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# School restrictions on outdoor activities and weight status in adolescent children after Japan's 2011 Fukushima Nuclear Power Plant disaster: a mid-term to long-term retrospective analysis

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## ABSTRACT

**Objective:** Radiation fears following Japan's 2011 Fukushima nuclear disaster affected levels of physical activity in local children. We assessed the postdisaster versus predisaster weight status in school children and evaluated to what extent school restrictions on outdoor activities that were intended to reduce radiation exposure risk affected child weight.

**Participants:** We considered children aged 13–15 years from 4 of the 5 secondary schools in Soma City (n=1030, 99.1% of all children in the city), located in 35–50 km from the Fukushima nuclear plant, postdisaster (2012 and 2015) and predisaster (2010).

**Methods:** Weight status, in terms of body mass index (BMI), percentage of overweight (POW) and incidence of obesity and underweight (defined as a POW ≥20% and ≤−20%, respectively) were examined and compared predisaster and postdisaster using regression models. We also constructed models to assess the impact of school restrictions on outdoor activity on weight status.

**Results:** After adjustment for covariates, a slight decrease in mean BMI and POW was detected in females in 2012 (−0.37, 95% CI −0.68 to −0.06; and −1.97, 95% CI −3.57 to −0.36, respectively). For male children, obesity incidence increased in 2012 (OR for obesity: 1.45, 95% CI 1.02 to 2.08). Compared with predisaster weight status, no significant weight change was identified in 2015 in either males or females. School restrictions on outdoor activities were not significantly associated with weight status.

**Conclusions:** 4 years following the disaster, weight status has recovered to the predisaster levels for males and females; however, a slight decrease in weight in females and a slight increase in risk of obesity were observed in males 1 year following the disaster. Our findings could be used to guide actions taken during the early phase of a radiological disaster to manage the postdisaster health risks in adolescent children.

## Strengths and limitations of this study

- This study sheds new light on risk factors for weight status in children following a major nuclear disaster.
- Data on nearly all Soma City school children aged 13–15 years for 2010, 2012 and 2015, living in the most affected areas following Japan's 2011 Fukushima nuclear disaster, were evaluated.
- School restrictions on outdoor activities, an important confounder for the effect of physical inactivity on weight status, were taken into account.
- Because physical inactivity is the only one possible explanation for the relationship between the disaster and weight status, it is necessary to consider other risk factors, such as generalised stress from the disaster and postdisaster dietary changes, in future studies.

## INTRODUCTION

Following Japan's Fukushima Daiichi Nuclear Power Plant disaster, triggered by the Great East Japan Earthquake and subsequent tsunami on 11 March 2011, radiation-related health threats have arisen in the radiation-affected areas.[1 2] Contrary to the significant concerns among the public, the likely low risk of radiation-related health consequences have been established by Hayano *et al* and Tsubokura *et al*'s continuing series of assessments of radiation exposure levels in the local population[3–7] as well as by two major international reports from WHO and United Nations Scientific Committee on the Effects of Atomic Radiation.[8 9] However, the potential health effects of the Fukushima disaster are not limited to those due to radiation exposure.

A major disaster often exerts a powerful influence on individual vulnerability to psychological stress, and/or changes in socioeconomic status, and thus affects people's health.[10–12] The chronic health impacts of the Fukushima disaster in adults have been well evaluated. Several studies reported significantly negative metabolic correlations with the disaster in its early phase (ie, within 12 months), such as body mass index (BMI), blood pressure, HbA1c and high-density lipoprotein cholesterol among the general population, including displaced residents in Fukushima Prefecture.[13 14] Longer term chronic health risks were also demonstrated by recent studies, which suggested increased prevalence of chronic diseases (eg, diabetes and hyperlipidaemia) in Fukushima in the 2–3 years following the disaster, which might be a result of decreased access to medical care due to the change in personal doctor or regular clinic/hospital, dietary change at evacuation sites and/or reduced physical activities.[15 16]

The assessment and monitoring of markers of physical and mental health is of crucial importance in children who are often deemed to be at highest risk of exposure and vulnerability (including lack of coping capacity) to such disasters.[17] However, studies of child health following the Fukushima disaster have been lacking with respect to the early, mid-term and long-term perspectives. Particularly, given that even small changes in physical activity and weight in adolescence can track into adulthood,[18] the current lack of studies evaluating the mid-term to long-term perspective (ie, years) following the disaster needs to be addressed.

According to a media report, the Fukushima nuclear disaster led to lowered levels of physical activity and to a consequent weight increase in children, attributed to restrictions by parents and schools on the amount of time children spent outdoors.[19] It is known that the time spent outdoors is positively associated with levels of physical activity.[20] Schools across the Fukushima Prefecture imposed restrictions on school-based outdoor activities after the disaster due to radiation concerns. Following the disaster, 449 (89.1%) of the 504 primary (ages 7–12 years) and secondary schools (13–15 years) in Fukushima set limits on the time children were permitted to spend outside; as of September 2012, restrictions were still in place at 71 schools (14.1%).[19]

Levels of physical activity have been closely linked to cardiorespiratory and muscular fitness, bone health and cardiovascular and metabolic health biomarkers.[21] There is evidence that childhood obesity is associated with various metabolic and psychological comorbidities.[22 23] In this context, lessons on how, when and to what extent Japan's Fukushima nuclear disaster has affected children's weight status will be leveraged for the development and implementation of adequate preparedness and effective response to future crises.

Since the Fukushima disaster, we have been supporting clinical care and research in Soma City, Fukushima Prefecture, Japan, located in 35–50 km from the Fukushima nuclear power plant, where some schools imposed restrictions on outdoor activities postdisaster, while others did not. The study objective, therefore, was twofold: (1) to assess the postdisaster versus predisaster weight status in school children in Soma City over a multiyear follow-up period and (2) to evaluate to what extent the school restrictions on outdoor activities have affected child weight.

## METHODS

### Setting and participants

We employed data from the School Health Examination Survey, which is administrated by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT)[24] and is performed annually from April to June. This survey selects schools across the country to perform the examination in a stratified random sample, while some non-selected schools also voluntarily conduct the examination. This means that not all the schools in Japan participated, and not every year; in particular, Soma City recently conducted the measurements for some of the schools in its territory in 2010 (predisaster), and in 2012 and 2015 (postdisaster). We collected the data from surveys undertaken in these years.

The School Health Examination Survey is implemented at each sampled and voluntarily participating school. All children in a participating school are included in the survey. Children are instructed to wear light clothing and remove their shoes and socks before their weight and height are measured (in increments of 0.1 kg and 0.1 cm, respectively). Prefectural governments (the highest level administrative division in Japan: n=47) then collect the results of the survey from the schools in their territory, and publish summary results on their websites.

With cooperation of the Soma City Office and Soma City Medical Association, we were able to obtain and consider in this paper the full survey data collected from four of the five secondary schools for 13–15-year-old children (3 grades) in Soma City, where a total of 1030 children were enrolled in 2015, representing 99.1% of all the secondary school children in the city in that year. We were not able to consider preschools (n=12: about 1200 children in 2015) or primary schools (n=10: about 1900 children in 2015) because very few preschools or primary schools in Soma City performed the examination in recent years.

Because Soma City has been outside of any postdisaster evacuation instructions issued by the central government,[25] the proportion of children moving to another school outside of Soma City postdisaster (eg, due to parents' job transfer) was the same as that predisaster (ie, about 1–2%). Note that if children lived inside the evacuation zone, they were forced to evacuate and moved to other schools outside of the evacuation zone. For those evacuated outside the evacuation zone but within their area of residence or neighbouring areas, local authorities set-up temporary schools within their localities and evacuated-children attended there. Therefore, the numbers of children who moved to schools in Soma City from the neighbouring areas following the disaster were very small. The geographical scope of the evacuation instructions and the location of Soma City, relative to the nuclear power plant, are shown in figure 1.

### School restrictions on outdoor activities

After the disaster, there were no central government guidelines regarding postdisaster school restrictions on outdoor activities. In Soma City, the City Board of Education put any decisions regarding such restrictions into the hands of each school; the radiological contamination varied from location to location, requiring a school-specific response to the disaster. According to our unstructured interviews with staff in the School Education Division at the Soma City Office, all the preschools and primary schools held all physical education classes indoors after the disaster and other class outdoor activities were restricted to <3 hours/day. Regarding the four secondary schools considered in this study, three schools (School ID 2, 3 and 4 in table 1) did not impose any restrictions, while one school (ID 1) put in place similar restrictions to those of the preschools and primary schools mentioned above. Within 1 year of the disaster, all the preschools, primary and secondary schools lifted the restrictions on the outdoor physical education classes and other class activities.

### Outcome measures

The following four outcomes were considered as indicators of weight status: continuous measures of (a) BMI and (b) percentage of overweight (POW); and binary measures of (c) obesity and (d) underweight, defined as a POW of ≥20% and ≤−20%, respectively.[26] POW (%) is calculated using the following formula:

$$\mathrm{POW} = 100 \times (\text{measured weight}/\text{standard weight}) - 100.$$

Standard weight is the age-specific and gender-specific weight for height on the basis of the data of the MEXT's Annual Report of School Health Statistics 2000.[27] The calculation formula is as follows:

$$\text{Standard weight } (kg) = \mathrm{A} \times \text{height (cm)} - \mathrm{B},$$

where the coefficients A and B can be found elsewhere.[28]

It should be noted that a constant BMI value cannot be used for the criteria of obesity/underweight in children because the standard BMI (calculated using an average height and weight for age) changes widely with age during childhood.[29] Instead, the BMI-for-age centile (BMI%) method is used in many countries, including in Europe and the USA, to define childhood obesity/underweight, in which, for example, obesity is defined as a BMI at or above the 95th centile for children of the same age and gender.

However, the use of BMI% also poses a challenge in weight evaluation in children. According to Dobashi *et al*,[29] when applying the BMI% method, tall children are more likely to be defined as being obese, while short children tend to be evaluated as being underweight. This is because, as Sugiura *et al*[30] acknowledged, taller individuals may have a high BMI even if their body proportions are equivalent to those of shorter individuals.

Meanwhile, in Japan, the POW method is used to define childhood obesity/underweight. Recently, Dobashi *et al*[29] demonstrated that the POW method is more appropriate than BMI% for school-age children in Japan.

### Analysis

As previous studies reported a strong gender effect on weight status in a postdisaster setting,[31 32] analyses below were conducted separately for male and female children.

First, to evaluate any difference in postdisaster versus predisaster weight status, the mean (and SD) of BMI and POW were calculated for each year, and postdisaster (2012 and 2015) compared to predisaster (2010) using univariate analysis of variance (parametric) and Kruskal-Wallis (non-parametric) tests, followed by Scheffé's multiple comparison test. Note that to assess whether our results were robust to the analytic approach, we used parametric and non-parametric tests. The rates of obesity and underweight were also calculated and compared by $\chi^2$ test and Scheffe's method of multiple comparison.

Second, we used a multivariate regression modelling approach to detect any difference in postdisaster versus predisaster weight status after adjustment for school grade. To take into account the fact that we can have multiple measurements for the participants and multiple subjects within the same school, we specified a multilevel (two-level) random-intercept linear regression model considering two clusters—schools (second-level) and individuals (first-level).

For BMI and POW, the linear regression model that we specified was the following (note that this equation was simplified (excludes random effects for individual and school) for the sake of clarity):

$$y = \alpha + \beta 1 \times \mathrm{D1} + \beta 2 \times \mathrm{D2} + \beta 3 \times \mathrm{D3} + \beta 4 \times \mathrm{D4}$$

where y represents dependent variable (ie, BMI/POW), D is independent dummy variable, α denotes y-intercept, and β refers to regression coefficients (ie, effects of D on y). For dummy variables, two categorical covariates (year and grade) were considered: D1=1 if year is 2012, 0 otherwise; D2=1 if year is 2015, 0 otherwise; D3=1 if grade is 2, 0 otherwise; and D4=1 if grade is 3, 0

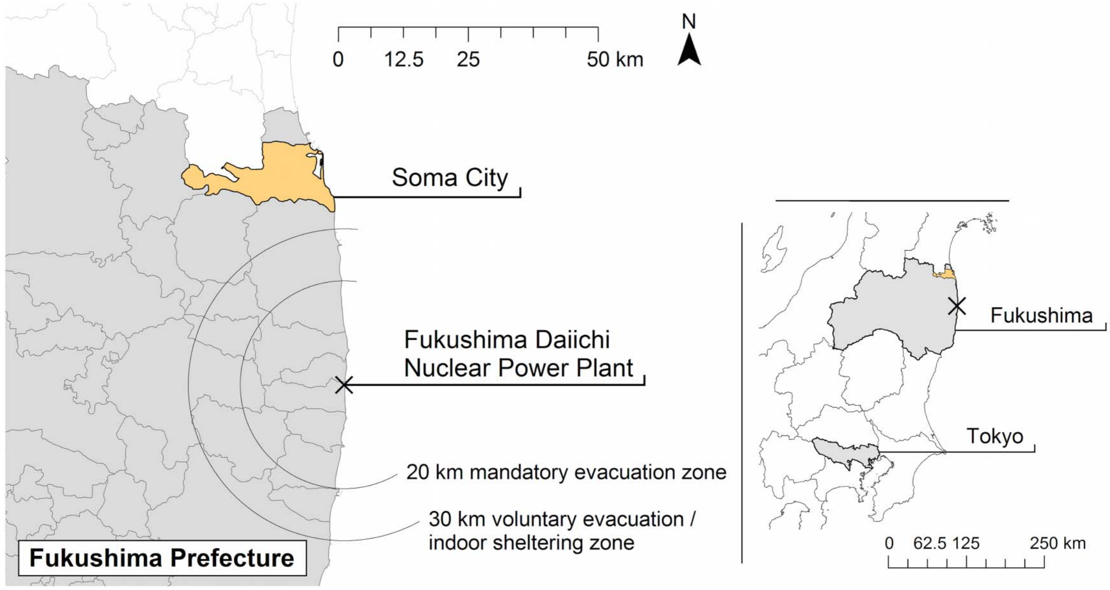


**Figure 1** Geographical location of Soma City.

otherwise. Our major interest was in the comparisons between 2012 vs 2010 and 2015 vs 2010 with respect to the variable 'year', the effect of which was expressed as β1 and β2, respectively.

For obesity and underweight, some modifications were made to the linear model by inclusion of a multinomial logistic function, which allowed for the use of a three-category outcome variable (ie, normal, obese and underweight) as the dependent variable (y). By the properties of the multinomial logistic model, the coefficients were separately computed for obesity and underweight. The effect of 'year' was presented as a multiplicative change (2012 and 2015 vs 2010) of odds of being obese/underweight relative to being normal weight, defined as POW between the cut-offs of −20 to 20%. Because of the properties of the multinomial logistic regression model, the odds were expressed as log β1 and log β2 in the model for the comparisons between 2012 vs 2010 and 2015 vs 2010, respectively.

Third, using only the 2012 data, we constructed multivariate regression models to assess the effect of postdisaster school restrictions on outdoor activities on weight status. As described earlier, in our data, while one school (ID 1) imposed restrictions, which lasted for 1 year following the disaster, three other schools (ID 2, 3 and 4) did not impose restrictions. This means that the 2012 data include some children who were exposed and some who were not exposed to the school restriction effects, which enabled us to conduct this analysis. Models were also adjusted for grade, but we could not include a school effect (neither random nor fixed) because the outdoor restrictions were imposed at school level, so the 'restriction' and 'school ID' were perfectly correlated so could not be included in the same model.

The regression model that we specified was as follows (note that this equation is also simplified):

$$y = \alpha + \beta1 \times D1 + \beta2 \times D2 + \beta3 \times D3$$

For dummy variables, one categorical covariate (grade) was considered: D1=1 if grade is 2, 0 otherwise; and D2=1 if grade is 3, 0 otherwise. In addition, we also considered one binary outcome 'school restrictions': D3=1 if the child experienced the school restrictions on outdoor activities, 0=if he/she did not. In this linear model, the effect of 'school restrictions'—of main interest in this analysis—was expressed as β3 for BMI/POW; and log β3 for obesity/underweight in the multinomial logistic model.

**Table 1** Number of participants by year and school (number of females, %)

| School ID | Year 2010 (pre) | 2012 (post) | 2015 (post) | Total |
|---|---|---|---|---|
| 1 | 371 (172, 46.4) | 382 (194, 50.8) | 418 (226, 54.1) | 1171 (592, 50.6) |
| 2 | 225 (120, 53.3) | 229 (119, 52.0) | 212 (93, 43.9) | 666 (332, 49.8) |
| 3 | 355 (158, 44.5) | 375 (174, 46.4) | 378 (195, 51.6) | 1108 (527, 47.6) |
| 4 | 68 (38, 55.9) | 52 (31, 59.6) | 22 (8, 36.4) | 142 (77, 54.2) |
| Total | 1019 (488, 47.9) | 1038 (518, 49.9) | 1030 (522, 50.7) | 3087 (1528, 49.5) |

We used R (V.3.1.2) and STATA/MP (V.13.1) for analyses, and a p-value of <0.05 is considered statistically significant.

## RESULTS

The study participant characteristics are shown in table 1. Approximately 50% of the children were female in each year. Summary statistics of BMI and POW are shown in table 2. For males and females, no statistical differences in mean and median BMI or POW were observed in any year-by-year comparisons (ie, 2012 vs 2010, 2015 vs 2010, 2015 vs 2012). However, it should be noted that the SD of BMI and POW in male children statistically significantly increased postdisaster: from 3.2 to 3.6 in 2012 (p<0.01: using the F test of variance comparison) and 3.6 in 2015 (p<0.01); and from 16.3% to 17.9% in 2012 (p<0.05) and 19.8% in 2015 (p<0.001), respectively. On the other hand, female children showed a decline in the SD of BMI and POW: from 3.3 to 3.0 in 2012 (p<0.05) and 3.1 in 2015 (p=0.08); and from 17.4 to 14.8 in 2012 (p<0.01) and 15.3 in 2015 (p<0.01), respectively. The obesity rate (%), defined as a POW of ≥20%, was, from 2010 to 2015, 11.6, 15.8 and 14.4 for males and 12.7, 11.8 and 12.7 for females. The rate of underweight (%), defined as a POW of ≤−20%, was, chronologically, 1.5, 2.3 and 2.6 for males and 2.0, 3.3 and 3.9 for females; these differences in obesity/underweight rates were not statistically significant in any comparisons of years, in either males or females.

The results of the regression analyses evaluating the adjusted differences in the four outcome measures postdisaster versus predisaster are presented in table 3. After adjustment for grade, for males, the mean difference in BMI and POW did not statistically differ between postdisaster and predisaster; however, the odds for obesity significantly increased in 2012 vs 2010 (OR: 1.45, 95% CI 1.02 to 2.08, p<0.05); significance disappeared in 2015. For females, a slight decrease in the mean in BMI and POW was detected in 2012 (−0.37, 95% CI −0.68 to −0.06, p<0.05; and −1.97, 95% CI −3.57 to −0.36, p<0.05, respectively); again the significance disappeared in 2015. In neither males nor females, no significant change in odds for underweight was detected following the disaster. As sensitivity analyses, we re-ran the same analyses excluding two individuals who had extremely high POW values (more than 100%) and who were considered outliers (male child with POW of 178.5% in 2015 and female child with POW of 168.4% in 2012), and similar results were obtained.

To clarify the results of the regression analyses above, we created a histogram of POW by gender and year (figure 2). When looking at the distributions of POW values in male children, it is visually noticeable that the weight distribution in 2012 was right skewed, while the histogram peak(s) shift slightly to the left, with the median value moving from −0.7% to −1.1%: table 2. This may explain why the odds of obesity (POW of ≥20%) showed a statistically significant increase in 2012 after adjustment for covariates, while the 'mean' difference was not statistically significant in the regression analyses. On the other hand, for females, while there is slight shift in the histogram peak(s) to the left in 2012, the distribution is not skewed to the right, which explains the statistically significant decrease in the mean POW in 2012 and an (insignificant) increase in odds of obesity in females in the regression analysis.

Table 4 shows the results of regression analyses to evaluate the effects of outdoor activity restrictions on weight status in 2012. After adjusting for grade, school-imposed restrictions on outdoor activities did not show any significant effect on weight status as assessed via any of the outcome measures. Note that although we could not adjust for the school effect in this model, there was no significant difference in the mean or median BMI and POW, or the rate of obesity or underweight between the schools predisaster (2010).

**Table 2** Summary statistics of BMI and POW

| | Year | Mean | SD | Median | Min | Max |
|---|---|---|---|---|---|---|
| *Male* | | | | | | |
| BMI | 2010 | 19.7 | 3.2 | 19.1 | 11.8 | 33.2 |
| | 2012 | 19.9 | 3.6 | 19.1 | 13.7 | 37.5 |
| | 2015 | 19.8 | 3.6 | 19.0 | 13.6 | 38.5 |
| POW | 2010 | 2.9 | 16.3 | −0.7 | −39.2 | 73.9 |
| | 2012 | 3.5 | 17.9 | −1.1 | −26.0 | 92.0 |
| | 2015 | 3.7 | 19.8 | −1.2 | −26.4 | 178.5 |
| *Female* | | | | | | |
| BMI | 2010 | 20.5 | 3.3 | 20.0 | 13.8 | 43.3 |
| | 2012 | 20.1 | 3.0 | 19.7 | 13.5 | 35.9 |
| | 2015 | 20.2 | 3.1 | 19.8 | 13.7 | 32.7 |
| POW | 2010 | 4.2 | 17.4 | 1.8 | −27.4 | 168.4 |
| | 2012 | 2.2 | 14.8 | 0.2 | −31.0 | 88.8 |
| | 2015 | 2.9 | 15.3 | 0.7 | −32.3 | 61.4 |

BMI, body mass index; POW, percentage of overweight.

## DISCUSSION

We assessed the weight status of school children following the Fukushima disaster and evaluated to what extent school restrictions on outdoor activities influenced child weight. We observed a slight decrease in the mean BMI and POW in female children and an increase in obesity incidence in male children in 2012, after adjustment for covariates. School restrictions on outdoor activities were not associated with weight status.

Recently, two prefecture-wide studies evaluated postdisaster obesity levels in children in Fukushima Prefecture. Yokomichi *et al*,[32] as a part of their postdisaster nationwide school survey on child health,[33] followed children aged 3–4 years at the time of the disaster for 9 months and reported that BMI in male and female infants in Fukushima was greater than those in un-affected prefectures in northeast Japan, after adjustment for baseline differences.[32] Similar results were reported by Yamamura,[31] who evaluated children aged 5–17 years using the same

**Table 3** Regression models for the detection of difference in postdisaster versus predisaster weight status on BMI and POW (expressed as coefficients), and obesity and underweight (expressed as ORs) with 95% CI

| Male | No. of observations | BMI | POW | Obesity | Underweight |
|---|---|---|---|---|---|
| Year | | | | | |
| 2010 | 531 | Ref. | Ref. | Ref. | Ref. |
| 2012 | 520 | 0.05 (−0.28 to 0.37) | 0.05 (−1.67 to 1.77) | 1.45 (1.02 to 2.08)* | 1.60 (0.65 to 3.96) |
| 2015 | 508 | 0.04 (−0.36 to 0.45) | 0.54 (−1.59 to 2.67) | 1.30 (0.91 to 1.88) | 1.76 (0.72 to 4.28) |
| Grade | | | | | |
| 1 | 528 | Ref. | Ref. | Ref. | Ref. |
| 2 | 522 | 0.80 (0.40 to 1.21)*** | 2.23 (0.11 to 4.35)* | 1.20 (0.85 to 1.70) | 0.74 (0.33 to 1.70) |
| 3 | 509 | 1.05 (0.72 to 1.37)*** | 0.95 (−0.78 to 2.67) | 1.00 (0.70 to 1.45) | 0.66 (0.28 to 1.55) |
| **Female** | | **BMI** | **POW** | **Obesity** | **Underweight** |
| Year | | | | | |
| 2010 | 488 | Ref. | Ref. | Ref. | Ref. |
| 2012 | 518 | −0.37 (−0.68 to −0.06)* | −1.97 (−3.57 to −0.36)* | 0.93 (0.64 to 1.37) | 1.59 (0.72 to 3.52) |
| 2015 | 522 | −0.16 (−0.53 to 0.21) | −1.00 (−2.90 to 0.91) | 1.03 (0.71 to 1.50) | 1.90 (0.88 to 4.11) |
| Grade | | | | | |
| 1 | 496 | Ref. | Ref. | Ref. | Ref. |
| 2 | 554 | 0.99 (0.62 to 1.35)*** | 2.03 (0.14 to 3.92)* | 1.39 (0.97 to 2.00) | 0.94 (0.48 to 1.84) |
| 3 | 478 | 1.45 (1.14 to 1.76)*** | 1.14 (−0.48 to 2.76) | 0.88 (0.59 to 1.32) | 0.61 (0.29 to 1.32) |

*p<0.05; **<0.01; ***<0.001.
BMI, body mass index; POW, percentage of overweight.

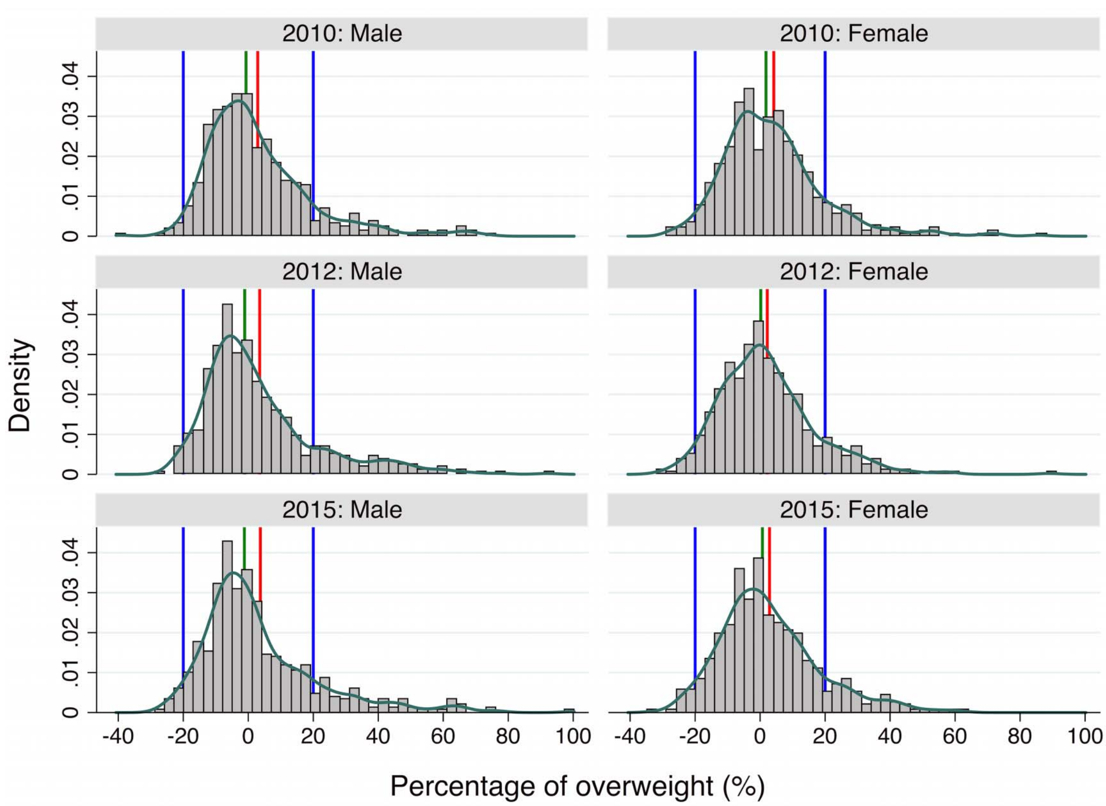


**Figure 2** Histogram of percentage of overweight (POW) with Kernel density curves, by gender and year. The red and green line on x-axis indicates the mean and median value in POW, respectively, and blue lines are the cut-offs of underweight and obesity (−20–20%). Actual values for mean and median lines can be found in table 2. Note that for better visibility of the figure, two individuals with high POW values were excluded in this figure: male child with POW of 178.5 in 2015, and female child with POW of 168.4 in 2012.

data of the School Health Examination Survey (see ‘Methods’ section for the detailed explanation of this survey) from 2008 to 2014. The author showed that the significant increase in BMI z score—an age-adjusted and gender-adjusted standardised score of BMI—was identified only in cohorts aged 5–7 years, but this increase persisted until 2014, 3 years following the disaster. Meanwhile, the disaster appears to have statistically

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**Table 4** Regression models for the effects of restrictions on BMI and POW in 2012 (expressed as coefficients), and obesity and underweight (expressed as ORs) with 95% CI

| Male | No. of observations | BMI | POW | Obesity | Underweight |
|---|---|---|---|---|---|
| Grade | | | | | |
| 1 | 182 | Ref. | Ref. | Ref. | Ref. |
| 2 | 172 | 0.84 (−0.07 to 1.76) | 2.75 (−1.82 to 7.31) | 1.26 (0.62 to 2.57) | 0.88 (0.20 to 3.88) |
| 3 | 166 | 1.05 (0.14 to 1.95)* | 1.25 (−3.27 to 5.78) | 0.89 (0.43 to 1.85) | 0.27 (0.03 to 2.32) |
| Restrictions | | | | | |
| No | 217 | Ref. | Ref. | Ref. | Ref. |
| Yes | 303 | −0.60 (−1.40 to 0.20) | −2.57 (−6.55 to 1.42) | 0.83 (0.45 to 1.52) | 5.52 (0.56 to 54.03) |
| **Female** | | **BMI** | **POW** | **Obesity** | **Underweight** |
| Grade | | | | | |
| 1 | 163 | Ref. | Ref. | Ref. | Ref. |
| 2 | 194 | 1.06 (0.34 to 1.78)** | 2.25 (−1.41 to 5.91) | 1.39 (0.66 to 2.91) | 0.71 (0.17 to 2.96) |
| 3 | 161 | 1.55 (0.79 to 2.31)*** | 1.55 (−2.30 to 5.39) | 1.08 (0.48 to 2.42) | 1.00 (0.24 to 4.13) |
| Restrictions | | | | | |
| No | 221 | Ref. | Ref. | Ref. | Ref. |
| Yes | 297 | 0.22 (−0.41 to 0.86) | 1.10 (−2.11 to 4.30) | 1.21 (0.63 to 2.32) | 0.98 (0.28 to 3.43) |

*p<0.05; **<0.01; ***<0.001.
BMI, body mass index; POW, percentage of overweight.

significantly decreased (but not by much) the BMI z-scores for adolescent children aged 11–17 years.

The findings of this study in secondary school children supports the results of the prefecture-wide study of adolescent children by Yamamura[31]; although the odds of obesity and underweight did not change postdisaster, a small but statistically significant decrease in mean BMI and POW was detected in secondary school female children in the year after the disaster (2012). However, this finding did not persist and had disappeared by 2015, indicating that the overall weight status in female children in Soma City had recovered to the predisaster level 4 years following the disaster.

For male children, while the POW histogram peak(s) suggested a slight shift towards lower weight status (figure 2), some children increased their POW values, resulting in a statistically significantly increase in obese children in 2012, although again this observation did not last and had disappeared by 2015, implying that male children also recovered their weight status to the predisaster level, 4 years after the disaster. However, even in 2015, the SD of BMI/POW in males was statistically significantly larger than that of predisaster (table 2), suggesting an increased risk in some children of straddling either cut-off values for obesity or underweight.

We undertook a systematic search for past studies evaluating child weight status following the 1986 disaster at the Chernobyl nuclear power plant in Ukraine, to permit comparison with findings from this earlier nuclear disaster. No relevant literature were identified, which highlights the novelty of these Fukushima studies evaluating postradiological disaster weight status in children.

## Potential explanations for the postdisaster weight decrease in female children

Effects of reduced physical activity on body weight can work in either direction: leading to decreased muscle bulk, and thus to decreased weight; or to reduced fat-burning, resulting in increased weight. A change in weight status at the population level could be determined by the balance of these opposing effects. Our results, and those of Yamamura,[31] showed that the former effect was probably larger than the latter in female children soon after the disaster (ie, when assessed in 2012).

Another possible explanation for the observed decrease in weight in female secondary school children is their concern about body weight, resulting in an attempt to maintain weight status even after the disaster. A previous study in Japan reported that the desire for thinness has become more common in adolescent female children,[34 35] and public concerns about the development of eating disorders, such as anorexia or bulimia nervosa, is growing.[34] For this reason, in female children, after the Fukushima disaster, less time spent in outdoor activities may have been fully or excessively compensated by indoor physical activity and/or changes in nutrition behaviours (including parental support for healthy eating, such as increased intake of fruit, vegetables, fibre or decreased intake of energy dense foods) motivated by a desire to maintain body shape. Similar discussion can be found elsewhere.[26 31]

## Potential explanations of weight status recovery 4 years following the disaster

Our findings demonstrated no significant difference in the mean BMI/POW or in the odds of obesity/underweight between 2015 vs 2010, which primarily suggests that children restored their physical activity levels to the predisaster level 4 years after the disaster. From within a couple of months of the disaster, the Fukushima Prefecture government and many local authorities in the prefecture implemented screening programmes for internal and external radiation exposure,[36] and offered residents counselling for radiation risks within these programmes.[37] Particularly, since 2013, all the schools in Soma City integrated the internal contamination screening into their annual school health check-up, which means that Soma City has almost 100% screening coverage for school children every year. Thanks to these local efforts following the disaster, public understanding of radiation exposure risk and consequent potential health effects has increased in the affected areas.[37] This understanding might help to ease anxiety related to radiation in children, and their parents and school teachers; and thus, the activity level in children, including physical aspects of their daily life, has probably been recovering to the predisaster level.

### Implications for future crisis

Our findings imply that as an early phase response to a major nuclear disaster, the careful monitoring of weight status in children should be promoted, with the possibility of weight loss or weight gain considered as a potential consequence. With respect to the mid-term to long-term perspective, when health practitioners, local leaders and/or civil societies evaluate the weight status of children at the area-level or population-level, they should consider not only the mean or median value of weight, but also the variance in weight, which might be a more important indicator for understanding those at prolonged risk of obese or underweight. In addition, it is also desirable that in postdisaster situations, factors potentially affecting weight status and health (including nutrition behaviour and/or factors, including self-esteem, stress, activity behaviours etc) should be routinely measured and collected at the individual level to enable more practical discussions on how to manage long-term risks.

Importantly, our study confirmed that in Soma City, postdisaster school restrictions on outdoor activities did not much affect the weight status in secondary school children, after adjustment for covariates (table 4). This may mean that rather than school restrictions on outdoor activities, personal characteristics, extracurricular activities, the home environment and/or community setting might hold a greater influence on levels of physical activity among children. For example, as a part of their evaluation of radiation dose in June 2012 in school children in Minamisoma City, located to the south of Soma City, Nomura *et al*[38] reported that 40% of parents in the city believed that their children were most exposed to radiation during the commuting hours; and 80% and 47% of parents who had primary and secondary school children, respectively, took their children to school by car for protection against the radiation, while other children went to school by bicycle or walked, which constitutes important daily physical activity. Therefore, to off-set any postdisaster weight loss/gain, after-school activities or activities on weekends, including indoor exercise, should be encouraged after a radiological disaster.

### Limitations

We identified several limitations in this study. The primary limitation is the difficulty in trying to generalise our findings to other ages and areas because our study participants were restricted to secondary age children in Soma City. For example, according to Yamamura,[31] the Fukushima disaster might have more affected weight status of children under 10 years old than those over 11 years old. One of the possible explanations of this age cohort difference is that primary school children are more likely to be advised/controlled by parents and teachers than secondary/high school children. Therefore, we should stress that a more pronounced effect might have been observed in younger children, had we been able to study a younger cohort. Using data from disaster-affected areas and non-affected areas and/or areas with and without school activity restrictions—namely difference-in-difference (DID) design, as used in Yamamura[31]—can more accurately estimate unbiased effects of the Fukushima disaster and the impact of school restrictions on child weight status, so will help our understanding of the impact of the disaster. However, note that Soma City, our study site, is the local authority where we have been supporting clinical care and research since the disaster, and so we were able to collect these valuable data with cooperation of the Soma City Office and Soma City Medical Association. Unfortunately, similar data of children from areas beyond Soma City, not affected by the Fukushima disaster, were not available, so we were not able to apply the DID method. However, it should be noted that because disaster impacts may vary from location to location depending on local conditions and context,[10] for example, physical inactivity due to radiation fears in the Fukushima case, locally specific analyses of the Fukushima disaster are invaluable to inform not only the specific health risk reduction planning and programmes for children for such crisis in the future, but also the health measurements for local children at the present time. Second, we were not able to examine the degree of physical activity in children; therefore, to address more practical implications for postdisaster response, a future study should consider levels of physical activity and/or physical fitness levels. Third, as mentioned earlier, although we argued that the decrease in weight was probably primarily due to reduced physical activity, we were not able to consider other potential pathways that may influence weight status in these children. Other pathways include generalised stress from the disaster[39–41] and postdisaster changes in nutrition behaviours that may have been adopted to compensate for less time spent in outdoor activities and/or to avoid internal contamination[37] etc. Therefore, to more adequately evaluate the effects of reduced physical activity on the weight status of children, a future study that quantifies these other influences is needed.

## CONCLUSIONS

This present study sheds new light on weight control in children following a nuclear disaster. Our findings suggest that 4 years following the Fukushima disaster, for males and females, the weight status had recovered to the predisaster level in secondary school children (aged 13–15 years), although some attention should be paid to the possibility that some male children continue to be at risk of obese/underweight as a consequence of an increase in the SD of BMI/POW.

We found no significant relationship between school restrictions on outdoor activities and weight status, indicating that school activities are probably not an important part of a child's physical activity level and other activities (eg, activities in evening and on weekends, including indoor exercise) should be encouraged to off-set any weight loss/gain. Our findings could be used to guide actions taken during the early phase of a radiological disaster to manage the postdisaster chronic health risks in adolescent children.

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## REFERENCES

1. Brumfiel G, Cyranoski D. Quake sparks nuclear crisis. *Nature* 2011;471:273–5.
2. Priest ND. Radiation doses received by adult Japanese populations living outside Fukushima Prefecture during March 2011, following the Fukushima 1 nuclear power plant failures. *J Environ Radioact* 2012;114:162–70.
3. Hayano RS, Tsubokura M, Miyazaki M, *et al*. Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter surveys. *Proc Jpn Acad Ser B Phys Biol Sci* 2013;89:157–63.
4. Hayano RS, Tsubokura M, Miyazaki M, *et al*. Comprehensive whole-body counter surveys of Miharu-town school children for three consecutive years after the Fukushima NPP accident. *Proc Jpn Acad Ser B Phys Biol Sci* 2014;90:211–13.
5. Hayano RS, Tsubokura M, Miyazaki M, *et al*. Whole-body counter surveys of Miharu-town school children for four consecutive years after the Fukushima NPP accident. *Proc Jpn Acad Ser B Phys Biol Sci* 2015;91:92–8.
6. Tsubokura M, Kato S, Morita T, *et al*. Assessment of the annual additional effective doses amongst minamisoma children during the second year after the Fukushima Daiichi nuclear power plant disaster. *PLoS ONE* 2015;10:e0129114.
7. Tsubokura M, Kato S, Nomura S, *et al*. Absence of internal radiation contamination by radioactive cesium among children affected by the Fukushima Daiichi nuclear power plant disaster. *Health Phys* 2015;108:39–43.
8. World Health Organization. Health risk assessment from the nuclear accident after the 2011 great east japan earthquake and tsunami, based on a preliminary dose estimation. Geneva: World Health Organization, 2013.
9. United Nations Scientific Committee on the Effects of Atomic Radiation. Annexa: levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami. New York: United Nations Scientific Committee on the Effects of Atomic Radiation, 2014.
10. Nomura S, Parsons AJQ, Hirabayashi M, *et al*. Social determinants of mid- to long-term disaster impacts on health: a systematic review. *Int J Disaster Risk Reduct* 2016;16:53–67.
11. Jhung MA, Shehab N, Rohr-Allegrini C, *et al*. Chronic disease and disasters medication demands of Hurricane Katrina evacuees. *Am J Prev Med* 2007;33:207–10.
12. Miller AC, Arquilla B. Chronic diseases and natural hazards: impact of disasters on diabetic, renal, and cardiac patients. *Prehosp Disaster Med* 2008;23:185–94.
13. Ishii T, Tsubokura M, Ochi S, *et al*. Living in contaminated radioactive areas is not an acute risk factor for noncommunicable disease development: a retrospective observational study. *Disaster Med Public Health Prep* 2016;10:34–7.
14. Tsubokura M, Takita M, Matsumura T, *et al*. Changes in metabolic profiles after the Great East Japan Earthquake: a retrospective observational study. *BMC Public Health* 2013;13:267.
15. Satoh H, Ohira T, Hosoya M, *et al*. Evacuation after the Fukushima Daiichi nuclear power plant accident is a cause of diabetes: results from the Fukushima health management survey. *J Diabetes Res* 2015;2015:627390.
16. Nomura S, Blangiardo M, Tsubokura M, *et al*. Postnuclear disaster evacuation and chronic health in adults in Fukushima, Japan: a long-term retrospective analysis. *BMJ Open* 2016;6:e010080.
17. Sugihara G, Suda S. Need for close watch on children's health after Fukushima disaster. *Lancet* 2011;378:485–6.
18. Shrestha R, Copenhaver M. Long-term effects of childhood risk factors on cardiovascular health during adulthood. *Clin Med Rev Vasc Health* 2015;7:1–5.
19. McCurry J. Fukushima radiation fears are linked to increase in obesity among children. 2012. http://www.theguardian.com/environment/2012/dec/27/fukushima-radiation-child-obesity-fears (accessed 17 Jun 2016).
20. Gray C, Gibbons R, Larouche R, *et al*. What is the relationship between outdoor time and physical activity, sedentary behaviour, and physical fitness in children? A systematic review. *Int J Environ Res Public Health* 2015;12:6455–74.
21. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ* 2006;174:801–9.
22. Pulgarón ER. Childhood obesity: a review of increased risk for physical and psychological comorbidities. *Clin Ther* 2013;35:A18–32.
23. Eriksson JG, Forsén T, Tuomilehto J, *et al*. Early adiposity rebound in childhood and risk of Type 2 diabetes in adult life. *Diabetologia* 2003;46:190–4.
24. Statistics Bureau. Chapter 24 health and sanitation. 1996. http://www.stat.go.jp/english/data/nenkan/1431-24e.htm (accessed 17 Jun 2016).
25. The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission. Overview of the damage

and how it spread. The official report of the Fukushima nuclear accident independent investigation commission. Tokyo: The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, 2012:30.
26. Shirasawa T, Ochiai H, Nanri H, *et al*. Trends of underweight and overweight/obesity among Japanese schoolchildren from 2003 to 2012, defined by body mass index and percentage overweight cutoffs. *J Epidemiol* 2015;25:482–8.
27. Ministry of Education C, Sports, Science and Technology. The Annual Report of School Health Statistics in 2000 [in Japanese]. 2000. http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001016209&cycode=0 (accessed 17 Jun 2016).
28. Murata M, Ito K. On the optimal weight in school age children. In: Murata M, ed. *Report of research on nutrition, exercise and recreation from the viewpoint of health and QOL in children, supported by Health and Labour Science Research Grants from Ministry of Health, Labour and Welfare for Research on Health Service in 2002 [Japanese]*. Tokyo: Ministry of Health, Labour and Welfare (Japan), 2003.
29. Dobashi K. Evaluation of Obesity in School-Age Children. *J Atheroscler Thromb* 2016;23:32–8.
30. Sugiura R, Murata M. Problems with body mass index as an index to evaluate physical status of children in puberty. *Pediatr Int* 2011;53:634–42.
31. Yamamura E. Impact of the Fukushima nuclear accident on obesity of children in Japan (2008–2014). *Econ Hum Biol* 2016;21:110–21.
32. Yokomichi H, Zheng W, Matsubara H, *et al*. Impact of the great east Japan earthquake on the body mass index of preschool children: a nationwide nursery school survey. *BMJ Open* 2016;6:e010978.
33. Matsubara H, Ishikuro M, Kikuya M, *et al*. Design of the Nationwide Nursery School Survey on child health throughout the Great East Japan Earthquake. *J Epidemiol* 2016;26:98–104.
34. Kaneko K, Kiriike N, Ikenaga K, *et al*. Weight and shape concerns and dieting behaviours among pre-adolescents and adolescents in Japan. *Psychiatry Clin Neurosci* 1999;53:365–71.
35. Vignerová J, Humeníkova L, Brabec M, *et al*. Long-term changes in body weight, BMI, and adiposity rebound among children and adolescents in the Czech Republic. *Econ Hum Biol* 2007;5:409–25.
36. Yasumura S, Hosoya M, Yamashita S, *et al*. Study protocol for the Fukushima Health Management Survey. *J Epidemiol* 2012;22:375–83.
37. Tsubokura M, Kato S, Nomura S, *et al*. Reduction of high levels of internal radio-contamination by dietary intervention in residents of areas affected by the Fukushima Daiichi nuclear plant disaster: a case series. *PLoS ONE* 2014;9:e100302.
38. Nomura S, Tsubokura M, Furutani T, *et al*. Dependence of radiation dose on the behavioral patterns among school children: a retrospective analysis 18 to 20 months following the 2011 Fukushima nuclear incident in Japan. *J Radiat Res* 2016;57:1–8.
39. Pervanidou P, Chrousos GP. Stress and obesity/metabolic syndrome in childhood and adolescence. *Int J Pediatr Obes* 2011;6 (Suppl 1):21–8.
40. Hasegawa A, Tanigawa K, Ohtsuru A, *et al*. Health effects of radiation and other health problems in the aftermath of nuclear accidents, with an emphasis on Fukushima. *Lancet* 2015;386:479–88.
41. Suzuki Y, Yabe H, Yasumura S, *et al*. Psychological distress and the perception of radiation risks: the Fukushima health management survey. *Bull World Health Organ* 2015;93:598–605.