RESEARCH ARTICLE

Indoor environment in relation to recurrent childhood asthma in Yancheng, China: a hospital-based case-control study

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Abstract

This investigation explored the association between indoor environmental factors and childhood asthma in Yancheng, China. Asthma case (201 children with recurrent asthma) and control cohorts (242 healthy subjects) were recruited from a Traditional Chinese Medical (TCM) Hospital in Yancheng city, based on the results of an ISAAC questionnaire. Questionnaires regarding environmental risk factors were completed by the child's primary caregivers. To compare data on environmental VOCs and formaldehyde contents between asthma and control cohorts, we passively conducted a 10-day indoor and outdoor sampling. Breastfeeding was a major protective indoor environmental factor for recurrent asthma (adjusted odds ratio [aOR]: 0.368, 95% confidence interval [CI]: 0.216–0.627). Our analysis revealed that childhood recurrent asthma was intricately linked to a family history of asthma. Recurrent asthma was also associated with passive smoking [aOR2.115 (95%-CI 1.275–3.508)]. Analogous correlations were observed between household renovation or new furniture introduction and recurrent asthma [aOR3.129(95%-CI1.542–6.347)]. Benzene and formaldehyde were present in all examined homes. Enhanced benzene and formaldehyde concentrations were strongly evident among asthma versus control cohorts, and they were strongly correlated with augmented recurrent asthma risk. Home environment heavily regulates incidences of childhood recurrent asthma. Hence, actions against the indoor environmental risk factors described in this study may assist in the prevention of recurrent asthma among children.

Keywords Asthma · Case-control · Children · Formaldehyde · VOCs

Introduction

Asthma is a common chronic respiratory condition marked with persistent airway inflammation and variable expiratory airflow limitation (Kuang et al. 2021). Over the past 20 years, there has been a steep global rise in the frequency of asthma and other diseases, affecting over 339 million people, particularly, children (Ambade et al. 2022; Kodate et al. 2016; Zhang et al. 2021). Asthma not only causes premature death, but also reduces quality of life of people involved. Relative to developed countries, low- and middle-income countries suffer disproportionally from the most

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severe asthma incidences and other diseases (Asher et al. 2006; Sankar et al. 2023). China is among the largest middle-income countries, and over the past few decades, there has been a substantial uptick in asthma cases in the country (Zhang et al. 2013).

In recent decades, numerous epidemiology investigations provided insight into the associations between asthma incidences and exposure to air pollutants. Some scholars reported that certain outdoor air pollution, such as living near major roads and particulate matter (PM), are potent asthma risk factors (Ambade and Ghosh 2013; Kumar et al. 2020). Alternately, children raised in urban and rural regions exhibit a reduced risk of allergies (Pennington et al. 2018). Additionally, house renovation and new furniture introduction were also reported as strong risk factors for childhood asthma during early childhood and pregnancy (Zhang et al. 2018). Several other factors, such as pets at home and family history of asthma, also contribute to childhood asthma (Arif 2018; Julia et al. 2020; Kansen et al. 2020; Zhang et al. 2020). Nevertheless, the most critical childhood asthma risk factors have not been sufficiently elucidated.

Indoor air quality, namely, temperature, humidity, and air pollutants, is critical regulator of most respiratory disease development. At present, a majority of individuals spend 90% of their time indoors (Athanasios 2019; Wang et al. 2021a). Volatile organic compounds (VOC) are commonly found in dwellings (Huang et al. 2021; Yang et al. 2020) and have already been linked to inflammatory response within airways of asthmatics and other respiratory challenges (Huang et al. 2017; Peel et al. 2020). Prior investigations revealed that reduced VOC household products potentially emit air pollutions, namely, VOCs and formaldehyde, which are potential risk factors for asthma, rhinitis, and eczema development among children (Chang et al. 2019; Franck et al. 2014). Nevertheless, the impact of VOCs and formaldehyde on childhood asthma remains undetermined.

To our knowledge, there are limited reports on the relationship between indoor environment and childhood asthma in China (Balram Ambade 2022, Luo et al. 2018, Sun et al. 2019). Moreover, all investigations did not confirm a link between the two (Hwang et al. 2011). This study is distinct from other asthma investigations in that it specifically investigated the association between indoor environment and recurrent asthma among children in Yancheng in Southeast of China. We utilized a hospital-based case-control design to identify long-term pediatric respiratory health impact factors, such as household decoration, living habits, dwelling characteristics, VOC and formaldehyde concentrations, indoor room temperature (RT), and relative air humidity (RAH). We also explored the influence of indoor microenvironments, such as breastfeeding, passive smoking, house decorations, family history of asthma, pets at home, and new furniture introduction on children with recurrent

asthma versus healthy controls (Eassey et al. 2018; Gilbert et al. 2015). Additionally, we compared both indoor and outdoor VOC and formaldehyde contents to elucidate possible VOC- and formaldehyde-induced effects and quantify exposure risk levels. Enhanced understanding of the close relation between indoor environment and childhood asthma may benefit the prevention of childhood asthma caused by indoor environmental pollutants.

Methods

Ethical statement

This work received ethical approval from the Chinese TCM Hospital and obtained informed consents from all participants or guardians prior to the commencement of the study.

Study area and period

This hospital-based case-control prospective study was conducted in the TCM-based district hospital in Yancheng, China, between July 2021 and February 2023.

Study design

The present prospective study (hospital-based case-control study) was conducted at the age of 3 to 6 years.

Source and study population

Our sample population included all children between 3 and 6 years who lived in the Yancheng city, who also sought care at the TCM Hospital during our data collection time. The TCM Hospital selected in this study is famous for treatment with children asthma, especially with childhood recurrent asthma in Yancheng City and other neighboring cities. The number of TCM hospital visitors was significantly more than other hospitals in preschool-age children (Huang et al. 2013). This specific age group was selected due to a lack of existing research on this age group, and due to this population spending more time inside the bedroom.

Inclusion and exclusion criteria

Included patients

Children between the ages of 3 and 6 years visited the participating hospital. Children with a history of respiratory symptoms (for example, wheezing, shortness of breath, chest tightness, or orthopnea) and recurrent asthma diagnosis by pediatricians based on the Global Initiative for Asthma criteria. Control children were selected from general outpatient

pediatrics; they were from the same age group as the asthmatic children, they had no respiratory disease diagnosis, and they, much like the asthmatic children, were recruited from regions away from industrial and traffic roads, thereby avoiding enhanced VOCs exposure. A team of physicians and two highly trained interviewers obtained patient information using standard questionnaire. The average ages of the asthmatic and non-asthmatic children were 5.02 ± 1.4 and 5.11 ± 1.3 (mean $\pm$ standard deviation), respectively.

Excluded patients

Among those excluded from analysis were children with acute bronchiolitis, pneumonia, stridor, and other respiratory diseases. We also eliminated healthy children who suffered from cold or cough within 6 months of study. Asthmatic children were eliminated from controls. Also excluded were children or primary caregivers who were severely ill or suffered from hearing or speech impairments.

Sampling

Sample size

We employed the single population equation to determine the sample population needed for this study. A prior epidemiological investigation indicated that the recurrence asthma incidence among children < 5 years of age was between 9.8 and 33.1%.(Ibrahim et al. 2021; Stanford et al. 2012) Herein, we selected the intermediate value 16% as the expected prevalence and maintained a margin of error of 5%. Our equation was as follows:

$$n = \frac{(Za/2)^2 p(1-p)}{d^2}$$

whereby n represented the minimum required sample size.

p denoted an estimate of the recurrent asthma prevalence.

Z represented the standard normal variable at $(1-\alpha)\%$ confidence level, with mostly 0.05 α, i.e., with 95% CI (z = 1.96).

D denoted tolerated error margin (%):

$$n = \left[(1.96)^2 \times 0.16(1-0.16)\right]/(0.05)^2 \approx 206$$

Sampling procedures

Among the 5 Class III Grade A hospitals within our district, we selected 3 using simple lottery. Subsequently, we acquired prospective eligible patient information until the aforementioned sample population was reached.

Study variables

Dependent variables: recurrent asthmatic children (Yes/No) between 3 and 6 years of age.

Questionnaires

This investigation employed a questionnaire to evaluate children health based on the International Study of Asthma and Allergy in Childhood (ISAAC) criteria. The questionnaire was provided to the parents of 443 children (Madureira et al. 2015), and it included a set of questions related to the potential risk factors for asthma recurrence, namely, gender (boy or girl), age, birth weight (kg), premature delivery, breastfeeding period, parent education, family asthma history (Yes/No), passive smoking (Yes/No), and so on. We also collected data on the residential environment, such as house location, traffic exposure (Yes/No), quantity of household members (n), household redecoration/new furniture introduction (Yes/No), presence of potted plants (Yes/No), and presence of pets (dog, cat, hamster) (Yes/No).

The respiratory health was assessed using the following medical questions: "ever been told you have asthma" and "still have asthma". A "yes" answer to both questions was regarded as having asthma. Conversely, "don't know" and "refused" answers were regarded as missing data.

Environmental exposure measurements

We collected indoor air samples from 443 households for exposure evaluation. Our analytical approach, as well as quality control and assurance evaluations, was done as follows:

Air samples and exposure assessment for VOCs and formaldehyde

We obtained indoor and outdoor air samples from 443 households for exposure evaluation. In brief, two professional building examiners visited each child's bedroom and other rooms where child spent the most time for equipment installation. Prior to obtaining an air sample, windows and doors were left open for 30 min to facilitate air circulation. Then, they were kept closed for at least 5 h. The air sample of VOCs and formaldehyde were collected by activated charcoal (DDY-1.5, Xingyu, China) in the living room at 150 cm above floor level and at least 30 cm from the wall. All samplings were conducted for 7 consecutive days at 0.5 L/min. The VOCs concentration was measured by a gas chromatograph with a mass spectrometer equipped a flame ionization detector (GC-MS/FID). The formaldehyde contents were determined by a visible spectrophotometry using the 3-methyl-2-benzothiazolinone hydrazine method.

Moreover, reviewers were blinded to the children disease condition (asthma vs. control). The outdoor sampler was positioned within a plastic box that was hung outside a house window, away from exhaust ducts and heat sources. It was also protected from rain and direct solar irradiation. We also measured children bedroom temperature (°C) and RAH (%) once every hour over a 1-week period, using a hygro-anemometer (Model: HHC261, Omega Engineering, Inc., Norwalk, CT, USA) (MitecSatelite-TH, Mitec Instrument AB, Säffle, Sweden).

Air samples and exposure assessment in relation to RT, RAH, and CO_2 content

We recorded the RT (°C), RAH (%), and CO_2 contents of bedrooms during a 90-min period when the children were typically present in the room and computed the averages. These measurements were simultaneously taken using Q-track, a direct reading apparatus, accompanied with a data logger (TSI Incorporated, ST Paul, MN, USA). The machine was positioned at 1.2 m above the floor, and at least 1.5 m from the children breathing zone and continuously at every hour for a week.

Data extraction and analysis

All data analyses employed the Statistical Package for Social Sciences (SPSSversion20.0 Ltd., USA). Categorical data was assessed using the chi-square test. Continuous data with normal (Gaussian) distribution employed the Student's t test, and those with non-normal distribution (for example, temperature, relative humidity, VOCs levels, and formaldehyde concentration) employed the Mann Whitney U test. Recurrent asthma risk factors were also assessed using the aforementioned methods. Multiple logistic regression was used to adjust potential confounders, namely, gender, age, birth weight, premature delivery, breastfeeding duration, and family asthma history. Adjusted odds ratios (ORs) for recurrent childhood asthma experiencing a 10 mg/m^3 rise in VOC exposure were computed with 95% confidence intervals (CIs). P-value < 0.05 was set as the significance threshold.

Results

Demographic profiles of analyzed children

In all, 1960 (91.1%), out of 2150 care-givers, responded to our residential air and asthma incidence survey. Among them, 201 (9.75%) corresponding children had asthma. Table 1 summarizes the personal profiles of all examined children with an average age of 5.11 years (SD1.6). Most

(86%) investigated children were between 3 and 6 years of age, and some (12%) were older (maximum7 years). Approximately 41.4% were girls. Among asthmatics and controls, the male-to-female ratio was 1.1:1 among asthmatic, and 0.8:1 among controls. Among the examined children, 10.7% had a history of pediatrician-identified asthma, 20.1% suffered from allergic rhinitis, and 36.7% from pneumonia.

Environmental risks or protective factors-related to asthma

Based on our analysis, asthma was strongly correlated with breastfeeding (P=0.001), family asthma history (P=0.004), passive smoking (P=0.000), redecoration or new furniture addition (P=0.005), pets at home (P=0.008), and potted plants at home (P=0.019). In contrast, it was not associated with sex, age, birth weight, premature delivery, education of parents, house location, home size, household dampness, and quantity of household members. Table 2

The average RT and RAH at 6- and 24-h

A total of 434 children bedrooms provided valid RT and RAH information (Table 3). Our analyses revealed elevated 6- and 24-h mean RTs in the bedrooms of asthmatic children versus controls; however, the values did not reach significance. The 6- and 24-h mean RAHs were not obviously different between the asthmatic and control children (Table 2).

The 6- and 24-h mean formaldehyde and CO_2 levels

We retrieved valid formaldehyde and CO_2 information from 417 child-bedrooms (Table 3). The formaldehyde concentrations ranged between 7.1 and 30.0 mg/m^3 (mean: 21.9mg/m^3) in the 6-h period and between 6.7 and 29.4 mg/m^3 (mean: 21.5mg/m^3) in the 24-h time period, which were lower than the Chinese test standard and other climate zones. The 6- and 24-h mean formaldehyde levels were substantially elevated among asthmatics, relative to controls (p-value <0.001). The 6- and 24-h mean CO_2 concentrations were generally less than 1000 ppm and were close to the 6-h concentration of 910.7 ppm (Table 4). The association between CO_2 level and asthma did not reach statistical significance.

Measurements of indoor and outdoor air pollution

VOC concentrations, namely, benzene, toluene, ethylbenzene, and xylene, were measured in both the indoor and outdoor environments of asthmatic and healthy children (Table 5). Among all the VOC concentrations, toluene had the highest GM indoor concentration (128.31 μg/m^3),

Table 1 Demographic and health information of study participants with and without asthma

Variables		Total, n (%)	Case, n (%)	Control, n (%)	χ^2/t value	p value
N		443	201	242	-	-
Sex	Boys	105 (44.69)	130 (55.31)	0.097	0.756
	Girls	96 (46.19)	112 (53.81)		
Age (yr)	3	82 (42.49)	111 (57.51)	4.904	0.179
	4	62 (43.97)	79 (56.03)		
	5	48 (55.81)	38 (44.19)		
	6	9 (39.13)	14 (60.87)		
Birth weight (kg)	Mean (SD)	3.10 (0.80)*	3.19 (0.79)*	− 1.358[a]	0.175
Premature delivery	No	176 (44.67)	218 (55.33)	0.033	0.850
	yes	13 (46.43)	15 (53.57)		
Breastfeeding period	≤ 6 months	116 (52.97)	103 (47.03)	10.081	0.001
	> 6 months	85 (37.95)	139 (62.05)		
Parents' education	High school or below	94 (43.98)	120 (56.02)	1.079	0.583
	Bachelor	102 (47.47)	113 (52.53)		
	Master or Doctor	5 (35.76)	9 (64.34)		
Family history of asthma	No	91 (38.90)	143 (61.10)	8.412	0.004
	Yes	110 (52.61)	99 (47.49)		
Passive smoking	No	62 (35.19)	114 (64.81)	12.126	0.000
	yes	139 (52.09)	128 (47.91)		
House's location	Urban	115 (46.91)	130 (53.09)	0.599	0.741
	Suburban	64 (42.09)	85 (57.91)		
	Rural	22 (44.89)	27 (55.11)		
Home size (m^2)	≤ 60	40 (44.00)	51 (56.00)	0.735	0.693
	60–100	92 (47.74)	101 (52.26)		
	> 100	69 (43.43)	90 (56.57)		
Household dampness	No	79 (42.55)	107 (57.45)	1.087	0.297
	Yes	122 (47.54)	135 (52.46)		
Redecoration/addition new furniture	No	156 (42.49)	212 (57.51)	7.794	0.005
	Yes	45 (60.00)	30 (40.00)		
Number of persons living in current home (n)	< 3	35 (53.00)	31 (47.00)	1.864	0.394
	3–4	99 (44.45)	124 (55.55)		
	> 4	67 (43.52)	87 (56.48)		
House location (surrounding traffic condition)	No	124 (47.52)	137 (52.48)	1.171	0.279
	Yes	77 (42.30)	105 (57.70)		
Pets at home	No	168 (43.10)	222 (56.90)	6.930	0.008
	Yes	33 (62.30)	20 (37.70)		
Potted plants at home	No	122 (50.41)	120 (49.59)	5.468	0.019
	Yes	79 (39.30)	122 (69.70)		

*Mean (standard deviation)

[a]Student t test, others: chi-square test

followed by benzene (6.91 µg/m^3) and xylene (6.41 µg/m^3). Ethylbenzene had the lowest GM concentration (4.68 µg/m^3). In Yancheng, toluene was the most abundant indoor air environment as for other cities (Huang et al. 2021). In case of outdoor pollution, the asthmatic children exhibited a much higher exposure to benzene, toluene, and xylene concentrations than healthy children. Similarly, benzene concentration (2.9 µg/m^3) was considerably higher among asthmatic children than healthy ones (1.67 µg/m^3, p = 0.000). Lastly, toluene concentrations were also elevated among asthmatic children (32.48 ± 7.93µg/m^3), relative to healthy ones (29.77 ± 8.24, p = 0.003). While comparing outdoor pollution, we revealed that the benzene concentration was markedly elevated among asthmatic children, relative to controls. Moreover, the benzene concentration was considerably high among asthmatic children (1.92 ±

Table 2 The average indoor climates of 434 child-bedrooms in Yancheng

Variables		434	199	235	p value[a]
In the child's bedroom ($N = 434$)		Total	Cases	Controls	
(1) T-24 h	Mean (±SD)	21.5 ± 6.2	22.1 ± 6.2	21.1 ± 6.1	0.080
	21–28°C, n %	132 (30.4)	62 (31.2)	70 (29.8)	0.486
	16–24°C, n %	138 (31.8)	58 (29.1)	80 (34.0)	0.061
(2) T-6 h (00:00–06:00)	Mean (±SD)	21.9 ± 6.3	22.3 ± 6.6	21.5 ± 6.0	0.184
	21–28 °C, n %	166 (38.2)	75 (37.7)	91 (38.7)	0.214
	16–24 °C, n %	150 (34.6)	66 (33.2)	84 (35.7)	0.142
(3) RH-24 h	Mean (±SD)	74.1 ± 9.3	74.4 ± 9.2	73.8 ± 9.3	0.555
	40–80%, n (%)	397 (91.5)	181 (91.0)	216 (91.9)	0.079
	30–60%, n (%)	150 (34.6)	64 (32.2)	86 (36.6)	0.072
(4) RH-6 h (00:00–06:00)	Mean (±SD)	76.6 ± 10.2	77.0 ± 10.8	76.2 ± 9.7	1.000
	40–80%, n (%)	384 (88.5)	173 (86.9)	211 (89.8)	0.052
	30–60%, n (%)	125 (28.8)	57 (28.6)	68 (28.9)	0.325

[a]Odds ratio (OR)

Table 3 The 6- and 24-h mean formaldehyde content in 434 child-bedrooms in Yancheng

Items	Total 417	Cases 185	Controls 232	p value
(1) Formaldehyde-24 h Mean (±SD) ($\mu g/m^3$)	51.5 ± 14.7 399 (99.0)	62.4 ± 10.7 183 (98.2)	45.4 ± 9.5 222 (99.6)	0.000 0.053
(2) Formaldehyde-6 h Mean (±SD) ($\mu g/m^3$)	51.4 ± 14.7 397 (98.5)	62.1 ± 11.6 181 (97.6)	45.8 ± 9.9 220 (99.2)	0.000 0.051

0.56$\mu g/m^3$), compared to healthy ones (1.52 ± 0.54$\mu g/m^3$, $p = 0.000$). Lastly, the average ΣVOCs concentrations were 81.37 $\mu g/m^3$ indoor and 32.00 $\mu g/m^3$ outdoor, thereby showing significant difference.

Table 5 illustrates the adjusted ORs of multiple logistic regression models for associations between asthma and benzene and formaldehyde exposures. Potential confounding factors, namely, pets at home, family allergic history, new furniture addition, kitchen ventilation condition, potted plants at home, and toluene and xylene presence, were considered in our analysis.

We demonstrated that breastfeeding over 6 months was protective against asthma [OR: 0.368 (95% CI:

Table 4 The 6- and 24-h mean CO_2 levels in 434 child-bedrooms in Yancheng

In the child's bedroom ($N = 434$)	Total 434	Cases 199	Controls 235	p value
CO_2-24 h Mean (±SD) (ppm) ≤ 1000	814.7 ± 256.1 380 (88.9)	815.8 ± 230.77 177 (88.9)	813.4 ± 290.5 205 (87.2)	0.998
CO_2-6 h (00:00–06:00) Mean (±SD) (ppm) ≤ 1000	910.7 ± 332.1 378 (87.1)	922.2 ± 340.7 175 (87.9)	896.6 ± 326.8 203 (86.4)	0.636

Table 5 VOC concentrations (indoor and outdoor) in the tested residences and the associations with recurrent childhood asthma ($\mu g/m^3$)

Variables	Indoor						Outdoor						p value
	Case ($n = 195$)			Control ($n = 231$)			Case ($n = 192$)			Control ($n = 232$)			
	GM[a]	Min	Max	GM[a]	Min	Max	GM[a]	Min	Max	GM[a]	Min	Max	
Benzene	6.91	1.28	15.26	4.67	1.02	12.36	2.92	0.46	4.32	2.52	0.43	3.64	0.000
Toluene	128.31	50.32	193.36	108.76	55.33	153.97	34.48	22.15	39.26	31.78	20.03	35.28	0.004
Ethylbenzene	4.68	1.88	9.39	4.42	0.92	11.26	2.47	0.59	4.07	2.28	0.67	3.98	0.034
Xylene	6.41	1.05	9.25	6.12	1.98	12.36	3.22	1.02	5.32	3.02	1.34	4.92	0.042

[a]95% confidence interval

0.216~0.627)]. Both family asthma history and passive smoking were strong risk factors for asthma [OR: 2.076(95% CI: 1.226~3.515)] and 2.115 (95% CI: 1.275~3.508), respectively]. Redecoration/new furniture addition was also a significant risk factor for asthma [OR3.129 (95% CI: 1.542~6.347)]. Additionally, benzene [OR6.819 (95% CI: 3.436~13.531)] and formaldehyde [OR11.985 (95% CI: 4.983~28.826)] exposures were large contributors to recurrent asthma among children (Table 6).

Discussion

This hospital-based case-control study was in agreement with prior investigations. We demonstrated that breastfeeding was highly protective against childhood asthma during the first 3–6 years of life. In cross-sectional investigations, prolonged exclusive breastfeeding (> 6 months), relative to never breastfeeding, was shown to protect children against asthma in their first 2–9 years of life (Abarca et al. 2018; Harvey et al. 2020; Huo et al. 2018). A hospital-based case-control investigation in China reported that exclusive breastfeeding (> 6 months) dramatically diminished asthma risk, compared to children who were never breastfed. A population-based childbirth cohort from 2017, examined by Annika et al., exhibited a direct link between breastfeeding and protection against asthma, relative to formula feeding at 3 months, 3 years, and 9 years of age (Annika Klopp et al. 2017). However, a Chinese study reported that a longer breastfeeding duration (> 6 months) was negatively correlated with an enhanced childhood asthma/allergy risk (Hu et al. 2021). Given this controversy, the true effect of breastfeeding on asthma remains undetermined. This is also reflected in the conflicting data produced by earlier research, which sometimes employed methods with considerable limitations and was influenced by the wide physiological variability in human milk. As such, additional epidemiologic and biomedical investigations are warranted to clarify the link between breastfeeding and asthma occurrence, to establish causality, and to elucidate the underlying mechanism(s).

Among the well-established contributors to wheezing and asthma are mothers' history of asthmatic diseases and children's respiratory infections (Arif 2018; Hallit et al. 2021). Herein, we verified that a family asthma history was intricately linked to enhanced asthma OR. Our results corroborated with the work of Mirzakhani et al., who revealed that, among a large American cohort of asthmatic and non-asthmatic mothers and their children, asthma risk is elevated among children whose mothers have uncontrolled asthma (Mirzakhani et al. 2019; Morales 2019). This suggests that both genetic and genomic factors contribute to the pathobiology of asthma (Morales 2019).

Passive smoking is another risk factor for asthma in children, even after confounder adjustment. However, there are reports that show either inverse or no correlation. A strong direct association between passive smoking and wheeze exists among 0–36-month-old Arco Ribeirinho region-born children, and 86.7% of these children present a minimum of 1 episode in the past 12 months (Rodrigues dos Santos et al. 2020). In a case-control investigation, children exposure to maternal smoking at 8–21 years of age was strongly correlated with pediatric and adult asthma (Neophytou et al. 2019). In a secondary cross-sectional investigation, the author demonstrated a strong link between passive smoking exposure and asthma among US adolescents (Merianos et al. 2018). Nevertheless, findings from an extensive prospective population-based lifelines cohort investigation in the Netherlands, involving 4–18-year-old children at baseline examinations, who were followed up for about 7 years, revealed that passive smoking exposure at home at baseline and during follow up was not associated with wheezing and asthma incidences (Mahon et al. 2021). Hence, our results reinforce the significance of avoiding indoor smoking for parents of young children. It is up to the public health authorities now to tailor the message for parents to avoid such behavior.

Emerging evidence revealed that home renovations, including indoor painting or buying new furniture and other

Table 6 The various predictors of childhood asthma

Variables	B	Wald	OR[a] (95%CI[b])	P
Breastfeeding	− 1.000	13.515	0.368 (0.216~0.627)	0.000
Family history of asthma	0.730	7.387	2.076 (1.226~3.515)	0.007
Passive smoking	0.747	8.421	2.115 (1.275~3.508)	0.004
Redecoration/addition new furniture	1.141	9.992	3.129 (1.542~6.347)	0.002
Benzene	1.920	30.142	6.819 (3.436~13.531)	0.002
Formaldehyde	2.484	30.764	11.985 (4.983~28.826)	0.000

Adjusted OR for age, sex, breastfeeding period, family history of asthma, passive smoking, redecoration/addition new furniture, pets at home, potted plants at home

[a]Odds ratio (OR)

[b]95% confidence interval

sources, can potentially enhance VOCs and formaldehyde emissions, which remain for 6 months (Wag et al. 2020). Based on a report involving a self-administered questionnaire on indoor paint-based chemical emissions and asthmatic children, certain VOCs aggravate airway inflammation. Moreover, new furniture introduction strongly associated with pneumonia among asthmatic children (Wang et al. 2021a; Wang et al. 2021b; Zhang et al. 2018). In a retrospective cohort investigation, involving 3–6-year-old children from 7 cities in northern and southern China, it was revealed that household renovation and new large furniture addition during pregnancy strongly correlated with childhood doctor-diagnosed lifetime and parent-reported asthmatic symptoms and current cough (Zhang et al. 2018). Given the aforementioned evidences, we speculated whether both household renovation and new furniture addition potentially influence the male sperm, which, in turn, negatively affects offspring health later in life. One case-control study involving 242 congenital malformation cases and 270 controls reported that exposure of the father to solvents strongly enhanced the risk of congenital malformations within the child (El-Helaly et al. 2011). Thus, it is better to avoid renovation during pregnancy.

Herein, we demonstrated that total VOCs exposure had a significant influence on pediatric asthma. Our model was also adjusted for breastfeeding, passive smoking, pets at home, house decorations, family asthma history, family allergic history, new furniture addition, and potted plants at home. A prior study conducted in Iran revealed a strong link between asthma and benzene (Shakerkhatibi et al. 2021). Thus, both benzene and formaldehyde can be considered as specific contaminants within the indoor environment. Moreover, the wide variety of indoor formaldehyde exposures may be due to the presence of several and distinct formaldehyde sources, emitting pollutants over a variable period of time. At this point, there are no data to confirm this. The inconsistencies associated with previous studies may be due to the study design, outcome classification, differing living conditions, differences in geographic locations, and population characteristics.

Since the total VOC indoor exposure had a significant influence on pediatric asthma, comprehensive asthma programs with multicomponent interventions that include indoor air quality improvement and indoor environmental asthma trigger avoidance are necessary to achieve better health outcomes for childhood asthma.

There are a few noteworthy limitations of this research. Firstly, this study only examined children between the ages of 3 and 6 years from select preschools in Yancheng. Our sample population was relatively low, which negatively affected our statistical power of analysis, and considerably increased our confidence interval. Owing to this selection process, our conclusions may not fully represent the general population, which may be subject to select bias. Secondly, despite stating that the "asthma" must be physician-diagnosed in the questionnaire, it is possible that the reported data may have error and/or bias. Thirdly, it is possible that some children may have had asthma-related airway diseases/symptoms, but no doctor-diagnosis. Finally, in China, since most of children aged 3 to 6 always spend a certain amount of time in kindergarten, the indoor air quality of kindergarten classrooms should also be considered. Hence, some bias may have been introduced during the asthma-control classification in this study.

Conclusion

This study was the first to report a strong link between indoor environmental pollution and recurrent childhood asthma risk in China's third-tier cities. We also provided the average RT and RAH between asthmatics and controls. Given our evidences, the indoor environment has a significant effect on asthmatic children, and passive smoking, redecoration within 1 year before pregnancy, and family asthma history substantially increase both the risk and severity of benzene and formaldehyde-induced asthmatic attacks in children.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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