A Cohort Study on the Use of Commercial Induction Heating Cookers by Pregnant Women and the Birth Weight of Their Infants

Yasuto Sato, Masao Taki, and Noriko Kojimahara

Abstract – The number of devices that generate intermediate-frequency electromagnetic fields (IF-EMFs) in living and working environments has been increasing. The present study was conducted to examine the possible health effects of IF-EMFs by clarifying the relationship between the use of commercial induction heating (IH) cookers in the workplace by pregnant women and the birth weight of their infants. Pregnant women were recruited from among survey monitors who were registered with an Internet research firm. In total, 8920 pregnant women responded to the baseline survey. In the follow-up survey, they were asked about the birth weight of their infants. The response rate for the follow-up survey was 60.9%. In total, 3126 women who had worked during pregnancy were included in the analysis. We examined the relationship between the use of commercial IH cookers and birth weight ($<$2500 g and $\geq$2500 g) using multivariate logistic regression models. The use of a commercial IH cooker did not significantly increase the odds ratio (OR) for low birth weight in either the first trimester (OR = 0.94; 95% confidence interval [CI]: 0.60 to 1.46) or the second trimester (OR = 0.52; 95% CI: 0.24 to 1.11). In the third trimester, none of the women who had used a commercial IH cooker in the workplace gave birth to an infant weighing $<$2500 g. Therefore, no associations were observed between the use of commercial IH cookers in the workplace by pregnant women and the birth weight of their infants.

1. Introduction

Intermediate-frequency electromagnetic fields (IF-EMFs) are electromagnetic waves with frequencies of 300 Hz to 10 MHz. In recent years, the number of devices that generate IF-EMFs in the living and working environments has been increasing [1]. Sources of IF-EMFs in these environments include wireless power transfer for mobile phones, antitheft gates and unlocking devices for security tags, and induction heating (IH) cookers. Among these devices, IH cookers are the most popular in Japan, with frequencies ranging from 20 kHz to 90 kHz. The IH cookers were first manufactured and sold in the USA in 1971 and have been manufactured and sold in Japan since 1974 [2]. The features of IH cookers include the following: they are safe because they do not use fire; they are flat and easy to clean; and they have a high thermal efficiency of 90% with little radiant heat. The downside is that IH cookers are more expensive than gas stoves. As of 2020, household IH cookers had a household penetration rate of 24% [3], and commercial IH cookers accounted for 14% of all cooking appliances in Japan [4].

The differences between household and commercial IH cookers are as follows. The output power of household IH cookers is up to about 2000 W, compared with up to about 5000 W for commercial IH cookers. The power supply for household IH cookers is single-phase 100 V or 200 V, compared with single-phase 200 V or three-phase 200 V for commercial IH cookers. Commercial IH cookers are also larger, especially in terms of height. Commercial IH cookers have a high heat exhaust capability for continuous use. Commercial IH cookers also have a fully automatic cooking function, whereas household IH cookers have only simple functions. The magnetic flux densities at a distance of 300 mm from IH cookers are reported to be 7.9 μT to 26 μT for household IH cookers and 4.2 μT to 57 μT for commercial IH cookers [5].

Some epidemiological studies on IF-EMFs have been conducted. Researchers [6] reported finding no effects of electronic article surveillance on miscarriage, premature birth, or reduced birth weight among women working in supermarkets. Other researchers [7] found no association between the penetration of household IH cookers and birth outcomes in an ecological study in Japan. The authors in [8] also found no association between the use of household IH cookers and delivery outcomes in a cohort study of pregnant women in Japan.

Few experimental studies have reported that IF-EMFs have adverse effects on organisms, and no epidemiological studies have identified any such associations. In addition, no particular mention has been made of the potential effects of IF-EMFs on pregnant women or fetuses. On the other hand, pregnant women have a protruding abdomen, which is closer to the device when cooking. Therefore, it is desirable to clarify the safety of IH cooker use. The present study was conducted to examine the possible

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Yasuto Sato and Noriko Kojimahara are with the Graduate School of Public Health, Shizuoka Graduate University of Public Health, 4-27-2 Kita Ando Aoi-ku, Shizuoka 420-0881, Japan; e-mail: yssato@s-sph.ac.jp, nkojimahara@s-sph.ac.jp.

Masao Taki is with the Graduate School of Systems Design, Tokyo Metropolitan University, 1-1 Minami-Osawa, Hachioji-shi, Tokyo 192-0397, Japan; e-mail: masao@tmu.ac.jp.

Table 1. Background characteristics of the study participants

	n	%
Gestational age at baseline survey		
First trimester (≤15th week)	553	17.7
Second trimester (16th week to 27th week)	900	28.8
Third trimester (≥28th week)	1673	53.5
Mother's age (years)		
20 to 24	48	1.5
25 to 29	977	31.3
30 to 34	1476	47.2
≥35	625	20.0
Infant's sex		
Male	1523	48.7
Female	1603	51.3
Birth weight (g)		
≥2500	2862	91.6
<2500	264	8.4

health effects of IF-EMFs by clarifying the relationship between the use of commercial IH cookers in the workplace by pregnant women and the birth weight of their infants.

2. Materials and Methods

Pregnant women were recruited from among survey monitors who were registered with an Internet research firm. In the baseline survey, the pregnant women were asked whether they had a job and whether they used commercial IH cookers in the workplace. In total, 8920 pregnant women responded to the baseline survey. In a follow-up survey, they were asked about the birth weight of their infants. In total, 5432 women responded to the follow-up survey, for a response rate of 60.9%. The survey was conducted from 2020 to 2022. The present study was approved by the Ethics Committee of Shizuoka Graduate University of Public Health (no. SGUPH_2021_005).

Of the 5022 women who gave birth to singleton infants, data from 3126 who worked during pregnancy were included in the analysis. First, the background characteristics of the subjects were tabulated. A cross-tabulation analysis was conducted on the subjects' background characteristics and the birth weight of their infants. Low birth weight was defined as <2500 g in accordance with

Table 2. Associations among background characteristics and birth weight

	Birth weight ≥2500 g (*n* = 2862)		Birth weight <2500 g (*n* = 264)				
	n	%	*n*	%	Total	Chi-square value	*P*
Mother's age (years)							
20 to 24	44	91.7	4	8.3	48	4.5409	0.2087
25 to 29	899	92.0	78	8.0	977		
30 to 34	1360	92.1	116	7.9	1476		
≥35	559	89.4	66	10.6	625		
Maternal smoking (early pregnancy)							
No	2666	91.6	245	8.4	2911	0.0459	0.8304
Yes	196	91.2	19	8.8	215		
Maternal drinking (early pregnancy)							
No	2740	91.5	253	8.5	2993	0.0055	0.9410
Yes	122	91.7	11	8.3	133		
Mother's education							
Junior high school	32	97.0	1	3.0	33	2.3038	0.5118
High school	410	92.1	35	7.9	445		
Junior college	833	90.7	85	9.3	918		
More than college	1587	91.7	143	8.3	1730		
Annual household income (million yen)							
<4	515	91.0	51	9.0	566	2.1258	0.5467
4 to 6	841	90.7	86	9.3	927		
6 to 8	734	92.0	64	8.0	798		
≥8	772	92.5	63	7.5	835		
Recurrent fetal loss							
No	2764	91.7	251	8.3	3015	1.5881	0.2076
Yes	98	88.3	13	11.7	111		
Hypertensive disorders during pregnancy							
No	2809	91.8	252	8.2	3061	8.6130	0.0033
Yes	53	81.5	12	18.5	65		
Gestational diabetes							
No	2753	91.6	251	8.4	3004	0.8023	0.3704
Yes	109	89.3	13	10.7	122		
Fetal growth restriction							
No	2839	91.6	259	8.4	3098	3.2368	0.0720
Yes	23	82.1	5	17.9	28		
Method of delivery							
Vaginal delivery	2355	92.7	186	7.3	2541	22.5026	<0.0001
Cesarean section	505	86.6	78	13.4	583		
Infant's sex							
Male	1422	93.4	101	6.6	1523	12.6347	0.0004
Female	1440	89.8	163	10.2	1603		

Table 3. Associations between commercial IH cooker use and birth weight

	Birth weight ≥2500 g		Birth weight <2500 g				
	n	%	*n*	%	Total	Chi-square value	*P*
First trimester (≤15th week of gestation)							
Not used	2695	91.6	248	8.4	2943	0.0644	0.9683
Used <4 h	139	91.4	13	8.6	152		
Used ≥4 h	28	90.3	3	9.7	31		
Total	2862		264		3126		
Second trimester (16th week to 27th week of gestation)							
Not used	2061	91.5	191	8.5	2252	1.8946	0.3878
Used <4 h	78	95.1	4	4.9	82		
Used ≥4 h	23	95.8	1	4.2	24		
Total	2162		196		2358		
Third trimester (≥28th week of gestation)							
Not used	1141	93.8	76	6.2	1217	1.7294	0.4212
Used <4 h	17	100.0	0	0.0	17		
Used ≥4 h	9	100.0	0	0.0	9		
Total	1167	76		1243			

the World Health Organization definition [9]. In addition, a cross-tabulation analysis was conducted on the use of commercial IH cookers in the workplace and infant birth weights. The usage time of the commercial IH cooker was divided into intervals of <4 h and ≥4 h because 8 h is the standard daily work time in Japan. Finally, multivariate analysis was performed using a logistic regression model. The objective variable was birth weight (<2500 g and ≥2500 g), and the explanatory variables were the use of a commercial IH cooker, mother's age, maternal smoking status, maternal drinking status, mother's education level, annual household income, recurrent fetal loss, hypertensive disorders during pregnancy, gestational diabetes, fetal growth restriction, method of delivery, and infant's sex. For the use of a commercial IH cooker, the mother's age, the mother's education level, and annual household income, the data were converted into categories shown in cross tabulations and entered into the multivariate logistic regression model. All statistical analyses were performed using SAS version 9.4.

3. Results

Table 1 shows the participants' background characteristics. Regarding gestational age at the baseline survey, the highest proportion of respondents was in the third trimester ($n = 1673$, 53.5%). Regarding the age of the mothers, the highest proportion was 30 to 34 years ($n = 1476$, 47.2%) of age. Regarding the infants, 51.3% ($n = 1603$) were female. The proportion of infants with a birth weight <2500 g was 8.4% ($n = 264$).

Table 2 shows the associations among background characteristics and birth weight. No significant differences were observed in the following: mother's age in years (20 to 24, 8.3%; 25 to 29, 8.0%; 30 to 34, 7.9%; and ≥35, 10.6%; $P = 0.2087$); maternal smoking (no, 8.4%; yes, 8.8%; $P = 0.8304$); maternal drinking (no, 8.5%; yes, 8.3%; $P = 0.9410$); mother's education (junior high school, 3.0%; high school 7.9%; junior college, 9.3%; and more than college, 8.3%; $P = 0.5118$); annual household income in million yen (<4, 9.0%; 4 to 6, 9.3%; 6 to 8, 8.0%; and ≥8, 7.5%; $P = 0.5467$); recurrent fetal loss (no, 8.3%; yes, 11.7%; $P = 0.2076$); gestational diabetes (no, 8.4%; yes, 10.7%; $P = 0.3704$); or fetal growth restriction (no, 8.4%; yes, 17.9%; $P = 0.0720$). However, statistically significant differences were observed in terms of hypertensive disorders during pregnancy (no, 8.2%; yes, 18.5%; $P = 0.0033$), method of delivery (vaginal delivery, 7.3%; cesarean section, 13.4%; $P < 0.0001$), and infant's sex (male, 6.6%; female, 10.2%; $P = 0.0004$).

Table 3 shows the associations between commercial IH cooker use and birth weight. No significant differences were found in the first trimester (not used, 8.4%; used <4 h, 8.6%; and used ≥4 h, 9.7%; $P = 0.9683$) or second trimester (not used, 8.5%; used <4 h, 4.9%; used ≥4 h, 4.2%; $P = 0.3878$). None of the women who used commercial IH cookers in the workplace during the third trimester gave birth to infants weighing <2500 g (not used, 6.2%; used <4 h, 0.0%; and used ≥4 h, 0.0%; $P = 0.4212$).

Table 4 shows the ORs for birth weight <2500 g by a multivariate logistic regression model. The use of a commercial IH cooker did not significantly increase the OR for low birth weight in either the first trimester (OR = 0.94; 95% confidence interval [CI]: 0.60 to 1.46) or the second trimester (OR = 0.52; 95% CI: 0.24 to 1.11). However, statistically significant increases in the ORs for low birth weight were found for hypertensive disorders of pregnancy (OR = 2.09; 95% CI: 1.01 to 4.33), method of delivery (OR = 1.88; 95% CI: 1.41 to 2.50), and infant's sex (OR = 1.57; 95% CI: 1.21 to 2.04) in the first trimester and fetal growth restriction (OR = 3.67; 95% CI: 1.19 to 11.35), method of delivery (OR = 2.09; 95% CI: 1.52 to 2.89), and infant's sex (OR = 1.66; 95% CI: 1.22 to 2.25) in the second trimester.

4. Discussion

The present study was conducted to examine the possible health effects of IF-EMFs by clarifying the relationship between the use of commercial IH cookers in the workplace by pregnant women and the birth weight of their infants. The results of cross tabulation revealed no associations for the use of commercial IH cookers in the first,

Table 4. The ORs for birth weight <2500 g by a multivariate logistic regression model

	First trimester			Second trimester		
	OR	95% CI		OR	95% CI	
Use of commercial IH cooker	0.94	0.60	1.46	0.52	0.24	1.11
Mother's age	1.09	0.92	1.30	1.05	0.86	1.28
Maternal smoking (early pregnancy)	1.05	0.64	1.74	1.29	0.74	2.24
Maternal drinking (early pregnancy)	0.86	0.45	1.65	0.78	0.35	1.75
Mother's education	1.07	0.90	1.27	1.07	0.87	1.32
Annual household income	0.91	0.80	1.03	0.93	0.81	1.08
Recurrent fetal loss	1.34	0.72	2.46	1.80	0.91	3.54
Hypertensive disorders of pregnancy	2.09	1.01	4.33	2.17	0.91	5.18
Gestational diabetes	1.00	0.52	1.94	1.06	0.51	2.18
Fetal growth restriction	1.80	0.59	5.44	3.67	1.19	11.35
Method of delivery	1.88	1.41	2.50	2.09	1.52	2.89
Infant's sex	1.57	1.21	2.04	1.66	1.22	2.25

second, or third trimester of pregnancy. In addition, no associations were observed on the basis of the results of multivariate logistic regression analysis.

The present study was a subset analysis of data from a study on the use of household IH cookers by pregnant women and delivery outcomes. The present study analyzed the use of commercial IH cookers and birth weight among mothers who continued to work during pregnancy. Because no associations were found with the use of household IH cookers [10], the analysis in the present study was performed by limiting exposure to commercial IH cookers.

Because the present study was a subset analysis, exposure information is limited. Although there is information on whether and how long commercial IH cookers were used, there is a lack of detailed information, such as on the type of IH cooker used, how the IH cooker was used, the distance from the IH cooker during use, and the size of the pan that was used. In future research, IF-EMFs from commercial IH cookers should be measured or manufacturer's data on IF-EMFs should be collected by identifying the specific equipment being used. All of the factors for which a significant increase in the ORs was observed in the multivariate logistic regression analysis are known risk factors for low birth weight [11]. Pregnant women who continue to work during pregnancy are considered to have no problems with the pregnancies. Therefore, the results of the present study may include the "healthy worker" effect. In other words, the present findings may have been the result of observing only healthy women. Therefore, future studies should also include those with various health problems.

5. Conclusion

In the present study, no association was observed between the use of commercial IH cookers in the workplace by pregnant women and the birth weight of their infants.

6. References

1. K. Yamazaki, M. Taki, and C. Ohkubo, "Safety Assessment of Human Exposure to Intermediate Frequency Electromagnetic Fields," *Electrical Engineering in Japan*, **197**, 4, December 2016, pp. 3-11.
2. K. Yamashita, "The Features of Induction Cooktop," *Journal of Cookery Science of Japan*, **54**, 2, April 2021, pp. 117-120.
3. Japanese Ministry of the Environment, "Statistical Survey of CO_2 Emissions in the Household Sector," https://www.env.go.jp/earth/ondanka/ghg/R2_CO2tokei_report_imp.pdf (Accessed 20 December 2023)(in Japanese).
4. Japan Kitchen Industry Association, "Fact-Finding Survey Regarding Commercial Kitchen Equipment," https://www.jfea.or.jp/books/books.html (Accessed 20 December 2023)(in Japanese).
5. A. Christ, R. Guldimann, B. Bühlmann, M. Zefferer, J. F. Bakker, et al., "Exposure of the Human Body to Professional and Domestic Induction Cooktops Compared to the Basic Restrictions," *Bioelectromagnetics*, **33**, 8, December 2012, pp. 695-705.
6. M. W. Khan, P. Roivainen, M. Herrala, M. Tiikkaja, M. Sallmén, et al., "A Pilot Study on the Reproductive Risks of Maternal Exposure to Magnetic Fields From Electronic Article Surveillance Systems," *International Journal of Radiation Biology*, **94**, 10, October 2018, pp. 902-908.
7. Y. Sato, K. Kiyohara, S. Takehara, and N. Kojimahara, "Ecological Study on the Penetration of Induction Heating Cookers and Birth Outcomes in Japan," *AIMS Public Health*, **7**, 2, June 2020, pp. 336-343.
8. A. Tokinobu, K. Tanaka, M. Arakawa, and Y. Miyake, "Maternal Use of Induction Heating Cookers During Pregnancy and Birth Outcomes: The Kyushu Okinawa Maternal and Child Health Study," *Bioelectromagnetics*, **42**, 4, May 2021, pp. 329-335.
9. World Health Organization an United Nations Children's Fund, "Low Birthweight: Country, Regional and Global Estimates," https://www.unscn.org/web/archives_resources/files/low_birthweight_from_EY.pdf (Accessed 20 December 2023).
10. Y. Sato, M. Taki, and N. Kojimahara, "Association Between the Use of Induction Heating Cookers and Delivery Outcomes in Pregnant Women: An Internet-Based Cohort Study," *Environmental Health Insights*, **17**, November 2023, pp. 1-8, doi: 10.1177/11786302231211114.
11. J. V. Bernabé, T. Soriano, R. Albaladejo, M. Juarranz, M. E. Calle, et al., "Risk Factors for Low Birth Weight: A Review," *European Journal of Obstetrics and Gynecology and Reproductive Biology*, **116**, 1, September 2004, pp. 3-15.