

## **Association Between the Use of Induction Heating Cookers and Delivery Outcomes in Pregnant Women: An Internet-Based Cohort Study**

Authors: Sato, Yasuto, Taki, Masao, and Kojimahara, Noriko

Source: Environmental Health Insights, 17(1)

Published By: SAGE Publishing

URL: <https://doi.org/10.1177/11786302231211114>

---

The BioOne Digital Library (<https://bioone.org/>) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (<https://bioone.org/subscribe>), the BioOne Complete Archive (<https://bioone.org/archive>), and the BioOne eBooks program offerings ESA eBook Collection (<https://bioone.org/esa-ebooks>) and CSIRO Publishing BioSelect Collection (<https://bioone.org/csiro-ebooks>).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at [www.bioone.org/terms-of-use](http://www.bioone.org/terms-of-use).

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

---

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

# Association Between the Use of Induction Heating Cookers and Delivery Outcomes in Pregnant Women: An Internet-Based Cohort Study

Yasuto Sato<sup>1</sup> , Masao Taki<sup>2</sup> and Noriko Kojimahara<sup>1</sup>

<sup>1</sup>Graduate School of Public Health, Shizuoka Graduate University of Public Health, Shizuoka, Japan. <sup>2</sup>Graduate School of Systems Design, Tokyo Metropolitan University, Tokyo, Japan.

Environmental Health Insights  
Volume 17: 1–8  
© The Author(s) 2023  
Article reuse guidelines:  
sagepub.com/journals-permissions  
DOI: 10.1177/11786302231211114



**ABSTRACT:** The number of devices that generate intermediate-frequency electromagnetic fields (IF-EMFs) in the living environment has been increasing. As the public has vague concerns about new devices, it is necessary to clarify the safety of IF-EMFs. Therefore, the present study aimed to examine the possible health effects of IF-EMFs by clarifying the relationship between the use of induction heating (IH) cookers and delivery outcomes. The study participants were pregnant women over the age of 20 years who were registered in panels with an Internet research firm. A total of 8920 pregnant women participated in the baseline survey. Of those who responded to the follow-up survey, 5022 who had a singleton birth were included in the analysis. We then examined the relationship between the use of IH cookers and gestational week at delivery (<37th/≥37th week) or birth weight (<2500/≥2500 g) using logistic regression models. No association was found between the use of IH cookers and birth weight, but weak associations were found between the use of stationary- and tabletop-type IH cookers and gestational week at delivery. After all considerations, we determined that the observed increased odds ratio did not indicate an increased risk of premature birth.

**KEYWORDS:** Epidemiology, intermediate-frequency electromagnetic field, induction stove, premature birth, low birth weight

**RECEIVED:** August 15, 2023. **ACCEPTED:** October 4, 2023.

**TYPE:** Original Research

**FUNDING:** The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by a Japanese Ministry of Internal Affairs and Communications grant for research on the biological electromagnetic environment (No. JPMM10001).

**DECLARATION OF CONFLICTING INTERESTS:** The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**CORRESPONDING AUTHOR:** Yasuto Sato, Graduate School of Public Health, Shizuoka Graduate University of Public Health, 4-27-2 Kita Ando, Aoi-ku, Shizuoka 420-0881, Japan. Email: yssato@s-ph.ac.jp

## 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 emit IF-EMFs in the living environment has been increasing.<sup>1</sup> Sources of IF-EMFs in the living environment include induction heating (IH) devices (eg, IH cookers), detectors that use electromagnetic fields (eg, antitheft and other electronic article surveillance [EAS] systems), video display terminals (VDTs) (eg, old television sets and monitors with cathode-ray tubes), and wireless power transfer systems. Among these devices, IH cookers are the main source of IF-EMFs in a typical Japanese household.<sup>1</sup>

The development of IH cookers began in the 1970s, and their use started to expand to Japanese households in the 1990s.<sup>2</sup> According to surveys conducted by the Japanese Ministry of Internal Affairs and Communications,<sup>3,4</sup> the proportions of households consisting of 2 or more people that owned an IH cooker were 18.2% in 2009 and 23.9% in 2014. According to a survey conducted by the Japanese Ministry of the Environment,<sup>5</sup> the penetration of IH cookers and non-IH electric cookers was 25.4% in total by 2020. Although the figures differ depending on the survey, it is reasonable to assume that about one-fourth of Japanese households use an IH cooker. The International Commission on Non-Ionizing Radiation Protection has issued guidelines for exposure to IF-EMFs.<sup>6–8</sup> On the other hand, there are mixed reports regarding whether the electromagnetic field emitted from IH cookers exceeds this standard level.<sup>9–11</sup> It is therefore necessary to clarify the safety

of IF-EMFs because the public has vague concerns about new devices that generate electromagnetic waves.<sup>12</sup>

Few experimental studies have clarified the effects of IF-EMFs on living organisms, and the results have been inconsistent, making it impossible to draw any definitive conclusions.<sup>13,14</sup> In an epidemiological study, Khan et al<sup>15</sup> reported finding no effects of EAS on miscarriage, premature birth, or reduced birth weight among women who worked in supermarkets. In an ecological study, Sato et al<sup>16</sup> found no association between the penetration of IH cookers and birth outcomes in Japan. However, because that study was a regional correlation study, it did not assess individual risk. In a cohort study of pregnant women, Tokinobu et al<sup>17</sup> also found no association between the use of IH cookers and delivery outcomes in Japan. However, in that study, only the use of IH cookers was evaluated, not the usage time or type of IH cooker use.

When cooking with an IH cooker, the abdomen is close to the device. As pregnant women have a protruding abdomen, it is closer to the device. Therefore, the present study aimed to examine the possible health effects of IF-EMFs on pregnant women by clarifying the relationship between the use of IH cookers and delivery outcomes.

## Materials and Methods

### Study design

The study participants were pregnant women aged ≥ 20 years who were registered in panels (preselected groups of individuals who have agreed to provide market research) with an



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without

Internet research firm that is one of the largest online research companies in Japan, with a registered panel of 2 million people. Baseline surveys were conducted in February 2020, September 2020, and February 2021. A total of 8920 pregnant women were enrolled. In the baseline survey, we asked questions about the use and type of IH cookers, the usage time, gestational age, mother's age, maternal smoking status, maternal drinking status, mother's education level, annual household income, and recurrent fetal loss, which is a pre-pregnancy situation. We also asked whether a doctor had ever told the participant about recurrent fetal loss before becoming pregnant. In the analysis, recurrent fetal loss was treated as a factor for preterm and premature birth, and was added as a covariate in the multivariate analysis. Three types of IH cookers are commercially available in Japan: a built-in type, which is built into the kitchen, a stationary type, which is placed in the cooking space of the kitchen, and a tabletop type, which is smaller and used on the table. All of these types of IH cookers are for home use, with outputs up to around 2000 W, and there are no major differences in their mechanisms, functionality, or use. All 3 types of these devices generate IF-EMFs of 20 to 90 kHz. In the questionnaire survey, the usage situation was investigated for each type of IH cooker. Postpartum follow-up surveys were conducted in August 2020, February 2021, and January 2022. In the follow-up surveys, we asked questions about hypertensive disorders during pregnancy, gestational diabetes, fetal growth restriction, method of delivery, gestational week at delivery, child's sex, and child's birth weight. Similar to the present study, previous studies on IH cooker use and birth outcomes have focused on birth weight and gestational age at birth. The survey was conducted through the website of the Internet research firm. A description of the survey was posted on the survey website, and only those who agreed with the survey content by selecting the consent button could participate in the survey. Those who responded to the survey were given incentives (points that can be used for shopping on the Internet) by the survey firm. The present study was approved by the Ethics Committee of Shizuoka Graduate University of Public Health (No. SGUPH\_2021\_005).

### Data analysis

In the present study, we analyzed the subjects who responded to the follow-up survey and who had a singleton birth. First, we collected background information of the participants. We compiled aggregated results for gestational age at baseline survey, 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, gestational week at delivery, child's sex, and birth weight. Regarding maternal smoking and drinking status, 74 (1.8%) and 40 (1.6%) of the participants reported smoking in the

second and third trimesters, respectively, and 38 (0.9%) and 20 (0.8%) reported drinking alcohol in the second and third trimesters, respectively, all of whom continued from the first trimester. Therefore, in the present study, we decided to use information on smoking and drinking status in the first trimester. Next, we created a cross-tabulation table to examine the relationship between each background factor and gestational week at delivery (<37th/≥ 37th week) or birth weight (< 2500/≥2500 g). Statistical significance was assessed using the chi-square test. All tests were 2-sided, and P values <.05 were considered statistically significant. In the same way, we examined the relationship between the use of an IH cooker (built-in, stationary, and tabletop types) by pregnancy period (first, second, and third trimesters) and gestational week at delivery (<37th/≥ 37th week) or birth weight (< 2500/≥2500 g). As with the above, statistical significance was assessed using the chi-square test, all tests were 2-sided, and P values <.05 were considered statistically significant.

Finally, we conducted multivariate analysis using a logistic regression model. Analyses were performed on the use of IH cookers that showed statistically significant differences in the cross-tabulation (use of a stationary-type IH cooker in the first trimester, use of a tabletop-type IH cooker in the first trimester, use of a stationary-type IH cooker in the second trimester, and use of a tabletop-type IH cooker in the second trimester). The objective variable was gestational week at delivery (<37th/≥ 37th week), and the covariates were 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 child's sex. All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

### Results

In total, 8920 women responded to the baseline survey in the present study, among whom, 5432 (60.9%) responded to the follow-up survey. Of these, 5087 reported giving birth. In the present study, 5022 women who had a singleton birth were included in the analysis.

Table 1 shows the participants' background information. As for gestational age at the baseline survey, the highest proportion was in the third trimester (≥28th week of gestation) (n=2565; 51.1%). As for the mother's age, the highest proportion was 30 to 34 years (n=2402; 47.8%). In addition, 7.3% (n=366) smoked and 4.1% (n=206) drank in the early pregnancy period. As for the mother's education level, the highest proportion was more than college (n=2692; 53.6%). As for annual household income, the highest proportion was 4 to 6 million yen (n=1635; 32.6%). In addition, 3.5% (n=177) had recurrent fetal loss before pregnancy, 1.8% (n=92) were diagnosed with a hypertensive disorder during pregnancy, 4.0% (n=201) had gestational diabetes, and 0.7% (n=37)

**Table 1.** Background characteristics of the study participants.

	N	%
Gestational age at baseline survey		
First trimester ( $\leq 15$ th week)	916	18.2
Second trimester (16th-27th week)	1541	30.7
Third trimester ( $\geq 28$ th week)	2565	51.1
Mother's age (years)		
20-24	80	1.6
25-29	1495	29.8
30-34	2402	47.8
$\geq 35$	1045	20.8
Maternal smoking (early pregnancy)		
No	4656	92.7
Yes	366	7.3
Maternal drinking (early pregnancy)		
No	4816	95.9
Yes	206	4.1
Mother's education		
Junior high school	57	1.1
High school	763	15.2
Junior college	1510	30.1
More than college	2692	53.6
Annual household income (million yen)		
< 4	997	19.9
4-6	1635	32.6
6-8	1249	24.9
$\geq 8$	1141	22.7
Recurrent fetal loss		
No	4845	96.5
Yes	177	3.5
Hypertensive disorders during pregnancy		
No	4930	98.2
Yes	92	1.8
Gestational diabetes		
No	4821	96.0
Yes	201	4.0
Fetal growth restriction		
No	4985	99.3
Yes	37	0.7
Method of delivery		
Vaginal delivery	4044	80.5
Cesarean section	966	19.2
Unknown	12	0.2

(Continued)

**Table 1.** (Continued)

	N	%
Gestational week at delivery		
$\geq 37$ th	4597	91.5
< 37th	394	7.8
Unknown	31	0.6
Child's sex		
Male	2487	49.5
Female	2535	50.5
Birth weight (g)		
$\geq 2500$	4356	86.7
< 2500	390	7.8
Unknown	276	5.5

experienced fetal growth restriction. As for the method of delivery, the highest proportion was for vaginal delivery ( $n = 4044$ ; 80.5%). As for gestational week at delivery, the highest proportion was  $\geq 37$ th week ( $n = 4597$ ; 91.5%). As for their child, 50.5% ( $n = 2535$ ) were female, and 86.7% ( $n = 4356$ ) weighed  $\geq 2500$  g at birth.

Table 2 shows the associations between background information and gestational week at delivery (<37th/ $\geq 37$ th week) or birth weight (< 2500/ $\geq 2500$  g). Regarding gestational week at delivery, statistically significant differences in maternal smoking (Yes 10.8%, No 7.7%;  $P = .033$ ), maternal drinking (Yes 13.4%, No 7.7%;  $P = .003$ ), recurrent fetal loss (Yes 16.1%, No 7.6%;  $P < .001$ ), hypertensive disorders during pregnancy (Yes 25.0%, No 7.6%;  $P < .001$ ), gestational diabetes (Yes 12.9%, No 7.7%;  $P = .007$ ), fetal growth restriction (Yes 18.9%, No 7.8%;  $P = .013$ ), and method of delivery (Yes 12.4%, No 6.8%;  $P < .001$ ) were observed. Regarding birth weight, statistically significant differences in hypertensive disorders during pregnancy (Yes 17.6%, No 8.0%;  $P < .001$ ), method of delivery (Yes 13.8%, No 6.9%;  $P < .001$ ), and child's sex (Female 9.9%, Male 6.5%;  $P < .001$ ) were observed.

Table 3 shows the associations between the use of IH cookers and gestational week at delivery (<37th/ $\geq 37$ th week) or birth weight (< 2500/ $\geq 2500$  g). Regarding gestational week at delivery, statistically significant differences in the use of a stationary-type IH cooker in the first trimester (Not used 7.3%, Use <1 hour per day 12.4%, Use  $\geq 1$  hour per day 13.3%;  $P < .001$ ), use of a tabletop-type IH cooker in the first trimester (Not used 7.4%, Use <1 hour per day 9.0%, Use  $\geq 1$  hour per day 14.2%;  $P = .003$ ), use of a stationary-type IH cooker in the second trimester (Not used 7.2%, Use <1 hour per day 7.5%, Use  $\geq 1$  hour per day 15.6%;  $P = .005$ ), and use of a tabletop-type IH cooker in the second trimester (Not used 7.0%, Use <1 hour per day 10.3%, Use  $\geq 1$  hour per day 12.2%;  $P = .006$ ) were observed. Regarding birth weight,

**Table 2.** Associations among background information and birth outcomes.

	GESTATIONAL WEEK AT DELIVERY; <37		GESTATIONAL WEEK AT DELIVERY; ≥37		TOTAL	P	BIRTH WEIGHT <2500 G		BIRTH WEIGHT ≥2500 G		TOTAL	P
	(N=394)		(N=4597)				(N=390)		(N=4356)			
	N	%	N	%			N	%	N	%		
Mother's age (years)												
20-24	7	9.0	71	91.0	78	.980	6	8.6	64	91.4	70	.442
25-29	119	8.0	1369	92.0	1488		109	7.7	1305	92.3	1414	
30-34	186	7.8	2203	92.2	2389		181	8.0	2087	92.0	2268	
≥ 35	82	7.9	954	92.1	1036		94	9.5	900	90.5	994	
Maternal smoking (early pregnancy)												
No	355	7.7	4275	92.3	4630	.033	361	8.2	4059	91.8	4420	.644
Yes	39	10.8	322	89.2	361		29	8.9	297	91.1	326	
Maternal drinking (early pregnancy)												
No	367	7.7	4422	92.3	4789	.003	375	8.2	4197	91.8	4572	.844
Yes	27	13.4	175	86.6	202		15	8.6	159	91.4	174	
Mother's education												
Junior high school	4	7.0	53	93.0	57	.663	4	7.5	49	92.5	53	.777
High school	68	9.0	686	91.0	754		61	8.4	663	91.6	724	
Junior college	115	7.7	1386	92.3	1501		125	8.8	1299	91.2	1424	
More than college	207	7.7	2472	92.3	2679		200	7.9	2345	92.1	2545	
Annual household income (million yen)												
< 4	85	8.6	902	91.4	987	.731	79	8.5	845	91.5	924	.170
4-6	123	7.6	1501	92.4	1624		144	9.2	1413	90.8	1557	
6-8	101	8.1	1142	91.9	1243		88	7.4	1097	92.6	1185	
≥ 8	85	7.5	1052	92.5	1137		79	7.3	1001	92.7	1080	
Recurrent fetal loss												
No	366	7.6	4451	92.4	4817	<.001	373	8.1	4209	91.9	4582	.308
Yes	28	16.1	146	83.9	174		17	10.4	147	89.6	164	
Hypertensive disorders during pregnancy												
No	371	7.6	4528	92.4	4899	<.001	375	8.0	4286	92.0	4661	.001
Yes	23	25.0	69	75.0	92		15	17.6	70	82.4	85	
Gestational diabetes												
No	368	7.7	4422	92.3	4790	.007	372	8.2	4184	91.8	4556	.520
Yes	26	12.9	175	87.1	201		18	9.5	172	90.5	190	
Fetal growth restriction												
No	387	7.8	4567	92.2	4954	.013	384	8.2	4327	91.8	4711	.054
Yes	7	18.9	30	81.1	37		6	17.1	29	82.9	35	
Method of delivery												
Vaginal delivery	272	6.8	3756	93.2	4028	<.001	266	6.9	3581	93.1	3847	<.001
Cesarean section	118	12.4	835	87.6	953		124	13.8	772	86.2	896	
Child's sex												
Male	189	7.6	2284	92.4	2473	.514	155	6.5	2216	93.5	2371	<.001
Female	205	8.1	2313	91.9	2518		235	9.9	2140	90.1	2375	

**Table 3.** Associations among the use of IH cookers and birth outcomes.

	GESTATIONAL WEEK AT DELIVERY; <37TH		GESTATIONAL WEEK AT DELIVERY; ≥37TH		TOTAL	P	BIRTH WEIGHT <2500 G		BIRTH WEIGHT ≥2500 G		TOTAL	P
	(N=394)		(N=4597)				(N=390)		(N=4356)			
	N	%	N	%			N	%	N	%		
First trimester (≤15th week of gestation)												
IH cooker (built-in type)												
Not used	262	7.4	3272	92.6	3534	.146	271	8.0	3108	92.0	3379	.425
Use <1 h per day	78	9.0	785	91.0	863		65	8.1	742	91.9	807	
Use ≥1 h per day	54	9.1	540	90.9	594		54	9.6	506	90.4	560	
IH cooker (stationary type)												
Not used	328	7.3	4143	92.7	4471	<.001	357	8.4	3904	91.6	4261	.435
Use <1 h per day	45	12.4	317	87.6	362		22	6.4	321	93.6	343	
Use ≥1 h per day	21	13.3	137	86.7	158		11	7.7	131	92.3	142	
IH cooker (tabletop type)												
Not used	307	7.4	3817	92.6	4124	.003	334	8.5	3601	91.5	3935	.123
Use <1 h per day	63	9.0	635	91.0	698		41	6.3	615	93.8	656	
Use ≥1 h per day	24	14.2	145	85.8	169		15	9.7	140	90.3	155	
Second trimester (16th to 27th week of gestation)												
IH cooker (built-in type)												
Not used	215	7.2	2770	92.8	2985	.544	239	8.3	2625	91.7	2864	.446
Use <1 h per day	43	7.8	510	92.2	553		41	7.9	479	92.1	520	
Use ≥1 h per day	46	8.5	495	91.5	541		51	9.9	465	90.1	516	
IH cooker (stationary type)												
Not used	276	7.2	3547	92.8	3823	.005	309	8.4	3349	91.6	3658	.901
Use <1 h per day	11	7.5	136	92.5	147		12	8.6	127	91.4	139	
Use ≥1 h per day	17	15.6	92	84.4	109		10	9.7	93	90.3	103	
IH cooker (tabletop type)												
Not used	248	7.0	3314	93.0	3562	.006	289	8.5	3123	91.5	3412	.879
Use <1 h per day	39	10.3	339	89.7	378		32	9.0	324	91.0	356	
Use ≥1 h per day	17	12.2	122	87.8	139		10	7.6	122	92.4	132	
Third trimester (≥28th week of gestation)												
IH cooker (built-in type)												
Not used	105	5.6	1780	94.4	1885	.340	129	7.1	1683	92.9	1812	.818
Use <1 h per day	25	7.5	309	92.5	334		20	6.3	296	93.7	316	
Use ≥1 h per day	22	6.6	310	93.4	332		24	7.6	292	92.4	316	
IH cooker (stationary type)												
Not used	142	5.9	2279	94.1	2421	.116	167	7.2	2154	92.8	2321	.097
Use <1 h per day	3	4.2	69	95.8	72		6	9.0	61	91.0	67	
Use ≥1 h per day	7	12.1	51	87.9	58		0	0.0	56	100.0	56	
IH cooker (tabletop type)												
Not used	133	5.9	2140	94.1	2273	.799	158	7.2	2026	92.8	2184	.261
Use <1 h per day	15	6.9	201	93.1	216		14	7.0	187	93.0	201	
Use ≥1 h per day	4	6.5	58	93.5	62		1	1.7	58	98.3	59	

Abbreviation: IH, induction heating.

**Table 4.** Odds ratios for delivery before the 37th week of gestation using a multivariate logistic regression model.

	USE OF STATIONARY-TYPE IH COOKER IN THE FIRST TRIMESTER			USE OF TABLETOP-TYPE IH COOKER IN THE FIRST TRIMESTER			USE OF STATIONARY-TYPE IH COOKER IN THE SECOND TRIMESTER			USE OF TABLETOP-TYPE IH COOKER IN THE SECOND TRIMESTER		
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
		LOWER	UPPER		LOWER	UPPER		LOWER	UPPER		LOWER	UPPER
Use of an IH cooker	1.38	1.13	1.70	1.27	1.04	1.54	1.44	1.12	1.84	1.37	1.10	1.71
Mother's age	0.96	0.83	1.10	0.95	0.83	1.10	0.92	0.79	1.08	0.92	0.78	1.07
Maternal smoking (early pregnancy)	1.18	0.81	1.72	1.19	0.82	1.73	0.99	0.63	1.57	1.02	0.64	1.60
Maternal drinking (early pregnancy)	1.49	0.95	2.33	1.51	0.97	2.37	0.93	0.50	1.74	0.95	0.50	1.77
Mother's education	1.02	0.89	1.17	1.02	0.89	1.17	0.98	0.84	1.15	0.99	0.85	1.16
Annual household income	1.04	0.94	1.15	1.05	0.94	1.16	1.13	1.00	1.27	1.12	1.00	1.26
Recurrent fetal loss	1.97	1.27	3.06	1.92	1.24	2.98	1.79	1.07	3.00	1.64	0.96	2.79
Hypertensive disorders during pregnancy	3.21	1.87	5.53	3.26	1.90	5.59	3.54	1.91	6.56	3.62	1.95	6.72
Gestational diabetes	1.23	0.76	1.99	1.23	0.76	1.98	1.38	0.83	2.28	1.31	0.78	2.20
Fetal growth restriction	1.00	0.37	2.71	1.10	0.41	2.93	1.03	0.31	3.42	1.10	0.33	3.65
Method of delivery	1.94	1.54	2.45	1.93	1.53	2.44	1.93	1.48	2.50	1.96	1.51	2.55
Child's sex	1.03	0.84	1.27	1.04	0.84	1.28	0.88	0.70	1.12	0.89	0.70	1.13

Abbreviations: OR, odds ratio; CI, confidence interval.

no statistically significant differences were found between the use of any type of IH cooker.

Table 4 shows the odds ratios (ORs) for delivery at <37th week of gestation by the multivariate logistic regression model. Hypertensive disorders during pregnancy was most strongly associated with delivery at <37th week of gestation in all models (use of a stationary-type IH cooker in the first trimester [OR = 3.21, 95% confidence interval: 1.87-5.53]; use of a tabletop-type IH cooker in the first trimester [OR = 3.26, 95% CI: 1.90-5.59]; use of a stationary-type IH cooker in the second trimester [OR = 3.54, 95% CI: 1.91-6.56]; and use of a tabletop-type IH cooker in the second trimester [OR = 3.62, 95% CI: 1.95-6.72]). Use of an IH cooker was weakly associated with delivery at <37th week of gestation in all models (use of a stationary-type IH cooker in the first trimester [OR = 1.38, 95% CI: 1.13-1.70]; use of a tabletop-type IH cooker in the first trimester [OR = 1.27, 95% CI: 1.04-1.54]; use of a stationary-type IH cooker in the second trimester [OR = 1.44, 95% CI: 1.12-1.84]; and use of a tabletop-type IH cooker in the second trimester [OR = 1.37, 95% CI: 1.10-1.71]).

## Discussion

The present study examined the possible health effects of IF-EMFs by clarifying the relationship between the use of IH cookers and delivery outcomes. No association was found

between the use of IH cookers and birth weight, but weak associations were observed between the use of stationary- and tabletop-type IH cookers and gestational week at delivery.

A statistically significant increase in ORs was observed for the use of both stationary- and tabletop-type IH cookers in association with preterm birth. According to Tarao et al,<sup>18</sup> stationary- and tabletop-type IH cookers emit more IF-EMFs than do built-in-type IH cookers. At 0.3 m from the center of the heating coil, the maximum magnetic field of both stationary- and tabletop-type IH cookers is approximately 9.0 mT, while that of built-in-type IH cookers is approximately 4.0 mT. Because built-in-type IH cookers are installed in the kitchen, they are considered to have less IF-EMF leakage. If IF-EMFs affect preterm birth, they may also affect the third trimester of pregnancy when the delivery date is close; however, in the present study, no significant increase in the OR was observed. In addition, if IF-EMFs affect preterm birth, they may also affect birth weight; however, in the present study, no increase in the OR for birth weight was observed with any type of IH cooker.

Statistically significant increases in ORs were found between the use of stationary- and tabletop-type IH cookers and preterm birth, but the ORs were small, ranging from 1.27 to 1.44. Eleven variables (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 child's sex) were considered as covariates for the adjustment of confounding factors. Stationary- and tabletop-type IH cookers are often cheaper than built-in-type IH cookers, so it is possible that the confounding factors associated with the use of stationary- and tabletop-type IH cookers were not sufficiently adjusted. As the present study was an observational study in which we examined relationships by repeating tests and combining trimesters, the types of IH cookers, and differences in outcomes, the statistically significant increases in ORs may have been observed by chance.

The mean proportion of singleton births with a birth weight of <2500 g was reported to be 7.9% according to Vital Statistics 2020.<sup>19</sup> In the present study, which was conducted from 2020 to 2022, this proportion was 7.8%, which is similar to the mean value in Japan. The proportion of preterm singleton births was reported to be 4.5% in Vital Statistics 2020.<sup>19</sup> In the present study, it was 7.8%, which is higher than the mean value in Japan. In the present study, birth weight was similar to that in the general population and was not associated with IH cooker use; however, in the present study, preterm births were more common than in the general population and weak associations were observed with IH cooker use. It is possible that stationary- and tabletop-type IH cooker users are biased to report more preterm births. On the survey website, birth weight was entered directly as a number. Gestational week at delivery was entered using a pull-down menu. In the pull-down menu, a total of 22 options were given for gestational week at delivery (<22, 22, 23, . . . 40, 41, ≥ 42 weeks). A total of 16 options were given for <37 weeks, so if the participant's memory was vague and the answers were random, there is a chance that they would choose preterm birth. It is also possible that the participants could remember the birth weight of their child easily, but not the gestational age at delivery. Most previous experimental studies using cells and animals have suggested that IF-EMFs are harmless.<sup>20-22</sup> Comprehensively judging the above, the increased ORs observed in the present study are unlikely to represent an increased risk.

The characteristics of the participants in the present study were as follows. According to the Comprehensive Survey of Living Conditions 2021,<sup>23</sup> 33.2% of people in their 20s and 30s have a household income of ≤ 4 million yen. In the present study, this was 20.6%, which is higher than that among the general population. According to the Population Census 2020,<sup>24</sup> 29.7% of married women in their 20s and 30s had an educational background of ≤ 12 years. In the present study, this was 17.7%, which is higher than that of the general population. As mentioned in the introduction section, the penetration of IH cookers in Japan is thought to be about 25%.<sup>3-5</sup> In the present study, this was 43.1%, which seems to be higher than that in the general population. As the participants in the present study had a higher educational background and a higher annual income compared with the general population,

it is thought that they tended to own more expensive IH cookers.

The strengths and limitations of the present study are as follows. The study participants were pregnant women who were registered in panels with an Internet research firm. The use of survey panels has the advantage of making it easier to collect samples and increasing the sample size. On the other hand, although survey firms manage the quality of survey panels, there is a limit to the reliability of the responses. If dishonest answers for the purpose of rewards (eg, points that can be used for shopping on the Internet) are randomly generated, the possible risk seems to disappear. If there is a tendency to associate baseline-investigated IH cooker use with follow-up-investigated delivery outcomes, the possible risk seems to increase. The results of the present study face the same general challenges posed by other Internet surveys.<sup>25,26</sup> In the present study, the data were collected by self-report, so we believe that there is a limit to the accuracy of the information, especially medical information in regard to pregnancy. In addition, follow-up surveys were conducted 3 times depending on the year and month of pregnancy. The recovery rates in the 3 follow-up surveys showed similar results at around 60%. We believe that the recovery rate was affected by the fact that the requests for the follow-up survey were sent via e-mail and that the respondents were busy rearing their children. According to Vital Statistics 2020 in Japan, only 0.82% of births were to mothers aged <20 years. As the present study did not include mothers <20 years of age, we considered that this did not significantly affect the results. Concerning the use of IH cookers, we examined the type of IH cooker and the hours of use per day. Distance from IH cookers, wattage of IH cookers, and diameter of commonly used utensils could not be considered.<sup>27</sup> The participants in the present study were considered to have high affinity for the Internet. On the other hand, the pregnant generation consists of younger people who are also considered to be a group with relatively high affinity for the Internet. From this point of view, we think that using an Internet survey panel as the subjects in the present study is acceptable. IH cookers are considered to be the main source of IF-EMF exposure to the abdomen in the living environment. In the workplace environment, special equipment such as industrial sealers and commercial IH cookers are possible sources of IF-EMF exposure. Although working pregnant women are unlikely to use these devices for long periods of time, IF-EMF exposure in the workplace environment should be investigated in future studies.

## Conclusion

In this study, a weak association was found between the use of stationary- and tabletop-type of IH cookers during pregnancy and premature birth. However, after all considerations, we determined that the observed increased OR did not indicate an increased risk of premature birth.



## Author Contributions

Yasuto Sato: Conceptualization, data collection, data analysis, and original draft. Masao Taki: Conceptualization, review, and editing. Noriko Kojimahara: Conceptualization, supervision, review, and editing.

## ORCID iD

Yasuto Sato  <https://orcid.org/0000-0003-4767-331X>

## REFERENCES

1. Yamazaki K, Taki M, Ohkubo C. Safety assessment of human exposure to intermediate frequency electromagnetic fields. *Elect Eng Jpn*. 2016;197:3-11.
2. Japan Institute of Invention and Innovation. Top 100 Innovations in Postwar Japan, IH Cooker. Accessed August 12, 2023. [http://koueki.jiii.or.jp/innovation100/innovation\\_detail.php?eid=00086&age=stable-growth&page=keii](http://koueki.jiii.or.jp/innovation100/innovation_detail.php?eid=00086&age=stable-growth&page=keii) (in Japanese)
3. Japanese Ministry of Internal Affairs and Communications. National Survey of Family Income and Expenditure, 2009 Report. Accessed August 12, 2023. <https://www.stat.go.jp/data/zensho/2009/index.html> (in Japanese).
4. Japanese Ministry of Internal Affairs and Communications. National Survey of Family Income and Expenditure, 2014 Report. Accessed August 12, 2023. <https://www.stat.go.jp/data/zensho/2014/index.html> (in Japanese)
5. Japanese Ministry of the Environment. Statistical Survey of CO<sub>2</sub> Emissions in the Household Sector, 2020 Report. Accessed August 12, 2023. [https://www.env.go.jp/earth/ondanka/ghg/R2\\_CO2tokei\\_report\\_imp.pdf](https://www.env.go.jp/earth/ondanka/ghg/R2_CO2tokei_report_imp.pdf) (in Japanese)
6. International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). *Health Phys*. 2020;118(5):483-524.
7. International Commission on Non-Ionizing Radiation Protection. ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). *Health Phys*. 2010;99:818-836.
8. International Commission on Non-Ionizing Radiation Protection. ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). *Health Phys*. 1998;74(4):494-522.
9. Aerts S, Calderon C, Valič B, et al. Measurements of intermediate-frequency electric and magnetic fields in households. *Environ Res*. 2017;154:160-170.
10. Gryz K, Karpowicz J, Zradziński P. Evaluation of the influence of magnetic field on female users of an induction hob in ergonomically sound exposure situations. *Bioelectromagnetics*. 2020;41(7):500-510.
11. Scientific Committee on Emerging Newly Identified Health Risks. Opinion on potential health effects of exposure to electromagnetic fields. *Bioelectromagnetics*. 2015;36:480-484.
12. Belyaev I, Dean A, Eger H, et al. EUROPAEM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses. *Rev Environ Health*. 2016;31(3):363-397.
13. Bodewein L, Schmiedchen K, Dechent D, et al. Systematic review on the biological effects of electric, magnetic and electromagnetic fields in the intermediate frequency range (300 Hz to 1 mhz). *Environ Res*. 2019;171:247-259.
14. Meroni D, Schreck S. Electromagnetic fields: activities in the European Commission with a focus on research projects and the Scientific Committee of emerging and newly Identified Health Risks (SCENIHR). *Electromagn Biol Med*. 2015;34(3):171-174.
15. Khan MW, Roivainen P, Herrala M, et al. A pilot study on the reproductive risks of maternal exposure to magnetic fields from electronic article surveillance systems. *Int J Radiat Biol*. 2018;94(10):902-908.
16. Sato Y, Kiyohara K, Takehara S, Kojimahara N. Ecological study on the penetration of induction heating cookers and birth outcomes in Japan. *AIMS Public Health*. 2020;7(2):336-343.
17. Tokinobu A, Tanaka K, Arakawa M, Miyake Y. Maternal use of induction heating cookers during pregnancy and birth outcomes: the Kyushu Okinawa Maternal and Child Health Study. *Bioelectromagnetics*. 2021;42(4):329-335.
18. Tarao H, Hayashi N, Isaka K. Survey of leakage magnetic fields from various induction heating ranges. 2017 Progress In Electromagnetics Research Symposium - Fall (PIERS - FALL); 2017:1546-1549. doi: 10.1109/PIERS-FALL.2017.8293378
19. Japanese Ministry of Health, Labour and Welfare. Vital Statistics, 2020 Report. Accessed August 12, 2023. <https://www.mhlw.go.jp/toukei/saikin/hw/jinkou/kakutei20/index.html> (in Japanese).
20. Lee HJ, Jin H, Ahn YH, et al. Effects of intermediate frequency electromagnetic fields: a review of animal studies. *Int J Radiat Biol*. 2023;99(2):166-182.
21. Nishimura I, Oshima A, Shibuya K, Mitani T, Negishi T. Absence of reproductive and developmental toxicity in rats following exposure to a 20-kHz or 60-kHz magnetic field. *Regul Toxicol Pharmacol*. 2012;64(3):394-401.
22. Yoshie S, Ogasawara Y, Ikehata M, et al. Evaluation of biological effects of intermediate frequency magnetic field on differentiation of embryonic stem cell. *Toxicol Rep*. 2016;3:135-140.
23. Japanese Ministry of Health, Labour and Welfare. Comprehensive Survey of Living Conditions, 2021 Report. Accessed August 12, 2023. <https://www.mhlw.go.jp/toukei/saikin/hw/k-tyosa/k-tyosa21/index.html> (in Japanese).
24. Japanese Ministry of Internal Affairs and Communications. 2020. Population Census, 2020 Report. Accessed August 12, 2023. <https://www.stat.go.jp/data/kokusei/2020/index.html> (in Japanese).
25. Eysenbach G, Wyatt J. Using the Internet for surveys and health research. *J Med Internet Res*. 2002;4:E13.
26. Rhodes SD, Bowie DA, Hergenrather KC. Collecting behavioural data using the world wide web: considerations for researchers. *J Epidemiol Community Health*. 2003;57:68-73.
27. Kitajima T, Schüz J, Morita A, et al. Measurement of intermediate frequency magnetic fields generated by household induction cookers for epidemiological studies and development of an exposure estimation model. *Int J Environ Res Public Health*. 2022;19(19):11912.