Children's lung function in relation to changes in socioeconomic, nutritional, and household factors over 20 years in Lanzhou

Sai Li[1#], Suzhen Cao[1#], Xiaoli Duan[1], Yaqun Zhang[2], Jicheng Gong[3], Xiangyu Xu[1], Qian Guo[1], Xin Meng[3], Mcswain Bertrand[1], Junfeng Jim Zhang[4,5,6]

[1]School of Energy and Environmental Engineering, University of Science and Technology Beijing, Beijing, China; [2]Gansu Provincial Design and Research Institute of Environmental Science, Lanzhou, China; [3]Beijing Innovation Center for Engineering Science and Advanced Technology, State Key Joint Laboratory for Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, And Center for Environment and Health, Peking University, Beijing, China; [4]Global Health Research Center, Duke Kunshan University, Kunshan, China; [5]Nicholas School of the Environment and Duke Global Health Institute, Duke University, Durham, USA; [6]Guangzhou Institute of Respiratory Health, The First Affiliated Hospital of Guangzhou Medical University, Guangzhou, China

Contributions: (I) Conception and design: JJ Zhang, J Gong, X Duan; (II) Administrative support: Y Zhang, S Cao; (III) Provision of study materials or patients: S Cao, Y Zhang, X Duan; (IV) Collection and assembly of data: S Li, X Xu, Q Guo; (V) Data analysis and interpretation: S Li, Q Guo, J Gong, X Meng; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work as co-first authors.

Correspondence to: Xiaoli Duan, PhD. University of Science and Technology Beijing, 30 Xueyuan Road, Beijing 100083, China. Email: jasmine@ustb.edu.cn.

Background: Lanzhou has experienced rapid urbanization, leading to changes in socioeconomic, nutritional, and household factors. These changes may affect children's lung function.

Methods: Two cross-sectional studies of school-age children (6–13 years of age) from the urban (Chengguan) (Period 1 in 1996 with n=390; Period 2 in 2017 with n=192) and the suburban (Xigu) (Period 1 n=344; Period 2 n=492) district were conducted. Demographic information, household factors, and nutrition status were obtained via a questionnaire survey. Forced vital capacity (FVC) and forced expiratory volume in the first second (FEV_1) were measured in each period. Student's t-test analysis of variance was used to assess the differences in FVC and FEV_1 between Periods 1 and 2. Generalized linear models were used to analyze the associations between questionnaire derived factors and lung function. Analyses were done separately for girls and boys.

Results: Children had significantly lower mean FEV_1 and FVC measures in Period 2 than in Period 1. This reduction was greater in children living in the urban area than those living in the suburban area. Obese children had significantly lower lung function but this was only statistically significant in Period 1.

Conclusions: Children's lung function (FVC and FEV_1) were lower in 2017 than in 1996. Rapid urbanization may have contributed to the decline of lung function. Obesity may be a risk factor for impaired lung function in children living in Lanzhou and possibly elsewhere.

Keywords: Lung function; nutritional status; anthropometrics; urban; schoolchildren

Introduction

Lung function tests using standard spirometry have been useful in the care of children with chronic respiratory diseases, including asthma, cystic fibrosis, and interstitial lung diseases (1). Lung function assesses diagnosis, follow-up, monitoring, and objective determination of the children's response to interventions. Lung function parameters are, however, affected by various factors, including anthropometric, nutritional status, ambient environment, and sociodemographic factors (2). People,

particularly women and children, spend most of their time indoors, which makes these groups more susceptible to household air pollution (HAP). Lung function has been used to assess the health impact of HAP (3,4). Pre-clinical studies of lung and respiratory tract cell lines have established the adverse effects of particulate matter (PM) emissions from biomass combustion (5). The place of domicile and the socio-economic class that children belong to could be a surrogate for the level and duration of exposure to PM and noxious gases both outdoors and indoors. These factors may affect lung function of children (6-8). Associations between low socio-economic status (SES) and impaired lung function both in children and adults have been studied mainly in European countries and North America (9,10).

Urban environments can also adversely affect health. This effect can be ascribed to several factors in addition to air pollution, including dietary habits, socioeconomic status, infections, stress, allergic exposure, and parasitic infections (11). Inner-city children appear to have more episodes of acute respiratory infection than those living in rural areas (11) and lung function growth rate is higher in rural children than urban children (12), although this effect could be reversible (13).

Many of these factors potentially affecting lung function have changed substantially in the past decades in Chinese cities experiencing rapid economic growth and urban expansion. Between 1993–1996, a cohort of elementary school children in Lanzhou performed lung function tests and were and surveyed for their family's socioeconomic status and household environmental conditions. To assess whether there are differences in children's lung function between then and more recent years, we conducted a follow-up study in children of the same age range living in the same areas of the city. In this paper, we aim to compare children's lung function between Period 1 (1996) and Period 2 (2017) and to explore the relative importance of an urban-rural setting and other potential risk factors for lung function. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/jtd-20-2232).

Methods

Site selection and subject recruitment

The two cross-sectional investigations took place in 1996 (Period 1) and 2017 (Period 2). Spirometry tests were conducted among children living in Lanzhou, a typical

industrial city in northwestern China. The municipality of this provincial capital of Gansu is comprised of 5 districts including Chengguan, Qilihe, Xigu, Anning, and Honggu, covering an area of approximately 13,085 km^2, with a population of about 3.7 million in 2017. Two primary schools were randomly selected from the urban district of Chengguan and the suburban district of Xigu, respectively. Children at these schools were enrolled into the study, upon their parents having signed a written consent form to voluntarily participate in a questionnaire survey and lung function tests. Children in grades 2 to 5 were randomly selected by gender and age for lung function tests. A total of 1,418 children underwent spirometry, 734 in Period 1 (53.1% urban; 50.9% male) and 684 in Period 2 (28.1% urban; 54.2% male). We excluded children from the study if they had lived at their current home for less than three years. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Biomedicine Research, Duke Kunshan University (No. FWA00021580).

Questionnaire survey

Questionnaires were filled out by children's parents to collect information on parental smoking habits, whether children sleep in own beds, whether children sleep in their own rooms, the style of kitchen, fuel for cooking, types of kitchen ventilators, parental occupation, and parental education levels. In the same year as the questionnaire survey, children performed spirometry in their schools. The questionnaire used in Period 1 was adapted from the American Thoracic Society (ATS) questionnaire (14). The questionnaire used in Period 2 maintained the same questions as long as they were still relevant (e.g., what became irrelevant).

Variables associated with housing factors are defined as, parental smoking [or environmental tobacco smoke (ETS)], sleeping in own room, sleeping in own bed, kitchen style, coal fuel use, and ventilation use. District refers to urban and suburban. ETS was defined as ETS at home, including paternal and maternal smoking. Kitchen style refers to separated and open kitchen types. Coal fuel use was defined from the question "What was the main fuel type for cooking?" and "What was the main fuel type for heating?" Ventilation use was defined by the "Yes" answer to the question "Was there a ventilation device in the kitchen when cooking?"

Distribution of indoor air pollution related variables

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(i.e., parental smoking, kitchen style, coal use for cooking and ventilation use) and socioeconomic factors (parental occupation and education) across the different studies were explored. We combined information on coal use for cooking and that for heating to create a binary variable: household coal use (yes *vs*. no). Similarly, the presence of all ventilation devices (chimney, hood, and exhaust fan) was collapsed to create a binary variable: ventilation use (yes *vs*. no). We combine parental information on education to make a binary variable: below senior high school *vs*. with or above high school. Parental information on occupation was classified by the manual laborer (e.g., farmers, factory workers and plasterer) versus nonmanual laborer (e.g., teachers, governmental office workers and doctor).

Anthropometric measurements

Children were measured for their body weight using a weighing scale (Jiangsu Suhong Medical Equipment Co. Ltd., China) to the nearest 0.5 kg and height using an RGZ-120 stadiometer (Jiangsu Suhong Medical Equipment Co. Ltd., China) to the closest 0.5 cm. Each study participant stood erect without shoes on the stadiometer. The children were required to put their feet together with their heels, buttocks, and occiput touching the wall while they look straight ahead to ensure accurate measurement of their height. Body mass index (BMI) in kg/m^2 was calculated from body weight and height. The evaluation criteria for stunting in children used in the present study followed the WHO 2006 definition (15). The National Health Commission of the People's Republic of China also issued the latest child development standards in 2018 (16). Height for age and sex measures were classified as no stunting (z-scores $\geq$–2SD) and stunting (z-scores <–2SD) (17). The evaluation criteria for overweight and obesity in teenagers (6–18 years) refer to the "*Screening for overweight and obesity among school-age children and adolescents*", published by The National Health Commission of the People's Republic of China (18). For example, for 6-year-old boys, they were overweight if having a BMI between 16.4 and 17.7 kg/m^2 and obesity if having a BMI $\geq$17.7 kg/m^2.

Measurement of lung function

The standardized spirometry protocol of the ATS was followed to measure lung function using computerized Warren E. Collins Survey II 8-liter water-seal volume Spirometers in Period 1 and Spiro-lab MIR, Italy in Period 2 by trained technicians (1). Children performed spirometry in the standing position in a dedicated room at each school. For this analysis, we assessed two lung function indices including forced vital capacity (FVC, mL) and the forced expiratory volume in one second (FEV_1, mL). For each participant, the spirometry test was repeated (up to five times) until acceptable, reproducible flow-volume loops were generated (1). Between one test and the next, the device evaluates the repeatability of the following parameters: repeatable when the difference between the two highest FVC value is $\leq$150 mL and the FEV_1 value is $\leq$150 mL. Acceptable spirograms were defined as a smooth flow-volume curve without artifacts and satisfactory exhalation of forced expiratory duration >6 s (3 s for children younger than 10 years). If the difference between the two largest FVC values were within 150 mL, the test was concluded. The highest acceptable values of FVC and FEV_1 were selected for statistical analysis.

Statistical methods

Descriptive analysis was utilized to characterize the study sample and lung function indices. In each study group, the mean ± SD was calculated for continuous variables, and frequencies (percentage) were calculated for categorical variables. Differences in lung function (continuous variable) between categorical variables (e.g., gender) or between the two study periods were analyzed using Student's *t*-test, whereas categorical variables between two study periods were analyzed using Pearson's Chi-square test and Fisher's exact test, as appropriate. Spearman's rank correlation tests were carried out to evaluate the relationship between anthropometric measurements and lung function indices.

We primarily examined the overall associations between residential location (urban *vs*. suburban), as well as overweight or obesity (overweight *vs*. normal; obesity *vs*. normal), and lung function parameters during Periods 1 and 2, respectively. Generalized linear regression models (GLM) were used to assess changes of lung function and their 95% confidence intervals (95% CIs) associated with the residential location and overweight or obesity in Periods 1 and 2. Age, height, weight, gender, and other socioeconomic and household factors were controlled in the models. In addition, we performed a sensitivity analysis to examine the associations between residential location/ overweight/obesity and lung function among girls and boys separately. The GLM was conducted using SPSS package (version 22, IBM Inc., Armonk, New York, NY, USA). We

tested the significance of all the statistics at a significance level of 0.05, and calculated 95% CIs.

Results

Study participants

A total of 1,418 (734 Period 1 and 684 Period 2) school children took part in the study. The mean (SD) age of school children was 10.2 (1.7) years in Period 1 and 9.4 (1.3) years in Period 2. There was no significant difference in the gender of the children in Period 1 (51.0% male) and Period 2 (54.2% male). Likewise, no difference was found in the breastfeeding rate. We included more urban participants in Period 1 (53.1%) compared to those in Period 2 (28.1%).

Difference in SES and household environmental factors between the two periods

Details about household characteristics and socioeconomic level are shown in *Table 1*. The proportion of children with ETS exposure (paternal or maternal smoking) was significantly greater in Period 1 (83.5%) than in Period 2 (57.2%). More families used coal as cooking and/or heating fuel in Period 1 than Period 2 (82.7% versus 4.5%). Using a ventilation device during cooking was more common in Period 2 (98.7%) than in Period 1 (87.1%). A higher proportion of children lived in overcrowded homes in Period 1 than in Period 2, for example, 20.6% of children slept in their own rooms in Period 1 versus 52.0% in Period 2. Fewer homes had closed kitchens in Period 1 (24.9%) than in Period 2 (35.7%).

The proportion of manual laborers among children's fathers was unchanged from Period 1 to Period 2, whereas the proportion among children's mothers was decreased from 77.7% in Period 1 to 71.5% in Period 2 (P=0.018). The proportions of lower educational attainment (below high school) in both fathers and mothers were significantly smaller in Period 2 than in Period 1 (see *Table 1*).

Nutritional status, anthropometric indices and lung function

The Periods 1–2 disparities in anthropometric indices, nutritional factors, and lung function parameters are presented in *Tables 1,2*. The mean (SD) weight of the 734 schoolchildren of Period 1 was 28.79 (7.45) kg, ranging from 16.0 to 63.8 kg. Their height ranged from 107.00 to 167.00 cm with a mean (SD) height of 133.83 (10.94) cm. Children of Period 2 were heavier and taller than Period 1 participants. Likewise, their BMI was significantly higher than that of the children in Period 1 (*Table 1*). Considering nutritional status, more children in Period 1 were stunted (P<0.001) compared to Period 2. Greater proportions of children in Perion 2 were overweight and obese in comparison to the children of Period 1 (P<0.001).

In Period 1, the mean (SD) FVC of the school children was 2,516.4 (635.3) mL, ranging from 1,092 to 4,932 mL. The mean (SD) FEV_1 was 2,098.9 (549.6) mL with arrange from 898 to 4,098 mL. In Period 2, the mean (SD) FVC of the participants was 1,933.4 (432.7) mL, ranging from 820 to 4,010 mL. The mean (SD) FEV_1 was 1,740.5 (374.6) mL, which ranged from 820 to 3,080 mL. Both the mean FEV_1 and mean FVC were significantly higher in Period 1 children than those of the Period 2 counterparts. The differences between the two periods remained statistically significant in gender stratified comparisons (*Table 2*).

Association of lung function with anthropometric indices, socio-demographic variables, household environmental factors, and nutritional status

In addition to age, anthropometric parameters like weight, height, and BMI were positively correlated with FEV_1 and FVC of the children (P<0.05) (*Tables 3,4*). Both FEV_1 and FVC had stronger correlations with age, weight, height, and BMI among the Period 1 children than among the Period 2 children.

Associations of lung function with sociodemographic variables, household factors, nutritional status in two periods are presented for boys in *Table 5* and for girls in *Table 6*. In Period 1, boys and girls from the urban area had significantly lower FVC and FEV_1 than those from the suburban area. For example, boys had mean (SD) FVC of 2,468 (566) in the urban *vs.* 2,727 (632) in the suburban area (P<0.001) and mean (SD) FEV_1 of 2,020 (471) *vs.* 2,256 (548) (P<0.001). Children from overcrowded homes (e.g., shared room and shared bed) had lower FVC and FEV_1 (P<0.05) than those who slept in their own bed/room. Boys from open kitchen families had significantly lower FVC and FEV_1 than those from separated kitchen families.

Boys with paternal non-manual laborer occupation had significantly higher FVC and FEV_1 than those with paternal manual laborer occupation. Stunting was significantly associated with lower FVC and FEV_1 among boys from

Table 1 Anthropometric and socio-demographic characteristics and potential risk factors, comparing between the two study periods

Characteristics	Period 1	Period 2	P value
Study participants, n	734	684	
Age, years	10.2 (1.7)	9.4 (1.3)	0.312
Male sex, n (%)	374 (51.0)	371 (54.2)	0.216
Urban, n (%)	390 (53.1)	192 (28.1)	<0.001
Breast feeding, n (%)	579 (78.9)	531 (77.6)	0.568
Housing factors, n (%)			
ETS[a]	613 (83.5)	391 (57.2)	<0.001
Sleep in own room	151 (20.6)	356 (52.0)	<0.001
Sleep in own bed	490 (66.8)	470 (68.7)	0.431
Separated kitchen	183 (24.9)	244 (35.7)	<0.001
Coal fuel use	607 (82.7)	31 (4.5)	<0.001
Ventilation use while cooking	639 (87.1)	675 (98.7)	<0.001
Socio-demographic			
Paternal occupation			
Manual laborer[b], n (%)	564 (77.8)	526 (76.9)	0.978
Maternal occupation			
Manual laborer, n (%)	565 (77.7)	489 (71.5)	0.018
Paternal education			
Below senior high school, n (%)	681 (93.8)	326 (47.7)	<0.001
Maternal education			
Below senior high school, n (%)	711 (96.9)	347 (50.7)	<0.001
Anthropometric indices			
BMI, kg/m^2	15.80 (1.97)	17.64 (4.04)	<0.001
Height, cm	133.83 (10.94)	137.82 (9.01)	<0.001
Weight, kg	28.79 (7.45)	33.86 (9.75)	<0.001
Nutrition status			
Stunting, n (%)	24 (3.3)	5 (0.7)	<0.001
Obesity levels, n (%)			
Overweight	17 (2.3)	97 (14.2)	<0.001
Obesity	10 (1.4)	85 (12.4)	<0.001

Values are mean (SD) or number (percentage). [a], defined as passive smoke at home, including paternal and maternal smoking; [b], categorized into manual laborer (famer and factory worker) and non-manual laborer (educational personnel, medical personnel, businessmen, civil servants and soldiers). ETS, environmental tobacco smoke; BMI, body mass index; SD, standard deviation.

Table 2 Lung function measurements of school-age children, comparing between the two study periods

Spirometry[a]	Period 1 (n=734)	Period 2 (n=684)	P value
FVC, mL	2,516.4±635.3	1,933.4±432.7	<0.001
Boy	2,588.8±610.4	2,012.4±418.8	<0.001
Girl	2,441.2±652.5	1,839.7±430.8	<0.001
FEV_1, mL	2,098.9±549.6	1,740.5±374.6	<0.001
Boy	2,129.6±520.9	1,802.1±348.8	<0.001
Girl	2,067.1±576.9	1,667.4±391.2	<0.001

Values are mean (SD). Lung function measurements are given in mL. [a], FVC and FEV_1 agreeing within 150 mL between the best two blows. FVC, forced vital capacity; FEV_1, forced expiratory volume in the first second; SD, standard deviation.

Table 3 Correlation between anthropometric indices and lung function in boys

Variables	Period 1				Period 2			
	Correlation coefficient with FVC	P value	Correlation coefficient with FEV_1	P value	Correlation coefficient with FVC	P value	Correlation coefficient with FEV_1	P value
Age, years	0.751	<0.001	0.739	<0.001	0.444	<0.001	0.479	<0.001
Weight, kg	0.826	<0.001	0.810	<0.001	0.588	<0.001	0.589	<0.001
Height, cm	0.888	<0.001	0.864	<0.001	0.669	<0.001	0.700	<0.001
BMI, kg/m^2	0.469	<0.001	0.472	<0.001	0.365	<0.001	0.345	<0.001

BMI, body mass index; FVC, forced vital capacity; FEV_1, forced expiratory volume in the first second.

Table 4 Correlation between anthropometric indices and lung function in girls

Variables	Period 1				Period 2			
	Correlation coefficient with FVC	P value	Correlation coefficient with FEV_1	P value	Correlation coefficient with FVC	P value	Correlation coefficient with FEV_1	P value
Age, years	0.736	<0.001	0.724	<0.001	0.496	<0.001	0.542	<0.001
Weight, kg	0.874	<0.001	0.849	<0.001	0.454	<0.001	0.440	<0.001
Height, cm	0.907	<0.001	0.898	<0.001	0.682	<0.001	0.710	<0.001
BMI, kg/m^2	0.606	<0.001	0.567	<0.001	0.169	0.003	0.141	0.0123

BMI, body mass index; FVC, forced vital capacity; FEV_1, forced expiratory volume in the first second.

Period 1 [mean (SD) FVC 2,056 (483) *vs.* 2,607 (607) mL; P=0.002) and mean (SD) FEV_1 1,730 (428) *vs.* 2,143 (519) mL; P=0.005)]. A similar effect of stunting was also observed in Period 1 girls. Boys and girls who were breastfed had significantly higher FVC and FEV_1 than those never breastfed. In Period 2, overweight and obese boys (but not girls) had a significantly higher FVC and FEV_1 than those with normal BMI from unadjusted analysis.

Effects of residential location and overweight/obesity on lung function in Period 1 and Period 2

Further multivariate regression analysis of residential location and overweight/obesity effect on lung function was conducted. Significant effects of living in the urban area on FVC and FEV_1 were observed among male and female participants in Period 2 but not in Period 1 (*Figure 1*). After adjusting for potential confounding variables, we estimated that living in

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Table 5 Sociodemographic and household variables and nutritional status in relation to boys' lung function by period

Variables	Period 1				Period 2			
	FVC (mL)		FEV$_1$ (mL)		FVC (mL)		FEV$_1$ (mL)	
	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value
Residential location								
Rural	2,727 (632)	<0.001	2,256 (548)	<0.001	2,047 (435)	0.025	1,802 (363)	0.665
Urban	2,468 (566)		2,020 (471)		1,924 (362)		1,802 (312)	
ETS								
No	2,358 (568)	0.049	1,929 (499)	0.063	2,037 (460)	0.550	1,808 (374)	0.776
Yes	2,632 (609)		2,167 (517)		1,994 (393)		1,800 (332)	
Sleeping in own room								
Yes	2,904 (696)	<0.001	2,398 (598)	<0.001	2,073 (438)	0.003	1,943 (386)	0.142
No	2,507 (559)		2,060 (476)		1,831 (360)		1,769 (334)	
Sleeping in own bed								
Yes	2,642 (621)	0.008	2,164 (529)	0.034	2,045 (438)	0.025	1,825 (355)	0.099
No	2,449 (561)		2,038 (490)		1,933 (358)		1,748 (327)	
Kitchen								
Open	2,541 (586)	0.010	2,092 (498)	0.028	2,002 (406)	0.511	1,780 (338)	0.123
Separated	2,751 (665)		2,257 (577)		2,031 (441)		1,841 (365)	
Coal fuel use								
No	2,658 (619)	0.329	2,176 (513)	0.414	2,021 (426)	0.085	1,805 (353)	0.333
Yes	2,575 (609)		2,121 (523)		1,824 (216)		1,698 (260)	
Ventilation use								
No	2,772 (687)	0.047	2,269 (567)	0.106	1,943 (206)	0.756	1,793 (273)	0.983
Yes	2,564 (596)		2,111 (512)		2,014 (421)		1,802 (350)	
Paternal occupation								
Nonmanual laborer	2,709 (674)	0.049	2,210 (563)	0.083	2,102 (450)	0.052	1,873 (373)	0.028
Manual laborer	2,555 (589)		2,107 (507)		1,985 (405)		1,780 (339)	
Maternal occupation								
Nonmanual laborer	2,664 (620)	0.136	2,203 (519)	0.066	2,055 (443)	0.256	1,813 (359)	0.491
Manual laborer	2,565 (607)		2,106 (520)		1,996 (408)		1,798 (345)	
Paternal education								
~Senior high school	2,750 (839)	0.487	2,253 (660)	0.393	2,022 (432)	0.789	1,794 (358)	0.343
Senior high school~	2,578 (592)		2,121 (510)		2,001 (404)		1,812 (338)	
Maternal education								
~Senior high school	2,779 (768)	0.493	2,276 (587)	0.380	2,023 (443)	0.695	1,813 (368)	0.728
Senior high school~	2,581 (603)		2,123 (518)		2,003 (395)		1,792 (330	

Table 5 (*continued*)

Table 5 (*continued*)

Variables	Period 1				Period 2			
	FVC (mL)		FEV$_1$ (mL)		FVC (mL)		FEV$_1$ (mL)	
	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value
Breast feeding								
No	2,418 (621)	<0.001	1,985 (501)	0.004	1,973 (374)	0.367	1,789 (343)	0.800
Yes	2,630 (602)		2,164 (521)		2,025 (432)		1,806 (351)	
Stunting								
No	2,607 (607)	0.002	2,143 (519)	0.005	2,012 (419)	NA	1,802 (349)	NA
Yes	2,056 (483)		1,730 (428)		NA		NA	
Obesity								
No	2,580 (616)	0.266	2,120 (523)	0.145	1,944 (374)	<0.00	1,754 (322)	<0.001
Overweight	2,803 (513)		2,338 (476)		2,090 (429)		1,854 (353)	
Obesity	2,699 (300)		2,297 (368)		2,224 (504)		1,954 (405)	

~Senior high school: below senior high school level; senior high school~: with/above senior high school. NA, no data available, which presents no male children in Period 2 were found stunting; FVC, forced vital capacity; FEV$_1$, forced expiratory volume in the first second; SD, standard deviation.

Table 6 Sociodemographic and household variables and nutritional status in relation to girls' lung function by period

Variables	Period 1				Period 2			
	FVC, mL		FEV$_1$, mL		FVC, mL		FEV$_1$, mL	
	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value
Residential location								
Rural	2,581 (679)	<0.001	2,208 (596)	<0.001	1,855 (437)	0.466	1,665 (393)	0.792
Urban	2,316 (603)		1,941 (529)		1,801 (414)		1,674 (388)	
ETS								
No	2,285 (587)	0.039	1,930 (502)	0.062	1,838 (413)	0.745	1,648 (373)	0.797
Yes	2,474 (662)		2,096 (588)		1,810 (410)		1,653 (387)	
Sleep in own room								
Yes	2,653 (663)	0.001	2,262 (613)	<0.001	1,897 (453)	0.023	1,732 (409)	0.005
No	2,386 (640)		2,017 (557)		1,780 (399)		1,601 (362)	
Sleep in own bed								
Yes	2,454 (671)	0.645	2,082 (597)	0.588	1,869 (444)	0.070	1,700 (397)	0.029
No	2,422 (625)		2,044 (545)		1,783 (399)		1,602 (373)	
Kitchen								
Open	2,411 (629)	0.340	2,036 (557)	0.190	1,826 (419)	0.516	1,656 (394)	0.449
Separated	2,521 (710)		2,151 (623)		1,866 (454)		1,688 (388)	

Table 6 (*continued*)

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Table 6 (*continued*)

Variables	Period 1				Period 2			
	FVC, mL		FEV$_1$, mL		FVC, mL		FEV$_1$, mL	
	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value	Mean (SD)	P value
Coal fuel use								
No	2,548 (665)	0.135	2,190 (592)	0.048	1,843 (429)	0.625	1,672 (391)	0.580
Yes	2,417 (648)		2,040 (571)		1,859 (446)		1,687 (402)	
Ventilation use								
No	2,511 (750)	0.763	2,128 (646)	0.653	1,783 (336)	0.873	1,550 (100)	0.564
Yes	2,430 (636)		2,057 (566)		1,840 (432)		1,669 (393)	
Paternal occupation								
Nonmanual laborer	2,481 (661)	0.437	2,130 (579)	0.200	1,902 (451)	0.203	1,710 (441)	0.439
Manual laborer	2,428 (650)		2,046 (576)		1,821 (424)		1,655 (375)	
Maternal occupation								
Nonmanual laborer	2,512 (658)	0.233	2,133 (544)	0.143	1,868 (416)	0.320	1,683 (417)	0.624
Manual laborer	2,421 (651)		2,049 (585)		1,828 (437)		1,661 (381)	
Paternal education								
~Senior high school	2,565 (512)	0.120	2,217 (465)	0.047	1,838 (431)	0.792	1,672 (390)	0.534
Senior high school~	2,430 (663)		2,054 (584)		1,841 (431)		1,663 (393)	
Maternal education								
~Senior high school	2,588 (561)	0.400	2,150 (546)	0.594	1,844 (416)	0.446	1,665 (380)	0.788
Senior high school~	2,438 (655)		2,065 (578)		1,835 (446)		1,670 (403)	
Breast feeding								
No	2,232 (613)	<0.001	1,894 (512)	<0.001	1,860 (396)	0.584	1,691 (364)	0.473
Yes	2,504 (652)		2,119 (586)		1,835 (440)		1,662 (398)	
Stunting								
No	2,465 (647)	<0.001	2,088 (572)	<0.001	1,844 (426)	0.072	1,671 (388)	0.085
Yes	1,758 (402)		1,462 (350)		1,552 (659)		1,452 (587)	
Obesity								
No	2,437 (644)	0.796	2,065 (570)	0.905	1,801 (413)	0.006	1,644 (390)	0.084
Overweight	2,465 (963)		1,991 (614)		2,046 (440)		1,797 (386)	
Obesity	2,733 (999)		2,283 (1043)		1,944 (507)		1,722 (386)	

~Senior high school: below senior high school level; senior high school~: with/above senior high school. FVC, forced vital capacity; FEV$_1$, forced expiratory volume in the first second; SD, standard deviation.
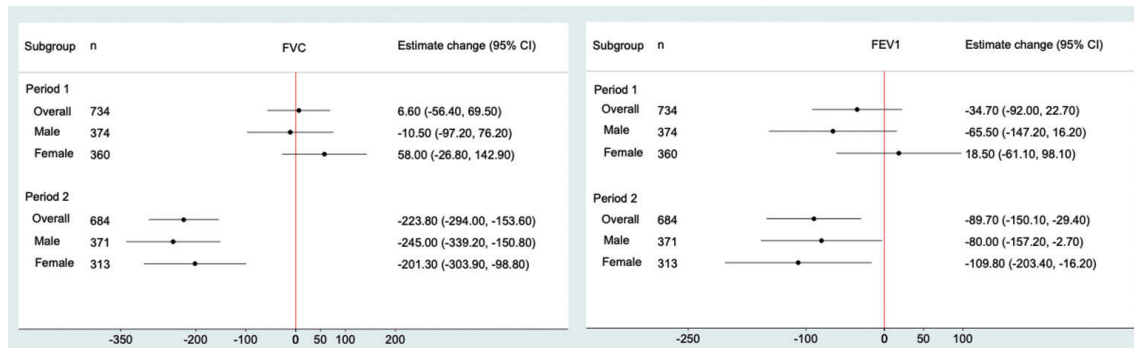
Figure 1 Adjusted changes and 95% CIs for lung function among boys and girls associated with residential location (urban *vs.* suburban) in 3 Period 1 and Period 2. Adjusted changes were estimated from regression models controlling height, weight, gender, age, ETS, sleep in shared room/bed, household coal use, kitchen mode, ventilation use while cooking, parental occupation, parental education level, breastfeeding and overweight/obesity. FVC, forced vital capacity; FEV$_1$, forced expiratory volume in the first second; SD, standard deviation; CI, confidence interval; ETS, environmental tobacco smoke.
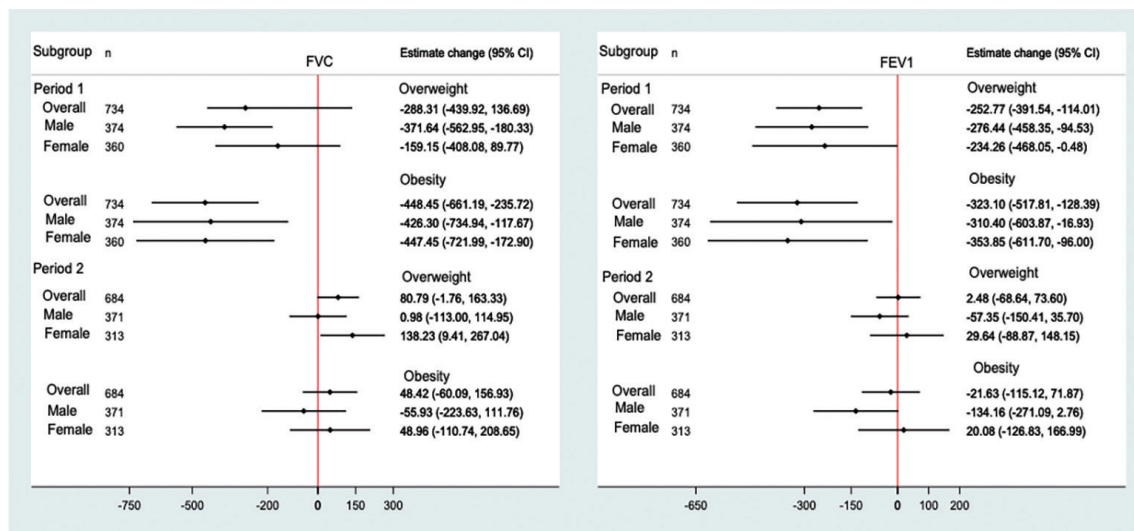
Figure 2 Adjusted changes and 95% CIs for lung function among boys and girls associated with overweight/obesity in Period 1 and Period 2. Adjusted changes were estimated from regression models controlling height, weight, gender, age, residential location, ETS, sleep in shared room/bed, household coal use, kitchen mode, ventilation use while cooking, parental occupation, parental education level and breastfeeding. FVC, forced vital capacity; FEV$_1$, forced expiratory volume in the first second; SD, standard deviation; CI, confidence interval; ETS, environmental tobacco smoke.

the urban area was associated with a –223.8 mL (95% CI: –294.0, –153.6 mL) reduction in FVC and an –89.7 mL (95% CI: –150.1, –29.4 mL) reduction in FEV$_1$ among the overall children during Period 2 (*Figure 1*). The largest differences were observed for boys' FVC (–245.0 mL; 95% CI: –339.2, –150.8 mL) and for girls' FEV$_1$ (–109.8 mL; 95% CI: –203.4, –16.2 mL).

Due to the low prevalence of reported stunting during

Period 2, no further analysis was conducted for the effects of stunting. The declines of lung function, after adjusting for height, weight and variables in *Table 1*, in overweight and obese children were significant in Period 1 but not in Period 2 (*Figure 2*). We estimated an FVC reduction of –371.64 mL (95% CI: –562.95, –180.33 mL) in overweight boys compared with normal weight boys in Period 1. The FVC reduction was observed in girls as well, although

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statistical significance was not reached. For FEV_1, a significant reduction was seen for both boys and girls in Period 1. Significant effects of obesity on lung function were observed among children in Period 1. Multivariable linear regression analysis confirmed an estimate change of –448.45 (95% CI, –661.19, –235.72) and –323.10 (95% CI: –517.81, –128.39) in Period 1 for FVC and FEV_1, respectively. Negative associations between obesity and lung function were more noticeable in girls during Period 1, with an estimated reduction of –447.45 (95% CI: –721.99, –172.90) for FVC and –353.85 (95% CI: –611.70, –96.00) for FEV_1.

Discussion

In the current analysis, we investigated the differences in lung function and associations with socio-economic, nutritional, and housing (household) factors between school children measured in 2017 (Period 2) and school children measured in 1996 (Period 1). Both cohorts of children had the same age range and lived in the same areas of Lanzhou. Socioeconomic level, household, and individual characteristics changed across the two study periods, as evidenced by substantial prevalence changes in ETS, room crowdedness, coal fuel use, cooking ventilation conditions, parental education attainment, overweight, and obesity. FVC and FEV_1 of boys and girls were all lower in the 2017 cohort than in the 1996 cohort. We observed an adverse effect of living in the urban area on FVC and FEV_1 during Period 2, after adjusting for potential confounders and in gender stratified analyses. Overweight and obesity were each significantly associated with lower FEV_1 in both boys and girls and with FVC in boys in Period 1.

Lung function depends on a variety of individual, behavioral and environmental factors (19-22). It is evident that these characteristics changed in China across two decades. Therefore, it is expected that lung function values would have changed with changing influencing factors (23). Some previous studies reported the changes of FVC and FEV_1 in children in Chinese cities, which present confusing trends in different cities in recent decades (24-26). Although differences in equipment or methodology may explain some of these variations, much of it appears to be real and must be a result of other causes such as socioeconomic changes. We found decreased lung function in Lanzhou across two cross-sectional study periods separated by more than twenty years (*Table 2*).

Compared with a survey conducted in 24 centers in

Northeast, North, Northwest, Southwest, South, East, and Central China, the percentage differences of previous Chinese studies ranged from –17.8% to 11.4%, which were found to significantly overestimate or underestimate lung function (27). This discrepancy in the temporal trend of lung function might be partly due to the sample size, age ranges, small local regions, as well as different study protocols and quality control. A previous study in Hong Kong reported spirometric values of this population have increased compared to Chinese populations of similar sex, age, and height two decades ago (28). All measured lung function parameters were strongly correlated with age. Among study subjects of the Hong Kong study (28), the average age was greater than our study.

This study demonstrated significantly smaller lung volumes and capacities (FVC and FEV_1) among children from Period 2 than age and sex-matched in Period 1. Furthermore, the study also highlighted that children from urban, overcrowded home, parental manual laborer, undernourished children and those exposed to noxious particulate and gaseous substances from the use of coal fuel and open kitchen have significantly lower lung function than their counterparts. Hegewald and Crapo (29) in a review of published work on the effects of socioeconomic class on the lung function of children and adults proposed a number of associated factors. Moreover, suboptimal housing environment like overcrowded homes commonly associated with low socioeconomic status has been associated with significantly lower lung function volumes and capacities (30). However, these characteristics were much improved in Period 2 compared to Period 1. In northwestern China where Lanzhou is located, the coal-burning source was generally associated with extensive burning for domestic heating (31). The priorities for an air pollution control area for Chinese administrators were also focused on that region, such as the replacement of coal with natural gas and electricity in North China (32,33). This regulated the use of coal, which then contributed to a decline in household coal use.

Undernourishment was more prevalent among the children in Period 1 during which 3.3% of the children were stunted compared to 0.7% in Period 2 children. The prevalence of overweight and the prevalence of obesity in Period 2 children were significantly higher than in Period 1 children, with 14.2% *vs*. 2.3% and 12.4% *vs*. 1.4% for overweight and obesity, respectively. The high prevalence of overweight or obesity among children in recent years in Lanzhou was also pointed out by Zhang *et al*. (34) and Xue *et al*. (35). Changes in the physical growth of children in

urban areas of Lanzhou from 2001 to 2010 were obvious, with increases in body height and body weight. However, problems such as overweight and obesity emerged in recent years (34). A latest study which covered four districts in Lanzhou reported the prevalence rate of obesity among 3,283 children was 5.76% (36). Currently, children are socially advantaged with access to basic necessities of life, including food and quality health care. This may be related to the fact that children in Period 2 were taller and more well-nourished than their Period 1 counterparts as shown in this study.

Our finding of adverse effects of living in urban areas on lung function among elementary school children in Lanzhou city in Period 2 was in conformity with those from earlier studies (37-39), including some conducted among developing countries (37,40). An international population-based study (38) investigated the influence of childhood living environment and biodiversity indicators on lung function, reporting fewer atopic sensitization and higher FEV_1 among those with early-life farm exposure. Further, accessibility and actual exposures related to farming environment obviously differ between urban and rural (or suburban in this study). Relevant studies have observed the "farm-effect" in children relative to the cumulative incidence of asthma, always resulted in poor lung function (41-43). Another two cross-sectional cohort study, conducted among school-age children (5–15 years of age) from the capital and the rural district in Mongolia (40), reported normal FEV_1 was actually 40% higher in rural Mongolian children than in urban children. The differences observed in lung function between the rural and urban areas were also pointed by other studies (37,44) and attributed to outdoor air pollution (12), exposure to farm animals (45), farming activities (46), and allergen exposure (11). While we initially intended to consider ambient air pollution as a risk factor, it was difficult to do this in our two cross-sectional design, due to difficulties in measuring personal exposure to outdoor and indoor air pollution. However, there are inconsistent conclusions about the urban-suburban disparity in lung function from previous studies (6,47). Children from rural areas are raised in homes with unclean fuel, homes which use biomass for cooking, lighting, and heating, and generally fall within the low socioeconomic class, which may contribute to lower lung function (47). The inconsistent results might be caused by differences in the study period and stage of city development. In our study, over a span of 20 years, the impact of urbanization was much more pronounced in Period 2. The expansion

of urban and the more prominent problem of urbanization could partly explain the conflicting results.

We found that obesity was negatively associated with FVC and FEV_1. This supports earlier work in children aged 6–11 years that found that FVC, FEV_1, forced expiratory flow 25–27%, and FEV_1/FVC were markedly reduced in overweight or obese children compared with those of normal weight (48). The reductions in FVC and FEV_1 reports in our study supports the notion that obesity induces symptoms similar to restrictive lung disease by increasing the external load on the chest wall, resistance in the respiratory system, respiratory muscle function, and airway structure or function (49). Obesity may alter airway function by increasing bronchial hyperreactivity (50). In addition, lung inflammation may be increased in obese children because adipose tissue is a source of pro-inflammatory cytokines and chemokines (50). A meta-analysis study report subjects who were obese (as compared with overweight) had an even further decreased FEV_1 and FVC (51). Physicians should be aware of adverse effects of obesity on lung function, and weight control should be considered in the management of airway disease among obese individuals.

There are several limitations to our study. First, we used indoor air pollution related household factors instead of actual personal exposure measurements. Second, the main aim of the lung function test performed in this study was to compare healthy Lanzhou children across the two periods. The study was limited in providing any causal evidence in observed relationships between lung function and exposure. Third, data on some potential risk factors were unavailable, including birth weight, household pets, or the number of children in the household. Finally, the questionnaire was self-reported and we were not in a position to confirm the accuracy of response.

Conclusions

Children with the same age range and living in the same areas of Lanzhou had significantly lower lung function (FVC and FEV_1) in 2017 than in 1996. Children's lung function measured in 1996 was adversely affected by overcrowded home conditions, parents being manual laborers, being undernourished, household use of coal for heating and cooking, being obese or overweight, and having an open kitchen. Living in the urban area had a negative effect on lung function in 2017. As overweight and obesity prevalence has increased markedly in recent years in Lanzhou and

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elsewhere, we commend the provision of weight control, in addition to air pollution exposure control, as a strategy to improve children's lung function.

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Footnote

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