Impact of maternal and paternal smoking on birth outcomes

Sachiko Inoue[1], Hiroo Naruse[2], Takashi Yorifuji[3], Tsuguhiko Kato[4], Takeshi Murakoshi[5], Hiroyuki Doi[6], S.V. Subramanian[7]

[1]Department of Nursing Science, Okayama Prefectural University, Okayama, Japan
[2]Department of Obstetrics, Kaba Memorial Hospital, Shizuoka, Japan
[3]Department of Human Ecology, Okayama University Graduate School of Environmental and Life Science, Okayama, Japan
[4]Department of Social Medicine, National Center for Child Health and Development, Tokyo, Japan
[5]Department of Obstetrics and Gynecology, Maternal and Perinatal Care Center, Seirei Hamamatsu General Hospital, Shizuoka, Japan
[6]Department of Epidemiology, Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences, Okayama, Japan
[7]Department of Social and Behavioral Sciences, Harvard School of Public Health, Boston, MA, USA
Address correspondence to Sachiko Inoue, E-mail: sinoue@fhw.oka-pu.ac.jp

ABSTRACT

Background The adverse effects of maternal and paternal smoking on child health have been studied. However, few studies demonstrate the interaction effects of maternal/paternal smoking, and birth outcomes other than birth weight have not been evaluated. The present study examined individual effects of maternal/paternal smoking and their interactions on birth outcomes.

Methods A follow-up hospital-based study from pregnancy to delivery was conducted from 1997 to 2010 with parents and newborn infants who delivered at a large hospital in Hamamatsu, Japan. The relationships between smoking and growth were evaluated with logistic regression.

Results The individual effects of maternal smoking are related to low birth weight (LBW), short birth length and small head circumference. The individual effects of paternal smoking are related to short birth length and small head circumference. In the adjusted model, both parents' smoking showed clear associations with LBW (odds ratio [OR] = 1.64, 95% confidence interval [CI] 1.18–2.27) and short birth length (−1 standard deviation [SD] OR = 1.38, 95% CI 1.07–1.79; −2 SD OR = 2.75, 95% CI 1.84–4.10).

Conclusions Maternal smoking was significantly associated with birth weight and length, but paternal smoking was not. However, if both parents smoked, the risk of shorter birth length increased.

Keywords birth length, birth weight, head circumference, smoking

Implications

The adverse effects of maternal smoking on birth outcomes are widely accepted. The effects of passive smoking, including second-hand and environmental tobacco smoke, are also well known. However, there are few studies on the interaction effect of maternal/paternal smoking on child health. Our study showed that maternal smoking is significantly associated with birth weight and length. If both parents smoked, the effect of smoking was stronger and the risk was higher for shorter birth length. This result highlights the adverse effects of smoking on child health.

Background

The adverse effects of maternal smoking on a number of birth outcomes are widely accepted. To date, most studies have targeted the risk of maternal smoking on low birth weight (LBW), small-size for gestational age (SGA) and intrauterine growth restriction.[1–7] Other studies have focused on the long-term effects of maternal smoking on children, including overweight, obesity, higher blood pressure, attention-deficit hyperactivity disorder and regular smoking habits.[8–14]

Sachiko Inoue, Associate Professor of Psychiatric and Mental Health Nursing
Hiroo Naruse, Obstetrician, Hospital Director
Takashi Yorifuji, Associate Professor of Department of Human Ecology
Tsuguhiko Kato, Director of Social Medicine, Researcher
Takeshi Murakoshi, Obstetrician, Director of Obstetrics and Gynecology Department
Hiroyuki Doi, Professor of Epidemiology
S.V. Subramanian, Professor of Population Health and Geography

Several previous studies demonstrated the effect of maternal smoking on fetal growth. Iñiguez *et al.*[15] found a dose–response relationship between smoking and fetal growth (e.g. biparietal diameter and femur length). Another study showed that a combination of smoking and low maternal body mass index (BMI) can cause high rates of preterm birth and SGA neonates as well as low mean birth weight.[16] These studies support the evidence that smoking affects fetal growth.

Birth length, head circumference and LBW are major indices of fetal growth measurement. However, compared with the number of studies relating to LBW, there is limited research on the impact of maternal smoking on birth length and head circumference.[17–22] Howe *et al.*[23] reported that maternal smoking during pregnancy was associated with shorter birth length, faster height growth in infancy and slower growth in later childhood. A recent study in Japan reported that birth length was associated with the chance of hospitalization due to all causes between 6 and 18 months of age; and this association was stronger than the association with birth weight, indicating the importance of birth length as a screening index.[24] Although the clinical significance of shorter or longer birth length has not been adequately evaluated, the impact of maternal smoking during pregnancy on birth length may be pronounced. Similarly, head circumference, routinely measured at birth in many countries, reflects a child's long-term cognitive outcomes[25] and possible influences on brain development.[26] While these three measurements are essential independent screening indices when infant health conditions are examined, evidence of the impact of paternal smoking and parental smoking on these factors is limited.

Some studies examined the effect of paternal smoking as passive smoking in pregnant women or preterm birth and showed adverse effects on fetus and infant health (https://ije.oxfordjournals.org/content/43/5/1355.full.pdf+html).[27–30] For example, via passive smoking, paternal smoking may reduce birth weight, induce earlier delivery[31] and increase the risk of heart defects.[32] Andriani and Kuo[33] also reported that, in addition to smoking mothers, infants born to smoking fathers or two smoking parents had a significant reduction in birth weight and gestational age, as well as an increased risk of LBW and preterm birth. However, Krstev *et al.*[34] concluded that an effect for environmental tobacco smoking exposure alone was not detected on any pregnancy outcomes. To our knowledge, few studies have examined the combined effects of maternal and paternal smoking on birth outcomes (https://ije.oxfordjournals.org/content/43/5/1355.full.pdf+html).[27–36] Therefore, we evaluated the relationship between maternal/paternal smoking and birth outcomes in newborn infants in Japan, using the birth indices of birth weight, birth length and head circumference. We also evaluated the interaction effects of maternal and paternal smoking.

Methods

Data source and participants

Deliveries at Seirei Hamamatsu General Hospital in Shizuoka Prefecture, Japan, from 1997 to 2010 were eligible for inclusion in the present study ($n = 21\,855$). Previous studies have used this dataset to demonstrate several effects of medical, environmental and social factors on maternal and child health.[37–40] Participant information was collected in general clinical practice and recorded in individual medical records. Inclusion criteria were: deliveries after the 37th gestational week that were singleton, live births; an Apgar score of 1 or more at 1 min after birth; and the infant's sex known (Supplementary data, Fig. S1, $n = 17\,162$). Participants were excluded if information about maternal and paternal smoking was unknown ($n = 766$). We did not consider marital status if both maternal and paternal smoking information was collected. In total, 16 396 participants were included for analyses in the present study. Participants whose baby's birth weight ($n = 16\,394$), birth length ($n = 16\,340$) and head circumference ($n = 16\,379$) were available were eligible for the final analysis. The restriction of birth after the 37th gestational week was to avoid confounding between mature and premature birth LBW.[41]

Exposure variables

To demonstrate the effect of maternal smoking and paternal smoking separately, information on the mother's and father's smoking habits were used as exposure variables. Maternal and paternal smoking information was dichotomized (Yes, No). To evaluate the interaction effect of maternal and paternal smoking, combination variables were used: (i) maternal smoking (no) and paternal smoking (no); (ii) maternal smoking (no) and paternal smoking (yes); (iii) maternal smoking (yes) and paternal smoking (no) and (iv) maternal smoking (yes) and paternal smoking (yes). This information was obtained from mothers' self-report by trained obstetricians or midwives at the time of prenatal examination when the expected due date was confirmed (at about 10 weeks' gestational age). Information was collected face-to-face, using a questionnaire constructed to collect general health information. Information on a father's smoking habits was obtained in the mother's interview.

Outcome variables

LBW, a shorter birth length at -1 standard deviation (SD) (dichotomous value with cutoff point at -1 SD) and at -2 SD (dichotomous value with cutoff point at -2 SD) and smaller head circumference at −1SD (dichotomous value with cutoff point at −1SD) and −2SD (dichotomous value with cutoff point at −2SD) were used as outcome variables. LBW was defined as a baby born under 2500 g. We calculated the SD values for birth length and head circumference based on current study participants. The population average for the study participants was 49.65 cm (1SD = 1.88 cm) for height and 33.61 cm (1SD = 1.41 cm) for head circumference in girls, and 50.13 cm (1SD = 1.84 cm) for height and 33.16 cm (1SD = 1.27 cm) for head circumference in boys. These values were similar to those of the Japanese guideline published by the Japan Pediatric Society and a report from the Japanese Ministry of Health, Labour and Welfare.[42,43]

Statistical analysis

Descriptive analyses were conducted to show demographic characteristics, maternal/paternal lifestyles and birth information for newborn infants. A logistic regression model was used to examine the effects of maternal and paternal smoking on LBW, short birth length and small head circumference. We estimated odds ratios (OR) and 95% confidence intervals (CI).

In the model, we first estimated the OR and 95% CI for either maternal or paternal smoking on birth outcomes. Three models were applied: adjusted for only maternal or paternal age (Model 1); additionally adjusted for partner's smoking (Model 2) and fully adjusted for other potential confounders (Model 3). In Model 3, for the analysis between maternal smoking and birth outcomes we considered maternal age, maternal BMI at baseline (pre-pregnancy) maternal occupational status, parity and newborns' sex as potential confounders. For the analysis between paternal smoking and birth outcomes, paternal age, paternal occupation, parity and newborns' sex were considered as potential confounders. In all models, maternal and paternal age were entered into the models as linear and quadratic terms, because a U-shaped association was expected between maternal or paternal age and birth outcomes. BMI was divided into three categories: under 17.9, 18.0–24.9 and over 25.0. Maternal and paternal occupation status was collected and used as a proxy for socioeconomic status. Occupational information was divided into five categories: unemployed/student; part-time worker; freelance-/self-employed worker; company-employed worker and professional worker. The information on occupational status did not include more specific job descriptors such as clerk, service worker or sales representative. Parity was categorized as none, 1, 2 or 3 or more. The information for newborns' sex (boy/girl) was obtained from medical records.

To examine the interaction effect of maternal and paternal smoking, maternal and paternal smoking information was entered into the same model using the combinations mentioned above. The combination of maternal nonsmoking and paternal nonsmoking was used as the reference. When we examined the interaction effect, we first adjusted for both maternal and paternal age (Model 1) and then adjusted for potential confounders (Model 3). We evaluated the interaction effect using an additive interaction model. We used Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) spreadsheets provided by Knol and VanderWeele[44] to calculate the proportion attributable to the interaction (AP), and the proportion of each birth outcome among those with both maternal and paternal tobacco exposure attributable to the interaction.[45] In the absence of interaction, AP = 0. AP > 0 means a positive interaction or more than additivity, and AP < 0 means a negative interaction or less than additivity.

A supplementary multiple linear regression analysis was conducted to examine the association of smoking with continuous birth outcome indicators (birth weight, birth length and head circumference). SPSS Version 20.0 (IBM Japan, Tokyo, Japan) was used for all statistical analyses.

Ethical issues

This study was approved by the Institutional Review Board of Okayama University on 29 November 2011 (No. 498) and by the Institutional Review Board of Seirei Hamamatsu General Hospital. The clinical research guidelines of Seirei Hamamatsu General Hospital were strictly followed with respect to the use of individual information.

Results

Characteristics of study participants are described in Table 1. Of the 16 396 participants, 580 mothers (3.5%) had a smoking habit during pregnancy. Mothers who smoked were more likely to have babies with LBW (12.1%), shorter birth length (20.3% in −1 SD; 7.2% in −2 SD) and smaller head circumference (21.9% in −1 SD). Mothers older than 45 years were more likely to have LBW newborns (18.2%) and newborns with shorter birth length (27.3% in −1 SD; 18.2% in −2 SD). Mothers whose BMI was under 18.0 were more likely to have LBW newborns, and newborns with shorter birth length or small head circumference. Mothers who were professional workers were unlikely to have a LBW baby, and no difference in maternal or paternal occupational status was found for birth length and head circumference.

Table 2 presents the adjusted ORs for the associations between maternal or paternal smoking and LBW. In the fully adjusted model, both parents' smoking was associated with LBW (OR = 1.57, 95% CI 1.21–2.04 for maternal smoking;

Table 1 Characteristics of study participants ($n = 16\,396$)

	Total		*LBW*		*Shorter length (−1 SD)*		*Shorter length (−2 SD)*		*Smaller HC (−1 SD)*		*Smaller HC (−2 SD)*	
	n	%	n	%	n	%	n	%	n	%	n	%
Total	16 396		1359	8.3	2703	16.5	562	3.4	3068	18.7	322	2.0
Maternal smoking habits												
No	15 816	96.5	1289	94.9	2585	95.6	520	92.5	2941	95.9	311	96.6
Yes	580	3.5	70	5.2	118	4.4	42	7.5	127	4.1	11	3.4
Paternal smoking habits												
No	9194	56.1	727	53.5	1442	53.4	280	49.8	1663	54.2	167	51.9
Yes	7202	43.9	632	46.5	1261	46.7	282	50.2	1405	45.8	155	48.1
Parental smoking habits												
Mother no/father no	7210	44.0	570	41.9	1194	44.2	231	41.1	1346	43.9	141	43.8
Mother no/father yes	5905	36.0	502	36.9	1040	38.5	224	39.9	1155	37.7	130	40.4
Mother yes/father no	120	0.7	16	1.2	23	0.9	5	0.9	27	0.9	2	0.6
Mother yes/father yes	385	2.3	46	3.4	82	3.0	31	5.5	87	2.8	8	2.5
Maternal age												
<24	1968	12.0	189	13.9	351	13.0	88	15.7	433	14.1	50	15.5
25–34	11 758	71.7	936	68.9	1898	70.2	382	68.0	2190	71.4	224	69.6
35–44	2657	16.2	232	17.1	451	16.7	90	16.0	443	14.4	48	14.9
>45	11	0.1	2	0.2	3	0.1	2	0.4	2	0.1	0	0.0
Paternal age												
<24	145	0.9	13	1.0	20	0.7	4	0.7	31	1.0	4	1.2
25–34	1301	7.9	105	7.7	170	6.3	27	4.8	214	7.0	20	6.2
35–44	845	5.2	69	5.1	96	3.6	26	4.6	125	4.1	10	3.1
>45	14 105	86.0	1172	86.2	2417	89.4	505	89.9	2698	87.9	288	89.4
Maternal BMI at baseline												
<17.9	2153	13.1	282	20.8	470	17.4	98	17.4	526	17.1	64	19.9
18–24.9	12 971	79.1	982	72.3	2059	76.2	431	76.7	2363	77.0	235	73.0
25<	1245	7.6	89	6.6	168	6.2	31	5.5	174	5.7	21	6.5
Parity												
0	9156	55.8	832	61.2	1544	57.1	324	57.7	1914	62.4	219	68.0
1	5560	33.9	395	29.1	869	32.2	170	30.3	903	29.4	84	26.1
2	1429	8.7	108	8.0	252	9.3	58	10.3	213	6.9	14	4.4
3 or more	239	1.5	23	1.7	37	1.4	10	1.8	36	1.2	4	1.2
Maternal occupation status												
Unemployed/student	9446	57.6	759	55.9	1600	59.2	325	57.8	1702	55.5	167	51.9
Part-time worker	560	3.4	48	3.5	93	3.4	16	2.9	121	3.9	12	3.7
Freelance/self-employed worker	164	1.0	16	1.2	33	1.2	8	1.4	28	0.9	2	0.6
Company-employed worker	3952	24.1	361	26.6	645	23.9	142	25.3	797	26.0	101	31.4
Professional worker	1391	8.5	108	8.0	212	7.8	51	9.1	265	8.6	24	7.5
Paternal occupation status												
Unemployed/student	126	0.8	10	0.7	25	0.9	9	1.6	30	1.0	7	2.2
Part-time worker	31	0.2	1	0.1	7	0.3	0	0.0	1	0.0	0	0.0
Freelance/self-employed worker	960	5.9	83	6.1	165	6.1	33	5.9	178	5.8	20	6.2
Company-employed worker	14 128	86.2	1194	87.9	2334	86.4	479	85.2	2668	87.0	285	88.5
Professional worker	764	4.7	45	3.3	115	4.3	32	5.7	126	4.1	6	1.9

Continued

Table 1 Continued

	Total		*LBW*		*Shorter length (−1 SD)*		*Shorter length (−2 SD)*		*Smaller HC (−1 SD)*		*Smaller HC (−2 SD)*	
	n	%	n	%	n	%	n	%	n	%	n	%
Newborn infant's sex												
Boy	8007	48.8	806	59.3	1598	59.1	345	61.4	1854	60.4	201	62.4
Girl	8389	51.2	553	40.7	1105	40.9	217	38.6	1214	39.6	121	37.6

LBW, low birth weight; HC, head circumference; SD, standard deviation; BMI, body mass index.

Table 2 Adjusted ORs and 95% CIs for maternal/paternal smoking habits and LBW

	Model 1			*Model 2*			*Model 3*		
	Adjusted for age			*Additionally adjusted for maternal/paternal smoking*			*Fully adjusted model*		
	OR	*95% CI*		*OR*	*95% CI*		*OR*	*95% CI*	
LBW									
Individual effect of maternal smoking									
No	Reference			Reference			Reference		
Yes	1.55	1.20	2.00	1.50	1.16	1.95	1.57	1.21	2.04
Individual effect of paternal smoking									
No	Reference			Reference			Reference		
Yes	1.12	1.00	1.25	1.10	0.98	1.23	1.11	0.99	1.24
Interaction effect of									
Mother (no)/Father (no)	Reference						Reference		
Mother (no)/Father (yes)	1.08	0.95	1.23				1.07	0.94	1.22
Mother (yes)/Father (no)	1.79	1.05	3.05				1.78	1.00	3.15
Mother (yes)/Father (yes)	1.58	1.15	2.18				1.64	1.18	2.27
Interaction term (AP, SE)							−0.06	−0.69	0.56

LBW, low birth weight; HC, head circumference; SD, standard deviation; BMI, body mass index; NA, not applicable.

Model 1: Individual effect of maternal smoking was adjusted for maternal age. Individual effect of paternal smoking was adjusted for paternal age. Interaction effect was adjusted for maternal age and paternal age.

Model 2: Individual effect of maternal smoking was adjusted for maternal age and paternal smoking. Individual effect of paternal smoking was adjusted for paternal age and maternal smoking. Interaction effect was not evaluated.

Model 3: Maternal smoking, paternal smoking (or four types of combination of interaction effect), maternal age, paternal age, maternal BMI at baseline (pre-pregnancy), maternal occupational status, parity and newborn infants sex were adjusted.

OR = 1.11, 95% CI 0.99–1.24 for paternal smoking). When examining the interaction effects, combinations of a smoking mother/smoking father, and a smoking mother/nonsmoking father had elevated risks, but the AP was not elevated. When we examined the effects on short birth length (Table 3), both maternal and paternal smoking habits were independently associated with the outcome (short length of −1 SD or −2 SD). In addition, when both parents were smokers, we observed higher effect estimates compared with other combinations: OR 1.38 (95% CI 1.07–1.79) for short length of −1SD and OR 2.75 (95% CI 1.84–4.10) for short length of −2SD compared with the combination of nonsmoking parents. AP was significantly elevated for the association between parental smoking and shorter birth length at −2 SD.

Table 3 Base ORs and 95% CIs for maternal/paternal smoking habits and short birth length

	Model 1			*Model 2*			*Model 3*		
	Adjusted for age			*Additionally adjusted for maternal/paternal smoking*			*Fully adjusted model*		
	OR	*95% CI*		*OR*	*95% CI*		*OR*	*95% CI*	
Short length of −1 SD									
Individual effect of maternal smoking									
No	Reference			Reference			Reference		
Yes	1.31	1.06	1.61	1.26	1.02	1.55	1.32	1.07	1.63
Individual effect of paternal smoking									
No	Reference			Reference			Reference		
Yes	1.14	1.05	1.24	1.13	1.04	1.23	1.13	1.04	1.23
Interaction effect of									
Mother (no)/father (no)	Reference			Reference			Reference		
Mother (no)/father (yes)	1.08	0.98	1.18				1.07	0.97	1.17
Mother (yes)/father (no)	1.19	0.76	1.89				1.22	0.75	1.98
Mother (yes)/father (yes)	1.36	1.06	1.75				1.38	1.07	1.79
Interaction term (AP, SE)							−0.07	−0.57	0.43
Short length of −2 SD									
Individual effect of maternal smoking									
No	Reference			Reference			Reference		
Yes	2.30	1.66	3.18	2.15	1.54	2.99	2.27	1.62	3.18
Individual effect of paternal smoking									
No	Reference			Reference			Reference		
Yes	1.30	1.10	1.54	1.24	1.04	1.47	1.32	1.11	1.57
Interaction effect of									
Mother (no)/father (no)	Reference			Reference			Reference		
Mother (no)/father (yes)	1.19	0.99	1.44				1.21	1.00	1.46
Mother (yes)/father (no)	1.31	0.53	3.25				1.15	0.42	3.17
Mother (yes)/father (yes)	2.65	1.79	3.91				2.75	1.84	4.10
Interaction term (AP, SE)							0.50	0.08	0.92

LBW, low birth weight; HC, head circumference; SD, standard deviation; BMI, body mass index; NA, not applicable.

Model 1: Individual effect of maternal smoking was adjusted for maternal age. Individual effect of paternal smoking was adjusted for paternal age. Interaction effect was adjusted for maternal age and paternal age.

Model 2: Individual effect of maternal smoking was adjusted for maternal age and paternal smoking. Individual effect of paternal smoking was adjusted for paternal age and maternal smoking. Interaction effect was not evaluated.

Model 3: Maternal smoking, paternal smoking (or four types of combination of interaction effect), maternal age, paternal age, maternal BMI at baseline (pre-pregnancy), maternal occupational status, parity and newborn infants sex were adjusted.

Finally, with regard to head circumference, maternal and paternal smoking habits were independently associated with small head circumference of −1 SD (Table 4). When we examined the interaction effect, a significant association was observed only when both parents were smokers (OR = 1.36, 95% CI 1.05–1.75), but AP was not elevated.

A supplementary analysis of the multiple linear regression analysis supported these results (Supplementary data, Table S1).

Discussion

Key results

After adjusting for sociodemographic and obstetric factors such as age, BMI and socioeconomic status, both maternal and paternal smoking habits were associated with birth outcomes, although the effect estimate was stronger for maternal smoking than for paternal smoking. Adverse effects were

Table 4 Base ORs and 95% CIs for maternal/paternal smoking habits and head circumference

	Model 1			*Model 2*			*Model 3*		
	Adjusted for age			*Additionally adjusted for maternal/paternal smoking*			*Fully adjusted model*		
	OR	*95% CI*		*OR*	*95% CI*		*OR*	*95% CI*	
Small head circumference of −1 SD									
Individual effect of maternal smoking									
No	Reference			Reference			Reference		
Yes	1.23	1.00	1.50	1.19	0.98	1.46	1.30	1.05	1.59
Individual effect of paternal smoking									
No	Reference			Reference			Reference		
Yes	1.10	1.01	1.19	1.09	1.01	1.18	1.10	1.01	1.19
Interaction effect of									
Mother (no)/father (no)	Reference						Reference		
Mother (no)/father (yes)	1.06	0.97	1.16				1.05	0.96	1.15
Mother (yes)/father (no)	1.26	0.82	1.95				1.30	0.82	2.07
Mother (yes)/father (yes)	1.27	0.99	1.63				1.36	1.05	1.75
Interaction term (AP, SE)							0.08	−0.36	0.52
Small head circumference of −2 SD									
Individual effect of maternal smoking									
No	Reference			Reference			Reference		
Yes	0.96	0.53	1.77	0.91	0.49	1.68	1.06	0.57	1.95
Individual effect of paternal smoking									
No	Reference			Reference			Reference		
Yes	1.19	0.95	1.48	1.19	0.96	1.49	1.17	0.94	1.47
Interaction effect of									
Mother (no)/father (no)	Reference						Reference		
Mother (no)/father (yes)	1.13	0.89	1.44				1.08	0.84	1.37
Mother (yes)/father (no)	0.85	0.21	3.47				0.92	0.22	3.79
Mother (yes)/father (yes)	1.06	0.52	2.19				1.07	0.52	2.22
Interaction term (AP, SE)							0.18	−0.94	1.31

LBW, low birth weight; HC, head circumference; SD, standard deviation; BMI, body mass index; NA, not applicable.
Model 1: Individual effect of maternal smoking was adjusted for maternal age. Individual effect of paternal smoking was adjusted for paternal age. Interaction effect was adjusted for maternal age and paternal age.
Model 2: Individual effect of maternal smoking was adjusted for maternal age and paternal smoking. Individual effect of paternal smoking was adjusted for paternal age and maternal smoking. Interaction effect was not evaluated.
Model 3: Maternal smoking, paternal smoking (or four types of combination of interaction effect), maternal age, paternal age, maternal BMI at baseline (pre-pregnancy), maternal occupational status, parity and newborn infants sex were adjusted.

observed on short birth length and small head circumference as well as LBW. In addition, the adverse effects were strongest when both parents were smokers, in particular for short birth length.

Effect of smoking on LBW, birth length and head circumference

Both maternal and paternal smoking habits were associated with the risk of LBW. Many studies to date have evaluated the effects of maternal smoking on LBW, with most results showing a strong association between maternal smoking and LBW.[1–7,46–48] These results are consistent with the present study. Although marginally significant, we also found paternal smoking was associated with the risk of LBW. Considering previous studies that have examined the effect of passive smoking on LBW,[47,49,50] the present result is also reasonable.

Few studies have examined the effects of parental smoking on birth length. Our findings demonstrated that the smoking habits of both parents affected birth outcomes. There is limited evidence showing smoking has significant effect on short birth length[20,21] which is consistent with the present study. For example, a recent study suggested a relationship between maternal smoking and shorter birth length that influenced faster height growth in infancy and slower growth in later childhood.[23] Another recent study indicated that birth length was an important predictor of subsequent health.[24] This suggests future studies evaluating the impact on birth length and its trajectories may have merit.

Our study found an adverse effect of parental smoking on head circumference. Previous studies suggest possible associations between maternal smoking and small head circumference,[8,11] and those findings are consistent with the present study. Although the mechanism is not known, there was no clear association between smoking habits and head circumference at −2 SD (i.e. a much smaller body composition). As mentioned, head size is an index of abnormal brain condition or neurodevelopmental delay in intelligence and cognitive function.[25] Further investigation of this outcome is also warranted.

Independent effects and interaction effects

The second aim of the present study was to examine the interaction effect of parental smoking in addition to the independent effects. With regard to independent effects, maternal smoking had a stronger impact on birth outcomes than paternal smoking. This result is consistent with a previous study,[51] and may be explained by different modes (active versus passive) of exposure. However, both active and passive smoking are reported to have long-term impacts on child development; for example, neurobehavioral development,[52] and both parents should refrain from smoking. Moreover, as evident in the interaction effect we examined, if both parents were smokers, the adverse effects of smoking were worse, in particular on short birth length. Cessation of smoking should therefore be recommended for both parents. This finding highlights the necessity of obtaining smoking information from both parents to comprehensively evaluate the adverse effect of parental smoking.

Limitations

There are some limitations in the present study. First, the study was conducted with data derived from one hospital in Japan. Seirei Hamamatsu General Hospital provides advanced medical care and the hospital accepts pregnant women with high-risk conditions, which may limit the generalizability of our findings. Second, there may be a social desirability bias. Information on smoking habits was collected by self-report, and there might be misclassification between smoking and nonsmoking, in particular for mothers. This may be due to social background, as smoking is considered an undesirable behavior in pregnant women. This might have weakened the results (i.e. moving effect estimates toward the null). Third, a previous study showed a dose–response relationship between maternal smoking during pregnancy and adverse outcomes (e.g. fetal biometry)[15]. However, as data on the amount of smoking were not collected, we could not evaluate dose–response relationship. Instead, we evaluated the interaction effect using an additive interaction model. This may help in understanding the dose–response effect. Fourth, measuring birth length and head circumference may have a possibility of measurement error, which might lead to non-differential misclassification moving the effect estimates toward null. Finally, only 3.5% of the mothers in the present study smoked. This might have reduced the statistical power.

Conclusions

Both maternal smoking and paternal smoking were associated with various birth outcomes such as LBW, short birth length and small head circumference. If both parents smoked, these effects were stronger, in particular on shorter birth length. Barker (1995) noted that being born small may harm child development[53] and smoking itself may increase the risk of behavioral problems and undesirable life habits.[8] Avoiding both maternal and paternal smoking during pregnancy will benefit the developing fetus and later child health.

Supplementary data

Supplementary data are available at the *PUBMED* online.

Authors' contributions

S.I. conceptualized and designed the study, carried out the initial analyses, drafted the initial manuscript and approved the final manuscript as submitted. T.Y. and T.K.conceptualized and designed the study, reviewed and revised the manuscript, and approved the final manuscript as submitted. H.N. and T.M. designed the data collection instruments, coordinated and supervised data collection, critically reviewed the manuscript and approved the final manuscript as submitted. H.D. and S.V.S. critically reviewed the manuscript, and approved the final manuscript as submitted.

Funding

This work was supported in part by Health and Labour Sciences Research Grants for Health Research on Children, Youth and Families.

Acknowledgements

We appreciate the contributions of the staff at Seirei Hamamatsu General Hospital in maintaining the perinatal dataset. This work was supported in part by Health and Labour Sciences Research Grants for Health Research on Children, Youth and Families.

Conflict of interest statement

None declared.

References

1 Blake KV, Gurrin LC, Evans SF *et al*. Maternal cigarette smoking during pregnancy, low birth weight and subsequent blood pressure in early childhood. *Early Hum Dev* 2000;**57(2)**:137–47.

2 Blatt K, Moore E, Chen A *et al*. Association of reported trimester-specific smoking cessation with fetal growth restriction. *Obstet Gynecol* 2015;**125**:1452–9.

3 Harrod CS, Reynolds RM, Chasan-Taber L *et al*. Quantity and timing of maternal prenatal smoking on neonatal body composition: the healthy start study. *J Pediatr* 2014;**165**:707–12.

4 Ko TJ, Tsai LY, Chu LC *et al*. Parental smoking during pregnancy and its association with low birth weight, small for gestational age, and preterm birth offspring: a birth cohort study. *Pediatr Neonatol.* 2014;**55(1)**:20–7.

5 Raatikainen K, Huurinainen P, Heinonen S. Smoking in early gestation or through pregnancy: a decision crucial to pregnancy outcome. *Prev Med* 2007;**44(1)**:59–63.

6 Secker-Walker RH, Vacek PM. Relationships between cigarette smoking during pregnancy, gestational age, maternal weight gain, and infant birth weight. *Addict Behav* 2003;**28(1)**:55–66.

7 Suzuki K, Tanaka T, Kondo N *et al*. Is maternal smoking during early pregnancy a risk factor for all low birth weight infants? *J Epidemiol* 2008;**18(3)**:89–96.

8 Agrawal A, Scherrer JF, Grant JD *et al*. The effects of maternal smoking during pregnancy on offspring outcomes. *Prev Med* 2010;**50(1–2)**:13–8.

9 Bauer NS, Anand V, Carroll AE *et al*. Secondhand smoke exposure, parental depressive symptoms and preschool behavioral outcomes. *J Pediatr Nurs* 2015;**30(1)**:227–35.

10 Ino T. Maternal smoking during pregnancy and offspring obesity: meta- analysis. *Pediatr Int* 2010;**52**:94–9.

11 Magee SR, Bublitz MH, Orazine C *et al*. The relationship between maternal-fetal attachment and cigarette smoking over pregnancy. *Matern Child Health J* 2014;**18**:1017–22.

12 Oken E, Levitan EB, Gillman MW. Maternal smoking during pregnancy and child overweight: systematic review and meta analysis. *Int J Obes* 2008;**32**:201–10.

13 Zhu JL, Olsen J, Liew Z *et al*. Parental smoking during pregnancy and ADHD in children: the Danish national birth cohort. *Pediatrics* 2014;**134(2)**:e382–8.

14 Wade KH, Skugarevsky O, Kramer MS *et al*. Prospective associations of parental smoking, alcohol use, marital status, maternal satisfaction, and parental and childhood body mass index at 6.5 years with later problematic eating attitudes. *Nutr Diabetes* 2014;**4**:e100. http://www.nature.com/nutd/journal/v4/n1/pdf/nutd201340a.pdf (4 May 2016, date last accessed).

15 Iñiguez C, Ballester F, Costa O *et al*. INMA Study Investigators. Maternal smoking during pregnancy and fetal biometry: the INMA Mother and Child Cohort Study. *Am. J. Epidemiol* 2013;**178(7)**:1067–75.

16 Voigt M, Jorch G, Briese V *et al*. The combined effect of maternal body mass index and smoking status on perinatal outcomes - an analysis of the german perinatal survey. *Z Geburtshilfe Neonatol* 2011;**215(1)**:23–8. https://www.thieme-connect.com/DOI/DOI?10.1055/s-0030-1254142 [Epub 2011 Feb 23] (4 May 2016, date last accessed).

17 Ekblad M, Korkeila J, Lehtonen L. Smoking during pregnancy affects foetal brain development. *Acta Paediatr* 2015;**104**:12–8.

18 Himes SK, Stroud LR, Scheidweiler KB *et al*. Prenatal tobacco exposure, biomarkers for tobacco in meconium, and neonatal growth outcomes. *J Pediatr* 2013;**162(5)**:970–5.

19 Källén K. Maternal smoking during pregnancy and infant head circumference at birth. *Early Hum Dev* 2000;**58(3)**:197–204.

20 Durmus B, Kruithof CJ, Gillman MH *et al*. Parental smoking during pregnancy, early growth, and risk of obesity in preschool children: the Generation R Study. *Am J Clin Nutr* 2011;**94(1)**:164.

21 Pavić I, Dodig S, Jurković M *et al*. The influence of mother's active smoking during pregnancy on body mass index of newborns. *Coll Antropol* 2011;**35(4)**:1149–54. http://www.ncbi.nlm.nih.gov/pubmed/22397252 (3 August 2015, date last accessed).

22 Pembrey M, Northstone K, Gregory S *et al*. Is the growth of the child of a smoking mother influenced by the father's prenatal exposure to tobacco? A hypothesis generating longitudinal study. *BMJ Open* 2014;**4(7)**:e005030.

23 Howe LD, Matijasevich A, Tilling K *et al*. Maternal smoking during pregnancy and offspring trajectories of height and adiposity: comparing maternal and paternal associations. *Int J Epidemiol* 2012;**41(3)**: 722–32.http://ije.oxfordjournals.org/content/41/3/722.long (4 May 2016, date last accessed).

24 Kato T, Yorifuji T, Inoue S *et al*. Association of birth length and risk of hospitalisation among full-term babies in Japan. *Paediatr Perinat Epidemiol* 2013;**27(4)**:361–70. http://www.ncbi.nlm.nih.gov/pubmed/15064172 (3 August 2015, date last accessed).

25 Fattal-Valevski A, Toledano-Alhadef H, Leitner Y *et al*. Growth patterns in children with intrauterine growth retardation and their correlation to neurocognitive development. *J Child Neurol* 2009; **24(7)**:846–51.

26 Król1 M, Florek E, Piekoszewski W *et al*. The impact of intrauterine tobacco exposure on the cerebral mass of the neonate based on the measurement of head circumference. *Brain Behav* 2012;**2(3)**:243–8. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3381629/pdf/brb30002-0243.pdf (4 May 2016, date last accessed).

27 Thacher JD, Gruzieva O, Pershagen G *et al*. Pre- and postnatal exposure to parental smoking and allergic disease through adolescence. *Pediatrics* 2014;**134**:428–34. http://pediatrics.aappublications.org/content/134/3/428.long (4 May 2016, date last accessed).

28 Ahluwalia IB, Grummer-Strawn L, Scanlon KS. Exposure to environmental tobacco smoke and birth outcome: increased effects on

pregnant women aged 30 years or older. *Am J Epidemiol* 1997;**146(1)**:42–7. http://aje.oxfordjournals.org/content/146/1/42.long (3 August 2015, date last accessed).

29 Newman RB, Momirova V, Dombrowski MP *et al.* The effect of active and passive household cigarette smoke exposure on pregnant women with asthma. *Chest* 2010;**137(3)**:601–8.

30 Windham GC, Hopkins B, Fenster L *et al.* Prenatal active or passive tobacco smoke exposure and the risk of preterm delivery or low birth weight. *Epidemiology* 2000;**11(4)**:427–33. http://www.ncbi.nlm.nih.gov/pubmed/10874550 (3 August 2015, date last accessed).

31 Ion RC, Wills AK, Bernal AL. Environmental tobacco smoke exposure in pregnancy is associated with earlier delivery and reduced birth weight. *Reprod Sci* 2015;**22(12)**:1603–11.

32 Forest S, Priest S. Intrauterine tobacco smoke exposure and congenital heart defects. *J Perinat Neonatal Nurs* 2016;**30(1)**:54–63.

33 Andriani H, Kuo HW. Adverse effects of parental smoking during pregnancy in urban and rural areas. *BMC Pregnancy Childbirth* 2014;**14**:414. http://bmcpregnancychildbirth.biomedcentral.com/articles/10.1186/s12884-014-0414-y (4 May 2016, date last accessed).

34 Krstev S, Marinković J, Simić S *et al.* The influence of maternal smoking and exposure to residential ETS on pregnancy outcomes: a retrospective national study. *Matern Child Health J* 2013;**17(9)**:1591–8. http://link.springer.com/article/10.1007%2Fs10995-012-1169-6 (4 May 2016, date last accessed).

35 Tabuchi T, Fujiwara T, Nakayama T *et al.* Maternal and paternal indoor or outdoor smoking and the risk of asthma in their children: a nationwide prospective birth cohort study. *Drug Alcohol Depend* 2015;**147C**:103–8.

36 Yerushalmy J. The relationship of parents' cigarette smoking to outcome of pregnancy—implications as to the problem of inferring causation from observed associations. *Int J Epidemiol* 2014;**43(5)**:1355–66.

37 Inoue S, Naruse H, Yorifuji T *et al.* Who is at risk of inadequate weight gain during pregnancy? Analysis by occupational status among 15,020 deliveries in a regional hospital in Japan. *Matern Child Health J* 2013;**17(10)**:1888–97.

38 Yorifuji T, Naruse H, Kashima S *et al.* Trends of preterm birth and low birth weight in Japan: a one hospital-based study. *BMC Pregnancy Childbirth* 2012;**12**:162.

39 Yorifuji T, Naruse H, Kashima S *et al.* Residential proximity to major roads and adverse birth outcomes: a hospital-based study. *Environ Health* 2013;**12(1)**:34.

40 Yorifuji T, Naruse H, Kashima S *et al.* Residential proximity to major roads and obstetrical complications. *Sci Total Environ* 2014;**508C**:188–92.

41 Wilcox AJ. On the importance–and the unimportance–of birth weight. *Int J Epidemiol* 2001;**30(6)**:1233–41.

42 Itabashi K. *et al.* Revised birth size standards by gestational age for Japanese neonates. *J Jpn Pediatr Soc* 2010;**114(8)**:1271–93 (in Japanese).

43 The Ministry of Health, Labor and Welfare in Japan. National Growth Survey on Preschool Children 2010. MHLW Japan, 2010 (in Japanese).

44 Knol MJ, VanderWeele TJ. Recommendations for presenting analyses of effect modification and interaction. *Int J Epidemiol* 2012;**41**:514–20.

45 Hosmer DW, Lemeshow S. Confidence interval estimation of interaction. *Epidemiology* 1992;**3**:452–6.

46 Wahabi HA, Alzeidan RA, Fayed AA *et al.* Effects of secondhand smoke on the birth weight of term infants and the demographic profile of Saudi exposed women. *BMC Public Health* 2013;**13**:341.

47 Perera FP, Rauh V, Whyatt RM *et al.* Molecular evidence of an interaction between prenatal environmental exposures on birth outcomes in a multiethnic population. *Environ Health Perspect* 2004;**12**:630–62. http://www.ncbi.nlm.nih.gov/pubmed/15064172 (3 August 2015, date last accessed).

48 Rauh VA, Whyatt RM, Garfinkel R *et al.* Developmental effects of exposure to environmental tobacco smoke and material hardship among inner-city children. *Neurotoxicol Teratol* 2004;**26**:373–85.

49 Norsa'adah B, Salinah O. The Effect of second-hand smoke exposure during pregnancy on the newborn weight in Malaysia. *Malays J Med Sci* 2014;**21(2)**:44–53. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4028571/ (3 August 2015, date last accessed).

50 Rubin DH, Krasilnikoff PA, Leventhal JM *et al.* Effect of passive smoking on birth-weight. *Lancet* 1986;**2(8504)**:415–7.

51 Makin J, Fried PA, Watkinson B. A comparison of active and passive smoking during pregnancy: long-term effects. *Neurotoxicol Teratol* 1991;**13(1)**:5–12. http://www.ncbi.nlm.nih.gov/pubmed/2046627 (3 August 2015, date last accessed).

52 Hernández-Martínez C, Arija Val V, Escribano Subías J *et al.* A longitudinal study on the effects of maternal smoking and secondhand smoke exposure during pregnancy on neonatal neurobehavior. *Early Hum Dev* 2012;**88(6)**:403–8.

53 Barker DJ. Fetal origins of coronary heart disease. *BMJ (Clinical Research Ed.)* 1995;**311**:171–4.