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Analysis of Urinary Arsenic Concentrations and Associations with Children's Anthropometric Measurements in a Select U.S. Population

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Abstract

Arsenic exposure remains a significant environmental health concern, particularly for children, due to its presence in groundwater and dietary sources. In early childhood, exposure to inorganic arsenic and its metabolites may interfere with growth and development. This study evaluates the relationship between urinary arsenic biomarkers and anthropometric measurements in young children using data from the 2017-2018 National Health and Nutrition Examination Survey (NHANES). Speciated urinary arsenic concentrations, including inorganic arsenic, monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA) were assessed in children aged 3 to 5 years and matched with body measurement data. Detection frequencies of arsenic species were examined, and associations with height, weight, Body Mass Index (BMI) and waist circumference were evaluated. Results demonstrated no clinically meaningful associations between detectable urinary DMA and anthropometric measurements across the studied age groups, apart from a small but statistically significant height difference observed among 4-year-old children. Overall, these findings suggest that low-level arsenic exposure, as indicated by urinary DMA detection, did not adversely affect physical development in early childhood, supporting the need for longitudinal studies to further evaluate potential long-term developmental effects.

Keywords

Arsenic, Inorganic Metabolites, Dimethylarsinic Acid, Anthropometric Measurements, Groundwater

1. Introduction

Arsenic is a naturally occurring element found in both organic and inorganic forms and remains a significant environmental and public health concern worldwide. Human exposure to arsenic occurs through a variety of environmental and occupational pathways, including contaminated drinking water, dietary intake, and industrial activities. Inorganic arsenic is recognized for its toxicity and has been associated with a wide range of adverse health outcomes when exposure exceeds established safety thresholds [1] [2].

In the United States (U.S.), regulatory actions have substantially reduced arsenic exposure from public drinking water sources. In 2001, the U.S. Environmental Protection Agency (EPA) lowered the maximum contaminant level for arsenic in public water systems from 50 μg/L to 10 μg/L, resulting in a measurable decline in urinary arsenic concentrations among users of regulated water supplies [3]. However, exposure risks persist due to unregulated private water sources and dietary contributors, particularly rice, seafood, and rice-based products that can accumulate arsenic from soil and water [4]-[6].

Children may be particularly vulnerable to arsenic exposure because of higher intake relative to body weight, unique dietary patterns, and critical periods of growth and development. Previous studies have linked excessive arsenic exposure during prenatal and early life stages to adverse outcomes including impaired neurodevelopment, altered growth patterns, and increased susceptibility to disease [7]-[9]. However, evidence regarding the relationship between low-level arsenic exposure and early childhood growth indicators in U.S. populations remains limited.

The present study uses data from the 2017-2018 National Health and Nutrition Examination Survey (NHANES) to evaluate associations between urinary arsenic biomarkers and anthropometric measures of growth in children aged 3 - 5 years. By focusing on speciated urinary arsenic metabolites, particularly dimethylarsinic acid (DMA), this analysis aims to contribute to the understanding of arsenic exposure patterns and their potential implications for early childhood growth using nationally sampled data.

Arsenic oral exposure thresholds have been established based on identified health outcomes referenced in literature. For example, the Food and Drug Administration (FDA) has set the allowable limit of arsenic in bottled water and single-strength apple juices at 10 parts per billion (ppb) while the permissible arsenic limit in infant rice cereal has been set at 100 ppb [10]. Other relevant thresholds also incorporate data supporting excessive arsenic exposure with a range of adverse health outcomes in adults, including skin lesions, respiratory disease, cardiovascular effects, and increased cancer risk [11]-[13]. Inorganic arsenic and its metabolites, including monomethylarsonic acid (MMA) and DMA, can cross the placenta, raising concerns regarding early-life exposure in children [7]. Elevated arsenic exposure during childhood has been linked to neurocognitive deficits, including impairments in attention, memory, and cognition [14] [15]. Prenatal and early childhood exposures have also been associated with adverse growth-related outcomes, such as reduced birth weight, shorter birth length, smaller head circumference, and altered growth trajectories, as well as disruptions in insulin-like growth factor 1 (IGF-1), an important marker of fetal and childhood growth [8] [9]. The current analysis employs a cross-sectional research design to investigate the interplay between the identification of urine arsenic biomarkers and concurrent anthropometric measurements within a pediatric population. Through this design, we aim to discern the potential associations and relationships that exist between the presence of arsenic biomarkers in urinary samples and adverse effects, if any, that would be reflected in the physical measurements and characteristics observed in children.

2. Methods

Data for this cross-sectional analysis were obtained from the 2017-2018 National Health and Nutrition Examination Survey (NHANES), a nationally representative program conducted by the Centers for Disease Control and Prevention (CDC) that combines interviews, physical examinations, and laboratory assessments to evaluate the health and nutritional status of the U.S. population [16]. The 2017-2018 NHANES cycle included 16,211 participants recruited from 30 survey locations across the United States, of whom 9254 completed interviews and 8704 underwent physical examinations.

Among NHANES participants, a subset with available speciated urinary arsenic measurements was identified (n = 2979). This subset was further restricted to children aged 3 - 17 years, as age 3 represents the youngest group with available urinary arsenic data. To ensure sufficient sample size for age-stratified analyses, the analytic sample was limited to children aged 3, 4, and 5 years who had complete urinary arsenic biomarker data and corresponding anthropometric measurements. The final analytic sample included 416 children, consisting of 116 three-year-olds, 147 four-year-olds, and 153 five-year-olds.

Urinary arsenic biomarkers evaluated in this study included inorganic arsenic species (arsenous acid and arsenic acid) and methylated metabolites MMA and DMA, which serve as indicators of arsenic exposure [17]. Laboratory analyses were conducted by the CDC using high-performance liquid chromatography (HPLC) coupled with inductively coupled plasma mass spectrometry with dynamic reaction cell technology (ICP-DRC-MS) to quantify speciated arsenic concentrations [18]. The lower limits of detection (LLOD) were 0.12 μg/L for arsenous acid, 0.79 μg/L for arsenic acid, 1.16 μg/L for arsenobetaine, 0.11 μg/L for arsenocholine, 0.20 μg/L for MMA, and 1.91 μg/L for DMA. For concentrations below the LLOD, imputed values were calculated as LLOD/√2 using CDC-recommended procedure [19]. Dimethylarsinic acid was selected as the primary exposure variable for inferential analyses because it was detected in more than 50% of samples across all evaluated age groups.

Anthropometric measurements included standing height (cm), weight (kg), waist circumference (cm), and body mass index (BMI; kg/m^2). These measurements were collected by trained NHANES personnel using standardized protocols and calibrated equipment during the physical examination component of the survey [20]. Body measurement data were not consistently available across the age groups. The included sample participants had a lower number of NHANES provided waist circumference measurements as compared with the remaining growth parameters (*i.e.*, height, weight, and BMI) when matched to arsenic biomarkers. See individual *n* values in **Table 1**.

Table 1. Geometric means (95% CI) of anthropometric measurements by urinary dimethylarsinic acid detection status and age group.

	Detect		Non-Detect		p
	n	GM (95% CI)	*n*	GM (95% CI)	
Standing Height (cm)	**279**	**106.7 (105.6, 107.7)**	**137**	**105.9 (104.8, 106.9)**	**0.33**
3-year-old	74	98.62 (97.61, 99.64)	42	98.70 (97.68, 99.71)	0.93
4-year-old	99	106.5 (105.5, 107.5)	48	104.6 (103.6, 105.7)	0.047
5-year-old	106	112.8 (111.7, 113.8)	47	114.0 (113.0, 115.0)	0.20
Weight (kg)	**279**	**18.56 (17.54, 19.59)**	**137**	**18.23 (17.19, 19.26)**	**0.40**
3-year-old	74	15.87 (14.83, 16.91)	42	15.91 (14.86, 16.96)	0.93
4-year-old	99	18.29 (17.26, 19.33)	48	17.88 (16.84, 18.93)	0.43
5-year-old	106	20.99 (19.95, 22.03)	47	20.99 (19.93, 22.04)	0.99
BMI (kg/m^2)	**279**	**16.33 (15.31, 17.34)**	**137**	**16.27 (15.25, 17.29)**	**0.79**
3-year-old	74	16.32 (15.29, 17.34)	42	16.34 (15.31, 17.37)	0.95
4-year-old	99	16.14 (15.11, 17.16)	48	16.34 (15.30, 17.37)	0.52
5-year-old	106	16.51 (15.49, 17.54)	47	16.14 (15.10, 17.19)	0.35
Waist Circumference (cm)	**251**	**52.98 (51.96, 53.99)**	**130**	**52.94 (51.92, 53.96)**	**0.95**
3-year-old	63	50.35 (49.33, 51.38)	37	51.39 (50.37, 52.42)	0.28
4-year-old	88	52.42 (51.40, 53.44)	46	52.94 (51.91, 53.96)	0.57
5-year-old	100	55.21 (54.18, 56.23)	47	54.20 (53.17, 55.23)	0.33

Note. n = sample size; GM = geometric mean; CI = confidence interval; BMI = body mass index. Statistical significance assessed at $p < 0.05$.

Descriptive statistics were calculated for demographic characteristics, urinary arsenic biomarkers, and anthropometric measurements. Geometric means (GM) and corresponding measures of variability were used to summarize arsenic biomarker concentrations and anthropometric measurements. For inferential analyses, children were classified based on detectable versus non-detectable urinary DMA concentrations, and independent-sample t-tests were used to compare anthropometric measures between detection groups within each age category (3, 4, and 5 years). Data stratification and associated statistical analyses were performed using Microsoft products (Access version 2510 and Excel version 16.104), SAS version 9.4 (2019), and XLSTAT version 2022.4.1, with statistical significance defined as $p < 0.05$. NHANES sampling weights were not applied in this analysis; therefore, results should be interpreted as internally valid but may not be fully generalizable to the U.S. pediatric population.

3. Results

The geometric mean (GM) height, weight, body mass index (BMI), and waist circumference were determined for each included age group per dichotomous DMA data category (*i.e.*, DMA detect versus DMA non-detect). The following data represent the GM for the DMA detected per age group. For 3-year-olds, the GM height, weight, and BMI (n = 74) were 98.62 cm (SD ± 1.05), 15.87 kg (SD ± 1.19), and 16.32 (SD ± 1.13), and the waist circumference (n = 63) was 50.35 cm (SD ± 1.11), respectively. For 4-year-olds, the GM height, weight, and BMI (n = 99) were 106.49 cm (SD ± 1.05), 18.29 kg (SD ± 1.18), 16.14 (SD ± 1.11), and waist circumference (n = 88) was 52.42 cm (SD ± 1.10), respectively. For 5-year-olds, the GM height, weight, and BMI (n = 74) were 112.75 cm (SD ± 1.06), 20.99 kg (SD ± 1.23), and 16.51 (SD ± 1.15), and waist circumference (n = 100) was 55.21 cm (SD ± 1.12), respectively

Of the total analytic sample (n = 416 children aged 3 - 5 years), 52.5% were female and 47.5% were male. The proportion of females within the 3-, 4-, and 5-year age groups was 47.1%, 56.5%, and 52.9%, respectively. Racial and ethnic composition of the sample was 21.5% non-Hispanic Black, 12.9% Mexican American, 35.1% non-Hispanic White, 7.6% other Hispanic, and 22.9% other or multiracial. These demographic characteristics are presented descriptively to characterize the study population and were not included in inferential analyses, consistent with prior NHANES-based analyses.

Urinary DMA concentrations in children aged 3 - 5 years (n = 416) ranged from the imputed non-detectable value of 1.35 μg/L to a maximum detected concentration of 50.71 μg/L. When both detected and imputed non-detectable values were included, the overall GM urinary DMA concentration was 3.07 μg/L (SD ± 2.12). Among children with detectable urinary DMA only (n = 279), the GM concentration was 4.59 μg/L (SD ± 1.80). Thus, the lower overall mean reflects the inclusion of imputed non-detectable values. Overall, 279 children (67%) had detectable urinary DMA, while 137 children (33%) were below the limit of detection.

As shown in **Table 1**, the subsample with detectable urinary DMA concentrations included 116 three-year-olds, 147 four-year-olds, and 153 five-year-olds, for a total of 416 participants. The GM DMA concentrations for 3-, 4-, and 5-year-old children were 4.6 μg/L (SD ± 1.8), 5.0 μg/L (SD ± 1.8), and 4.3 μg/L (SD ± 1.8), respectively, based on DMA detection status (**Figure 1**).

A statistically significant association between urinary DMA detection and anthropometric measurements was observed only for height among 4-year-old children. Specifically, 4-year-olds with detectable urinary DMA (n = 99) had a higher

GM height (106.5 cm) compared with those without detectable DMA (n = 48; GM = 104.6 cm; p = 0.047) (**Figure 2**). No statistically significant differences in height were observed among 3-year-olds (n = 116) or 5-year-olds (n = 153). Additionally, no significant associations were identified between urinary DMA detection status and weight, waist circumference, or BMI in any age group (all p > 0.05). Corresponding graphical summaries are presented for each anthropometric measurement. Standing height comparisons are shown in **Figure 2**, body weight comparisons in **Figure 3**, BMI comparisons in **Figure 4**, and waist circumference comparisons in **Figure 5**.

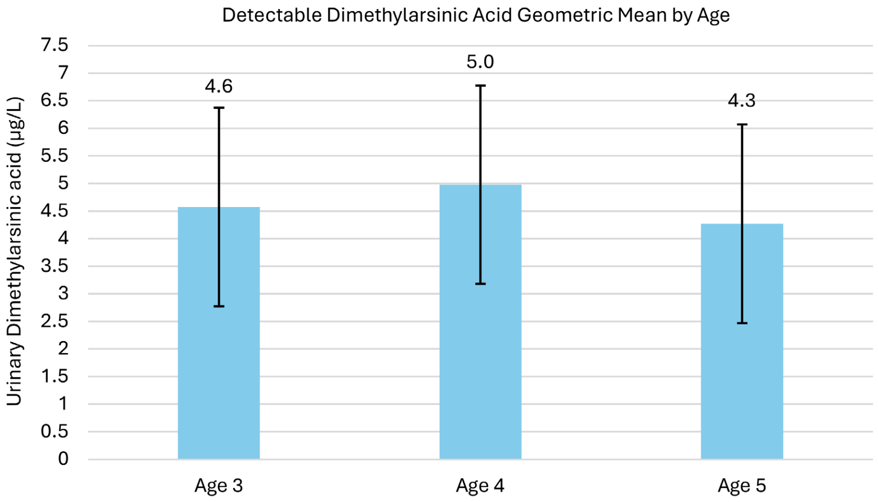

Figure 1. Detectable geometric mean urinary dimethylarsinic acid (DMA) concentrations by age group (3, 4, and 5 years) among children with available urinary arsenic measurements from NHANES 2017-2018. Error bars represent standard deviation.

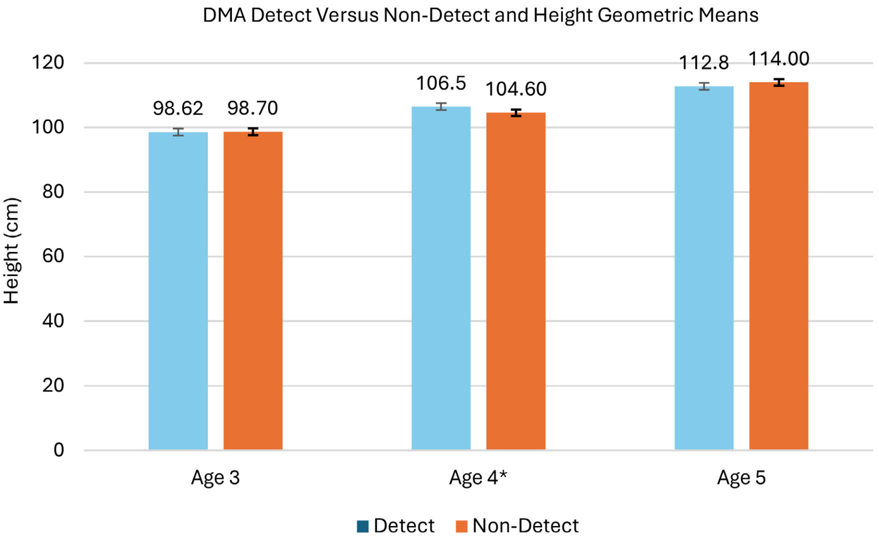

Figure 2. Comparison of geometric mean standing height (cm) between children with detectable and non-detectable urinary dimethylarsinic acid (DMA), stratified by age (3, 4, and 5 years). * = A statistically significant difference was observed only among 4-year-old children (p = 0.047). Error bars represent standard deviation.

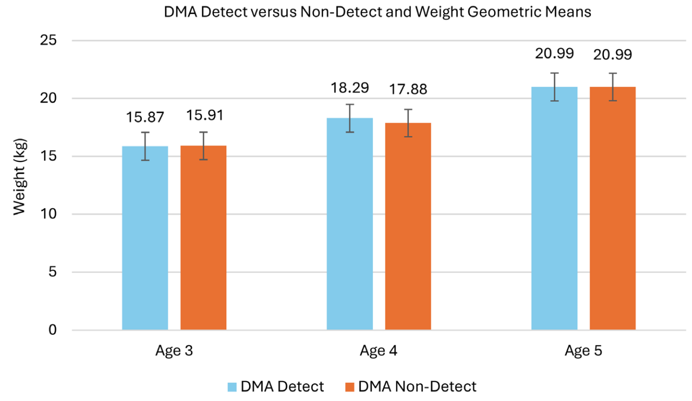

Figure 3. Comparison of geometric mean body weight (kg) between children with detectable and non-detectable urinary dimethylarsinic acid (DMA), stratified by age (3, 4, and 5 years). No statistically significant differences were observed. Error bars represent standard deviation.

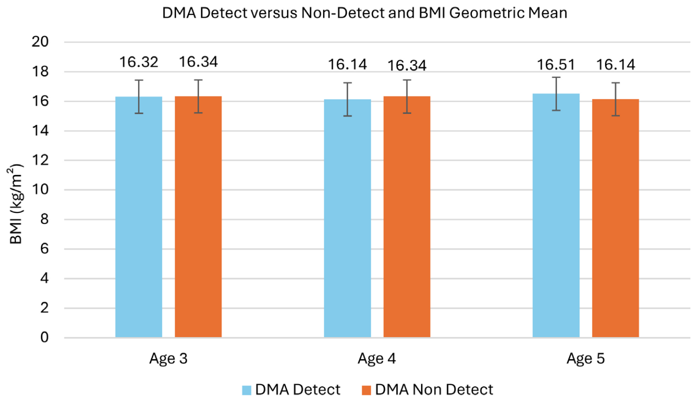

Figure 4. Comparison of geometric mean body mass index (BMI; kg/m^2) between children with detectable and non-detectable urinary dimethylarsinic acid (DMA), stratified by age (3, 4, and 5 years). No statistically significant differences were observed. Error bars represent standard deviation.

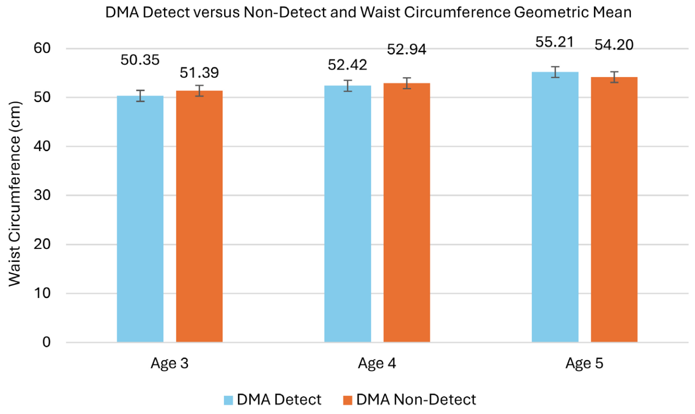

Figure 5. Comparison of geometric mean waist circumference (cm) between children with detectable and non-detectable urinary dimethylarsinic acid (DMA), stratified by age (3, 4, and 5 years). Analyses were limited to participants with complete waist circumference data. No statistically significant differences were observed. Error bars represent standard deviation.

4. Discussion

Among the inorganic and organic urinary arsenic metabolites evaluated in children aged 3 - 5 years, inorganic arsenic species (arsenic acid and arsenous acid) were detected less frequently than the organic metabolite DMA, a pattern consistent with the distribution observed in the analytic sample. This finding aligns with established toxicokinetic evidence indicating that, following exposure, inorganic arsenic undergoes hepatic reduction and oxidative methylation, resulting in the formation of MMA and DMA. These methylated arsenic species are more water-soluble and are more readily eliminated in urine than their inorganic counterparts, although substantial interindividual variability in arsenic metabolism has been documented [17]. While certain intermediate metabolites, such as trivalent MMA, may exhibit transient toxicity, methylation is generally considered a detoxification pathway that facilitates arsenic excretion. The predominance of DMA observed in the present study is therefore consistent with both known biotransformation mechanisms and national biomonitoring data summarized by the Agency for Toxic Substances and Disease Registry (ATSDR) [17].

Dietary intake is considered the primary route of arsenic exposure in children, particularly during early childhood [21] [22]. Rice and rice-based products tend to contain higher concentrations of inorganic arsenic than other cereal grains because rice is commonly cultivated under flooded conditions, which enhances arsenic mobilization and uptake from soil and irrigation water [23]. As rice-based foods are frequently introduced early in life and are commonly used to thicken infant formula, this exposure pathway may contribute substantially to overall arsenic intake in infants and young children [24].

Previous studies evaluating early-life arsenic exposure and developmental outcomes have reported mixed findings. Prenatal arsenic exposure has been associated with an increased risk of infections during infancy, particularly respiratory and gastrointestinal illnesses requiring medical attention [25]. Other studies have linked higher prenatal arsenic exposure to neurodevelopmental outcomes, including reduced motor development in early childhood [26]. In contrast, some longitudinal analyses have reported transient alterations in growth trajectories, with slower early linear growth followed by catch-up growth during infancy, suggesting that arsenic-related effects on physical development may vary by exposure timing, dose, and developmental window [27] [28].

Recent public health monitoring efforts have highlighted the ongoing issue of arsenic presence in the food supply, including products commonly consumed by children. In January 2026, the Florida Department of Health (FDOH) published results from its Healthy Florida First initiative, reporting that arsenic was detected in 28 out of 46 commercially available candy products tested from 10 different manufacturers. The detected levels varied across product types, and, per FDOH, some samples exceeded health-based screening levels established for children's dietary exposure. Although the Florida testing did not distinguish between inorganic and organic arsenic species, the findings raise important considerations for childhood arsenic intake beyond traditional exposure sources such as rice and drinking water. These results underscore the potential for non-traditional dietary contributors to arsenic exposure in pediatric populations and support the need for comprehensive exposure assessment in both ongoing evaluation (e.g., FDOH) and future research, particularly given children's unique dietary patterns and increased vulnerability during early development [29]. Such surveillance complements biomonitoring efforts like NHANES and reinforces the importance of evaluating multiple exposure pathways when interpreting arsenic exposure and its potential health effects.

5. Conclusions

This study examined the association between urinary arsenic biomarkers and anthropometric growth measurement among U.S. children aged 3, 4, and 5 years using data from the 2017-2018 National Health and Nutrition Examination Survey. Although a statistically significant difference in height was observed among four-year-old children with detectable urinary DMA compared with those without detectable DMA, the magnitude of this difference was small and unlikely to be clinically meaningful. No other consistent associations were identified between urinary arsenic biomarker detection and height, weight, body mass index, or waist circumference across the evaluated age groups.

The predominance of DMA observed in this study is consistent with established arsenic biotransformation pathways, in which inorganic arsenic undergoes hepatic reduction and oxidative methylation to form more water-soluble metabolites that are readily eliminated in urine. The urinary biomarker profile identified in this sample aligns with toxicokinetic evidence and previously reported population-level biomonitoring data, suggesting that the exposure levels captured in NHANES reflect low-level, background arsenic exposure typical of the U.S. population.

Some limitations should be considered when interpreting the current study findings. The cross-sectional design precludes assessment of temporal or causal relationships, and urinary arsenic concentrations reflect recent exposure rather than long-term body burden. Additionally, blood arsenic was not used as a biomarker in this analysis, as blood arsenic levels were not available in NHANES data. Importantly, urinary arsenic is widely recognized as the preferred matrix for assessing recent inorganic arsenic exposure in population-based studies. Blood arsenic is less sensitive than urinary arsenic as a biomarker of exposure; its half-life in blood is on the order of a few hours compared to several days in urine, and the invasive nature of blood collection further limits its utility in large epidemiological studies [30]. Furthermore, because intake of foods containing organic arsenic compounds of marine origin may substantially increase blood arsenic concentrations and arsenic speciation in blood is difficult, blood is not a reliable biomarker for distinguishing inorganic arsenic exposure specifically [30] [31]. For these reasons, speciated urinary arsenic - particularly DMA - remains the most practical and informative biomarker for characterizing inorganic arsenic exposure in studies such as NHANES. In addition, the sample size within individual age strata limited statistical power, and potential confounding factors such as dietary intake, socioeconomic status, and environmental exposure sources were not evaluated in the present analysis. These factors may influence both arsenic exposure and growth outcomes and warrant consideration in future research. Lastly, the current study did not adjust the statistical evaluation to account for multiple t-tests.

Overall, the findings suggest that, at the exposure levels observed in this sample population, urinary arsenic biomarkers were not strongly associated with adverse anthropometric growth measurements in early childhood. Future studies employing longitudinal designs, larger pediatric samples, and more detailed exposure characterization are needed to clarify whether chronic, low-level arsenic exposure during early life may influence growth trajectories or developmental outcomes over time.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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