



Modern life makes children allergic. A cross-sectional study: associations of home environment and lifestyles with asthma and allergy among children in Tianjin region, China

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Abstract

Purpose In the past 60 years, the prevalences of asthma and allergy among children have increased around the world. Neither genetic nor outdoor environmental factors can explain this increase.

Methods We performed a cross-sectional study of 7366 children in Tianjin, China, on associations of home environment and lifestyles with asthma and allergy.

Results The prevalences of diagnosed asthma, rhinitis and eczema among 0- to 8-year-old children in the Tianjin area were 4%, 9% and 39%. Home environment and lifestyle, together with infections, were strong risk factors. For asthma and allergy, the population attributable fraction (PAF) due to modern floors and wall coverings (i.e., laminated wooden floors and painted walls compared to tile floors and lime-coated walls) was 22%. Window condensation in winter and air conditioner use in summer, both of which are proxies for less ventilation, accounted for 7–17% of rhinitis and eczema. Cesarean delivery accounted for 10% of eczema symptoms. We developed a modern life index from appropriate home characteristics and lifestyle and food consumption habits and found it to have a clear dose–response relationship with asthma and allergy in Tianjin children.

Conclusions The results indicate that a “modern” home environment together with a modern lifestyle is associated with increased prevalences of asthma and allergies among children. Appropriate indoor environmental interventions and education of children’s caregivers are important in the management of childhood asthma and allergy.

Keywords Asthma and allergy · Home environment · Lifestyle · Modern decoration · Ventilation · Child

Abbreviations

AC Air conditioner
ADHD Attention–deficit/hyperactivity disorder

AOR Adjusted odds ratios
CCHH China, children, health and home
CI Confidence interval
ETS Environmental tobacco smoke
SVOC Semivolatile organic compound
VOC Volatile organic compound

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Background

Childhood asthma, allergic rhinitis, and atopic eczema are important public health concerns, not only with respect to monetary costs but also for school absenteeism and quality of life (Braman 2006). During the past 60 years, the incidence of children's asthma and allergies has been increasing dramatically worldwide, and presently is the highest in developed countries (Mallol et al. 2013).

Intense medical research at the molecular or genome level has not yet explained the rapid increase in allergies. Genetic changes cannot be the principal cause as the time interval is too short. The rapid increase must be due to environmental, and/or epigenetic changes. But what in the environment? Are we exposed to more allergens today? Is our home environment too clean, as suggested by the "Hygiene Hypothesis"? Have there been changes in the gut microbial flora caused by changing diet? Is it increased ambient air pollution? Adults spend an average of 90% of their time indoors (Brasche and Bischof 2005), and small children even more time. The drive to save energy has meant reduced ventilation. At the same time, many new buildings and furnishing materials have come into use, producing a new suite of indoor pollutants that because of reduced ventilation remain for a longer period of time in indoor air. Meanwhile, indoor air pollution has been much less studied and understood than outdoor air pollution (Sundell 2017). Indoor environments, especially in homes, deserve attention for their potential role in the development and exacerbation of asthma and allergies among children.

Since 2000, studies of children's asthma and allergy as related to home environments have been performed in countries in Europe, America and Asia, including Sweden (2000) (Bornehag et al. 2005a), Bulgaria (2004) (Naydenov et al. 2008), Denmark (2007) (Clausen et al. 2012), Texas, USA (2008) (Sun and Sundell 2011), Singapore (2004) (Tham et al. 2007), Taiwan (2006) (Hsu et al. 2012), and South Korea (2009) (Choi et al. 2014). In 2010, China joined this global study with the China, Children, Health and Home (CCHH) study (Sundell et al. 2013; Zhang et al. 2013).

China's profoundly rapid modernization and urbanization in the past two decades has resulted in dramatic changes in indoor environmental exposures. Some 300 million persons have migrated from rural areas to urban areas in the last 20 years, from rural homes to apartments in cities. In China, a newly purchased apartment is usually an empty shell without any furnishing or furniture. Families decide on floor covering, wall covering and fill in the empty chamber with new furniture. Along with urbanization, a "westernization" has happened with regard to

culture and food. Western fast food restaurants are popular. The mode of childbirth has dramatically shifted towards cesarean delivery (c-section). More than 45% of births in 2007–2008 were by c-section (Lumbiganon et al. 2010). During the time of China's growth, the prevalence of childhood asthma in China has increased from 0.91% in 1990 to 1.50% in 2000 (National Cooperation Group on Childhood Asthma, 2004), and in the last decade to 6.8% (Zhang et al. 2013).

Numerous epidemiological studies have looked at a single or a few risk factors for asthma and allergies. To our knowledge, few studies have as yet evaluated the wide range of home environmental and lifestyle risk factors to identify the most important risk factors. A pilot study among 211 Old Order Mennonite (OOM) families in Upstate New York living predominantly on farms and having low modern product use, showed that OOMs had significantly lower exposures to bisphenol A and phthalates (Martina et al. 2012), and had a very low rate of allergic disease (asthma, rhinitis, eczema) compared to a sample of the US population of similar age, sex, and race (Martina et al. 2016). In China, a large traditional lifestyle population remains, making China ideal to study aspects of modern vs. traditional Chinese lifestyle. In the present study, we search for possible causes in the home environment and lifestyle, comparing traditional with modern aspects, for example, changes in building, furniture and home decorating materials; food consumption (fast food, breastfeeding); in giving birth; and in daycare attendance. We analyze an exhaustive list of possible risk factors to identify the important factors and sort them into a hierarchy.

Methods

This study is a part of the CCHH project. Our present research consists of two phases: Part I, a cross-sectional study and Part II, a case-control study. This paper is based on the cross-sectional study. Its foundation is the questionnaire and protocols originally developed for the Swedish study (Bornehag et al. 2005a) and subsequently used in global investigations (Sundell et al. 2013). To the Swedish questionnaire, we added questions about household annual income, baby delivery method, rank-ordered asthma and allergy severity, incidence of attention-deficit/hyperactivity disorder (ADHD) and autism that have also increased in prevalence, and the frequency of fast food consumption. We also adapted some questions on housing to better reflect Chinese housing styles. The questionnaire was tested in a pilot study of 100 children in a previous CCHH study in Chongqing in 2010 (Zhang et al. 2013). The entire questionnaire is shown in the online supplementary material. Phase I was conducted from May 2013 to Dec. 2014. Questionnaires were sent to daycare centers and elementary schools.

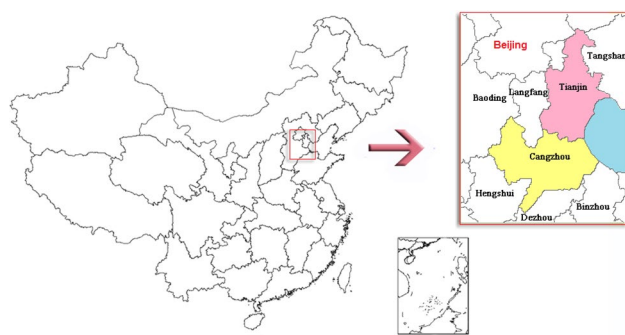


Fig. 1 Locations of Tianjin metropolis and Cangzhou city, China

Parents responded to the questionnaire, giving us information on their 0–8-year-old children. We analyzed these health outcomes: wheeze ever, wheeze current, dry cough current, diagnosed asthma, rhinitis ever, rhinitis current, diagnosed rhinitis, eczema ever, eczema current and diagnosed eczema.

The study was of the Tianjin metropolis and its satellite city Cangzhou (100 km south of Tianjin metropolis), as shown in Fig. 1. Metropolitan Tianjin occupies an area of 11,920 km² and has a population of 15 million, although with seasonal migrant workers, the population is possibly 18 million. Cangzhou's area is 13,420 km² and its population is 7 million, or with seasonal migrant workers possibly 9 million. In 2014, the GDP per capita for Tianjin metropolis and Cangzhou city were \$16,500 and \$5,800, respectively (National Bureau of Statistics of China 2018). The average outdoor air temperatures for spring, summer, autumn and winter are 13.4 °C, 25.7 °C, 13.6 °C and −1.7 °C in Tianjin and Cangzhou (Meteorological Data Center of China Meteorological Administration 2017).

Statistical analysis

Statistical analysis was performed with SPSS 20. We accepted a *P*-value < 0.05 as significant. We first analyzed children's demographic information, health outcomes, home environmental factors, lifestyles and biological factors and then bivariate associations of these factors with asthma and/or allergy. Finally, those factors with *P*-value < 0.05 were used in multivariate logistic regression models to identify the most important risk factors for asthma and allergy among children. The home environmental factors were visible mold/damp spots on walls or ceilings, condensation on window panes in winter, perceived dry air, perceived moldy air, floor covering material, wall covering material, use of air conditioner for cooling, fuel burning for cooking and heating, environmental tobacco smoke, exposure to pets, and pollutant infiltration from ambient air (e.g., from traffic). Lifestyle factors were daycare attendance, fast food consumption, and frequency of sun-cured bedding. Biological factors were

mode of birth (natural vs. c-section), length of breastfeeding (either exclusive or partial), weight at birth, and infection (pneumonia, croup, ear infection) ever.

Population attributable fractions were calculated using the equation proposed by Rockhill et al. (1998).

$$1 - \frac{p_0}{p_t}$$

where p_t is the cumulative proportion of the total population developing disease over the specified interval and p_0 is the cumulative proportion of unexposed persons who develop the disease over the interval.

The Research Office at Tianjin University granted ethical approval for the study.

Results

As shown in Fig. 2, 7865 families answered the questionnaire yielding a response rate of 78%. Ages were not reported for 204 children, and 295 children were outside our 0–8 age boundary. Therefore, our final analysis was of 7366 children of whom 52% were boys and 48% girls. Family's allergic history, defined as siblings and/or parents reporting an allergy, was reported for 14% of the children.

Health outcomes

As shown in Table 1, 4.4% had diagnosed asthma, 9.5% diagnosed rhinitis and 39.1% diagnosed eczema. Prevalences were consistently and significantly greatest in urban areas followed in order by suburban and rural areas, as shown in Supplementary Table S1.

Home environmental exposure and associations with asthma and allergy

Moisture problems, condensation and odor perception

The frequencies of self-reported moisture problems, condensation on window pane in winter, and odor perception

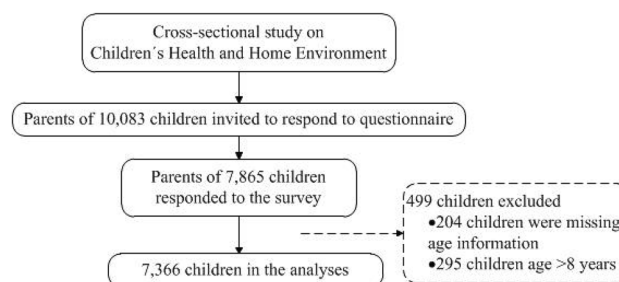


Fig. 2 Flowchart of data collection and analysis

Table 1 Prevalences of asthma and allergy among children 0–8 years old in Tianjin region, China, *n* (%)

	Total, 7366	0–2 years, 225	3–5 years, 3238	6–8 years, 3903
Asthma				
Wheeze ever	693 (10.2)	25 (11.7)	306 (10.3)	362 (10.0)
Wheeze current	333 (4.9)	18 (8.5)	172 (5.8)	143 (4.0)
Dry cough current	937 (13.6)	33 (15.4)	488 (16.0)	416 (11.4)
Diagnosed asthma	302 (4.4)	7 (3.3)	131 (4.3)	164 (4.5)
Rhinitis				
Rhinitis ever	2593 (38.8)	75 (36.2)	1163 (39.7)	1355 (38.3)
Rhinitis current	2002 (29.8)	63 (30.9)	960 (32.3)	979 (27.6)
Diagnosed rhinitis	636 (9.5)	8 (4.0)	258 (8.7)	370 (10.4)
Eczema				
Eczema ever	2594 (37.9)	109 (50.7)	1143 (37.8)	1342 (37.1)
Eczema current	998 (14.9)	63 (30.3)	494 (16.7)	441 (12.5)
Diagnosed eczema	2624 (39.1)	105 (50.7)	1288 (43.3)	1231 (34.9)

in homes are shown in Supplementary Table S2. Air was perceived as dry in > 50% of homes, while condensation on window pane in winter was reported for > 25% of homes. Condensation and dry air perception, as well as visible mold/damp spot(s) and moldy air perception, were strong risk factors for children's asthma and allergies, as shown in Supplementary Table S3.

Home decoration and use of air conditioner

Home characteristics with respect to decoration and furnishing are shown in Supplementary Table S4. By far, most people live in apartments (67.3%), while 32.7% live in Pingfang. Pingfang is a one-story house for a single family, with cement/tile floor covering, lime wall covering and wooden frame windows. 50% (76%) of all dwellings had air conditioning units and had modern construction technologies, as for example, insulation on outer walls, plastic frame windows, and double glass panes. Modern decorative finishing, such as laminated wood for floors (42%) and painted walls (72%) were common. Associations between building characteristics and asthma and allergy are shown in Supplementary Table S5. This table shows that buildings with modern technologies and materials (insulation on outer walls, laminated wood floor covering, painting or latex paint as wall covering, double glass pane or double glass pane with gas fill, air conditioning units) were associated with increased prevalences of asthma and allergies.

Fuel burning for cooking and heating

The proportion of homes in Tianjin region that use solid fuel burning for heating and/or cooking is summarized in Supplementary Table S6. Rural homes use a stove/kang for heating (37%), and coal/biomass for cooking (33%) more than urban homes (0.7% heating, 0.5% cooking). Associations

between fuel burning and asthma and allergy among children are shown in Supplementary Table S7. There is no clear association between fuel burning in homes and children's asthma and allergy.

Environmental tobacco smoke (ETS) exposure at home

The proportion of ETS exposure in current homes was 56% (3808). During children's early life, 116 (2.4%) mothers smoked and 3189 (47.3%) fathers smoked. Associations of current and early life ETS exposure with children's asthma and allergy are shown in Supplementary Table S8. Current ETS had no association with children's asthma and allergy, while parents' smoking, especially mother's smoking, during the early life of a child was a significant risk factor for children's wheezing and diagnosed asthma.

Pet exposure at home

The pet raising status in Tianjin is shown in Supplementary Table S9. Associations of pet raising with asthma and allergy are shown in Supplementary Table S10. Our data show no protective effect from keeping pets. Moreover, there is a clear "avoidance behavior" (i.e., getting rid of pets and/or refraining from pets due to allergy) related to children's health and pet keeping, i.e., families with sick children get rid of pets.

Ambient air: traffic (proximity to highway)

About 35% of all homes, whether urban or rural, were near to a highway. The negative effects of living close to a highway reached significance for eczema ($P < 0.05$), as shown in Supplementary Table S11.

Lifestyles and their associations with asthma and allergy

Daycare attendance

Daycare attendance is shown in Supplementary Table S12. Rural children tended to be taken care of at home compared to urban children and started daycare at an older age. Associations of daycare attendance with asthma and allergy among children are shown in Supplementary Table S13.

Fast food consumption

Children's fast food habits are shown in Supplementary Table S14. The association of fast food consumption with asthma and allergies is shown in Supplementary Table S15. Fast food was a mild risk factor for asthma and allergies among children.

Sun-cured bedding

A total of > 45% of homes in Tianjin sun-cures bedding often, especially in rural areas, as shown in Supplementary Table S16. Lower frequency of sun-cured bedding was significantly associated with child's asthma and allergy, as shown in Supplementary Table S17.

Biological factors and their associations with asthma and allergy

Breast feeding

Breast feeding durations are shown in Supplementary Table S18. Seventy-three percent of investigated children were breast fed (either exclusively or partially) for more than 6 months. There is no clear association between asthma and allergies and duration of breast feeding, as shown in Supplementary Table S19.

Child delivery method

Child delivery methods in Tianjin area are summarized in Supplementary Table S20. 62% of Tianjin children (68.4% in Tianjin inner city) were delivered by c-section, which was a significant risk factor for rhinitis and eczema (see Supplementary Table S21).

Low birth weight

In the Tianjin region, 5.3% children had low birth weight (< 2.5 kg). Low birth weight was positively but

non-significantly associated with asthma and most allergies. Demographic and risk data are shown in Supplementary Tables S22 and S23 respectively.

Infections and use of antibiotics

Among all children, 9.2% had croup ever, 29% had pneumonia ever, 11.5% had ear infections ever, and 31.3% had common cold ≥ 3 times in the last 12 months, as summarized in Supplementary Table S24. Sixty percent of the children had at least one of these infections. Associations between infections and asthma and allergy are shown in Supplementary Table S25. Infection is a very strong risk factor for asthma and allergy among children.

Among all children, 55.3% children took antibiotics. Reasons for using antibiotics are summarized in Supplementary Table S26. The top three reasons for using antibiotics among children were common cold/flu, high fever and pneumonia. After antibiotic use was stratified, the association of infections with asthma and allergy remained strong and positive (see Supplementary Table S27).

Multivariate logistic regression models: associations of combined home environmental factors, lifestyle behaviors and biological factors with asthma and allergy

The associations of home environmental factors, lifestyles, biological factors with asthma and allergy were analyzed in multivariate logistic regression models, as shown in Table 2. The association of asthma and allergy with moldy odor perception, daycare attendance as observed in bivariate logistic regression models disappeared (See Supplementary Table S3 and S12). The negative influences of indoor dampness, pet keeping and outdoor pollution (as indicated by proximity to highway) on asthma and allergy weakened in this multivariate analysis. The remaining risk factors were condensation on windows, dry air perception, modern wall covering and wall paint, use of air conditioning (AC), less sun-curing of bedding, fast food consumption, c-section delivery and infections.

The population attributable fractions (PAFs) of these risk factors are shown in Table 3. PAFs estimate the proportional reduction in diseases that would be achieved by eliminating the exposure of interest. It shows that the most prominent attributable factors are infections (~37%), followed by modern floors and wall coverings (~22%), use of air conditioning (~15%), less sun-curing of bedding (15%), condensation on window pane (~8%), dry air perception (~8%), cesarean delivery (~8%) and fast food consumption (~5%).

We created a "modern index" to estimate the influence of modern materials and lifestyle practices on children's asthma and allergy prevalences. The index consists of: modern

Table 2 Odds ratios of home environmental factors, lifestyles and biological factors for asthma and allergy among children in Tianjin area, China

Environmental exposure																		
	Lifestyle											Biological factor						
	Mold/damp spot ^e	Conden- sation ^b	Perceived moldy air ^c	Perceived dry air ^d	Modern floor ^e	Modern wall ^f	Use of AC ^g	Use of biomass/ coal ^h	ETS exposure, early ⁱ	Pet keeping ^j	Near to the highway ^k	Daycare attendance ^l	(Less) Sun- curing of bedding ^m	Fast food consumption ⁿ	(Less) Breast feeding ^o	Cesarean delivery ^p	Low birth weight ^q	Infection ever ^r
Wheeze ever	1.67 (1.04, 2.69)		1.51 (1.07, 2.13)	1.50 (1.14, 1.96)	1.50 (1.14, 1.96)	1.50 (1.00, 2.26)												3.59 (2.56, 5.04)
Wheeze current			2.46 (1.61, 3.74)	1.56 (1.04, 2.35)														3.39 (2.25, 5.11)
Dry cough current	1.58 (1.06, 2.36)		1.54 (1.14, 2.08)										1.33 (1.05, 1.68)	1.34 (1.01, 1.77)				1.84 (1.48, 2.30)
Diag. asthma				1.99 (1.29, 3.07)					1.46 (1.02, 2.09)									4.06 (2.63, 6.28)
Rhinitis ever		1.35 (1.13, 1.62)	1.33 (1.03, 1.71)			1.39 (1.13, 1.72)						1.31 (1.12, 1.55)						1.42 (1.21, 1.68)
Rhinitis current		1.46 (1.22, 1.75)	1.36 (1.05, 1.76)	1.34 (1.11, 1.61)		1.52 (1.19, 1.95)								1.26 (1.01, 1.58)				1.56 (1.30, 1.86)
Diag. rhinitis			1.45 (1.02, 2.05)											1.40 (1.02, 1.94)				2.37 (1.81, 3.09)
Eczema ever			1.42 (1.11, 1.82)	1.30 (1.09, 1.56)			1.30 (1.08, 1.56)			1.33 (1.08, 1.65)	1.20 (1.02, 1.40)		1.25 (1.07, 1.47)		1.23 (1.05, 1.45)			1.56 (1.34, 1.83)
Eczema current				1.36 (1.08, 1.71)			1.48 (1.13, 1.94)			1.35 (1.03, 1.77)					1.40 (1.10, 1.75)			1.36 (1.08, 1.71)
Diag. eczema		1.35 (1.13, 1.62)	1.55 (1.21, 1.99)			1.55 (1.25, 1.93)							1.23 (1.05, 1.45)					1.80 (1.54, 2.11)

Odds were calculated in multivariate logistic regression using all column variables plus gender, age, family allergic history and home location. The forward selection (conditional) method was used

^aVisible mold or damp spots in child's room, yes vs. no (ref.)

^bCondensation on window pane in winter: yes vs. no (ref.)

^cPerceived moldy air in child's room, often vs. not often (ref.)

^dPerceived dry air perception in child's room, often vs. not often (ref.)

^eFloor covering: modern floor covering (linoleum, PVC, carpet, wood, laminated wood) vs. traditional covering (stone or cement) (ref.)

^fWall covering: modern wall covering (paint, latex paint, wall paper, wood, textile) vs. traditional covering (stone, tile, lime) (ref.)

^gUse of air conditioner: yes vs. no (ref.)

^hUse of biomass/coal for cooking or heating

Table 2 (continued)

- ⁱETS, early: parents smoked during pregnancy or the child's first year. yes vs. no (ref.)
- ^jPet keeping at current home: yes vs. no (ref.)
- ^kNear to highway, yes vs. no (ref.)
- ^lDaycare attendance: child goes to daycare center vs. stays at home (ref.)
- ^mSun-cured bedding: sometimes/never vs. often (ref.)
- ⁿFast food consumption: $\geq$ once per week vs. occasionally (ref.)
- ^oBreast feeding, < 6 months vs. > 6 months (ref.)
- ^pDelivery of child: c-section vs. natural (ref.)
- ^qBirth weight, < 2.5 kg vs. > 2.5 kg (ref.)
- ^rInfection (pneumonia, croup, ear infection and common cold): yes vs. no (ref.)

decoration (modern floor coverings or wall covering), lack of ventilation (use of air conditioning in summer or condensation on window pane in winter), fast food consumption, infrequent sun-curing of bedding, and c-section delivery. To evaluate whether there is a dose–response relationship, we chose ≤ 1 factors as the reference, and calculated odds ratios for 2–4 factors and ≥ 4 factors for health endpoints. Figure 3 shows dose–response relationships of the modern index with each asthma and allergy-related health endpoint for children in the Tianjin region, China.

Discussion

This study shows strong associations between characteristics of modern life and asthma and allergy diseases in the Tianjin region, China. The strongest and most consistent risk factors are family allergic history, infections, home furnishing materials (new flooring materials and paint), indicators of a low ventilation rate (condensation on windows in winter, and air conditioning use in summer) and dry air perception. Low ventilation rates increase the concentrations of indoor-sourced pollutants, including those modern material emissions that appear to be risks for asthma and allergies. Elective c-section is a modern lifestyle behavior, and we found it to be a risk factor for asthma and allergy. Finally, living in a high-rise apartment building makes it almost impossible to sun-cure bedding, and this study found that lack of sun-cured bedding is also an asthma and allergy risk factor.

The historic trends of asthma and allergy prevalences have run parallel to the development of modern building materials and lifestyles. Asthma and allergy prevalence first increased in highly developed regions—western Europe, USA, Australia and New Zealand (Asher 1998). As developing countries progressed, their asthma and allergy prevalences increased. A prime example implicating changing lifestyle is that of west and east Germany. Prior to re-unification, prevalence was higher in the developed west than in the less-developed east. Following re-unification in 1990, prevalences in the east increased rapidly to where they caught up with those in the west (Krämer et al. 2015). Another example implicating reduced ventilation is that of northern Sweden where coincident with the drive to conserve energy in the 1970s (following the 1973 OPEC oil embargo), asthma and allergy prevalences increased (Aberg et al. 1995; Wickman et al. 1991).

The history of asthma and allergy prevalence in China is consistent with these worldwide trends. The proportion of children aged 0–14 diagnosed with asthma diagnosis increased by 2.5 times (from 0.46 to 1.15%) between 1990 and 2000 in Tianjin (National Cooperation Group on Childhood Asthma 2004). We found an even higher prevalence rate of diagnosed asthma (4.4%) in this Tianjin study. In

Table 3 Population attributable fractions of genetic factor (family history), home environmental exposures, lifestyles, and biological factors for asthma and allergy among children in Tianjin, China

	Wheeze ever (%)	Wheeze current (%)	Dry cough (%)	Diag. asthma (%)	Rhinitis ever (%)	Rhinitis current (%)	Diag. rhinitis (%)	Eczema ever (%)	Eczema current (%)	Diag. eczema (%)
Genetic										
Family allergic history	23	23	9	32	8	12	27	7	16	8
Home environment										
Visible mold/damp spot	8		3							
Condensation					7	8				5
Dry air perception	8	14	10		5	6	11	4		4
Use of AC unit								12	17	
Modern floor covering	23	29		30		23	11	13		
Modern wall covering	27				17	29				22
ETS parents, early				7						
Pet keeping								2	5	
Near to highway								3		
Life style										
Fast food consumption			4							
Less sun-curing of bedding			21		15		7	12		15
Biological										
C-section										
Infection ever	58	57	33	68	20	24	40	10	9	21

Beijing, surveys performed in 1990 (National Cooperation Group on Childhood Asthma 1993), 2000 (Ma et al. 2002), 2008 (Zhao et al. 2010) and 2011 (Qu et al. 2013) reported the prevalences of physician-diagnosed asthma to be 0.78%, 2.05%, 3.15% and 6.30%, respectively. In Shanghai, the prevalence of asthma for 3- to 7- year-old children has increased significantly, almost fivefold, from 2.1% in 1990 to 10.2% in 2011 (Huang et al. 2015). Prevalences of asthma and allergies among children in China are now as high as those in many developed countries, e.g., Singapore, Sweden and Germany (Asher 1998).

Although many Chinese, especially city dwellers, have adopted modern lifestyles, there remains a large segment of the population, mostly rural, whose lifestyle remains traditional. The present study has sufficiently different populations, modern Tianjin city dwellers and rurally based Cangzhou village citizens, that we can test the hypothesis that modern materials and lifestyle behaviors are related to the increasing prevalences of asthma and allergy in China.

A “modern” home in China is usually furnished with a laminated wooden floor instead of traditional cement/tile floors, and painted walls instead of traditional lime walls. Modern floor and wall materials, as well as the furnishings, emit more volatile organic compounds (VOCs) and semi-VOCs (SVOCs) than the traditional materials (Bornehag et al. 2005b; Choi et al. 2010), but because buildings have been more tightly constructed so as to be more energy efficient, the ventilation rates have been reduced, increasing the indoor concentrations of indoor-generated pollutants. In previous studies in Sweden and Texas, it was found that PVC flooring, as well as laminated wall covering, was associated with a significant increase of asthma prevalence among children (Sun and Sundell 2011; Bornehag et al. 2004a; Larsson et al. 2010). In China, laminated wooden floors and painted walls are popular in newly built homes, and both are strongly associated with asthma and allergies (Table 2). Moreover, plastic frame windows and AC units, which are proxies for less ventilation in homes, are risk factors. All these results are consistent with a previous study in Texas (Sun and Sundell 2011), which found that “fancy”, “modern” homes characterized by reduced outdoor fresh air and increased exposure to indoor chemicals were a greater risk for asthma and allergy than mobile trailers.

“Dampness” in this study was a risk factor, as has been reported in many studies (Bornehag et al. 2004b). Window pane condensation in winter was reported (Supplementary Table S2) far more frequently, 25.7%, than other dampness indicators. However, in addition to being a sign of dampness, condensation is an indicator of insufficient ventilation. Energy saving and “modern” building construction technologies make homes tighter, with less ventilation. A series of studies in Sweden showed that the air change rates in homes were reduced from 1.2 h^{-1} in 1948, to 0.8 h^{-1}

in 1968, 0.4 h^{-1} in 1991, and 0.25 h^{-1} in 2000 (Bornehag et al. 2005c; Sundell et al. 1995). In a Tianjin dormitory study, condensation was reported more often in newly built buildings and in rooms with plastic frame windows (compared to wooden frame windows) (Sun et al. 2009). Less ventilation does not efficiently remove indoor moisture, and consequently provides a suitable environment for house dust mite (HDM) infestation (Sundell et al. 1995). Sun-cured bedding is a simple but efficient way to protect children from exposure to HDM allergens, thereby addressing one known dampness-related health problem (Wang et al. 2013).

Another interesting finding in this study is that the perception of dry air is a strong risk factor for children’s allergies, consistent with previous office study (Sundell 1994a). Importantly, the sensation of “dryness” has been found most frequently to be due to polluted air, rather than to physical dry air (Andersen et al. 1974; Sundell and Lindvall 1994b).

Of the potential biological factors, c-section and infections were risk factors for childhood allergies. In our study, the cesarean delivery rate was 62% overall and 68% in Tianjin city, higher than the national level of 46% (Lumbiganon et al. 2010) and far exceeding the recommended upper threshold by WHO of 15% (Althabe and Belizán 2006). The potential mechanism underlying the increased risk of allergies with c-section is less exposure to microbes at birth. Additionally, a WHO survey in Asia showed that among all the cesarean deliveries, 25% were done without medical indications, and 62% of these were attributed to hospitals’ financial incentives (Lumbiganon et al. 2010).

An explanation for the rise in prevalence of allergic diseases is the “hygiene hypothesis” (Strachan 1989), which posits that allergic disease develops more often in tidy places and among people whose immune system is seldom challenged by infections. However, in this study, we found the opposite. As shown in Table 2 and Supplementary Table S25, infection, namely croup, ear infection, pneumonia and the common cold, had a significant positive association with children’s asthma and allergy ($P < 0.05$). Humans are usually infected indoors rather than outdoors (Norbäck et al. 2017; Zhuge et al. 2018). Our data demonstrates that day-care attendance has significant association with infections (See Supplementary Figure S1). Children who started day-care earlier in crowded centers were reported to have more infections. Fifty-five percent of the children in our study had always used antibiotics, for which 98% were because of infections/inflammations (See Supplementary Table S26). After adjusting for infections, the significant negative influence of antibiotics on current wheeze and current eczema disappeared (see Supplementary Table S28). This indicates that use of antibiotics is a proxy for infections rather than a contributor to children’s asthma and allergies.

In the present study, we have endeavored to include all potential risk factors for asthma and allergies in the hopes of

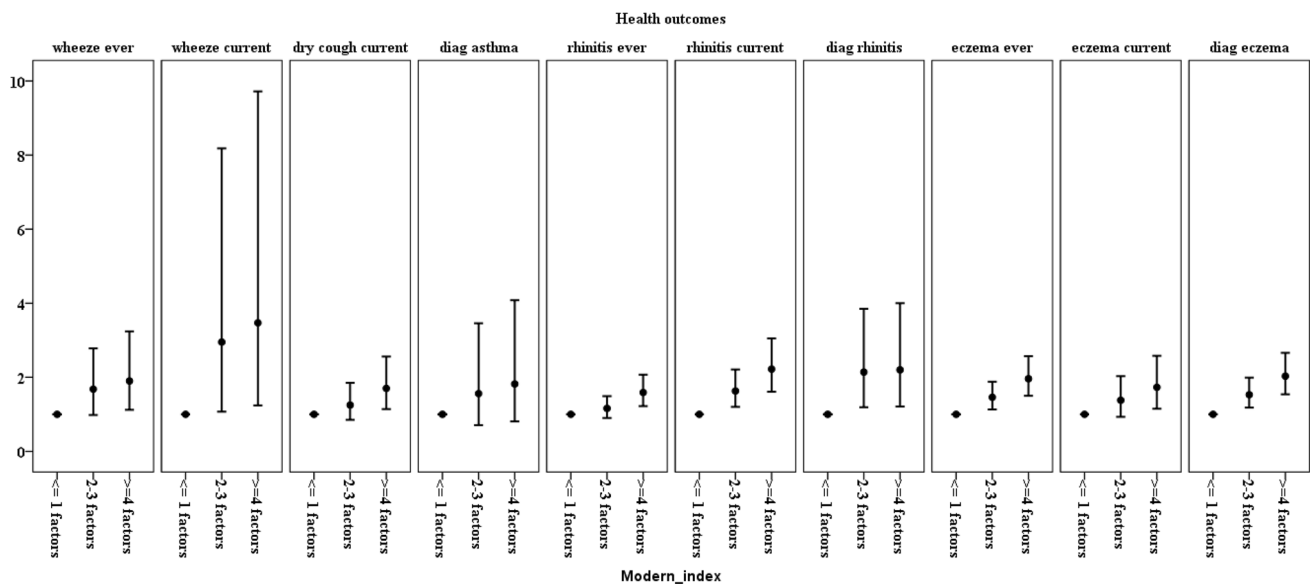


Fig. 3 Adjusted odds ratios for associations between the number of modern life factors and asthma/allergy diseases among children in the Tianjin region, China. The modern index consists of modern decoration (modern floor covering and wall covering), lack of ventilation

(indicated by use of air conditioner and condensation on window pane), fast food consumption, infrequent sun-curing of bedding, and c-section delivery. Odds ratios are adjusted for gender, age, family allergic history, and home location

identifying any pattern(s). The one clear pattern we identified is that modern materials and lifestyle behaviors pose the strongest risk. Our basis for comparison, the large segment of the Chinese population living in dwellings constructed from pre-modern materials, strengthens our conclusion. To summarize our findings, the greatest risks are associated with infections, family allergic history, various indoor factors (i.e., laminated wood floors compared to tile/cement, painted walls compared to lime-coated walls, low rates of ventilation), less sun-curing of bedding, and c-section delivery. In agreement with many previous studies, dampness as approximated by the presence of various indicators, was also a strong risk. We note however that one of the objective dampness indicators, window condensation, is also an indicator of low ventilation rate.

Limitations

This study is subject to the limitations inherent in any cross-sectional study. Data were collected retrospectively relying on parental reports, and could therefore be subject to recall bias. However, questions on health outcomes and exposures in our study have been validated in previous studies, which have showed that self-reported allergic symptoms are consistent with medical examinations and that parental reports on dampness exposures were more reliable than onsite inspections (Sun et al. 2007). Some studies have demonstrated that parental reports of childhood asthma can

identify more than 94% cases of diagnosed asthma (Mak et al. 1982). The response rate in the present study was 78%, which reduces the likelihood of selection bias. Ideally, our questionnaire would have addressed even more issues, but we limited the number of questions so as to obtain a high response rate.

Conclusions

Children in damp homes with laminated floor and painted walls reported more wheeze, rhinitis and eczema. Infection, rather than use of antibiotics, is a substantial risk factor for developing or exacerbating allergic symptoms among children. Perceived dryness in homes, which indicates polluted air, is a significant risk factor for asthma and all allergic diseases. In general, a “modern” home environment (i.e., with more modern materials, less ventilation) together with a modern lifestyle (i.e., more fast food consumption, more c-section, less sun-curing of bed sheets) increases the prevalence of asthma and allergies among children. Management of asthma and allergy among children requires an encompassing environmental approach. Increasing ventilation rate in homes and daycares, controlling indoor potential VOC and SVOC sources, educating children’s caregivers on smoking habits, and educating parents on delivery methods are important.

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Author contributions YS and JS designed the study, performed the questionnaire survey, analyzed the data and wrote the manuscript. LW and YS analyzed the data and wrote the manuscript. JH and XK performed the questionnaire survey. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethical approval Ethical approval was obtained from the Research Office at Tianjin University. Our participants provided verbal informed consent to participate in this study. This study is an anonymous questionnaire survey. It involves no risk to the subjects. The study could not be carried out practically with written consent. Completed surveys reflected participant consent. The completed surveys were stored in a lock cabinet. The Tianjin University Research Office approved this consent procedure.

Conflict of interest The authors declare that they have no competing interests.

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