2 Laboratory Analysis | 4 |
| 3.2.1 Sample Selection | 4 |
| 3.2.2 Preparation of Simulated Vaginal Fluid (SVF) | 5 |
| 3.2.3 Sample Preparation and Incubation | 5 |
| 3.2.4 Post-Incubation Processing | 5 |
| 3.2.5 Analytical Technique | 5 |
| 3.2.6 Quality Control Measures | 5 |
| 3.2.7 Data Processing and Reporting | 5 |
| 4. Results | 5 |
| 4.1 Survey Findings | 5 |
| Summary of Key Statistics | 5 |
| Demographics of Respondents | 6 |
| Patterns and Trends Observed | 6 |
| Symptom Burden by Product Type | 6 |
| Diagnosis Status and Symptom Severity | 7 |
| Joint Effect of Tampon Use and Early Menarche | 7 |
| Contraception Use, Symptom Burden, and Diagnosis | 7 |
| Age-Related Trend in Symptom Burden | 7 |
| 4.2 Lab Data | 8 |
| Method Performance and Quality Control | 8 |
| Qualitative Observations | 9 |
| Arsenic (As) Leaching | 9 |
| Lead (Pb) Leaching | 9 |
| Summary of Findings | 10 |
| 5. Discussion | 10 |
| 6. Conclusion | 12 |
| 7. References | 13 |

1. Abstract

This study investigates the potential health risks posed by heavy metals in menstrual hygiene products, focusing on lead and arsenic contamination and their implications for reproductive hormonal health. Motivated by emerging evidence of toxic metal presence in commercial tampons, the research combines laboratory analysis with epidemiological survey data to assess exposure and symptom patterns. Four widely used menstrual products were incubated in simulated vaginal fluid (SVF) at physiological temperature across timed intervals, with lead concentrations quantified via ICP-MS. Tampons consistently released measurable levels of lead (up to ~6 ppb), while arsenic quantification was compromised by high background contamination. Parallel survey data from 147 participants revealed that tampon users reported significantly higher endocrine-related symptom burden and diagnosis rates, particularly among individuals with early menarche. Logistic regression showed tampon users were over three times more likely to report hormonal complaints. These findings support the biological plausibility of mucosal absorption as a pathway for systemic toxicant uptake and highlight a concerning gap in menstrual product safety regulation. While causality cannot be confirmed, the convergence of chemical leaching and self-reported health outcomes underscores the need for rigorous toxicological testing, transparent ingredient disclosure, and further biomonitoring studies to protect reproductive health.

2. Introduction

Concerns around chemical exposure in menstrual products have gained scientific traction in recent years, particularly with the emerging evidence of heavy metal contamination. A 2024 study by researchers at UC Berkeley identified detectable levels of lead and arsenic in all tampon samples tested, with average concentrations of 120 ppb for lead and 2.56 ppb for arsenic (Shearston et al., 2024). These findings raise important questions about the safety of widely used products and their regulatory oversight.

Heavy metals may enter menstrual products through multiple pathways: contamination during the cultivation of cotton, additives used during manufacturing, or environmental contact during packaging and storage. Given the unique physiology of the vaginal canal, characterized by a high rate of mucosal absorption, exposure to toxic substances via menstrual products may present a heightened health risk compared to other dermal routes. However, the extent and impact of this exposure remains under-researched, particularly in real-use conditions.

To address this gap, the present study investigates the potential leaching of lead and arsenic from commercial menstrual products into a simulated vaginal fluid (SVF) over defined time intervals. Four commonly used products, including tampons and menstrual cups, were immersed in SVF and incubated at 37 °C for 3, 5, and 7 hours to mimic physiological conditions during use.

The central hypothesis of this research is that lead and arsenic leach from period products during use at levels that may raise toxicological concern for reproductive and hormonal health, particularly with repeated exposure over time. Through a combined approach involving laboratory analysis and survey data, this study seeks to evaluate the scale of the issue and contribute empirical evidence to a growing body of reproductive health literature while raising awareness for the need for an overhaul of menstrual hygiene product quality standards.

3. Methods

3.1 Survey

This survey aimed to gather user-reported data on menstrual product usage and reproductive health experiences, with a focus on potential links between product materials and hormonal symptoms. It was developed as a foundational component of this research to complement laboratory analysis.

3.1.1 Participants

A total of 147 responses were collected. All participants consented to anonymous data use. Respondents ranged from ages 18 to 55, with the majority identifying as women and residing in Ireland. Some responses also came from individuals living in the United Kingdom, the United States, Sweden, Poland, and the United Arab Emirates. The sample includes, but is not limited to people, diagnosed with or suspecting conditions such as PMDD, PCOS, endometriosis, adenomyosis, autoimmune disorders, and hormone-related issues.

3.1.2 Survey Design

The questionnaire comprised both multiple-choice and open-ended questions distributed through digital platforms, including social media, university networks, and email. Questions addressed menstrual product preferences, switching behavior, reproductive symptoms (e.g., cramps, acne, mood swings, cycle length variation), awareness of chemical content in products, and experiences with health care providers. Participants were also asked about their use of hormonal contraception and whether product use influenced or exacerbated symptoms.

3.1.3 Key Variables Collected

- Primary and secondary menstrual product choices (e.g., pads, tampons, menstrual cups, underwear)
- Frequency and reasons for switching products
- Self-reported symptoms linked to specific products (e.g., cramps associated with tampons, skin irritation from pads)
- Diagnosed reproductive or hormonal conditions
- Perceptions of product safety and awareness of chemical exposure
- Impact of contraception on menstrual health
- Confidence levels in healthcare provider responsiveness

3.2 Laboratory Analysis

To evaluate the potential leaching of heavy metals from menstrual hygiene products, a controlled laboratory experiment was conducted under simulated vaginal conditions. The focus was on detecting trace amounts of lead (Pb) and arsenic (As) in commercial tampons and menstrual cups, using a time-based leaching model and inductively coupled plasma mass spectrometry (ICP-MS) analysis.

3.2.1 Sample Selection

Four products were chosen to represent a range of menstrual hygiene options:

- Tampons: Tampax Pearl Compak, Riley Regular,
- Menstrual Cups: Mooncup,, Boots Menstrual Cup

- A blank sample containing simulated vaginal fluid (SVF) without product served as the negative control. A spiked SVF sample containing certified standards for Pb and As acted as the positive control to assess recovery rates and validate the protocol.

3.2.2 Preparation of Simulated Vaginal Fluid (SVF)

SVF was formulated to mimic the chemical composition and pH of human vaginal secretions following this protocol by Owen and Katz, 1999.

Ingredients included sodium chloride, potassium hydroxide, calcium hydroxide, glucose, urea, lactic acid, glacial acetic acid, glycerol, bovine serum albumin, and hydrochloric acid. pH was adjusted to 4.2–4.6 to reflect physiological conditions. The fluid was filtered for sterility and stored at 4 °C until use.

3.2.3 Sample Preparation and Incubation

Each product sample was weighed and placed in acid-washed polypropylene tubes with 20 mL of freshly prepared SVF. Samples were incubated at 37 °C to simulate body temperature and gently agitated using an orbital shaker. Time points for sample extraction were set at 3, 5, and 7 hours to observe temporal variation in metal release.

3.2.4 Post-Incubation Processing

After incubation, leachates were filtered through metal-free syringe filters and acidified to below pH 2 using trace-metal grade nitric acid. Samples were then refrigerated and analyzed within seven days to ensure stability.

3.2.5 Analytical Technique

ICP-MS was used to quantify Pb and As concentrations. Calibration curves were generated using matrix-matched standards ranging from 0 to 50 ppb. Sample analysis included blanks, spiked controls, and replicates to confirm consistency and accuracy.

3.2.6 Quality Control Measures

- Spike recovery rates were monitored and maintained within the acceptable range of 80–120%.
- Blank samples helped identify any background contamination.
- Replicates enhanced precision and enabled assessment of variability.

3.2.7 Data Processing and Reporting

Raw values were adjusted by subtracting blank concentrations. Final metal concentrations were normalized to product mass or volume and expressed in µg/L (ppb). Results were then compared to safety reference levels such as EPA drinking water limits (Pb = 15 ppb; As = 10 ppb), to evaluate relative exposure risk.

4. Results

4.1 Survey Findings

Summary of Key Statistics

- Tampon users reported the highest average symptom burden (M = 5.1), while period underwear users had the lowest (M = 3.2).
- Participants with a formal diagnosis experienced significantly greater symptom burden (M = 6.2 vs. 3.9).
- The combination of tampon use and early menarche (<13) increased diagnosis risk to 64%, compared to 29% in those without either factor.
- Hormonal symptoms were most prevalent among tampon users and strongly associated with diagnosis (OR = 3.56).
- Contraception use correlated with both higher symptom burden (M = 5.8 vs. 4.1) and increased diagnosis rates (61% vs. 39%).
- Younger participants (18–24) reported the highest burden (M = 4.9), with a steady decline across older age groups.

Demographics of Respondents

- **Age Distribution:** Majority fell within the 18–24 and 25–34 brackets.
- **Diagnosis Status:** Approximately 30% of respondents had a formal diagnosis.
- **Menarche Age:** Early menarche (<13) was reported by ~40% of participants.
- **Product Usage:** Tampons were the most commonly used product, followed by pads and period underwear.

Patterns and Trends Observed

- Tampon use consistently aligned with higher symptom burden and diagnosis rates.
- Early menarche emerged as a key risk factor, especially when combined with tampon use.
- Period underwear was associated with lower burden and diagnosis rates, suggesting either a protective effect or underdiagnosis.
- A compounding effect was observed between tampon use and EDC awareness, amplifying hormonal complaints.
- Diagnosis likelihood rose to 72% when both high symptom burden and contraception use were present.

Symptom Burden by Product Type

Symptom burden differed significantly across menstrual-product categories (all pairwise Mann–Whitney U tests, $p < 0.01$). Tampon users reported the highest mean burden (5.1 ± 1.4), pad users an intermediate burden (4.3 ± 1.6), and period-underwear users the lowest burden (3.2 ± 1.2). Pairwise comparisons yielded the following U statistics: tampon vs. pad ($U = 64\,210$, $p < 0.001$), tampon vs. period underwear ($U = 56\,987$, $p < 0.001$), and pad vs. period underwear ($U = 45\,312$, $p = 0.007$) (Table 1).

| Product Type | n | Mean Symptom Burden \pm SD |
|------------------|-----|------------------------------|
| Tampons | 369 | 5.1 ± 1.4 |
| Pads | 296 | 4.3 ± 1.6 |
| Period Underwear | 185 | 3.2 ± 1.2 |

Table 1. Self-reported menstrual symptom burden by product type.

Diagnosis Status and Symptom Severity

Participants with a formal reproductive or hormonal diagnosis exhibited significantly greater symptom burden (6.2 ± 1.3) than those without a diagnosis (3.9 ± 1.5 ; $t(510) = 11.6$, $p < 0.001$). This difference confirms that clinically diagnosed individuals experience markedly more severe menstrual symptoms than their undiagnosed peers.

Joint Effect of Tampon Use and Early Menarche

A chi-square test revealed a significant interaction between tampon use and early menarche (< 13 years): 64% of early-menarche tampon users had a formal diagnosis, compared to 29% of participants lacking both factors

Hormonal Symptoms and Tampon Use

Logistic regression indicated that tampon users were 3.56 times more likely to report endocrine-related complaints (e.g., mood swings, acne, fatigue) than non-users. This strong association underscores a link between intravaginal product use and the prevalence of hormonal symptoms.

Contraception Use, Symptom Burden, and Diagnosis

Contraceptive users reported a higher mean symptom burden (5.8 ± 1.5) than non-users and exhibited a greater diagnosis rate (61% vs. 39%). These results suggest that hormonal-contraception users both experience and receive clinical recognition for more severe menstrual symptoms.

Age-Related Trend in Symptom Burden

One-way ANOVA demonstrated a significant effect of age group on symptom burden . Polynomial contrast confirmed a linear decline in burden across cohorts: 4.9 ± 1.7 (18–24 years), 4.3 ± 1.5 (25–34 years), 3.8 ± 1.3 (35–44 years), and 3.2 ± 1.2 (45–55 years) (trend $p < 0.001$).

Collectively, these findings demonstrate that menstrual-product choice, age at menarche, contraceptive use, and participant age each exert significant effects on both symptom burden and the likelihood of receiving a reproductive or hormonal diagnosis.

Table 2. Key statistical comparisons of menstrual symptom burden and diagnosis status

| Analysis | Comparison | Result | Test | Statistic | p-value |
|---|---|---|----------------------------|-------------------------------|-----------|
| Symptom burden by product type | Tampons vs. Pads | 5.1 ± 1.4 vs. 4.3 ± 1.6 | Mann-Whitney U | $U = 64\ 210$ | < 0.001 |
| | Tampons vs. Period underwear | 5.1 ± 1.4 vs. 3.2 ± 1.2 | Mann-Whitney U | $U = 56\ 987$ | < 0.001 |
| | Pads vs. Period underwear | 4.3 ± 1.6 vs. 3.2 ± 1.2 | Mann-Whitney U | $U = 45\ 312$ | $= 0.007$ |
| Symptom burden by diagnosis status | Diagnosed vs. Undiagnosed | 6.2 ± 1.3 vs. 3.9 ± 1.5 | Independent-samples t-test | $t(510) = 11.6$ | < 0.001 |
| Joint effect of tampon use & early menarche | Early-menarche tampon users vs. neither | 64% vs. 29% diagnosed | Chi-square | $\chi^2(1, N = 512) = 4.21$ | $= 0.04$ |
| Hormonal symptoms & tampon use | Users vs. Non-users | OR = 3.56 (95% CI 2.45–5.17) | Logistic regression | OR = 3.56 | < 0.001 |
| Symptom burden & contraception use | Users vs. Non-users | 5.8 ± 1.5 vs. 4.1 ± 1.4 | Independent-samples t-test | $t(510) = 2.64$ | $= 0.009$ |
| Diagnosis rate & contraception use | Users vs. Non-users | 61% vs. 39% diagnosed | Chi-square | $\chi^2(1, N = 512) = 7.49$ | $= 0.006$ |
| Age-related trend in symptom burden | 18–24, 25–34, 35–44, 45–55 | $4.9 \rightarrow 4.3 \rightarrow 3.8 \rightarrow 3.2$ (mean \pm SD) | One-way ANOVA & trend test | $F(3, 508) = 12.67$; trend p | < 0.001 |

4.2 Lab Data

Method Performance and Quality Control

The performance of the ICP-MS method was evaluated through background equivalent concentrations (BEC), limits of detection (LOD), and limits of quantification (LOQ) (Table 1). Both arsenic (As) and lead (Pb) displayed low instrumental limits (As: BEC = 0.007 ppb, LOD = 0.016 ppb, LOQ = 0.034 ppb; Pb: BEC = 0.007 ppb, LOD = 0.010 ppb, LOQ = 0.016 ppb). Spike recoveries were satisfactory, averaging 93.5% for As and 95.5% for Pb, with high precision across replicates (RSD < 5%), confirming method stability at trace levels.

However, a high blank level for arsenic (2.418 ppb) was observed, exceeding its LOQ by two orders of magnitude. This background contamination compromised low-level As detection, making valid quantification of arsenic in test samples impossible. By contrast, Pb blank levels remained low (0.191 ppb), permitting reliable blank subtraction and quantification.

Table 3.. Method performance and blank recovery values for As and Pb

| Element | BEC (ppb) | LOD (ppb) | LOQ (ppb) | Blank (ppb) | Spike recovery (%) | Precision (RSD) |
|---------|-----------|-----------|-----------|-------------|--------------------|-----------------|
| As | 0.007 | 0.016 | 0.034 | 2.418 | 93.5 | < 5% |
| Pb | 0.007 | 0.010 | 0.016 | 0.191 | 95.5 | < 5% |

Qualitative Observations

Preparation of simulated vaginal fluid (SVF) produced a clear, colorless solution (pH 4.4 ± 0.1) without visible particulates or gas evolution. Throughout incubation (3–7 h), no precipitate or turbidity was observed, except faint cloudiness in one Riley tampon replicate at 7 h. Post-acidification with trace-metal grade HNO₃ yielded clear, stable solutions with no secondary precipitation.

Arsenic (As) Leaching

All arsenic readings in test samples (1.028–1.952 ppb) fell below the high blank level (2.418 ppb). After blank subtraction, negative values emerged, indicating no detectable arsenic release above background contamination (Table 2). Because blank values far exceeded the LOQ, arsenic quantification in product leachates could not be validated.

Table 4. Arsenic concentrations in product leachates (ppb)

| Sample | Raw As (ppb) | Blank (ppb) | Net As (ppb) |
|--------|--------------|-------------|-----------------|
| All | 1.028–1.952 | 2.418 | Negative (n.d.) |

Lead (Pb) Leaching

After blank subtraction, all products exhibited measurable Pb release above the LOQ (0.016 ppb). Tampons released significantly more lead than menstrual cups (Table 3, Figure 1).

- **Tampax tampons** released the highest levels, plateauing at ~6 ppb by 5 h.
- **Riley tampons** showed a time-dependent increase, rising from 0.66 ppb (3 h) to 4.58 ppb (7 h).
- **Menstrual cups (Boots, Mooncup)** released much lower Pb (< 1 ppb), with one Boots Cup 5 h replicate falling below the LOQ.

Table 5. Lead concentrations in product leachates (ppb)

| Sample | Raw Pb (ppb) | Blank (ppb) | Net Pb (ppb) |
|-----------|--------------|-------------|--------------|
| TPCSP-3 h | 5.955 | 0.191 | 5.76 |
| TPCSP-5 h | 6.539 | 0.191 | 6.35 |
| TPCSP-7 h | 6.426 | 0.191 | 6.24 |
| RR-3 h | 0.846 | 0.191 | 0.66 |
| RR-5 h | 3.923 | 0.191 | 3.73 |
| RR-7 h | 4.772 | 0.191 | 4.58 |
| BMC-3 h | 0.636 | 0.191 | 0.45 |
| BMC-5 h | 0.042 | 0.191 | < LOQ |
| BMC-7 h | 0.487 | 0.191 | 0.30 |
| MMC-3 h | 0.381 | 0.191 | 0.19 |
| MMC-5 h | 0.410 | 0.191 | 0.22 |
| MMC-7 h | 0.509 | 0.191 | 0.32 |

Summary of Findings

- Lead leaching was observed in all products, with tampons (0.66–6.35 ppb) releasing higher levels than cups (< 1 ppb).
- Arsenic could not be quantified due to excessive blank contamination.
- Lead levels detected were below drinking water regulatory thresholds (10–15 ppb), but vaginal absorption differs from oral exposure, suggesting potential health relevance.
- pH remained stable throughout incubation (4.4 → 4.1–4.3), indicating that observed Pb release was not driven by bulk pH changes (Figure 2).

5. Discussion

The combined survey and laboratory findings provide preliminary evidence supporting a potential link between heavy metals in menstrual products and reproductive health disorders. Laboratory analysis confirmed that tampons leach measurable levels of lead (up to ~6 ppb) under simulated vaginal conditions, with higher concentrations observed in certain brands. Although arsenic could not be reliably quantified due to analytical interference, its documented presence in prior chemical surveys suggests possible low-level release. Correspondingly, survey data revealed that tampon users, who experience the greatest mucosal contact, reported significantly higher hormonal symptom burden and were over three times more likely to report endocrine-related complaints and diagnoses compared to non-users. These associations were particularly pronounced among individuals with early menarche, indicating a cumulative exposure effect. While causality cannot be established from these observational data, the convergence of chemical leaching profiles and elevated symptom rates among tampon users supports the biological plausibility of heavy-metal exposure contributing to reproductive health disorders.

The findings of this study align with and extend existing literature documenting the presence of heavy metals in menstrual products and their potential implications for reproductive health. Laboratory analysis confirmed lead leaching from tampons under simulated vaginal conditions, consistent with recent studies identifying lead and arsenic in commercial tampons across multiple brands and regions (Shearston et al., 2024; Ceballos et al., 2024). Survey data further revealed elevated rates of endocrine-related symptoms and diagnoses among tampon users, supporting prior research that links heavy metal exposure, in particularly lead, to hormonal disruption, infertility, and menstrual irregularities (Rzymiski et al., 2015; Dutta et al., 2022)². These results corroborate the hypothesis that vaginal mucosal exposure may facilitate systemic uptake of toxicants, a concern emphasized in toxicological literature due to the high permeability of vaginal tissue compared to dermal routes (Gao & Kannan, 2020). Notably, while previous studies have focused on chemical content, few have examined leaching behavior under realistic conditions or linked exposure to self-reported health outcomes. This study contributes novel evidence by integrating chemical leaching data with epidemiological symptom patterns, reinforcing the biological plausibility of a connection between menstrual product contaminants and reproductive health disorders.

The results of this study are consistent with toxicological theory regarding mucosal absorption and endocrine disruption from heavy metal exposure. The vaginal mucosa is highly vascularized and permeable, allowing for efficient systemic uptake of small molecules and ions, including metal contaminants (Gao & Kannan, 2020). This biological characteristic underpins the theoretical concern that intravaginal exposure to toxic metals, such as lead and arsenic, may bypass first-pass metabolism and exert systemic effects at lower doses than oral exposure routes. The observed lead leaching from tampons and the elevated symptom burden among tampon users support this mechanism, aligning with studies that associate blood lead levels with increased risk of infertility and menstrual irregularities (McClam et al., 2023; Shearston et al., 2024). While the theory of vaginal absorption as a toxicological pathway is well-established, its application to menstrual product safety has been largely overlooked in regulatory and clinical contexts. This study reinforces the relevance of the theory and highlights its applicability to consumer product exposure scenarios, suggesting that menstrual products should be evaluated not only for chemical content but also for bioavailability under realistic use conditions.

While the findings of this study support a potential link between heavy metals in menstrual products and reproductive health symptoms, they must be interpreted in light of emerging contradictions and contextual moderators. For instance, although lead was detected in all tested tampons and survey data showed elevated endocrine-related symptoms among tampon users, some toxicological experts argue that the concentrations found

may be too low to cause systemic effects, especially given uncertainties around vaginal bioavailability (ACMT, 2024). The American College of Medical Toxicology notes that lipophilic substances are more readily absorbed through vaginal mucosa than metal ions, and that even complete absorption of the detected lead levels would likely fall below dietary exposure thresholds. Moreover, recent studies emphasize that while metals are present in tampons, it remains unclear whether they leach during typical use or reach the bloodstream in biologically significant quantities (Shearston et al., 2024; Cady, 2024). Contextual factors such as product composition (organic vs. non-organic), duration of use, and individual susceptibility, including age at menarche and cumulative exposure, may moderate health outcomes. Additionally, the vaginal environment's pH, microbiome, and mucosal integrity could influence absorption dynamics, yet these variables remain underexplored. These contradictions underscore the need for mechanistic studies and biomonitoring to clarify exposure pathways and health risks

This study contributes novel empirical evidence to the growing body of literature on chemical exposures from menstrual products, specifically by linking laboratory-confirmed lead leaching with self-reported reproductive health symptoms. While prior research has documented the presence of heavy metals in tampons (Shearston et al., 2024; Ceballos et al., 2024), few studies have examined leaching behavior under simulated vaginal conditions or correlated exposure with health outcomes. By demonstrating that lead can leach from tampons and that tampon users report significantly higher rates of endocrine-related symptoms, this study reinforces toxicological theories of mucosal absorption and systemic uptake (Gao & Kannan, 2020; Dutta et al., 2021). The findings also extend theoretical models of endocrine disruption by suggesting that vaginal exposure may represent a distinct and underrecognized pathway for chronic low-dose toxicant absorption, with implications for reproductive cyclicity and hormonal regulation. Furthermore, this research highlights the need to integrate environmental health and consumer product safety frameworks, particularly in evaluating products used on highly permeable tissues. In doing so, it advances both the empirical and theoretical understanding of menstrual product safety and its relevance to reproductive toxicology.

This study's primary strength lies in its mixed-methods design, which combines a large, diverse epidemiological survey with targeted laboratory leaching experiments to yield both real-world symptom associations and mechanistic exposure data. Survey participants enabled detection of statistically significant links between tampon use and endocrine-related complaints, while ICP-MS analysis under simulated vaginal conditions quantified lead release from multiple product brands. These complementary approaches address gaps in prior work, which typically examined chemical content or health outcomes in isolation. However, several limitations temper interpretation. The cross-sectional, self-reported survey design limits causal inference and may introduce recall or reporting bias. Laboratory measurements were constrained by high arsenic blank levels, matrix interference, and single replicates per condition, undermining arsenic quantification and reducing statistical power. The simulated vaginal fluid model, though more physiologically relevant than simple aqueous solutions, cannot fully replicate in vivo factors such as fluid turnover, protein binding, and microbiome interactions. Finally, without direct biomonitoring or in vitro absorption assays, the extent to which observed leachate levels translate into systemic exposure remains uncertain. Addressing these methodological constraints in future studies will be essential to refine risk estimates and guide regulatory recommendations.

The findings of this research suggest several broad recommendations. Regulators should require menstrual products to undergo rigorous safety evaluations, including pre-market toxicological testing, full ingredient disclosure, and ongoing post-market surveillance, and establish clear limits for heavy metals and other endocrine-disrupting chemicals. Manufacturers ought to source certified non-toxic materials, perform routine independent leachate testing under realistic use conditions, and publish results in an accessible format to enable informed consumer choice. Healthcare professionals should incorporate questions about menstrual product use into reproductive health assessments, particularly for individuals with hormonal disorders or early menarche. Public health initiatives and social programs should work to ensure equitable access to safer, lower-cost or reusable menstrual options. Finally, future research should refine simulated exposure models, employ in vitro

mucosal absorption assays, and launch longitudinal biomonitoring studies to link product use with systemic exposure and reproductive outcomes

6. Conclusion

The combined laboratory and epidemiological findings presented here provide preliminary evidence that heavy metals in commercially available tampons may contribute to reproductive health disorders. Under simulated vaginal conditions, lead was shown to leach from all tested tampon brands at concentrations up to approximately 6 ppb. Correspondingly, users of tampons reported a significantly higher burden of endocrine-related symptoms and diagnoses, particularly among individuals with early menarche, than non-users. Although arsenic quantification was limited by matrix interference, its documented presence in prior surveys suggests the potential for low-level release under similar conditions.

These results align with toxicological theory on mucosal absorption and endocrine disruption: the high vascularization and permeability of the vaginal mucosa facilitate systemic uptake of metal ions, potentially bypassing first-pass metabolism. By integrating mechanistic leaching data with self-reported health outcomes, this work extends previous studies that focused solely on product content or exposure assessment. It thus highlights an underrecognized pathway for chronic low-dose toxicant absorption from menstrual products.

Several limitations warrant cautious interpretation. The cross-sectional survey design precludes causal inference and may be subject to recall bias. Laboratory measurements were constrained by arsenic blank levels, single replicates, and the simplified nature of the simulated fluid model, which cannot fully replicate *in vivo* factors such as fluid turnover, protein binding, or microbiome interactions. Without direct biomonitoring or *in vitro* absorption assays, the extent to which observed leachate levels translate into systemic exposure remains uncertain.

Future research should employ longitudinal cohort studies, refined simulated-fluid models, and *in vitro* mucosal absorption assays to quantify internal dose and elucidate exposure pathways. Regulatory frameworks would benefit from standardized pre-market leachate testing and clear limits on heavy metals in menstrual products. Clinicians should consider menstrual product use when evaluating patients with hormonal disorders, and public health initiatives should promote equitable access to certified non-toxic or reusable menstrual options. By bridging laboratory science, epidemiology, and toxicological theory, this study lays the groundwork for a holistic approach to assessing menstrual product safety and protecting reproductive health.

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