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Environmental radon and childhood asthma

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1 | INTRODUCTION

Asthma is the most common chronic disease of childhood in the United States, affecting more than 4 million (6%) children under the age of 18 years.[1] Multiple factors contribute to asthma symptoms, diagnosis and morbidity including indoor air pollutants.[2] More than 90% of time is spent indoors,[3] making indoor exposure to respiratory irritants particularly important.

Radon (^{222}Rn) is a naturally occurring noble gas, formed from the radioactive decay of uranium in soil, rocks, and groundwater. It can permeate through cracks and accumulate in poorly ventilated or closed areas, thereby affecting indoor air-quality. Inhaled radon decay products (^{214}Po,^{218}Po) emit α-rays, causing damage to the respiratory epithelium, which is a well-established cause of lung cancer[4] and more recently has been associated with chronic obstructive pulmonary disease (COPD) morbidity.[5]

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AUTHOR CONTRIBUTIONS

Lana Mukharesh: Writing – original draft; methodology; writing – review & editing; conceptualization; formal analysis; investigation; data curation. **Kimberly F Greco:** Formal analysis; data curation; methodology; conceptualization; investigation; writing – review & editing. **Tina Banzon:** Writing – review & editing; investigation. **Petros Koutrakis:** Funding acquisition; data curation; methodology; investigation; conceptualization; writing – review & editing; formal analysis. **Longxiang Li:** Formal analysis; data curation. **Marissa Hauptman:** writing – review & editing; investigation; methodology. **Wanda Phipatanakul:** Funding acquisition; writing – review & editing; investigation; methodology; data curation; supervision; conceptualization. **Jonathan M Gaffin:** Conceptualization; writing – review & editing; methodology; supervision; funding acquisition; investigation; data curation; formal analysis.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Based on the mechanism of airway injury and recent findings in COPD, we hypothesized that radon exposure would be associated with asthma diagnosis and asthma symptoms in children.

2 | MATERIALS AND METHODS

This was a cross-sectional study utilizing screening survey data from three prospective National Institutes of Health/National Institute of Allergy and Infectious Diseases-funded elementary school-based clinical studies; School Inner-City Asthma Study; SICAS-1 (n = 1358), which was conducted between 2008 and 2013, SICAS-2 pilot (n = 44), from 2013 to 2014, and SICAS-2 (n = 1862), which was conducted between 2015 and 2020. These studies were broadly aimed to assess the effect of the indoor environment on asthma morbidity in school-age children with asthma. For each of these studies, parents of children in Northeastern United States elementary schools completed a brief screening questionnaire regarding asthma diagnosis and specific asthma symptoms. Surveys were distributed in school classrooms to all children to be completed by their caregiver and collected by the study team upon return. Additional details regarding the methods have been published previously.[6,7]

For the current analysis, the primary outcome, asthma diagnosis, was determined by answering “yes” to a physician diagnosis of asthma and/or current use of a medication for asthma on a study population screening eligibility form. Secondary outcomes included report of symptoms of wheezing, nighttime difficulty breathing, nocturnal cough, and missed school days. The answers were dichotomized to “never” versus “sometimes” or “a lot.”

Estimates of monthly radon concentrations were calculated for each participant’s school ZIP Code Tabulation Area in the region from 2005 to 2018 through a two-stage machine learning model that has been published previously.[8] Moving averages were calculated for 1, 5, 7, 12, and 24 months of exposure before the outcome assessment.

A logistic regression model was used to evaluate the association of asthma and symptoms with ground radon exposure (pCi/L) adjusting for age, race, cohort, and year of assessment.

3 | RESULTS

There were 3264 respondents to the screening survey with complete school exposure data that were included in the analysis. The mean age of the participants was 8 years (range 3 to 15 years), 27% self-identified as Black, 22% as White, 7% as Mixed, and 44% identified as Other race. The prevalence of asthma was 25%. Reported respiratory symptoms of nocturnal coughing was 36%, wheezing was 29%, nighttime difficulty breathing was 14%, and missed school days was 13%. Ranges of radon monthly estimates (pCi/L) in the school environment are shown in Table 1. Logistic regression analysis demonstrated a significant association between short-term (1, 5, and 7 months) radon exposure and asthma diagnosis as well as short- and long-term (12 and 24 months) radon exposure and having twice the odds of school absences ($p < 0.05$). The effect of short- and long-term radon

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exposure windows and respiratory symptoms was almost universally positive but did not reach statistical significance (Table 2).

4 | DISCUSSION

In this school-based cohort of children screened for asthma morbidity and respiratory symptoms, we found short- and long-term radon exposure at schools were associated with an increased odds of having an asthma diagnosis and school absenteeism. We consistently found nonsignificant positive associations with radon exposure and report of noisy breathing, nighttime cough and nighttime difficulty breathing. These findings fit our hypothesized model that radon exposure is associated with asthma diagnosis and morbidity. Children were screened in the spring of the academic year in anticipation of recruitment into the research study for the following academic year.[6] We characterized our short-term exposures to capture the current academic year—1, 5, and 7 months—as this was reflective of time the subjects had experienced school-based exposures for the majority of their days for over half a year at the time of completing the survey. The longer-term assessments—12 and 24 months—may be less precise, as the possibility of not having the school as the primary source of exposure increases with longer periods of measurements, such as during vacations and weekends. Additionally, the children may not have attended the same school in the prior years; however, we believe this is unlikely to materially affect our results since the average participant was 8-year-old (approximately second grade) and likely attended kindergarten and first grade in the same school as their exposure assessment.

Our previous work has identified significant contributions of school exposures to respiratory symptoms,[9–11] and it appears radon may have a similar effect. When evaluating our secondary outcomes, we found increased odds of reported respiratory symptoms with radon exposure; however, this association was not statistically significant. It bears highlighting that the estimated radon levels in our study cohort were all lower than the actionable level of 4 pCi/L recommended by the U.S. Environmental Protection Agency (EPA) for radon mitigation.[12] Despite these low levels, we were able to find an association between radon exposure and asthma, suggesting that health effects of radon may be able to be felt at levels that would not trigger an intervention in public or private buildings. It is worth noting that the EPA has not determined a safe radon level of exposure,[12] and mitigation can decrease levels to less than 0.5 pCi/L.[13]

While provocative, these findings are limited by the nature of the cross-sectional study design which assesses the outcome at one point in time, limiting confidence in causal inferences relating the exposure to outcome. Assessment of radon was modeled from local measured and geospatial constructs, and the outcome was determined by parental report, both of which may lead to imprecision in the actual exposure and outcome. However, the radon model used a two-step method which increases the accuracy of the estimated levels.[8] The prevalence of asthma in this study is also notably high, however not far from the range that may be seen in urban school districts in the United States. Nevertheless, some level of reporting bias may be present in the asthma outcome, though unlikely to have influenced the associative findings of radon on that outcome. Lastly, due to the brief nature of the screening survey, adjusting for potential confounders including participants' demographic,

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home address, medical history and other environmental exposures was not possible. Our study was a school-based cohort, therefore we only focused on school-level exposures. Future longitudinal studies are necessary to investigate radon exposure at both the school and home environment to validate our findings and determine a causal relationship between radon and asthma.

In conclusion, to our knowledge, this is the first study to implicate radon as an important modifiable risk factor for childhood asthma.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLE 1

Ranges of radon estimates in the school environment (pCi/L)

Exposure window	Radon estimates
1 month moving average	0.96–1.71
5 month moving average	1.02–1.77
7 month moving average	1.04–1.78
12 month moving average	1.01–1.73
24 month moving average	1.03–1.70

Abbreviation: pCi/L, picocuries per liter of air.

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TABLE 2

Radon exposure and respiratory outcomes

Radon exposure duration	Asthma diagnosis	Noisy breathing	Nighttime difficulty breathing	Nocturnal cough	Missed school days
N	3242	3192	3188	3228	3225
1 month moving average	1.86 (1.16–2.99) *	1.27 (0.81–2.01)	1.08 (0.60–1.95)	1.02 (0.66–1.57)	2.25 (1.23–4.15) **
5 month moving average	1.97 (1.25–3.11) **	1.46 (0.94–2.26)	1.23 (0.70–2.18)	1.18 (0.78–1.78)	2.37 (1.32–4.28) **
7 month moving average	1.89 (1.19–2.99) **	1.40 (0.90–2.18)	1.21 (0.68–2.14)	1.12 (0.74–1.70)	2.23 (1.2–4.05) **
12 month moving average	1.65 (1.00–2.73)	1.16 (0.72–1.88)	1.03 (0.55–1.92)	0.96 (0.61–1.51)	2.00 (1.04–3.83) *
24 month moving average	1.72 (0.99–3.00)	1.19 (0.70–2.02)	1.02 (0.51–2.02)	1.01 (0.61–1.66)	2.25 (1.10–4.60) *

Note: Logistic regression analysis adjusted for age, race, cohort, and year. Data are presented as odds ratio and 95% confidence interval.

* $p < 0.05$

** $p < 0.01$.

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