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Research Article

Maternal Exposure to Emission of Using New Furniture during Pregnancy and Preterm Birth

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Abstract

Objectives: To evaluate the association between maternal exposure to emission of using new furniture during Pregnancy and Preterm Birth (PTB). To further assess potential modification effects on this association from maternal prenatal care utilization, working on irregular shifts periconceptionally and multivitamin intake during pregnancy.

Methods: We used data from a nested case-control study in Wuhan, China, from June 10, 2011 to June 9, 2013. This case-control study was based on a prospective cohort study, which followed all pregnant women in the seven urban districts of Wuhan. Data collection for each birth was completed within 42 days after delivery, through questionnaire survey during a home-visit interview. Binary logistic regression models were built to evaluate the association, adjusting for potential confounders. Potential effect modifiers were assessed by introducing interaction terms in the model and by using stratified analyses.

Results: 2,393 PTBs and 4,263 controls (full-term births with normal birth weight) were included in the final sample. We observed a significant association between maternal exposure to indoor pollution from new furniture during pregnancy and increased PTB risk, while adjusting for potential confounders (adjusted OR: 1.22, 95% CI: [1.09, 1.35]). Stronger associations were observed when women did not obtain adequate prenatal care, when women had irregular work shifts periconceptionally, and/or when women did not take a multivitamin during pregnancy. However, among all three examined modification effects, only the one from maternal prenatal care utilization was statistically significant.

Conclusion: Maternal exposure to emission of using new furniture during pregnancy was significantly associated with increased PTB risk in Wuhan, China, from 2011 to 2013. Adequate prenatal care utilization mitigated this association toward the null.

Keywords: Effect modifier; Environmental pollution; Furniture; Prenatal care; Preterm birth; Wuhan

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Introduction

The new furniture emits a large amount of toxins, including Organophosphate Esters (OPEs) (flame retardants), Bisphenol A (BPA), Polycyclic Aromatic Hydrocarbons (PAHs), Volatile (VOCs) and Semi Volatile Organ Compounds (SVOCs), and other endocrine disrupting chemicals [1,2]. These toxins may cause adverse birth outcomes, including PTB [1-14]. To date, limited studies have examined the effects of using new furniture on PTB [2-4,11-17]. Furthermore, potential effect modifiers of the association between maternal exposure to indoor pollution from new furniture and PTB were not identified previously in the literature. For example, maternal prenatal care utilization, irregular shift work, and multivitamin intake during pregnancy, have been related to PTB risk [18-20]. They would have important public health implications on preventing PTB if they modified the association between maternal exposure to indoor pollution from new furniture and PTB, because they are modifiable through implementation of new policies or regulations. China has gone through a tremendous economic growth, accompanied with fast urbanization progress [2]. As a result, an increasing number of people have moved to new homes, and numerous pieces of new furniture have been purchased [2]. In Chinese culture, using new furniture represents a good start of the family. New couples and expected parents are more likely to purchase new furniture when they establish their new home [2-4,15-17].

Therefore, our study was to investigate the association between maternal exposure to indoor pollution, defined as using new furniture during pregnancy and PTB. We further evaluate the modification effect from maternal prenatal care utilization, irregular work shift, and multivitamin intake during pregnancy. We used the data from a prospective cohort nested case-control study in the city of Wuhan, China, because in their cohort study stage, they followed all pregnant women in the seven districts to minimize selection bias [21]. In addition, we would also minimize impact of residual confounders relating to different prenatal care systems, because Wuhan is unique with its single prenatal care system, thereby increasing our statistical power [21]. Our main hypothesis is that maternal exposure to indoor pollution, defined as using new furniture during pregnancy, was significantly associated with increased PTB risk in Wuhan, China from 2011 to 2013. We further hypothesize that maternal prenatal care utilization, periconceptional irregular work shift, and multivitamin intake during pregnancy modified this association significantly.

Methods

Study location and population

Wuhan has a single prenatal care system, which is managed and regulated by the Wuhan Medical and Health Center for Women and Children (WMHCWC) [21]. This center is also responsible for electronically collecting and storing all information relating to maternal pregnancy and birth outcomes for all women in the city [21]. During our study period, under the former regulation of "One-Child" policy, the birth rate in Wuhan was approximately 13.7% and most of the deliveries were from nulliparous women [21,22].

Nested case-control study

Exclusion criteria of our birth cohort were women that were non-permanent residents, not living in the core-districts, without clear home addresses, children born with a birth defect, extreme birth weight (< 500g or > 5000g), extreme gestational ages (< 20 weeks or >46 weeks), and non-singleton births, 95,911 births were left from the original cohort [21]. Data collection was initiated within two weeks of delivery, and all PTBs within the original cohort were included [21]. Controls were selected to match PTBs' birth date and birth location during sampling [21]. A home-visit interview was conducted for each PTB and its matched control soon after sampling and a comprehensive questionnaire survey was asked to be completed within 42 days after delivery [21]. This data collection was administered by trained nurses and medical staff from WMHCWC [21]. The study protocol and use of data were approved by the Institutional Review Board of Saint Louis University, MO, USA.

Preterm birth data

We defined our cases as PTB that was a live birth before 37 complete weeks of gestation, according to the World Health Organization [23]. Control was defined as full-term birth (> 37 complete weeks gestation) with normal birth weight (> 2500 g). In the original case-control study, 63.8% of the total sampled births completed the questionnaire [21]. Among them, we identified all PTBs as our cases and included all their controls as our controls.

Exposure and covariates

Exposure and covariates were measured by information provided in the questionnaire survey. Indoor pollution defined as using new furniture during pregnancy was assessed by asking this question in the questionnaire: "Did you buy or make new furniture when you moved into your most recent residence (Yes/No)?" Answer "yes" to the first question will be considered as maternal exposure to indoor pollution from using new furniture and will be considered as our exposure of interest in this study. Covariates were selected and constructed based on our literature review. Age is defined as maternal age at delivery (<21, 21-30, or >30) [24]. Pre-pregnancy BMI is defined as maternal BMI measured on the closest date before their current pregnancy [25,26]. Pre-pregnancy BMI was categorized based on the international standard (underweight / normal weight / overweight / obese) [27,28]. Education is defined as the highest maternal educational achievement at the time of delivery (primary school or lower / high school / college or higher / others) [21]. Parity is defined as the number of deliveries that had an infant capable of survival [21]. Living district is defined as maternal living district during their current pregnancy [21]. Self-rated health status is measured by asking this question in the questionnaire: "Would you say that, in general, your health is: poor/fair/good/very good?" Answer "poor" and "fair" was considered as "not good" of self-rated health status, due to low prevalence of the answer of "not good" (< 1%); answer "good" and "very good" was considered as "good" and "very good" of self-rated health status, respectively. Physical activity is defined as duration of maternal daily outdoor sports during pregnancy, in minutes, which was further categorized based on the international standard of recommended duration of physical activity for pregnant women (< 20 minutes/day, 20 -30 minutes/day, or >30 minutes/day; recommendation: 20-30 minutes/day) [29-31]. Prenatal care utilization is defined as maternal capability to initiate prenatal care at the earliest point of pregnancy and to attend as many as possible of the recommended prenatal care visits, which is measured by the Chinese Ministry of Health (inadequate, intermediate, adequate, or more than adequate) [18]. Periconceptional work shift was measured by asking new mothers their work shifts before and/or during their latest pregnancy and irregular work shift is defined as women who worked on a schedule before and/or during pregnancy that is not a regular day shift [19]. Multivitamin intake during pregnancy is measured by asking new mothers whether they took multivitamins during their latest pregnancy (yes / no).

Statistical analysis

Distributions of maternal characteristics among cases and controls, including demographics, socioeconomic status, use of new furniture during pregnancy, and main covariates, were described and analyzed. We used Pearson's Chi-square test and Student's t-test to analyze categorical variables and continuous variables, respectively [32,33].

We used binary logistic regression analyses to evaluate the association between maternal exposure to indoor pollution, defined as using new furniture during pregnancy and PTB risk. In particular, we used univariate regression models to calculate crude Odds Ratios (OR) and 95% Confidence Intervals (95% CI), and multivariate regression models to calculate adjusted ORs and their 95% CIs. Covariates were selected if: (1) they were risk factors of PTB based on our literature review and (2) they could change the point estimate by more than 5% [21,34].

We used multivariate regression models to assess our three identified effect modifiers, maternal prenatal care utilization, irregular shift work and multivitamin intake during pregnancy [21]. For each effect modifier, we built one multivariate regression model with all identified potential confounders, this specified effect modifier, and the interaction term of maternal exposure to indoor pollution from new furniture during pregnancy and the specified effect modifier [21]. P-value of the interaction term will be used to indicate the significance of potential modification effect [21,35]. The association between maternal exposure to indoor pollution from new furniture and PTB was further assessed in each subgroup of our study population, which was generated by stratifying our study population according to their exposure status for each one of the three effect modifiers [36].

Sensitivity analysis

In our data, some participants reported their education levels as others. In our sensitivity analysis, we excluded these participants and thus generated a subgroup of our study population. We tested our final model in this subgroup to assess the robustness of our study results against the decision we made for covariate construction [21,36] . In addition, 8.4% of our study population moved to a new address during their pregnancy [21]. We narrowed our study population to exclude these women who moved during pregnancy. We further tested our final model in this subgroup to assess the robustness of our study results against changing of residual confounders in relation to the woman's living environment [21]. Two tailed p< 0.05 was set as the significance level for all our analyses. SAS University Edition (SAS Institute Inc. 2018) was used to conduct all our statistical analyses.

Results

Descriptive results

Our final sample comprised 6,656 births and their general characteristics are shown in table 1. From the 6,656 births, 2,393 were PTBs (cases) and 4,263 were full term births (controls). 45.6% of our pregnant women used new furniture during their pregnancy and most of them were in the PTB group than in the control group. Most of our pregnant women were young, normal weighted, healthy and nulliparous. A higher proportion of women who delivered PTBs were older than 30 years old, as compared to those who delivered full term birth with normal birth weight (controls). The average pre-pregnancy BMI of the PTB group was higher than it was in the control group, with more overweight women in the PTB group than the control group. More than half of our pregnant women had an education level of college or higher, and most of the other half had an education level of high school. In our study population, a higher proportion of women who delivered PTB reported poor health status during their pregnancy, as compared to those who delivered full term birth with normal birth weight. Women in the control group had more time to do exercise during their pregnancies than women in the PTB group. A higher proportion of women in our control group held a regular-shift work job and/or attended adequate prenatal care during their pregnancy than those in our PTB group. A slightly higher proportion of women in our PTB group took multivitamins during their pregnancy than those in our control group.

In our seven core-districts of Wuhan, the proportion of pregnant women who used new furniture during their pregnancy was slightly higher in Hanyang, Wuhchang, Hongshan and Qingshan districts (Table 2). Our pregnant women who used new furniture during pregnancy were older than those who did not. In particular, a higher proportion of women who used new furniture were older than 30 years, as compared to those who did not use. Pre-pregnancy BMI was evenly distributed between women who used new furniture and who did not use new furniture during their pregnancy. In our study population, a higher proportion of women who used new furniture had an education background of college or higher, reported being nulliparous, and in very good health status during their pregnancy, as compared to those who did not purchase new furniture during pregnancy.

Model analyses

Our results showed the significant association between maternal exposure to indoor pollution, defined as using new furniture during pregnancy and increased risk of PTB (crude OR=1.13, 95% CI: [1.03,

Characteristics	Total births No. (%)[a]	PTBs No. (%)[a]	Controls No. (%)[a]	*p-value*
	6656 (100.0)	2393 (36.0)	4263 (64.1)	
Living district				
Jiangan	1256 (18.9)	496 (20.7)	760 (17.8)	< 0.05
Jianghan	821 (12.3)	294 (12.3)	527 (12.4)	
Qiaokou	933 (14.0)	345 (14.4)	588 (13.8)	
Hanyang	997 (15.0)	363 (15.2)	634 (14.9)	
Wuchang	1172 (17.6)	395 (16.5)	777 (18.2)	
Hongshan	967 (14.5)	327 (13.7)	640 (15.0)	
Qingshan	510 (7.7)	173 (7.2)	337 (7.9)	
Age, years				
Mean (SD)	27.46 (3.64)	27.83 (3.95)	27.24 (3.44)	< 0.05
< 21	118 (1.8)	43 (1.8)	75 (1.8)	< 0.05
21-30	5408 (81.3)	1842 (77.0)	3566 (83.7)	
> 30	1130 (17.0)	508 (21.2)	622 (14.6)	
Pre-pregnancy BMI[b]				
Mean (SD)	20.64 (2.62)	20.74 (2.69)	20.58 (2.57)	< 0.05
Underweight (<18.5)	1325 (19.9)	456 (19.1)	869 (20.4)	> 0.05
Normal weight (18.5-24.9)	4892 (73.5)	1763 (73.7)	3129 (73.4)	
Overweight (25-29.9)	405 (6.1)	161 (6.7)	244 (5.7)	
Obese (>30)	34 (0.5)	13 (0.5)	21 (0.5)	
Education				
Primary school or lower	131 (2.0)	51 (2.1)	80 (1.9)	> 0.05
High school	3038 (45.6)	1045 (43.7)	1993 (46.8)	
College or higher	3460 (52.0)	1284 (53.7)	2176 (51.0)	
Others	27 (0.4)	13 (0.5)	14 (0.3)	
Parity				
0	5537 (83.2)	1956 (81.7)	3581 (84.0)	< 0.05
> 1	1119 (16.8)	437 (18.3)	682 (16.0)	
Self-rated health status				
Not good	1364 (20.5)	625 (26.1)	739 (15.1)	< 0.05
Good	2903 (43.6)	1033 (43.2)	1870 (43.9)	
Very good	2389 (35.9)	735 (30.7)	1654 (38.8)	
Physical activity[c]				
Mean (SD), minutes/day	43.39 (24.30)	42.13 (23.64)	44.02 (24.61)	< 0.05
< 20 minutes/day	2033 (30.5)	860 (35.9)	1173 (27.5)	< 0.05
20 - 30 minutes/day	2612 (39.2)	897 (37.5)	1715 (40.2)	
> 30 minutes/day	2011 (30.2)	636 (26.6)	1375 (32.3)	
Prenatal care utilization[d]				
Inadequate care	1207 (18.1)	483 (20.2)	724 (17.0)	< 0.05
Intermediate care	4192 (63.0)	1575 (65.8)	2617 (61.4)	
Adequate care	923 (13.9)	256 (10.7)	667 (15.7)	
Adequate plus care	334 (5.0)	79 (3.3)	255 (6.0)	
Periconceptional work shifts				
Regular day shift	2773 (41.7)	968 (40.5)	1805 (42.3)	> 0.05
Irregular work shift	3255 (48.9)	1212 (50.7)	2043 (47.9)	
Not working	628 (9.4)	213 (8.9)	415 (9.7)	
Multivitamin intake during pregnancy				

Yes	3524 (52.9)	1307 (54.6)	2217 (52.0)	< 0.05
No	3132 (47.1)	1086 (45.4)	2046 (48.0)	
Indoor pollution (Using new furniture during pregnancy)				
Yes	3032 (45.6)	1138 (47.6)	1894 (44.4)	< 0.05
No	3624 (54.5)	1255 (52.4)	2369 (55.6)	

Table 1: Maternal characteristics and distribution of exposure by cases and controls, Wuhan, China, from June 10, 2011, to June 9, 2013.

a. Numbers may not add to 100% because of rounding

b. BMI was calculated and categorized according to International standards [27,28].

c. Maternal daily physical activity duration of 20 - 30 minutes is recommended by the international standard [29,31].

d. Maternal prenatal care utilization was measured by the Chinese Ministry of Health [18].

Characteristics	Using new furniture during pregnancy		
	Yes No. (%)[a]	No No. (%)[a]	*p-value*
	3032 (45.6)	3624 (54.5)	
Living district			
Jiangan	495 (16.3)	761 (21.0)	< 0.05
Jianghan	345 (11.4)	476 (13.1)	
Qiaokou	340 (11.2)	593 (16.4)	
Hanyang	521 (17.2)	476 (13.1)	
Wuchang	552 (18.2)	620 (17.1)	
Hongshan	498 (16.4)	469 (12.9)	
Qingshan	281 (9.3)	229 (6.3)	
Age, years			
Mean (SD)	27.82 (3.50)	27.15 (3.73)	< 0.05
< 21	39 (1.3)	79 (2.2)	< 0.05
21-30	2436 (80.3)	2972 (82.0)	
> 30	557 (18.4)	573 (15.8)	
Pre-pregnancy BMI[b]			
Mean (SD)	20.62 (2.57)	20.65 (2.65)	> 0.05
Underweight (<18.5)	591 (19.5)	734 (20.3)	> 0.05
Normal weight (18.5-24.9)	2259 (74.5)	2633 (72.7)	
Overweight (25-29.9)	168 (5.5)	237 (6.5)	
Obese (>30)	14 (0.5)	20 (0.6)	
Education			
Primary school or lower	28 (0.9)	103 (2.8)	< 0.05
High school	1184 (39.1)	1854 (51.2)	
College or higher	1807 (59.6)	1653 (45.6)	
Others	13 (0.4)	14 (0.4)	
Parity			
0	2676 (88.3)	2861 (79.0)	< 0.05
> 1	356 (11.7)	763 (21.1)	
Self-rated health status			
Not good	590 (19.5)	774 (21.4)	< 0.05
Good	1270 (41.9)	1633 (45.1)	
Very good	1172 (38.7)	1217 (33.6)	
Physical activity[c]			
Mean (SD), minutes/day	43.38 (23.61)	43.40 (24.90)	> 0.05
< 20 minutes/day	858 (28.3)	1175 (32.4)	< 0.05
20 - 30 minutes/day	1195 (39.4)	1417 (39.1)	
> 30 minutes/day	979 (32.3)	1032 (28.5)	
Prenatal care utilization[d]			
Inadequate care	472 (15.6)	735 (20.2)	< 0.05
Intermediate care	1883 (62.1)	2309 (63.7)	
Adequate care	490 (16.2)	433 (12.0)	
Adequate plus care	187 (6.2)	147 (4.1)	
Periconceptional work shifts			
Regular day shift	1338 (44.1)	1435 (39.6)	< 0.05
Irregular work shift	1380 (45.5)	1875 (51.7)	
Not working	314 (10.4)	314 (9.7)	
Multivitamin intake during pregnancy			
Yes	1756 (57.9)	1768 (48.8)	< 0.05
No	1276 (42.1)	1856 (51.2)	

Table 2: Maternal characteristics by exposure to indoor pollution defined as using new furniture, Wuhan, China, from June 10, 2011, to June 9, 2013.

a. Numbers may not add to 100% because of rounding.

b. BMI categorized according to International standards [27,28].

c. Maternal daily physical activity duration of 20 - 30 minutes is recommended by the international standard [29-31].

d. Maternal prenatal care utilization was measured by the Chinese Ministry of Health [18].

1.25]) (Model 1, Table 3). The effect magnitude of this positive association was increased while adjusting for potential confounders. In particular, the effect magnitude was increased by 1% while adjusting for potential confounders identified previously in the literature, including maternal age, pre-pregnancy BMI, education level and parity (adjusted OR: 1.14, 95% CI: [1.03, 1.26]) (Model 2, Table 3). The largest increase in effect magnitude (8%) was observed after adjusting for additional covariates identified in our study, including maternal living district, self-rated health status, physical activity duration and prenatal care utilization during pregnancy. Finally, 22% increase in the odds of PTB was attributable to maternal exposure to indoor pollution, defined as using new furniture during pregnancy(adjusted OR: 1.22, 95% CI: [1.09, 1.35]) (Model 3, Table 3). This effect estimation did not change significantly in our sensitivity analyses. After excluding women with unclear education background, this association remained significantly positive (adjusted OR: 1.21, 95% CI: [1.09, 1.35]) (Model 4, Table 3). After excluding women who moved during pregnancy, but this association remained significantly positive (adjusted OR: 1.19, 95% CI: [1.07, 1.33]) (Model 5, Table 3).

Modification effects

A significant interaction existed between maternal prenatal care utilization and maternal exposure to indoor pollution, defined as using new furniture during pregnancy, on their associations with PTB ($p<0.05$) (Table 4). Adequate prenatal care attenuated the association between maternal exposure to indoor pollution from new furniture and increased PTB risk. In particular, for women who did not have adequate prenatal care, the adverse effect of indoor pollution from using new furniture on their PTB risk was significant (adjusted OR: 1.19, 95% CI [1.04, 1.36]) (Table 4). Whereas, for women who had adequate prenatal care, this adverse effect of using new furniture during pregnancy on PTB was attenuated and no longer significant (adjusted OR: 1.06, 95% CI [0.78, 1.45]) (Table 4).

Model[a]	Odds ratio	95% confidence interval
Model 1	1.13	1.03, 1.25
Model 2	1.14	1.03, 1.26
Model 3	1.22	1.09, 1.35
Model 4 (sensitivity analysis)	1.21	1.09, 1.35
Model 5 (sensitivity analysis)	1.19	1.07, 1.33

Table 3: Association between maternal exposure to indoor pollution, defined as using new furniture during pregnancy and PTB, in Wuhan, China, from June 10, 2011, to June 9, 2013.

a. Model 1 is the crude model from the univariate analysis; Model 2 was adjusted for covariates from previous literature, including maternal age, pre-pregnancy BMI, education level, and parity; Model 3 was adjusted for all covariates from model 2 and also adjusted for covariates from our confounder analysis, including maternal living district, self-rated health status, physical activity duration, and prenatal care utilization, during pregnancy; Model 4 was the Model 3 tested among our study population after excluded mothers with unclear educational background; Model 5 was the Model 3 tested among our study population after excluded mothers who moved during pregnancy.

We also observed an interaction between maternal work shift and maternal exposure to indoor pollution from using new furniture during pregnancy (Table 4), on their associations with PTB risk. In particular, for women who had an irregular-shift work periconceptionally, their exposure to indoor pollution from using new furniture during pregnancy was significantly associated with increased PTB risk (adjusted OR: 1.24, 95% CI [1.03, 1.48]). This adverse effect of using new furniture during pregnancy on PTB risk was attenuated and became non-significant for women who had a regular-shift job periconceptionally (adjusted OR: 1.18, 95% CI [0.97, 1.43]). However, this interaction is not significant in our study (p>0.1) (Table 4).

Another interaction was observed between maternal multivitamin intake and maternal exposure to indoor pollution from using new furniture during pregnancy on their associations with PTB risk (Table 4). For women who did not take multivitamins during their pregnancy, the adverse effect of indoor pollution from using new furniture on their PTB risk was significant (adjusted OR: 1.26, 95% CI [1.08, 1.47]). For women who took multivitamins during pregnancy, this adverse effect of indoor pollution from using new furniture on PTB was attenuated and no longer significant (adjusted OR: 1.13, 95% CI [0.98, 1.31]). However, this interaction was not significant in our study (p>0.1) (Table 4).

		Adjusted		
Subgroup		OR	95% CI	*p-value*
Prenatal care utilization[a,b]	Inadequate	1.19	(1.04, 1.36)	< 0.05[e]
	Adequate	1.06	(0.78, 1.45)	
Maternal work shift[c]	Irregular	1.24	(1.03, 1.48)	> 0.1[f]
	Regular	1.18	(0.97, 1.43)	
Multivitamin intake during pregnancy[d]	Yes	1.13	(0.98, 1.31)	> 0.1[g]
	No	1.26	(1.08, 1.47)	

Table 4: The association between maternal exposure to indoor pollution defined as using new furniture during pregnancy and PTB, stratified by potential effect modifiers, in Wuhan, China, from June 10, 2011, to June 9, 2013.

OR: odds ratio; 95% CI: 95% confidence interval.

a. Maternal prenatal care utilization was measured by the Chinese Ministry of Health [18].

b. Adjusted for maternal age, pre-pregnancy BMI, education level, parity, living district, self-rated health status, physical activity duration, and prenatal care utilization, during pregnancy.

c. Adjusted for maternal age, pre-pregnancy BMI, education level, parity, self-rated health status, prenatal care utilization, home decoration, and periconceptional work shift, during pregnancy.

d. Adjusted for maternal age, pre-pregnancy BMI, education level, parity, self-rated health status, physical activity duration, prenatal care utilization, and multivitamin intake, during pregnancy.

e. P value for the interaction term for the two groups of maternal prenatal care utilization (inadequate/adequate).

f. P value for the interaction term for the two groups of maternal periconceptional work shift (irregular work shift/regular work shift).

g. P value for the interaction term for the two groups of maternal multivitamin intake (multivitamin intake during pregnancy/no multivitamin intake during pregnancy).

Discussion

In this population-based prospective cohort nested case-control study, we found that maternal exposure to indoor pollution from using new furniture during pregnancy was significantly associated with increased PTB risk, thus confirming our main hypothesis. We further identified one effect modifier for this association, maternal prenatal care utilization during pregnancy. In particular, adequate prenatal care utilization reduced the adverse effect of indoor pollution from using new furniture during pregnancy on PTB risk, thus confirming one of our sub-hypotheses.

The potential mechanism by which exposure to new furniture during pregnancy contributes to PTB could be that new furniture inside a home emits a significantly higher amount of chemicals than older furniture, such as PAHs and VOCs [1-4,15-17]. Perinatal use of new furniture has been linked to inflammatory medical conditions in both parents and their offspring, such as allergic diseases/symptoms, asthma and pneumonia [2-4,15-17]. It is plausible to hypothesize that new furniture may activate maternal inflammatory responses, leading to uterine activation and then PTB [2-4,15-17]. For example, PAHs and VOCs are two major pollutants from both soil vapor intrusion and new furniture emissions [1,32,33]. While no direct evidence can be obtained on the associations between exposures to these two pollutants due to using new furniture, observational studies of soil vapor intrusion did report their associations with adverse birth outcomes, including PTB [1,37,38]. Similarly, both PAHs and VOCs also exist in the emissions from household renovation [1,39]. Two studies from China reported a significant association between exposure to household renovation and increased PTB risk [1,39]. During our model construction, we controlled for maternal exposure to home decoration, which did not increase our effect estimation by more than 1%, so we did not include it as a potential confounder in our final model. This non-significant change of our effect estimation by controlling for maternal exposure to home decoration might indicate that some pollutants emitted from new furniture were different from those emitted from decoration materials, but they still have adverse effects on PTB risk.

Evidence from observational studies of this adverse effect of maternal exposure to new furniture on PTB has been lacking in the field. We were able to identify only one related study in China, which was a retrospective cohort study in Changsha, China in 2019 [3]. However, they reported a non-significant association between maternal exposure to indoor pollution from new furniture and PTB (adjusted OR: 1.15, 95% CI [0.58, 2.26]) [3]. This inconsistency might be caused by residual confounders that both studies were not be able to control for, such as furniture sources [3]. Despite of this limitation of both studies, our study is in a better position to evaluate this association between maternal exposure to indoor pollution from new furniture and PTB risk, because the previous study was retrospective in nature, with data collection started a couple of years after delivery, so their study participants may not be able to recall whether they purchased new furniture when they were pregnant a couple of years earlier, leaving their study results prone to recall bias [3]. Our study also has a much larger sample size, which is 6,656 births, with 46% of our pregnant women having been exposed to new furniture during pregnancy, while the earlier study's sample was 3,509 preschool children, with 12% of the participants' mothers having been exposed to new furniture during pregnancy [3], which might be the reason that they had a much larger 95% CI for effect estimations than ours. In addition, their study might be subject to selection bias, because they only recruited participants from 36 kindergartens in the city [3]. The previous study may be lacking data for children who moved out of the city after birth and children who did not go to those 36 kindergartens. Our study recruited all pregnancies in the city, minimizing this selection bias [21].

Our study has several limitations. The measurement of our covariates was based on self-report data, so might be subjected to self-reporting bias. We did not have information on the duration, frequency, and strength of maternal exposure to indoor pollution from new furniture during pregnancy. However, during our model construction, we controlled for home ventilation, number of windows and doors of the living space, and area per family member of the living space, and they changed our effect estimation less than 5%. This indicates that these differences on the exposure duration, frequency, and strength of maternal exposure to indoor pollution from new furniture among our study population may not be significant enough to change our effect estimation, so we did not include them in our final model. Our study may be subject to misclassification bias, because we do not have data on the exact toxic chemicals emitted from new furniture and we did not know if the used furniture that our pregnant women had during their pregnancy also emitted those chemicals. This could lead to overestimation of our effect estimation if our pregnant women who used new furniture were also exposed to the same toxic chemicals from their used furniture, and lead to underestimation if our pregnant women who bought their new furniture shortly before becoming pregnant and did not report themselves as using new furniture during current pregnancy. We also did not have data on maternal exposure to new furniture during pregnancy at an environment outside their home, such as the work place, which could lead to underestimation of our effect estimation. For the modification effect of maternal periconceptional shift work and the modification effect of postconceptional multivitamin intake, we could not control for the variety of irregular work shifts and/or different doses and types of multivitamins taken by pregnant women. Lacking such data may be the reason that these two modification effects were not significant in our study. In addition, there might be residual confounders that we were unable to control for [40,41]. For example, we lacked information on maternal dampness-related exposures and ambient air pollution exposures during pregnancy, which were reported as potential confounders of the association between maternal household renovation and PTB [1,3,21,39,42]. Therefore, we suggest further study to include information on these potential confounders.

Our study also offers important strengths. We collected data on other indoor pollutants, such as cooking fuel, heating fuel, second-hand smoking, home decoration, contact with pets, contact with deformity toxin, proximity to pollution sites, proximity to traffic on a main road, exposure to certain noises, and time spent outdoors during pregnancy. All have been considered previously in the literature as potential confounders of the association between maternal exposure to indoor pollution of new furniture and/or home decoration and PTB risk [1,3,39] (Supplementary table S1). However, in our data analysis, we did not observe significant changes in our effect estimation by controlling for these covariates (< 5%), so we did not include them in our final model. Similarly, we also examined the potential confounding effect from maternal chronic health conditions before and/or during pregnancy [1,3,39], and we did not observe a change of effect estimation by more than 5%. We also identified potential confounders that other studies did not control for, such as maternal self-rated health condition, prenatal care utilization and physical activity duration during pregnancy. These potential confounders could have indicated that maternal self-perception of health and behaviors during pregnancy might influence the association between maternal exposure to indoor pollution from new furniture and PTB risk, though no significant relationship was found in our study.

In light of our finding on the association between maternal exposure to indoor pollution from new furniture and increased PTB risk, we suggest that manufacturers of furniture avoid using chemicals that pose reproductive health hazards and inform their customers and advertisers of the chemical compositions of their furniture. We also suggest the government improves regulations on availability and utilization of hazardous chemicals on furniture and publicize the information of potential health hazards of chemicals found in furniture. Our finding of the modification effect of maternal prenatal care utilization on the association between maternal exposure to indoor pollution from new furniture and increased PTB risk sheds light on the potential mitigating tool for pregnant women to protect themselves from possible PTB risk attributed to exposure to new furniture. We thus recommend pregnant women attend adequate prenatal care, meaning that they should initiate their first prenatal care as early as possible and attend all recommended prenatal care visits on time [18,43].

Conclusion

We found a significant association between maternal exposure to indoor pollution, defined as using new furniture, during pregnancy and increased PTB risk, after adjusting for potential confounders. Adequate maternal prenatal care utilization mitigated this association significantly in our study site, Wuhan, China. Maternal periconceptional irregular shift work and no use of multivitamins during pregnancy strengthened this association, but these two modification effects were not statistically significant in our study population.

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Author's Commitment

Jia Sun contributes to data analysis and manuscript writing. Rong Yang contributes to protocol development and manuscript editing.

Jia Sun and Rong Yang contributed equally to this work. Hong Xian contributes to methodology and manuscript editing. Bin Zhang contributes to methodology and data collection. Guang-Hui Dong contributes to manuscript editing. Pamela K. Xaverius contributes to conceptualization and methodology. Hualiang Lin contributes to methodology. Morgan LeBaige contributes to manuscript editing. Tongzhang Zheng contributes to data collection and management. Zhengmin Qian contributes to protocol development, data management, conceptualization, methodology, validation, investigation, manuscript editing and funding acquisition. Aifen Zhou contributes to methodology, validation, conceptualization, funding acquisition and manuscript editing. Zheng Min Qian and Ai Fen Zhou contributed equally as corresponding authors. All emails and questions should be directed to Professor Aifen Zhou at april1972@163.com.

Competing Interest Declaration

Authors of this work declare that they have no conflict of interest.

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Supplemental Table

Characteristics	**Total births No. (%)a**	**PTBs No. (%)**	**Controls No. (%)**	***p-value***
	6656 (100)	2393 (36.0)	4263 (64.1)	
Home decoration				
Yes	2797 (42.0)	1041 (43.5)	1756 (41.2)	> 0.05
No	3859 (58.0)	1352 (56.5)	2507 (58.8)	
Cooking fuel in the residence				
Natural gas	3882 (58.3)	1418 (59.3)	2464 (57.8)	> 0.05
Liquefied petroleum gas	2500 (37.6)	872 (36.4)	1628 (38.2)	
Electricity	192 (2.9)	66 (2.8)	126 (3.0)	
Coal	63 (1.0)	28 (1.1)	35 (0.8)	
Wood	3 (0.1)	1 (0.0)	2 (0.1)	
Other	16 (0.2)	8 (0.3)	8 (0.2)	
Heating fuel in the residence				
Electricity	4423 (66.5)	1591 (66.5)	2832 (66.4)	> 0.05
Gas	180 (2.7)	59 (2.5)	121 (2.8)	
Liquefied petroleum gas	13 (0.2)	7 (0.3)	6 (0.1)	
Coal	26 (0.4)	13 (0.5)	13 (0.3)	
Wood	2 (0.0)	1 (0.0)	1 (0.0)	
Others	43 (0.7)	14 (0.6)	29 (0.7)	
No heating	1969 (29.6)	708 (29.6)	1261 (29.6)	
Maternal second-hand smoking				
Yes	3836 (57.6)	1426 (59.6)	2410 (56.5)	< 0.05
No	2820 (42.4)	967 (40.4)	1853 (43.5)	
Living near pollution site				
Yes	456 (6.9)	154 (6.4)	302 (7.1)	> 0.05
No	6200 (93.2)	2239 (93.6)	3961 (92.9)	
Contact with pets				
Never	5915 (88.9)	2114 (88.3)	3801 (89.2)	> 0.05
Sometimes	630 (9.5)	236 (9.7)	394 (9.2)	
Always	111 (1.7)	43 (1.8)	68 (1.6)	
Maternal chronic health conditions				
Yes	1110 (18.9)	459 (19.2)	651 (15.3)	< 0.05
No	5546 (83.3)	1934 (80.8)	3612 (84.7)	

Exposure to deformity toxin				
Yes	201 (3.0)	87 (3.6)	114 (2.7)	< 0.05
No	6455 (97.0)	2306 (96.4)	4149 (97.3)	
Living near traffic main road				
Yes	4296 (64.5)	1592 (66.5)	2704 (63.4)	< 0.05
No	2360 (35.5)	801 (33.5)	1559 (36.6)	
Noise exposure during pregnancy				
Yes	2985 (44.9)	1086 (45.4)	1899 (44.6)	> 0.05
No	3671 (55.2)	1307 (54.6)	2364 (55.5)	
Stay outdoor, hours/day				
Means (SD)	1.91 (1.08)	1.84 (1.06)	1.95 (1.08)	< 0.05

Table S1: Distribution of other maternal exposures during pregnancy, by case and control, Wuhan, China, from June 10, 2011, to June 9, 2013.