Title	Obesity and glucose metabolism abnormalities by post-disaster evacuation
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Citation	Pediatrics international : official journal of the Japan Pediatric Society. 65(1): e15400
Issue Date	2023-01
URL	http://ir.fmu.ac.jp/dspace/handle/123456789/2206
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DOI	10.1111/ped.15400
Text Version	author

Pediatrics International Original Article Re-revised Manuscript PED-00043-2022.R2
Obesity and glucose metabolism abnormalities by post-disaster evacuation

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Short title: Obesity and glucose metabolism abnormalities after disaster

Funding Source: This survey was supported by the National Health Fund for Children and Adults Affected by the Nuclear Incident.

Financial Disclosure: No authors have any financial relationships relevant to this article to disclose.

Conflict of Interest: No authors have any conflicts of interest to disclose.

Number of text pages 18, numbers of words 3168, reference pages 2, tables 4, figure 2

Abstract

Background: The objectives of this study were to determine the longer-term trends in childhood obesity and glucose metabolism abnormalities among residents of Fukushima Prefecture 5 years after the Great East Japan Earthquake. ***Methods:*** We evaluated the changes for height, weight, body mass index (BMI), BMI SD score, fasting plasma glucose (FPG) concentration, and hemoglobin A1c (HbA1c) in elementary and junior high school residents who had lived in the evacuation zone between 2011 and 2015. ***Results:*** 1) Of the Residents, 11,112 received health checks, while in 2012, 2013, 2014 and 2015, 5,737, 4,522, 4,297 and 3,405 received health checks, respectively. 2) The mean BMI SD score for all participants in 2011 was 0.149, and this score gradually decreased from 2011 to 2015. 3) FPG levels and HbA1c levels for all participants with a BMI value≧+2SD in 2011 were higher than those in residents with a BMI value < +2SD. 4) The frequency of participants with a FPG level ≧126 mg/dl and the frequency of participants with a HbA1c level ≧6.5 % in 2011 were higher than those in 2012, 2013, and 2015. ***Conclusions:*** These results suggest that a number of pediatric residents suffered from obesity and glucose metabolism abnormalities. Furthermore, the longer-term observations indicated an improvement in obesity and glucose metabolism abnormalities. There was a strong association observed between obesity and glucose metabolism, thus, it is considered important to continue with health checks for children with

obesity and strive to improve their health.

The Pacific coast of northern Japan was struck by the most destructive earthquake ever recorded in the history of Japan at 14:46 (Japan Standard Time) on March 11, 2011. This earthquake had a magnitude of 9.0 on the Richter scale. It was the most powerful earthquake ever known to have hit Japan, and one of the 5 most powerful earthquakes in the world since modern record-keeping began in 1900 [1-4]. The earthquake and subsequent tsunami caused a serious accident at the Fukushima Daiichi Nuclear Power Plant, forcing more than 160,000 residents participants of Fukushima Prefecture to be evacuated. To monitor the long-term health of residents, the Fukushima Health Management Survey (FHMS) was started immediately after the disaster. The early results of the FHMS have already shown increases in body weight and higher incidences of diabetes, dyslipidemia, atrial fibrillation, hypertension, renal dysfunction and metabolic syndrome among adult residents [5-9], and some residents aged 15 years or under were reported to have developed obesity and hyperlipidemia in 2011. [10]

Although more than 10 years have passed since the disaster, over 33,000 residents of Fukushima Prefecture have not yet returned to their homes. Previous assessments of childhood obesity and glucose metabolism abnormalities using FHMS data showed that the mean body weight and glucose metabolism abnormalities had decreased in both males and females in 2012 in comparison to 2011. These results reflected only the relatively short-term effects; however, the longer-term effects of the disaster on health and lifestyle factors associated with obesity and glucose metabolism abnormalities remain unclear. Therefore, the objectives of this study were to determine the longer-term trends in obesity and glucose metabolism abnormalities among residents of Fukushima Prefecture 5 years after the disaster.

Methods

The study was carried out under the auspices of the Committee for Human Experiments at the Fukushima Medical University School (Institutional Review Board Approval No 18022). Informed consent was obtained from all participants aged 15 years or under (or their parents) who received health checks.

The Fukushima prefectural government decided to conduct what it called the FHMS to assist in the long-term health management of residents, to evaluate the health impacts of the accident, to promote the future well-being of residents, and to determine whether long-term low-dose radiation exposure has any effect of their health [6-8]. Comprehensive health checks (CHCs) are part of the overall FHMS and we sought to review the data regarding evacuee health, assess the incidence of various diseases, and improve their overall health status.

Target group

The target group consisted of elementary and junior high school residents who had lived in Hirono-machi, Naraha-machi, Tomioka-machi, Kawamata-machi Kawauchi-mura, Okuma-machi, Futaba-machi, Namie-machi, Kazurao-mura, Iitate-mura, Minami-soma City, Tamura City or part of Date City specifically recommended for evacuation, and received health checks at 656 pediatric medical institutions in and outside the prefecture since January

2011.

Evaluation items

In addition to assessing the effects of radiation, other variables were specified according to age in order to assess health, prevent lifestyle-related diseases, and identify or treat diseases at an early stage. The survey items for elementary and junior high school children consisted of height, weight, blood pressure, red blood cell (RBC) count, hematocrit (Hct), hemoglobin (Hb), platelet count, and white blood cell (WBC) count. Upon request, aspirate aminotransferase (AST), alanine aminotransferase (ALT), γ-glutamyl transpeptidase (γ-GTP), triglyceride (TG), high-density lipoprotein cholesterol (HDL-CHO), low-density lipoprotein cholesterol (LDL-CHO), hemoglobin A1c (HbA1c), fasting plasma glucose (FPG) concentration, serum creatinine (Cr), and uric acid (UA) were also assessed. Among of these variables, we evaluated the changes in height, weight, body mass index (BMI), BMI SD score, FPG concentration, and HbA1c from 2011 to 2015.

Definitions

The following laboratory data were obtained from all participants: height, weight, HDL-CHO, LDL-CHO, and TG. Borderline diabetes was diagnosed when FPG was 110 to 126 mg/dl, and diabetic type was diagnosed in patients with a FPG level of more than

126mg/dl. An HbA1c (international standard value) value of 6.5% or more was also considered to represent a diabetic state.

BMI was calculated as weight in kilograms divided by height in meters squared. Due to the fact that BMI in childhood changes substantially with age, the comparison of BMI among children of different age groups is difficult. For that reason, it was necessary to standardize the data. Cole constructed centile curves for BMI using the lambda-musigma method, which was adopted by Inokuchi *et al.* for the Japanese population. [11,12] Therefore, we are now able to express BMI as an SDS value. We converted the BMI of all children to BMI SDS using calculation software. [11-14]

Statistical analysis

Means or prevalence for baseline variables of interest were compared between the participants with a greater than BMI +2SD score and those with a less than BMI +2SD score, using Student's t-test or chi-squared tests. Based on 2011, changes in FPG and HbA1c levels each year from 2012 to 2015 were compared using a Student's paired t-test, McNemar's test or binomial link model.

SAS version 9.3 (SAS Institute, Cary. North Carolina. USA) was used for all analyses. All probability values for statistical tests were two-tailed and p values of <0.05 were regarded as statistically significant.

Results

1) Baseline characteristics for elementary and junior high school participants from 2011 to 2015

Table 1 shows in 2011, 11,112 of the participants received health checks, whereas 5,737, 4,522, 4,297, and 3,405 of the participants received health checks in 2012, 2013. 2014, and 2015, respectively.

2) BMI SD score and glucose metabolism abnormalities, including FPG concentration and HbA1c values, in elementary and junior high school participants in 2011 (Table 2)

The mean BMI SD scores for all participants, the male group and the female group were 0.149(-6.425 ~3.521), 0.170(-6.425 ~2.846), and 0.126(-5.189 ~3.521), respectively.

The mean FPG concentration for all participants, the male group and the female group were 88.6 ± 9.6, 89.4 ± 9.6, and 87.7 ± 9.5 mg/dl, respectively. The number of participants with a FPG concentration > 110 mg/dl and the number of participants with a FPG concentration > 126 mg/dl were 219 (1.98 %) and 40 (0.36 %) among all participants, 113 (2.03 %) and 20 (0.36 %) among males, and 106 (1.93 %) and 20 (0.36 %) among females, respectively.

The mean HbA1c values (%) for all participants, the male group and the female group were 5.26 ± 0.33, 5.28 ± 0.34, and 5.25 ± 0.32, respectively. The number of participants with a HbA1c level > 6.5 % and the number of participants with a HbA1c level > 7.0 % were 25 (0.23 %) and 10 (0.09 %) among all participants, 14 (0.25 %) and 5 (0.09 %) among males, and 11 (0.20 %) and 5 (0.09 %) among females, respectively. Further, there were 4 residents (3 male and one female) with a FPG levels > 126 mg/dl and a HbA1c values > 6.5 %.

Table 3 shows a comparison of FPG concentration and HbA1c levels between participants with a BMI score more than +2SD and those with a BMI score less than +2SD in 2011.

A comparison of BMI SD score between participants with a score more than +2SD and those with a score less than +2SD in 2011 revealed that FPG concentration and HbA1c values for all participants, the male group and the female group with a BMI score more than +2SD were higher than those in participants with a BMI score less than +2SD.

3) The changes in BMI SD score and glucose metabolism abnormalities, including FPG concentration and HbA1c values, in elementary and junior high school participants from 2011 to 2015

a) BMI SD score

For all participants, the male group and the female group, the BMI SD score tended to decrease over the 5-years period ($p<0.0001$), with the BMI SD scores in 2011 higher than those in 2012, 2013, 2014, and 2015 (Table 4). Furthermore, the frequency of participants with a BMI score more than +2SD among 2011 in all participants and the female group were higher than those in 2014 and 2015, with the frequency of participants with a BMI score more than +2SD decreasing with time over the 5 years. The frequency of participants with a BMI score more than +2SD in 2011 in the male group was higher than that in 2014 (Figure 1).

b) FPG

For all participants, the male group and the female group, the FPG concentrations tended to decrease over the 5-years period ($p<0.0001$), with the FPG concentrations in 2011 higher than those in 2012, 2013, 2014, and 2015 (Table 4). Among all participants, the frequency of participants with a FPG concentrations more than 110 mg/dl and the frequency of participants with a FPG concentrations more than 126 mg/dl in 2011 were higher than those in 2012, 2013, 2014 and 2015 (Figure 1).

c) HbA1c

For all participants, the frequency of participants with a HbA1c value more than 6.5 % in 2011 was higher than those in 2015 (Figure 2). Further, there were no participants with a FPG level > 126 mg/dl and a HbA1c value > 6.5 %.

Discussion

The Great East Japan Earthquake and Fukushima Daiichi nuclear disaster forced people to evacuate their homes without notice, caused them to change their lifestyle in terms of diet, exercise patterns, and other personal habits, to adapt to a completely new situation, and produced a good deal of anxiety with regard to radiation exposure. In response to this situation, the Fukushima prefectural government made the decision to implement what they termed the FHMS to assist in the long-term health management of residents and to evaluate the health impact of the nuclear disaster and forced evacuation. We previously reported, in a comparison of height, body weight, and lipid function between 2011 and 2012, that the mean height increased whereas the mean body weight decreased in both males and females in 2012 in comparison to 2011; however, there were no differences in the frequency of male or female residents with high low-density lipoprotein-cholesterol (LDL-CHO) or high triglyceride (TG) values between 2011 and 2012.[10] In addition, a 5-year follow-up study to examine changes in lipid function and obesity showed improvement in obesity, although the improvement in lipid abnormalities was delayed compared with that in obesity. On the other hand, with regard to glucose metabolism abnormalities, the prevalence of glucose metabolism abnormalities in males and females in the elementary and junior high school residents in 2011 were higher than those in 2012 [10]. However, there have been no reports on the relationship between pediatric obesity and glucose metabolism abnormalities after the disaster based on a long-term follow-up. Thus, in order to clarify the influence of obesity and glucose metabolism abnormalities over a long period after such a disaster, we evaluated BMI SD scores, FPG concentrations, and HbA1c values over a 5-year period in elementary and junior high school residents. Our results found that the frequencies of participants with FPG concentrations > 110 mg/dl and those with FPG concentrations > 126 mg/dl in 2011 were higher than those in 2012, 2013, 2014 and 2015. Furthermore, the frequency of participants with HbA1c values > 6.5 % among all groups in 2011 were higher than those in 2015.

Confirmation of chronic hyperglycemia is essential for the diagnosis of childhood diabetes. Classification of glucose metabolism using blood glucose level, categorizes a diabetic type as (1) a fasting blood glucose level of 126 mg/dl or more, or (2) an OGTT 2 hour value of 200 mg/dl or more, or (3) an occasional blood glucose level of 200 mg/dl or more. A fasting blood glucose level <110 mg/dl and an OGTT 2 hour value < 140 mg/dl are classified as normal type, and those that are neither diabetic nor normal type are classified as borderline type. In addition, (4) a HbA1c (NGSP) value of 6.5% or more is judged to be . diabetic. Diagnosis of diabetes requires confirmation of the diabetic type more than once. If the same blood sample shows a diabetic type (any of (1) to (3) and (4)), diabetes can be diagnosed with only one test [15]. In our study, the number of people with a definitive diagnosis of DM was 4, and while participants with glucose intolerance were identified in 2011 and no participants with FPG levels > 126 mg/dl and HbA1c values> 6.5 % were identified in 2015.

On the other hand, childhood obesity is a serious public health problem. According to the Central for Disease Control and Prevention, the prevalence of obesity in children aged 6 to 11 years has increased substantially from 7% in 1980 to nearly 18% in 2012. Likewise, the prevalence of obesity in adolescents aged 12 to 19 years has increased from 5% to nearly 21% during the same period. [16-18] Childhood obesity is associated with a range of health problems both in childhood and later life. Conditions once limited to the adult population, such as type 2 diabetes mellitus and fatty liver disease, are now being documented in children. Strong evidence has indicated the persistence of childhood obesity into adulthood, with childhood obesity considered a multisystem disease. Close to 90% of children and adolescents with obesity have at least one feature of the metabolic syndrome [15,19]. With regard to pediatric obesity after the Great East Japan Earthquake, this study shows that the mean BMI SD scores for all participants, the male group and the female group in 2011 were 0.113, 0.116, and 0.109, respectively, indicating that the mean BMI in each of the three groups was higher than that in the general Japanese population for elementary and junior high school children. In our study, both obesity and impaired glucose tolerance were observed in 2011, suggesting that the onset of impaired glucose tolerance is associated with obesity. Furthermore, as to the change in childhood obesity over the 5 years, the mean BMI SD scores among all participants, the male group and the female group gradually decreased from 2011 to 2015.

As to the relationship between obesity and glucose intolerance, FPG concentrations and HbA1c values among participants with a BMI score of more than +2SD were higher than those in participants with a BMI score less than +2SD. These findings suggested that glucose intolerance was associated with obesity. Furthermore, the longer-term observations for 5 years showed that glucose intolerance tended to improve with improvements in obesity.

Being overweight or obese may cause insulin resistance, and insulin resistance in the liver leads to a decrease in its ability to suppress glucose production. Evidence has shown that insulin resistance and glucose tolerance may improve through exercise and/or dietary modification [19,20]. Ford et al. demonstrated that a reduction in BMI-SDS > 0.25 improved insulin resistance, with further benefit accrued if BMI-SDS was reduced by > 0.5 [21]. Reinehr et al. investigated change in insulin sensitivity in relation to change in BMI-SDS. There was no change in insulin sensitivity for groups with small or moderate levels of weight-loss [22]. In the group that achieved a large level of weight-loss, insulin sensitivity was improved.

The causes of the increases in obesity and glucose metabolism abnormalities in pediatric residents in Fukushima Prefecture after the Great East Japan Earthquake were identified as follows. 1) After the accident at the Fukushima Daiichi Nuclear Power Plant, the children ceased to play outside to avoid radiation exposure, and their motivation decreased; 2) The evacuated children often ate instant food; and 3) Their lack of sleep and excessive mental stress increased during the evacuation. However, it seems that these risk factors have gradually decreased and obesity and glucose metabolism abnormalities have improved over the course of the five years since the earthquake. Thus, we think that the improvement in obesity and glucose metabolism abnormalities associated with normalization of the residents' lifestyle, diet, exercise patterns, mental stress levels, and sleep patterns after the disaster has gradually improved over the five-year period.

The limitations of our study include the following. 1) There is no data available on the laboratory findings for pediatric participants who were living in the evacuation zone before the Great East Japan Earthquake. Thus, we must judge the impact of the earthquake on participants by using changes in data after the disaster. Especially, as to obesity, children in Fukushima Prefecture were originally obese compared to children in other prefectures. In this manuscript, BMI SD scores were used to assess obesity compared to all Japanese children, but could not be compared to post-earthquake because there was no assessment of subject obesity before the earthquake. Since obesity has improved over time after the earthquake, it is presumed that obesity was present retrospectively. 2) This examination was only at the request of the residents and was not mandatory, so it was not possible to evaluate individuals for a long period of time. Therefore, the longitudinal changes of each children remain unclear. 3) There is a decline in the frequency at which participants receive health checks over time. These findings appear to indicate a decrease in interest in the health checks provided by the Fukushima Health Management Survey. This decrease in the number of child participants who received health checks could affect the results of our study.

In conclusion, the findings presented herein suggest that a number of children living in the evacuation zone at the time of the disaster suffered from obesity and glucose metabolism abnormalities, with a strong association observed between the two conditions. Furthermore, longer-term (5-year) observations indicated an improvement in obesity and glucose metabolism abnormalities. It is considered important to continue with health checks for children with obesity and strive to improve their health.

Acknowledgements

We wish to thank the staff of the Fukushima Health Management Survey for their cooperation. The findings and conclusions of this research are the sole responsibility of the authors and do not represent the official views of the Fukushima prefectural government. We would like to offer our thanks to the Fukushima Health Management Survey Group Chairpersons.

Disclosure

The authors declare no conflicts of interest.

Author contributors

Drs Kawasaki, Nakano and Hosoya conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript.

Drs Yasumura, Ohira, Satoh, Suzuki, Sakai, Shimabukuro, Takahashi, Hayashi and Ohto designed the data collection instruments, collected data, carried out the initial analyses, and reviewed and revised the manuscript.

Dr Kamiya conceptualized and designed the study, coordinated and supervised data collection, and critically reviewed the manuscript for important intellectual content.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Figure legends

Figure 1: The changes in the frequency of participants with a BMI score more than +2SD or with a FPG concentration > 110 mg/dl or with a FPG concentration > 126 mg/dl,

a. The change in the frequency of participants with a BMI score more than +2SD
b. The change in the frequency of participants with a FPG concentration > 110 mg/dl
c. The change in the frequency of participants with a FPG concentration >126 mg/dl

*p<0.05, **p<0.01, ***p<0.001, ****p<0.0001

Figure 2: The changes in the frequency of participants with a HbA1c value > 6.5 % or HbA1c value >7.0 %

a. The change in the frequency of participants with a HbA1c value > 6.5 %
b. The change in the frequency of participants with HbA1c value > 7.0 %

*p<0.05, ****p<0.0001

Table 1 : A comparison of the characteristics of the participants from the first grade of elementary school to the third grade of junior high school who received health checks from 2011 to 2015

	2011	2012	2013	2014	2015
The number of participants	11,112	5,737	4,522	4,297	3,405
The mean age (years)	10.9 (2.6)	10.7 (2.6)	10.5 (2.6)	10.5 (2.6)	10.6 (2.6)
Gender (male:female)	5,589 : 5,523	2,930 : 2,807	2,310 : 2,212	2,202 : 2,095	1,794 : 1,611

Table 2: BMI SD score, fasting plasma glucose concentration and HbA1c in participants in 2011

	All participants	Male participants (n=5,589)	Female participants (n=5,523)
The mean BMI SD± score	0.149 (-6.425~3.521)	0.170 (-6.425~2.846)	0.126 (-5.189~3.521)
The mean FPG (mg/dl)	88.6 ± 9.6	89.4 ± 9.6	87.7 ± 9.5
The mean HbA1c levels (%)	5.26 ± 0.33	5.28 ± 0.34	5.25 ± 0.32

Table 3: Comparison of FPG and HbA1c levels between participants with a BMI score more than +2SD and those with a BMI score less than +2SD in 2011

	All			Male			Female		
BMI score	Participants with a BMI score more than +2SD (n=389)	Participants with a BMI score less than +2SD (n=10,723)	P	Participants with a BMI score more than +2SD (n=214)	Participants with a BMI score less than +2SD (n=5,375)	P	Participants with a BMI score more than +2SD (n=175)	Participants with a BMI score less than +2SD (n=5,348)	P
FPG concentration(mg/dl)	90.2±10.8	88.5±9.5	P<0.003	90.7±10.1	89.4±9.6	P<0.05	89.6±11.6	87.6±9.4	P<0.03
HbA1c (%)	5.37±0.34	5.26±0.33	P<0.0001	5.39±0.32	5.27±0.34	P<0.0001	5.34±0.36	5.25±0.32	P<0.001

Table 4: Comparisons among BMI-SD, FPG, and HbA1c for all participants, the male group and female group who received health checks from 2012 to 2015 with those in 2011

	2011	2012		2013		2014		2015	
	Mean (SD)	Mean (SD)	P for 2011	Mean (SD)	P for 2011	Mean (SD)	P for 2011	Mean (SD)	P for 2011
BM SD									
All	0.149 (1.016)	0.035 (1.080)	<0.0001	0.034 (1.072)	<0.0001	-0.006 (1.046)	<0.0001	0.012 (1.042)	<0.0001
Male	0.170 (1.036)	0.061 (1.102)	<0.0001	0.064 (1.110)	0.0005	0.019 (1.081)	<0.0001	0.019 (1.089)	<0.0001
Female	0.126 (0.995)	0.008 (1.056)	<0.0001	0.003 (1.031)	<0.0001	-0.031 (1.008)	<0.0001	0.004 (0.988)	0.0002
FPG concentration (mg/dl)									
All	88.6 (9.6)	86.3 (8,1)	<0.0001	86.7 (7.8)	<0.0001	87.2 (7.5)	<0.0001	87.0 (7.2)	<0.0001
Male	89.4 (9.6)	87.1 (8,6)	<0.0001	87.5 (8.3)	<0.0001	88.2 (7.0)	<0.0001	87.9 (7.3)	<0.0001
Female	87.7 (9.5)	85.4 (7.5)	<0.0001	85.9 (7.2)	<0.0001	86.2 (7.9)	<0.0001	86.0 (6.9)	<0.0001
HbA1c (%)									
All	5.26 (0.33)	5.26 (0.25)	0.89	5.26 (0.24)	0.33	5.29 (0.25)	<0.0001	5.28 (0.24)	0.005
Male	5.28 (0.34)	5.27 (0.25)	0.85	5.27 (0.25)	0.58	5.31 (0.25)	0.0001	5.30 (0.24)	0.1
Female	5.25 (0.32)	5.25 (0.25)	1	5.24 (0.23)	0.83	5.28 (0.25)	0.0005	5.27 (0.23)	0.18

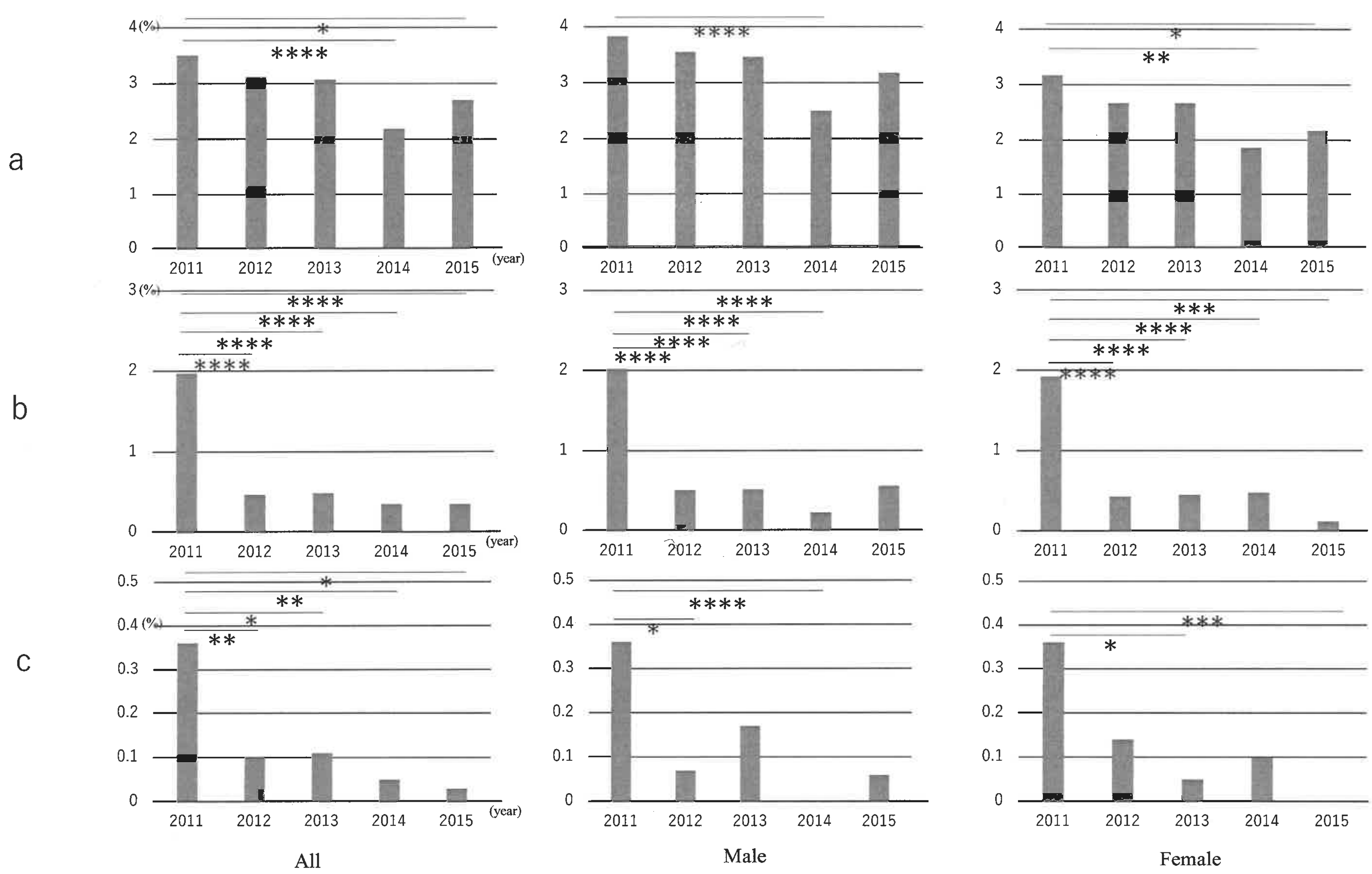

Figure 1

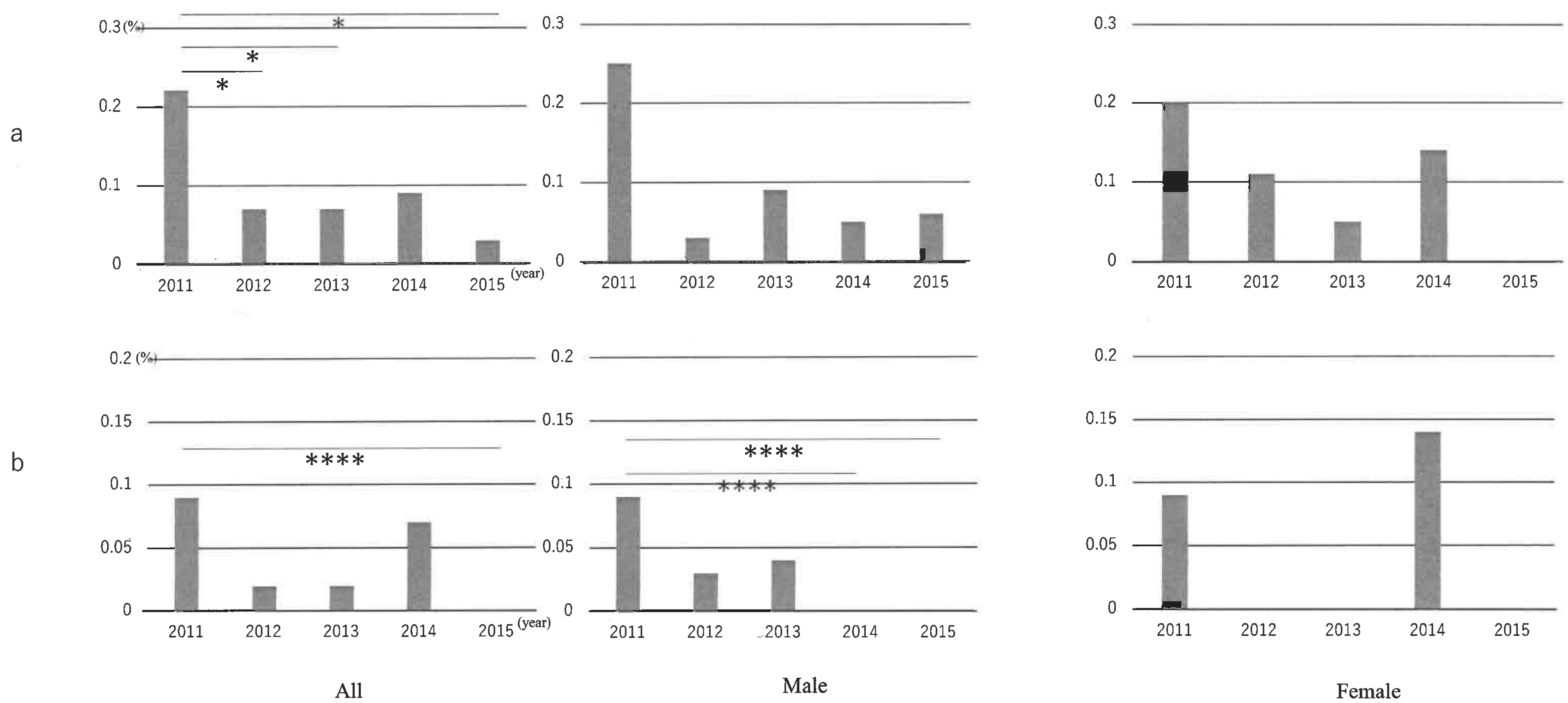
a
b
0.3 (%)
0.2 (%)
0.3
0.2
0.15
0.1
0.05
0
*
****
2011
2012
2013
2014
2015
(year)
All
Male
Female

Figure 2