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Temporal Trends of Exposure to the Herbicide Glyphosate in the United States (2013–2018): Data from the National Health and Nutrition Examination Survey

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Abstract

Glyphosate, the most widely used herbicide in the United States, is applied to control broadleaf weeds and grasses. Public concern is mounting over how pesticides affect human and environmental health. Glyphosate toxicity in animals is known, but human carcinogenicity is controversial, and limited epidemiologic evidence suggests associations between exposure and respiratory diseases (e.g., asthma) and adverse child neurodevelopment. Understanding the extent of the general U.S. population exposure to glyphosate is important. To examine temporal trends in exposure to glyphosate, we determined urinary concentrations of glyphosate among U.S. children and adults from three cycles of the National Health and Nutrition Examination Survey (NHANES) conducted 2013–2018. Most of the population (70.0%–81.7%, depending on cycle) was exposed, including children as young as 3 years of age. Concentrations decreased from 2013 to 2018 by 38%; the decline was smaller in younger age groups. The downward trend likely reflects changes in glyphosate use resulting, at least in part, from changes in agricultural practices, regulatory actions, and shifts in public awareness regarding glyphosate toxicity. Continuing glyphosate biomonitoring will help understand how changes in use and actions to restrict applications of this common pesticide affect human exposures.

Keywords

Glyphosate; NHANES; Exposure; Temporal Trends

1. Introduction

Glyphosate (N-(phosphonomethyl)glycine) is the most widely used herbicide in the United States and worldwide. Glyphosate is applied in agriculture and forestry, and in lawns and gardens as a non-selective, broad-spectrum weedkiller and as a pre-harvest crop desiccant to regulate plant growth and ripening, and facilitate harvesting (Van Bruggen et al., 2018). As the applied volume of glyphosate formulations in the United States grew about 100-fold during the first three decades after its introduction in the 1970s (Benbrook, 2016),

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glyphosate is frequently detected in the environment (e.g., air, water, soil, dust) and foods (e.g., fruits, cereals) (ATSDR, 2020).

Animal models suggest harmful effects of glyphosate and glyphosate formulations on the brain, lungs, liver, intestines, and endocrine and reproductive systems (ATSDR, 2020; Van Bruggen et al., 2018). In humans, no agreement has been reached regarding the carcinogenicity of glyphosate. The International Agency for Research on Cancer classified glyphosate as “probably carcinogenic in humans” in 2015, but other organizations, including the U.S. Environmental Protection Agency and the European Chemicals Agency concluded that glyphosate was unlikely to be a human carcinogen (ATSDR, 2020). On the other hand, limited human data suggest associations between glyphosate exposure and other health outcomes such as respiratory diseases including asthma (ATSDR, 2020) and neurological disorders (Agostini et al., 2020).

Exposure to glyphosate can occur through ingestion, dermal contact, and inhalation; diet is believed to be the main exposure pathway (Ospina et al., 2022). After exposure, humans quickly eliminate glyphosate in urine. Thus, glyphosate concentrations in urine serve as useful biomarkers for recent exposures. The U.S. Centers for Disease Control and Prevention (CDC) has evaluated exposure to glyphosate among the U.S. general population since 2013 (CDC, 2022). This report describes trends in glyphosate exposure during 2013–2018.

2. Methods

2.1. Data collection

We used data from three cycles (2013–2014, 2015–2016, 2017–2018) of the National Health and Nutrition Examination Survey (NHANES). NHANES (CDC, 2017) is designed to assess the health and nutritional status of adults and children in the United States. NHANES combines interviews, physical examinations and collection of biological specimens from a nationally-representative sample of ~5,000 persons each year. The National Center for Health Statistics (NCHS) Institutional Review Board approved the NHANES study protocol. All participants gave informed written consent; parents/guardians provided consent for participants <18 years. We analyzed urine samples collected from one-third subsample of persons aged ≥6 years (for each cycle), a common approach for some laboratory or examination components of NHANES (CDC, 2024b), and the full sample of children 3–5 years of age (for 2015–2016 and 2017–2018). NCHS chose subsamples at random with the specified sampling fraction (i.e., one-third) according to NHANES’s protocol for the specific laboratory component. Each subsample, which has its own designated sample weight, is designed to be a nationally representative sample of the target population (CDC, 2024b). We determined urinary concentrations of glyphosate by using a Clinical Laboratory Improvement Amendments (CLIA)-certified on-line ion-chromatography isotope dilution tandem mass spectrometry method (Schutze et al., 2021).

2.2 Data analysis

We used SAS (version 9.4; SAS Institute Inc., Cary, NC) and SUDAAN (version 11.0.3; RTI International, Research Triangle Park, NC) that incorporate sample weights and design variables to account for the stratified, multistage, and probability-cluster design of NHANES. We followed NCHS guidelines to analyze NHANES data and substituted glyphosate concentrations below the limit of detection (LOD) with LOD divided by the square root of 2 for calculations (CDC, 2024a). We log-10 transformed the glyphosate concentrations for analyses because concentrations were not normally distributed. Age was categorized in years at the last birthday in four groups (3–5, 6–11, 12–19, 20+), and race/ethnicity in five groups (all Hispanic, Mexican American, non-Hispanic Asian, non-Hispanic Black, non-Hispanic White). For each 2-year cycle, we estimated the weighted detection frequency for the entire population sample. We also calculated geometric means (GMs) and distribution percentiles for both volume-based (μg/L) and creatinine-corrected (μg/g creatinine) concentrations of glyphosate for the entire population sample and by sex, age, and race/ethnicity (CDC, 2024b). We conducted one-way ANOVA testing and report pairwise comparisons between the GM concentrations in 2013–2014 and in 2017–2018 for the whole population and by age, sex and race/ethnicity. We report P-values for these comparisons; statistical significance was set at $P < 0.05$.

3. Results

Depending on the NHANES cycle, the weighted detection frequency of glyphosate was 81.2% (2013–2014), 70.0% (2015–2016) and 81.7% (2017–2018). Creatinine corrected glyphosate GM concentrations decreased 38% (Table 1) from 0.443 μg/g creatinine (2013–2014) to 0.273 μg/g creatinine (2017–2018) for the total population; a similar decrease (36%) was noted for the uncorrected GM concentration during the same period (Table S1). Downward trends were also observed by age, sex and race/ethnicity. Compared to other demographic groups, children 6–11 years of age had the highest creatinine corrected GMs and the smallest decrease (26%) in GM concentrations; the largest decrease (42%) was observed for adults age 20 and older between 2013 and 2018. Glyphosate concentrations were only available for participants 3–5 years of age for the 2015–2016 and 2017–2018 NHANES cycles. The decrease from 2015 to 2018 in this age group was 28%, 24% for participants both in the 6–11 and 12–19 year age groups, and 27% for participants 20 years and older. The decrease in creatinine corrected GM concentrations by race/ethnicity groups ranged from 35% to 38%, and by sex from 37% to 40% between 2013 and 2018 (Table 1).

4. Discussion

Glyphosate exposure in the U.S. general population is widespread and occurs even at young ages. NHANES data show that glyphosate exposure significantly declined from 2013 to 2018 for the entire population. Although a similar decline was observed regardless of age, sex and race/ethnicity, children 6–11 years old had the lowest percent decrease in concentrations likely because diet and physical activities (e.g., outdoor play) that can affect exposure differ by age (Ospina et al., 2022).

Reasons for the general downward exposure trend are probably multifactorial and likely relate to changes in agricultural use of glyphosate during those years. In 2018, the U.S. Geological Survey estimated glyphosate use to be 275 million pounds, a 5% decrease from the 290 million pounds used in 2013 (USGS, 2024). Adoption of genetically-modified technologies can reduce pesticide spraying (Brookes & Barfoot, 2020). Furthermore, modified agricultural practices recommend rotating herbicides to manage or prevent the spread of glyphosate resistance (Livingston et al., 2015). Therefore, the combined use of several pesticides with different and complementary modes of action for weed management may have contributed to overall decrease in glyphosate use (MacDonald, 2023).

Additionally, during the last 9 years, several states, municipalities, and local entities throughout the United States have restricted the use of pesticides, and enacted regulations to limit use of synthetic pesticides, including glyphosate (NTC, 2024; Wilcox, 2021). For example, Irvine, CA in 2016 and Tucson, AR in 2018 promoted an organics-first policy to support control of weeds without chemical pesticides. At the same time, according to the Organic Trade Association website, sales of organic food grew by about 60% in 2013–2018 (OTA, 2023). Negative public perception regarding glyphosate and concerns about consumption of genetically-modified crops have increased (McCabe, 2020); there are also legal challenges related to select glyphosate-based formulations (Gaines, 2024). Collectively, these factors may have influenced the general population's use of glyphosate-based formulations or consumption of glyphosate-treated foods that resulted in the observed decline in exposure.

While this report has several strengths including the robustness of the analytical method used and comparability of results across cycles, the findings are also subject to several limitations. First, exposure assessment relied on the concentration of glyphosate from a single urine sample per person, and these concentrations fluctuate considerably because of episodic exposure and the short elimination half-life of glyphosate (5.5–10 hours) (ATSDR, 2020; Connolly et al., 2019; Zoller et al., 2020). However, concentrations from a single sample obtained from a sufficient number of persons, like in NHANES, adequately describe a population's average concentration despite considerable variability at the individual level (Aylward et al., 2014), thus minimizing exposure misclassification. Second, NHANES results are representative of the U.S. general population. While national-representativeness is a major strength, NHANES data may not adequately represent populations in specific locations (e.g., living near agricultural fields) for whom agricultural glyphosate spray can be an important exposure source (Curl et al., 2023). Third, because urinary concentrations of glyphosate reflect all potential pathways of exposure (e.g. dietary, inhalation, dermal contact) and NHANES did not collect information that can be used for source identification, we recommend caution when interpreting the reasons behind the observed downward trend in exposure to glyphosate.

Public concern exists over the potential adverse impact of pesticides on human and environmental health (CR, 2024). The detection of glyphosate in urine does not mean that glyphosate causes disease or adverse effects. Additional studies, other than NHANES, can determine which levels are safe and which may be associated with disease. Moreover, targeted studies, particularly among children, will increase the understanding of exposure sources and whether those differ by demographic group. A better knowledge of behaviors and practices associated with exposure and whether those negatively affect health can guide interventions to reduce such exposures. Decreased exposure to chemical pesticides, including glyphosate, may be achieved through activities such as consuming USDA certified organic foods and adhering to integrated pest management strategies. Continuing the NHANES glyphosate biomonitoring program will help evaluate exposure trends and, if applicable, the effectiveness of interventions to reduce exposure to this chemical.

5. Conclusion

Glyphosate creatinine corrected geometric mean (GM) concentrations decreased 38% from 2013–2018 for a representative sample of the United States total population. These findings may reflect reduced agricultural use of glyphosate and changes in consumer behaviors to limit exposures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Glyphosate Urinary Geometric Mean Concentration (95% CI) in µg/g Creatinine by NHANES Cycle

Demographic Categories	2013–2014	N	2015–2016	N	2017–2018	N	% Change 2013–2018
Total Population	.443 (.406-.482)	2309	.373 (.351-.396)	2427	.273 (.249-.299)	2329	−38%
Age 3–5 years	NA		.900 (.804–1.01)	351	.643 (.568-.729)	325	-
Age 6–11 years	.653 (.579-.738)	337	.640 (.553-.741)	324	.484 (.391-.600)	245	−26%
Age 12–19 years	.414 (.372-.460)	348	.322 (.291-.357)	309	.245 (.223-.270)	297	−41%
Age 20+ years	.429 (.392-.469)	1624	.343 (.323-.366)	1443	.250 (.226-.277)	1462	−42%
Male	.388 (.357-.421)	1152	.338 (.311-.368)	1208	.245 (.225-.268)	1160	−37%
Female	.502 (.450-.559)	1157	.409 (.379-.441)	1219	.303 (.272-.337)	1169	−40%
All Hispanic[a]	.391 (.349-.439)	585	.369 (.338-.402)	804	.248 (.229-.270)	577	−37%
Mexican American[a]	.378 (.333-.429)	380	.379 (.333-.431)	493	.247 (.222-.275)	367	−35%
Non-Hispanic Asian	.444 (.384-.512)	238	NC	219	NC	271	−
Non-Hispanic Black	.362 (.309-.423)	464	.328 (.303-.356)	522	.223 (.193-.258)	485	−38%
Non-Hispanic White	.476 (.431-.526)	930	.385 (.354-.419)	758	.297 (.264-.333)	839	−38%

NA: not applicable (urine was not collected from participants 3–5 years of age in 2013–2014); NC: not calculated (proportion of results below the limit of detection (LOD) was too high (>40%) to provide a valid result. LOD (in µg/L) for 2013–2014, 2015–2016, and 2017–2018 was 0.2, 0.2, and 0.1, respectively).

[a]Persons self-identified as Mexican American are also included in the all Hispanic race/ethnicity demographic category.