BMJ Open

Impact of the great east Japan earthquake on the body mass index of preschool children: a nationwide nursery school survey

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2015-010978
Article Type:	Research
Date Submitted by the Author:	24-Dec-2015

Complete List of Authors:	Yokomichi, Hiroshi; University of Yamanashi, Department of Health Sciences Zheng, Wei; Peking University, Department of Social Medicine and Health Education Matsubara, Hiroko; Tohoku University, Department of Disaster Public Health Ishikuro, Mami; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Kikuya, Masahiro; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Isojima, Tsuyoshi; The University of Tokyo, Department of Pediatrics Yokoya, Susumu; National Center for Child Health and Development, Center for Clinical Research Data Tanaka, Toshiaki; Japanese Association for Human Auxology Kato, Noriko; National Institute of Public Health of Japan, Department of Health Promotion Chida, Shoichi; Iwate Medical University, Department of Pediatrics Ono, Atsushi; Fukushima Medical University, Department of Pediatrics Hosoya, Mitsuaki; Fukushima Medical University, Department of Pediatrics Tanaka, Soichiro; Tohoku University, Department of Pediatrics Kuriyama, Shinichi; Tohoku University, Department of Disaster Public Health; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Kure, Shigeo; Tohoku University, Department of Pediatrics Yamagata, Zentaro; University of Yamanashi, Department of Health Sciences

Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Paediatrics, Emergency medicine, Nutrition and metabolism, Diabetes and endocrinology, Public health
Keywords:	body mass index, earthquake, Fukushima nuclear accident, preschool child, growth

SCHOLARONE™
Manuscripts

Impact of the great east Japan earthquake on the body mass index of preschool children: a nationwide nursery school survey

Hiroshi Yokomichi[1], Wei Zheng[2], Hiroko Matsubara[3], Mami Ishikuro[4], Masahiro Kikuya[4], Tsuyoshi Isojima[5], Susumu Yokoya[6], Toshiaki Tanaka[7], Noriko Kato[8], Shoichi Chida[9], Atsushi Ono[10], Mitsuaki Hosoya[10], Soichiro Tanaka[11], Shinichi Kuriyama[3,4], Shigeo Kure[11] and Zentaro Yamagata[1]

[1]Department of Health Sciences, University of Yamanashi, Yamanashi, Japan

[2]Department of Social Medicine and Health Education, Peking University, Beijing, China

[3]Department of Disaster Public Health, International Research Institute of Disaster Science, Tohoku University, Miyagi, Japan

[4]Department of Preventive Medicine and Epidemiology, Tohoku Medical Megabank Organization, Miyagi, Japan

[5]Department of Pediatrics, The University of Tokyo, Tokyo, Japan

[6]Center for Clinical Research Data, National Center for Child Health and Development, Tokyo, Japan

[7]Japanese Association for Human Auxology, Tokyo, Japan

[8]Department of Health Promotion, National Institute of Public Health of Japan, Saitama, Japan

[9]Department of Pediatrics, Iwate Medical University, Iwate, Japan

[10]Department of Pediatrics, Fukushima Medical University, Fukushima, Japan

[11]Department of Pediatrics, Tohoku University, Miyagi, Japan

Corresponding author:

Hiroshi Yokomichi

Yokomichi H et al.

1110 Shimokato, Chuo City, Yamanashi, postal code 4093898, Japan

E-mail: hyokomichi@yamanashi.ac.jp

Tel: +81-(0)55-273-9566

Keywords: body mass index; earthquake; Fukushima nuclear accident; preschool child; growth

Word count: 3812

ABSTRACT

Objective: To evaluate the impact of the 2011 Great East Japan Earthquake on body mass index of preschool children.

Design: Retrospective cohort study and ecological study.

Setting: Affected prefectures (Fukushima, Miyagi and Iwate) and unaffected prefectures in northeastern Japan.

Participants: The study assessed a total of 2033 boys and 1909 girls from 310 nursery schools located in 3 affected prefectures and a total of 1707 boys and 1658 girls from 238 nursery schools located in 3 unaffected prefectures, all aged 3–4 years at the time of the earthquake.

Primary and secondary outcome measures: Post-disaster changes in body mass index (BMI) were compared between children living in affected and unaffected prefectures.

Results: One month after the earthquake, increased BMIs were observed among girls (+0.087 kg/m^2 vs. the unaffected areas, $P = 0.02$) in Fukushima and both boys (+0.165 kg/m^2 vs. the unaffected areas, $P < 0.0001$) and girls (+0.124 kg/m^2 vs. the unaffected areas, $P = 0.002$) in Iwate. Nineteen months after the earthquake, increased BMIs were detected among boys (+0.137 kg/m^2 vs. the unaffected areas, $P = 0.0003$) and girls (+0.200 kg/m^2 vs. the unaffected areas, $P < 0.0001$) in Fukushima, whereas prolonged decreases in BMI was observed among boys (−0.218 kg/m^2 vs. the unaffected areas, $P < 0.0001$) and girls (−0.082 kg/m^2 vs. the unaffected areas, $P = 0.011$) in Miyagi.

Conclusion: These results suggest that in the affected prefectures, preschool children gained weight immediately after the earthquake. The longer term impact of the earthquake on early childhood growth was more variable among the affected prefectures, possibly as a result of different speeds of recovery.

Yokomichi H et al.

61 **Word count: 267 words**

Strengths and limitations of this study

- The study analysed a unique dataset on child body mass index before and after a disaster.
- The study establishes a reference group for comparison as children mature.
- The study was limited by the lack of information on past diet and physical activity.
- The cohort of affected participants included only those who did not relocate and not those who died or relocated.

INTRODUCTION

The Great East Japan Earthquake of 2011, with a magnitude of 9.0,[1] was the fourth largest earthquake ever recorded and the largest in Japan.[2] This earthquake together with the subsequent tsunami[3] and the nuclear power plant accident in Fukushima[4] caused immense damage to the Pacific coast of northeastern Japan.[5] The disaster resulted in a significant human and property toll: 19,466 people were killed, 6,152 were injured, 124,663 houses were destroyed and 274,638 homes were damaged.[6] The tragedy also affected daily life in the region, disrupting the normal eating and exercise habits of the inhabitants of Fukushima, Miyagi and Iwate Prefectures (Figure 1).[7] Experts in child growth have been very concerned about the short-term and long-term detrimental health effects of the earthquake and associated events on young children.[8, 9] In particular, schoolteachers and local paediatricians have focused on assessing potential weight gain among the children, since the affected children mainly consumed high-carbohydrate diets after the earthquake and were not allowed to play outdoors to avoid exposure to radiation from the damaged nuclear power plant.[10] Despite this warning about potential child obesity, there have been no reliable analyses on children's body weight since the earthquake. In addition, to the best of our knowledge, no study has investigated weight changes among resident children affected by other large natural disasters. The present study was driven by the question of whether the body mass indices (BMIs) of affected children had changed relative to the BMIs of comparable but unaffected children. Additionally, this report compared the prevalence of overweight children between affected and unaffected areas of Japan in an ecological study.

METHODS

Study participants and measurements

On 27 August 2012, the Ministry of Health, Labour and Welfare of Japan sent a letter to nursery schools across Japan (some of which were undestroyed and still in operation in affected prefectures) through domestic administrators requesting the recipients' participation in the Nationwide Nursery School Survey on Child Health.[11] Nursery school records on student height and weight in the affected and unaffected areas of northeastern Japan were collected for the participating children born between 2 April 2006 and 1 April 2007 (Japanese fiscal year 2006). Thus, the children evaluated were 4–5 years old during the month of the first primary outcome evaluation (April 2011) and were 6–7 years old when data collection was completed in 2013. Participating children were weighed in their underwear and without shoes. Measurements were based on weight scales and stadiometres, which are legally required equipment at all Japanese nursery schools and kindergartens that undergo half-yearly standardisation by certified measurers.[12] The children were assessed biannually in April and October, and the nursery schoolteachers mailed the records on each child's height and weight to the central agency. Accordingly, we defined the half-yearly time points as every April and October from 2008 to 2012. Missing data included data for those children who moved out of the areas or died and were not included in the analyses. Analyses of the obtained longitudinal data were based on the assumption of missing at random.[13] BMI was calculated as each child's weight in kilograms divided by the square of their height in metres.

Comparison of BMI changes

First, to gain an overview of the trends in children's BMIs, we represented the mean BMIs of children living in the affected prefectures facing the Pacific Ocean (i.e. the Fukushima, Miyagi and Iwate Prefectures) and then separately the children living on the other side of northeastern Japan in unaffected areas (i.e. the Yamagata, Akita and Aomori Prefectures) according to a fixed-effects model that estimates chronological means.[13, 14] For the representations, we separately generated 4 models with an explanatory variable of the time points for the 3 affected prefectures and the pooled unaffected areas. According to the estimated coefficients, we graphically plotted the mean BMIs for the affected prefectures and the unaffected areas. Second, for the primary comparisons of interest using a retrospective cohort design, we compared the BMI changes separately among the children from affected vs. unaffected prefectures. The BMI changes after the earthquake were evaluated from a reference baseline time point of October 2010, the last measured time point prior to the date of the earthquake (11 March 2011), through April 2011, October 2011, April 2012 and October 2012. We compared the BMI changes for children in each affected prefecture with those of the unaffected areas in a single fixed-effects model,[14] a type of linear mixed-effects model that is useful for analysis of longitudinal data.[13] A binary explanatory variable was set for whether children lived in an affected or unaffected area, and the analyses were adjusted using a covariate of age in month. The following fixed-effects model was employed:

$$BMI_{ijk} = (\text{Time point})_i + (\text{Time point*Area group})_{ij} + (\text{Age in month})_k + \varepsilon_{ijk}$$

$$\varepsilon_{ijk} \sim N(0, \sigma^2)$$

where *i* represents index time points of October 2010, April 2011, October 2011, April 2012 or October 2012; *j* represents indices for each affected prefecture or unaffected area; and *k* represents indices for individuals. $(\text{Time point})_i$ equals zero when i equals October 2010 (the reference baseline time point). $(\text{Time point*Area group})_{ij}$ represents for an interaction term between $(\text{Time point})_i$ and $(\text{Area group})_j$, and equals zero at any time points when j equals unaffected area. $(\text{Age in month})_k$ is a covariate of adjustment for child age. ε_{ijk} represents the random effect of the error term in the model.

Consequently, we applied 3 models for comparison of BMI changes within the 3 affected prefectures with a single reference for the unaffected areas. According to the coefficients in the model, we also graphically plotted the BMI changes and then statistically evaluated the differences in BMI change between each affected prefecture and the unaffected areas with the statistical significance of the interaction term. All statistical analyses were performed with sex stratification using SAS statistical software (version 9.4, SAS Institute, Cary, NC, USA). Descriptive statistics are reported as means and standard deviations (SDs)/standard errors (SEs). All reported *P* values are from 2-sided analyses, with *P* values <0.05 considered statistically significant.

Comparison in the prevalence of overweight children

For the secondary comparisons in an ecological study design, the prevalence of overweight boys and girls in Fukushima, Miyagi and Iwate Prefectures and throughout Japan were assessed for 6–17-year-old children attending primary, junior high and high schools using the descriptive data provided through the School Health Statistics Research of Japan.[15] The investigation by the School Health Statistics Research, which selects examined schools in a stratified random sampling under Japanese law,[16] is conducted annually from April to June. Because of widespread school dysfunction immediately after the disaster in March 2011, the examination could not be conducted in the 3 affected prefectures in 2011. Therefore, we compared the prevalence of overweight children from the 2012 examination with the prevalence from the 2010 examination for the 3 prefectures and across Japan to determine whether or not the prevalence had increased after the earthquake. The sources for nation-wide data comprised 4.8% of all Japanese schoolchildren in 2010 and 4.9% in 2012. In both 2010 and 2012, 270,720 primary school children aged 6−11 years, 225,600 junior high school students aged 12−14 years and 126,900 high school students aged 15−17 years were included. With these data, the definition of being overweight was weighing 20% or greater than a standard weight, where percent overweight = (measured weight − standard weight) × 100/standard weight for each given age, sex and height in accordance with the guidelines of

The Japanese Society for Pediatric Endocrinology.[17, 18] Because the source data were based on the prevalence of this definition of being overweight, the definitions of overweight children from the International Obesity Task Force[19] and the World Health Organization[20] could not be used. Owing to the nature of the source data, tests of statistical significance were not performed.

RESULTS

Comparison of BMI changes

For the affected participants, data were collected from 646 boys and 597 girls that attended 97 nursery schools in Fukushima (nursery school participation rate [NPR], 31%); 904 boys and 854 girls from 132 nursery schools in Miyagi (NPR, 38%) and 483 boys and 458 girls from 81 nursery schools in Iwate (NPR, 23%). For the unaffected participants, we collected data from 307 boys and 285 girls attending 42 nursery schools in Yamagata (NPR, 17%); 762 boys and 739 girls from 88 nursery schools in Akita (NPR, 35%) and 638 boys and 634 girls from 108 nursery schools in Aomori (NPR, 23%).

Table 1 shows the baseline anthropometrics in October 2010. The mean age in the affected and unaffected areas was 4.1 (SD, 0.3) years for boys and girls. The mean BMI in the affected areas was 15.7 (SD, 1.2) kg/m^2 for boys and 15.6 (SD, 1.3) kg/m^2 for girls. In the unaffected areas, the mean BMI was 15.6 (SD, 1.2) kg/m^2 and 15.6 (SD, 1.3) kg/m^2 for boys and girls, respectively.

190 **Table 1** Baseline characteristics of participating boys and girls in October 2010 in northeast

191 Japan

Anthropometric measurements	Affected areas		Unaffected areas	
	Boys (n = 2033)	Girls (n = 1909)	Boys (n = 1707)	Girls (n = 1658)
Age, years	4.1 (0.3)	4.1 (0.3)	4.1 (0.3)	4.1 (0.3)
Height, cm	100.6 (4.3)	99.6 (4.1)	100.8 (4.2)	100.0 (4.2)
Weight, kg	15.9 (2.0)	15.5 (1.9)	16.0 (1.9)	15.6 (2.0)
Body mass index, kg/m^2	15.7 (1.2)	15.6 (1.3)	15.6 (1.2)	15.6 (1.3)

192 All values are presented as mean (standard deviation).

193

194 Figure 2 and Supplementary Table 1 present the estimated BMIs from April 2008 to

195 October 2012 graphically and numerically, respectively. For the primary cohort-design

196 comparisons, Figure 3 and Supplementary Table 2 illustrate the estimated changes in BMI

197 from October 2010 to October 2012 graphically and numerically, respectively, for children

198 residing in each affected prefecture in comparison with those residing in the unaffected areas.

199 Compared to the unaffected areas, BMI observed in the Fukushima Prefecture was

200 significantly higher among boys in October 2012 (+0.137 kg/m^2, $P = 0.0003$) and among

201 girls in April 2011 (+0.087 kg/m^2, $P = 0.02$), April 2012 (+0.122 kg/m^2, $P = 0.0013$) and

202 October 2012 (+0.200 kg/m^2, $P < 0.0001$).

203 Compared to the unaffected areas, BMI observed in the Miyagi Prefecture was

204 significantly lower among boys in October 2011 (−0.076 kg/m^2, $P = 0.02$), April 2012

205 (−0.165 kg/m^2, $P < 0.0001$) and October 2012 (−0.218 kg/m^2, $P < 0.0001$) and among girls in

206 October 2012 (−0.082 kg/m^2, $P = 0.011$).

Compared to the unaffected areas, BMI observed in the Iwate Prefecture was significantly higher among boys in April 2011 (+0.165 kg/m^2, $P < 0.0001$) and among girls in April 2011 (+0.124 kg/m^2, $P = 0.002$).

Comparison of the prevalence of overweight children

The secondary ecological study compared the prevalence of overweight boys and girls in Fukushima, Miyagi and Iwate Prefectures as well as across Japan in both 2010 and 2012 (Figure 4). We observed increases in the prevalence of overweight individuals among primary school boys in the 6−11 age group in Fukushima, the 6−12 age group in Miyagi, the 6−9 age group in Iwate and the 6−10 age group across Japan. We also found increases in the prevalence of overweight primary school girls in the 6−10 age group in Fukushima, the 8−11 age group in Miyagi and the 6−11 age group across Japan. Among the girls aged 6−7 years in Miyagi, we also observed a slightly decreased prevalence of overweight children. No noteworthy change in the prevalence of overweight children was observed among primary school girls (6−12 years) in Iwate. In the 3 affected prefectures and across Japan, there were no consistent trends in the prevalence of overweight individuals among junior high and high school students aged 12−17 years.

DISCUSSION

Main results

Our data on post-disaster BMI changes (Figure 3) showed immediate increases in BMI among the preschool boys and girls residing in each affected prefecture, as if in response to the disaster in March 2011. In addition, there was evidence of a prolonged increase in BMI among the boys and girls residing in Fukushima. On the other hand, in Miyagi, we identified a trend of immediate weight gain with subsequent weight loss in both boys and girls. In Iwate, the BMIs of boys and girls gradually approached those of the children living in unaffected areas. In the ecological study (Figure 4), there were increases from 2010 to 2012 in the prevalence of overweight boys and girls in Fukushima and overweight boys in Miyagi and Iwate in their early primary school years, although the results were inconsistent among girls in Miyagi and Iwate that were also in early primary school. Although the psychological harm that natural disasters cause to children has been reported,[21] the present results have provided additional evidence of an immediate and potentially prolonged increase in BMI among young children following a major disaster.

Possible explanations

At the time of the 2011 earthquake, electricity, gas lines, water supply lines, sewage systems, railways and traffic transportation were all interrupted.[5] The interruption in daily transportation resulted in severe shortages of meat, fish, egg and vegetables.[22] As typically occurs with disasters, administrative and non-political/non-profit organisations supplied carbohydrates such as rice balls and bread to affected populations.[8, 23] In the 3 affected prefectures, the priority was to supply meals to the affected children.[24] The affected children are presumed to have gained weight due to the carbohydrate-based diet that was supplied, which may account for the weight gain observed in boys and girls in 3 prefectures immediately after the earthquake, either with or without statistical significance (Figure 3). Furthermore, school gymnasiums were used as shelters for residents, and school playgrounds were opened for provisional housing at that time.[23] In Fukushima, where the nuclear power plant station experienced hydrogen explosions, there were few chances to play outside due to fear of radiation exposure, the lack of available playgrounds and an overall mournful mood among the population. Additionally, on 19 April 2011, the Ministry of Education, Culture, Sports, Science and Technology of Japan issued a notice to all schools in Fukushima that principals needed to restrict the availability of school buildings and playgrounds as long as the schools were exposed to 1 mSv or more of radiation per year.[25] The limited outdoor activity may have been reflected in the prolonged BMI increases observed among children living in Fukushima. In contrast, in Miyagi, city infrastructure, hospitals, school education and corporate activities have been recovering much sooner than in Fukushima.[26, 27] This contrast may in part explain the different trends in weight loss observed among boys and girls living in Miyagi. However, how they lost weight has not been established. In Iwate, one report has described a worsening of the mean plasma glucose and haemoglobin A1c levels in 63 affected patients with diabetes from 109.4 mg/dL (SE, 3.9, 6.08 mmol/L [SE, 0.22]) to 134.3 mg/dL (SE, 7.2, 7.46 mmol/L [SE, 0.40]) and from 5.9 % (SE, 0.2, 6.8 mmol/L [SE, 0.3]) to 6.5 % (SE, 0.2, 7.8 mmol/L [SE, 0.3]), respectively, 4 months after the earthquake.[28] The authors were physicians in charge of following up with these patients and they witnessed unbalanced diets heavy with sweets, canned products and boil-in-the-bag foods provided to the evacuees. The authors have speculated that the worsening of the glycaemic control was partly due to unbalanced diets. As was the case in Fukushima and Miyagi, the reported situation of limited access to an adequate diet in Iwate may partly explain the immediate BMI increases observed among preschool boys and girls after the earthquake. Because the Iwate Prefecture is relatively far from the epicentre of the earthquake and the damaged nuclear power plant, the daily lives of its inhabitants may have returned to normal sooner than it did for those in Fukushima.[26, 27]

Comparison with previous studies

Extraordinary experiences during major disasters change the lives of inhabitants and lead to an array of physical and mental problems.[29-31] A study from medical examinations has shown a +0.2−0.3 BMI change in a year among Fukushima evacuees.[32] Another report from a cohort in Miyagi has described a +0.25 kg/m^2 BMI change among city officials engaging in post-quake recovery and a −0.09 kg/m^2 BMI change among the general population in 2011 after adjusting for sex and age.[33] Our results comparing children in Fukushima and Miyagi are consistent with these previous reports that investigated changes among adults. As described above, the observed BMI increases immediately after the disaster may be partly attributed to unbalanced diet and elevated hormone levels induced by psychological stresses. At the 1995 Great Hanshin (Kobe) earthquake in Japan (7.3 magnitude on the Richter scale), physicians have also reported worsened glycaemic controls among diabetic patients.[34] The authors, who were members of disaster relief teams, have explained that the exacerbations were partly due to unhealthy high-carbohydrate diets and overeating, in responses to sleeplessness and a fear of hunger. At the 2004 Mid-Niigata earthquake (6.8 magnitude on the Richter scale), a report from health check-up data for overworked male prefectural governmental staff members has described an average +0.2 kg/m^2 yearly BMI increase among victims and an average +0.1 kg/m^2 yearly BMI increase among non-victims.[35] At the 1999 Taiwan earthquake (7.2 magnitude on the Richter scale), a study has reported that increased sympathetic hormone levels of leptin and cortisol associated with hyperarousal.[36] Because leptin regulates food intake and body weight,[37] and cortisol is induced by psychological stress,[38] hormonal changes in hypervigilant individuals following major earthquakes may cause disturbances in their appetite and BMI.

302 **Practical implications**

303 Medical attention pertaining to mental health and life-style-related issues must be provided adults and in particular elderly adults with a chronic condition during earthquake recovery.[39] With most natural disasters, the focus has been traditionally placed mainly on the health problems of adults and not on the needs of children. This study sheds new light on the risks that a disaster can pose to childhood growth and their risk of obesity after a disaster. The mean BMI levels among male children in Fukushima and male and female children in Iwate, all approximately 4 years old at the time that the earthquake struck, appear to show a relatively earlier adiposity rebound, with both immediate and prolonged weight gain (Figure 2). In paediatrics, adiposity rebound is defined as the point of the minimal BMI that comes at 5–6 years old on average.[40] There is a consensus that early adiposity rebound predicts diabetes and obesity in adulthood,[41, 42] although discussion continues about whether the reason for undesirable outcomes at adult age is due to children's lifestyles,[43] to their foetal lives[44] or to other causal mechanisms.[45] Hence, if earlier adiposity rebound indeed occurs in a subset of children after natural disasters due to lack of diet and exercise, administrative agencies and local paediatricians should pre-emptively address this source of future cardiovascular diseases. Because being physically active during the preschool ages reduces BMI over a long term,[46] in the immediate aftermath of an earthquake, play space availability should be ensured, balanced diets should be supplied, and schools should be reopened at the earliest possible date. Additionally, endocrinological and metabolic abnormalities often appear in preschool children with a 12-month history of being overweight.[47] Indeed, stress experienced in early childhood can persist and cause future neurologic and endocrine-related cardiovascular disease.[48] Thus, paediatricians need to assure long term follow-up and pay close attention to the health of children affected by a disaster.

Limitations and strengths

The present study had several limitations. First, the lack of information on diet and physical activity may limit the comparability of outcomes between the affected and unaffected areas studied. Because the Pacific side of northeastern Japan receives less snow than the opposite side, exercise may be more frequent in the affected areas than in the unaffected areas. This cultural factor may induce bias toward decreasing BMIs of the affected children residing on the Pacific Ocean side. Considering this negative bias in BMI, the weight gains among children living in Fukushima and Iwate might be larger, and the weight loss observed in Miyagi might be smaller than thought. To correct for this potential bias, study initiation with a matching method based on cultural confounders for a quasi-experimental design might have reduced the bias. Even so, we minimised the bias by selecting an unaffected reference group from the northeastern region of Japan, where the diet was considered to be similar to that in the three affected prefectures.[49] Second, the results were limited with no use of z score (standard deviation score) for BMI,[50-52] which might have more properly adjusted for age. Although the standardisation by z score may be ideal for comparison of raw BMI values, the need for comparison of the BMI changes did not allow us to use the standardisation. Thus, we chose instead to compare BMI changes between two groups and make the simple adjustment of a covariate for child age in month in the model. A third limitation was the representativeness of the sample population in affected areas of northeastern Japan. The registered children for available data attended nursery schools that responded to the request letter. Therefore, the data did not include children who died, children in ruined or dysfunctional nursery schools without schoolteachers or children who had moved away from the area. Because there is no data on whether those most affected children gained or lost

351 weight, the direction and the amount of this bias in BMI has not been determined. Conversely,
352 the study design could have specifically focused on children that experienced severe suffering.
353 Because in the study design, the definition of 'affected' children did not identify those who
354 were evacuated to provisional houses or who were physically impacted by the tsunami, the
355 observed influence of the disaster on child growth may have been reduced.

356 The assembled longitudinal data would be strengthened by its uniqueness in recording
357 child growth before and after a disaster. Although medical attention to the physical and
358 mental health of people affected by a disaster has recently increased, surveys pertaining to
359 this particular disaster have just begun.[53] A number of studies originating from these
360 surveys should provide evidence to bolster disaster medicine. Another strength of this study is
361 comparison of affected children with the unaffected children, who were considered to have
362 been normally growing. For example, although one report described the health status of Iraqi
363 refugees before immigration to the U.S. with an obesity prevalence of 24.6% and a
364 hypertension prevalence of 15.2%,[54] the lack of information on unaffected Iraqis prevented
365 an estimation of the influence of refugee life on human health. Similarly, the impact of a
366 study that reported a high prevalence of mental disorders in Iraqi children during a war,[55]
367 would be weakened because of the lack an unexposed comparator reference group. The
368 evaluation of BMIs in growing children is usually difficult. However, we believe that an
369 epidemiological answer has been provided to the study question on whether children's BMIs
370 were influenced by the disaster. Furthermore, the phenomenon of an increased prevalence of
371 overweight early-year primary school children in Fukushima has been observed in the
372 ecological study. Although an ecological fallacy may exist, it is interesting that this
373 phenomenon has appeared in Fukushima, where there are reports of delayed reconstruction.

374

Conclusion

The data from earthquake-stricken northeastern Japan have shown an immediate increase in BMI among children living in three affected prefectures. The data have also indicated trends of prolonged BMI increases among children in Fukushima and prolonged BMI decreases among children in Miyagi. These data emphasise the need for attention to and follow-up for affected children after a natural disaster to prevent undesirable health outcomes.

Acknowledgments We especially thank Prof. Rafael Perera-Salazar, Dr. Richard Stevens, Dr. Jason Oke, Dr. Jan Verbakel, Dr. Joseph Lee and other biostatistics team members at the Nuffield department of Primary Care Health Sciences in the University of Oxford for their insightful advice, which helped to improve the analysis and discussion of the manuscript.

Contributors SKure, ZY, WZ and HY conceived and designed the study. WZ and HY analysed the data. HY wrote the draft. HM, MI, MK, TI, SY, TT, NK, SC, AO, MH, ST, SKuriyama and SKure collected the data. All authors interpreted the results and critically reviewed the manuscript for important intellectual content.

Competing interests None declared.

Funding This work was supported by the Ministry of Health, Labour and Welfare of Japan as Jisedai-Shitei, Fukkoku H24-007 and Jisedai-Ippan H25-002 and by the Ministry of Education, Culture, Sports, Science and Technology of Japan as Scientific Research (C) 15K08730 and Challenging Exploratory Research 15K15221. The Ministry of Health, Labour and Welfare of Japan cooperated the data collection. The funders had no role in study design, analysis, decision to publish or preparation of the manuscript.

Ethics approval The research was approved by the Ethics Committee of Tohoku University School of Medicine (approval number: 2012-1-125).

Data sharing statement No additional data are available.

Yokomichi H et al.

REFERENCES

1. Lin W, Conin M, Moore JC, et al. Stress state in the largest displacement area of the 2011 Tohoku-Oki earthquake. *Science* 2013;339:687–90.

2. Dunbar P, McCullough H, Mungov G, et al. 2011 Tohoku earthquake and tsunami data available from the National Oceanic and Atmospheric Administration/National Geophysical Data Center. *Geomat Nat Hazards Risk* 2011;2:305–23.

3. Maeda T, Furumura T, Sakai Si, et al. Significant tsunami observed at ocean-bottom pressure gauges during the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 2011;63:803–8.

4. Christodouleas JP, Forrest RD, Ainsley CG, et al. Short-term and long-term health risks of nuclear-power-plant accidents. *New Engl J Med* 2011;364:2334–41.

5. Mimura N, Yasuhara K, Kawagoe S, et al. Damage from the great east Japan earthquake and tsunami-a quick report. *Mitig Adapt Strateg Glob Chang* 2011;16:803–18.

6. National Police Agency of Japan. Damage situation and police countermeasures associated with 2011 Tohoku district - off the pacific ocean earthquake. 2015. Available: https://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf (accessed 17 Dec 2015)

7. Yanagihara H, Hatakeyama Y, Iwasaki T. Coordination by registered dieticians for nutritional and dietary support in disaster in Japan. *Western Pac Surv Resp J* 2012;3: 46–51.

8. Inoue T, Nakao A, Kuboyama K, et al. Gastrointestinal symptoms and food/nutrition concerns after the great east Japan earthquake in March 2011: survey of evacuees in a temporary shelter. *Prehosp Disaster Med* 2014;29:303–6.

9. Kotozaki Y. The nutritional status of women of the coastal region of the great east Japan earthquake disaster area: three years after. *Integr Mol Med* 2015;2: 106–8.

10. Yoshii H, Saito H, Kikuchi S, et al. Report on maternal anxiety 16 months after the great east Japan earthquake disaster: anxiety over radioactivity. *Glob J Health Sci* 2014;6: 1–10.

11. 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* 2015: (in press).

12. Ministry of Economy, Trade and Industry of Japan. Measurement Act (English version). 1992. Available: http://www.japaneselawtranslation.go.jp/law/detail/?id=82&vm=02&re=02&new=1 (accessed 17 Dec 2015)

13. Verbeke G, Molenberghs G. Linear mixed models for longitudinal data. Verlag, New York: Springer 2009.

14. Allison PD. Fixed effects regression methods for longitudinal data using SAS. Cary, North Carolina: SAS Institute, 2005.

15. Ministry of Education, Culture, Sports, Science and Technology of Japan. Annual report of the School Health Statistics Research. 2013. Available: http://www.mext.go.jp/b_menu/toukei/chousa05/hoken/1268826.htm. Japanese. (accessed 17 Dec 2015)

16. Ministry of Communications and Internal Affairs of Japan. Statistics Act (English version). 2007. Available: http://www.japaneselawtranslation.go.jp/law/detail/?id=148&vm=02&re=01&new=1 (accessed 17 Dec 2015)

17. Asayama K, Ozeki T, Sugihara S, et al. Criteria for medical intervention in obese children: a new definition of 'obesity disease' in Japanese children. *Pediatr Int* 2003;45:642–6.

18. The Japanese Society for Pediatric Endocrinology. Obesity in Japanese children. 2015. Available: http://jspe.umin.jp/public/himan.html. Japanese. (accessed 17 Dec 2015)

19. Cole TJ, Bellizzi MC, Flegal KM, et al. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;320:1240.

20. WHO Multicentre Growth Reference Study Group. WHO child growth standards based on length/height, weight and age. *Acta Pædiatr* 2006;95:76–85.

21. Hagan JF. Psychosocial implications of disaster or terrorism on children: a guide for the pediatrician. *Pediatrics* 2005;116:787–95.

22. Tsuboyama-Kasaoka N, Hoshi Y, Onodera K, et al. What factors were important for dietary improvement in emergency shelters after the great east Japan earthquake? *Asia Pac J Clin Nutr* 2014;23:159.

23. Sakamoto M. The rise of NGOs/NPOs in emergency relief in the great east Japan earthquake. *Jpn Soc Innov J* 2012;2:26–35.

Yokomichi H et al.

461 24. Tsuboyama-Kasaoka N, Purba MB. Nutrition and earthquakes: experience and
462 recommendations. *Asia Pac J Clin Nutr* 2014;23:505.

463 25. Minisry of Education, Culture, Sports, Science and Technology of Japan. The tentative
464 way of thinking for judgement about availability of school buildings and playgrounds in
465 Fukushima Prefecture. 2011. Available:
466 http://www.mext.go.jp/a_menu/saigaijohou/syousai/1305173.htm. Japanese. (accessed 17
467 Dec 2015)

468 26. Zhou Y. How will the 3.11 earthquake transform the population and labor market in Iwate,
469 Miyagi and Fukushima?: knowledge gained from existing studies of disasters. *Jpn Labor*
470 *Rev* 2012;9:64–85.

471 27. National Institute for Resarch Advancement. Recovery and reconstruction indexes from
472 the great east Japan earthquake: current status and issues of 3 affected prefectures. 2013.
473 Available: http://www.nira.or.jp/pdf/1301report.pdf. Japanese. (accessed 17 Dec 2015)

474 28. Ogawa S, Ishiki M, Nako K, et al. Effects of the great east Japan earthquake and huge
475 tsunami on glycaemic control and blood pressure in patients with diabetes mellitus. *BMJ*
476 *Open* 2012;2:e000830.

477 29. Kario K, McEwen BS, Pickering TG. Disasters and the heart: a review of the effects of
478 earthquake-induced stress on cardiovascular disease. *Hypertens Res* 2003;26:355–67.

479 30. Fonseca VA, Smith H, Kuhadiya N, et al. Impact of a natural disaster on diabetes
480 exacerbation of disparities and long-term consequences. *Diabetes Care* 2009;32:1632–8.

481 31. Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after
482 disasters. *Epidemiol Rev* 2005;27:78–91.

483 32. 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.

486 33. Konno S, Hozawa A, Munakata M. Blood pressure among public employees after the great east Japan earthquake: the Watari study. *Am J Hypertens* 2013:hpt065.

488 34. Kirizuka K, Nishizaki H, Kohriyama K, et al. Influences of the great Hanshin-Awaji earthquake on glycemic control in diabetic patients. *Diabetes Res Clin Prac* 1997;36:193–6.

491 35. Azuma T, Seki N, Tanabe N, et al. Prolonged effects of participation in disaster relief operations after the Mid-Niigata earthquake on increased cardiovascular risk among local governmental staff. *J Hypertens* 2010;28:695–702.

494 36. Liao S-C, Lee M-B, Lee Y-J, et al. Hyperleptinemia in subjects with persistent partial posttraumatic stress disorder after a major earthquake. *Psychosom Med* 2004;66:23–8.

496 37. Ahima RS, Prabakaran D, Mantzoros C, et al. Role of leptin in the neuroendocrine response to fasting. *Nature* 1996;382:250–2.

498 38. Dickerson SS, Kemeny ME. Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psychol Bull* 2004;130:355.

500 39. 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.

40. Whitaker RC, Pepe MS, Wright JA, et al. Early adiposity rebound and the risk of adult obesity. *Pediatrics* 1998;101:e5.

41. Rolland-Cachera M-F, Deheeger M, Bellisle F, et al. Adiposity rebound in children: a simple indicator for predicting obesity. *Am J Clin Nutr* 1984;39:129–35.

42. Eriksson JG, Forsen T, Tuomilehto J, et al. Early adiposity rebound in childhood and risk of type 2 diabetes in adult life. *Diabetologia* 2003;46:190–4.

43. Rolland-Cachera M. Obesity among adolescents: evidence for the importance of early nutrition. *Hum Growth Context* 1999:245–58.

44. Rolland-Cachera M, Deheeger M, Maillot M, et al. Early adiposity rebound: causes and consequences for obesity in children and adults. *Int J Obes* 2006;30:S11–S17.

45. Lumeng JC, Taveras EM, Birch L, et al. Prevention of obesity in infancy and early childhood: a national institutes of health workshop. *JAMA Pediatr* 2015;169:484–90.

46. Dunton G, McConnell R, Jerrett M, et al. Organized physical activity in young school children and subsequent 4-year change in body mass index. *Arch Pediatr Adolesc Med* 2012;166:713–8.

47. Shashaj B, Bedogni G, Graziani MP, et al. Origin of cardiovascular risk in overweight preschool children: a cohort study of cardiometabolic risk factors at the onset of obesity. *JAMA Pediatr* 2014;168:917–24.

48. Pervanidou P, Chrousos GP. Stress and obesity/metabolic syndrome in childhood and adolescence. *Int J Pediatr Obes* 2011;6:21–8.

Yokomichi H et al.

49. Homma N, Tateyama C. Regional characteristics from the family income and expdenditure survey of Japan: confirmation from 2006 investigation. *Bull Soc Life Cult Niigata* 2009;15:7–14. Japanese.

50. Onis Md, Onyango AW, Borghi E, et al. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007;85:660–7.

51. Cole TJ. The LMS method for constructing normalized growth standards. *Eur J Clin Nutr* 1990;44:45–60.

52. Kato N, Takimoto H, Sudo N. The cubic functions for spline smoothed L, S and M values for BMI reference data of Japanese children. *Clin Pediatr Endocrinol* 2011;20:47.

53. Suzuki Y, Kim Y. The great east Japan earthquake in 2011; toward sustainable mental health care system. *Epidemiol Psychiatr Sci* 2012;21:7–11.

54. Ramos M, Orozovich P, Moser K, et al. Health of resettled Iraqi refugees—San Diego County, California, October 2007–September 2009. *JAMA* 2011;305:459–61.

55. Al-Jawadi AA, Abdul-Rhman S. Prevalence of childhood and early adolescence mental disorders among children attending primary health care centers in Mosul, Iraq: a cross-sectional study. *BMC Public Health* 2007;7:274.

Figure Legends

Figure 1 Affected and unaffected areas in northeast Japan.

Figure 2 Mean body mass indices (BMIs) of nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan.

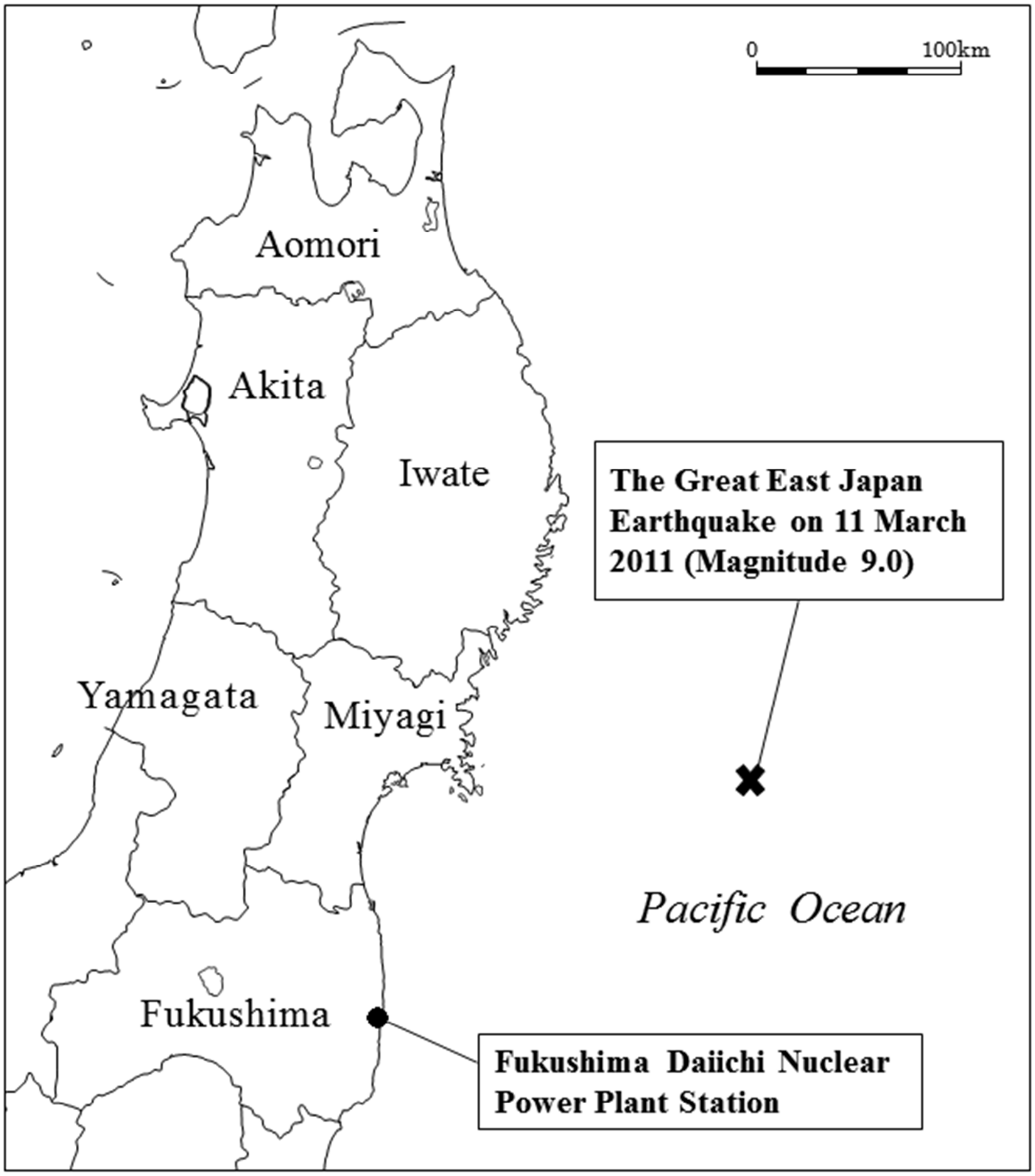
Figure 3 Estimated changes in body mass index (BMI) after October 2010 among nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan. Statistical tests evaluated the P values of the interaction terms in the model. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

Figure 4 Prevalence of overweight children in Fukushima, Miyagi and Iwate Prefectures and throughout Japan in 2010 versus 2012 from the School Health Statistics Research of Japan. The term 'overweight' was defined as weighing 20% or more than standard weight in accordance with the guidelines of The Japanese Society for Pediatric Endocrinology.

Yokomichi H et al.

556 **Figures**

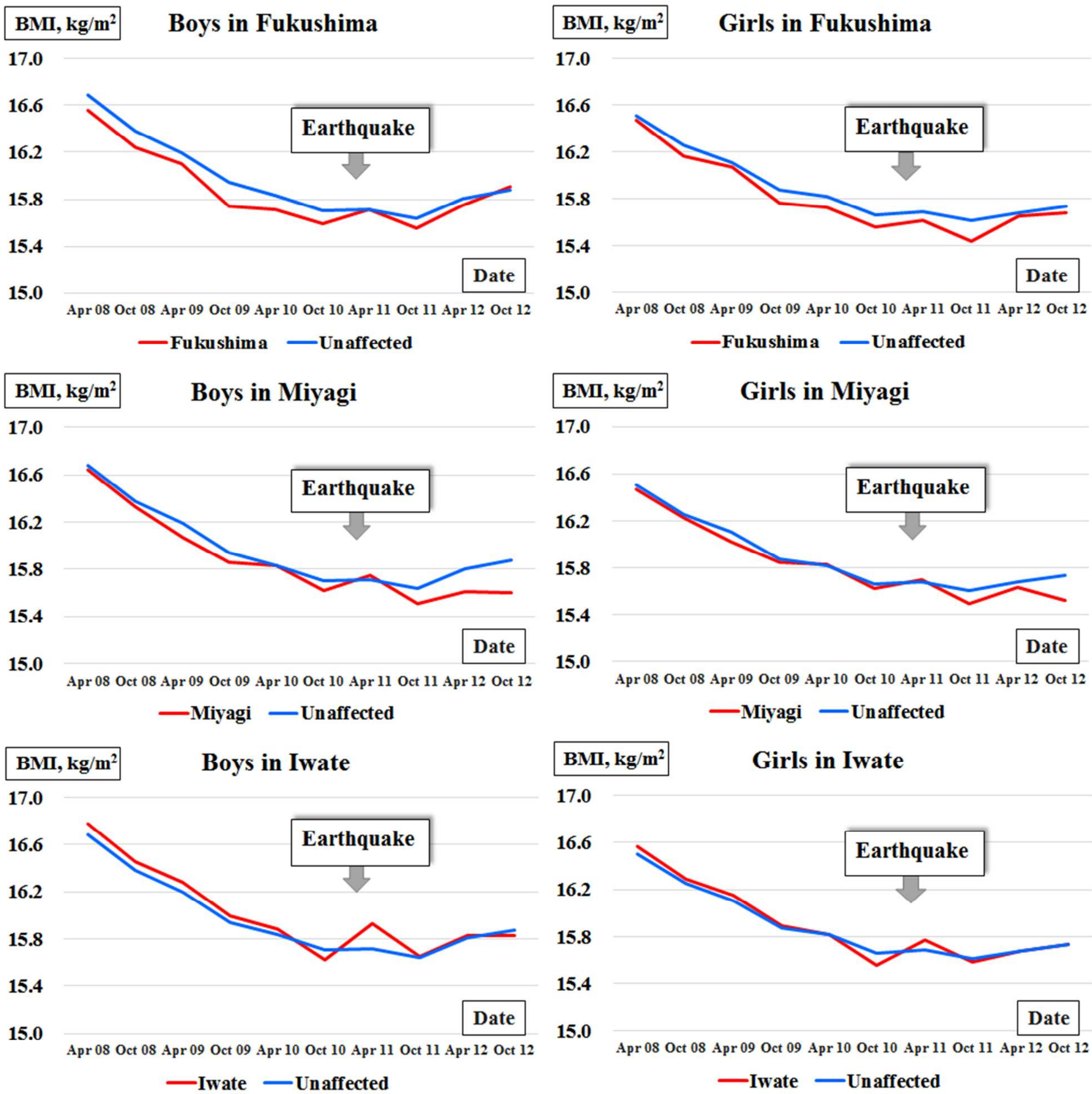
557 **Figure 1** Affected and unaffected areas in northeast Japan.



558

Yokomichi H et al.

Figure 2 Mean body mass indices (BMIs) of nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan.



Yokomichi H et al.

Figure 3 Estimated changes in body mass index (diff BMI) after October 2010 among nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan. Statistical tests evaluated the *P* values of the interaction terms in the model. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

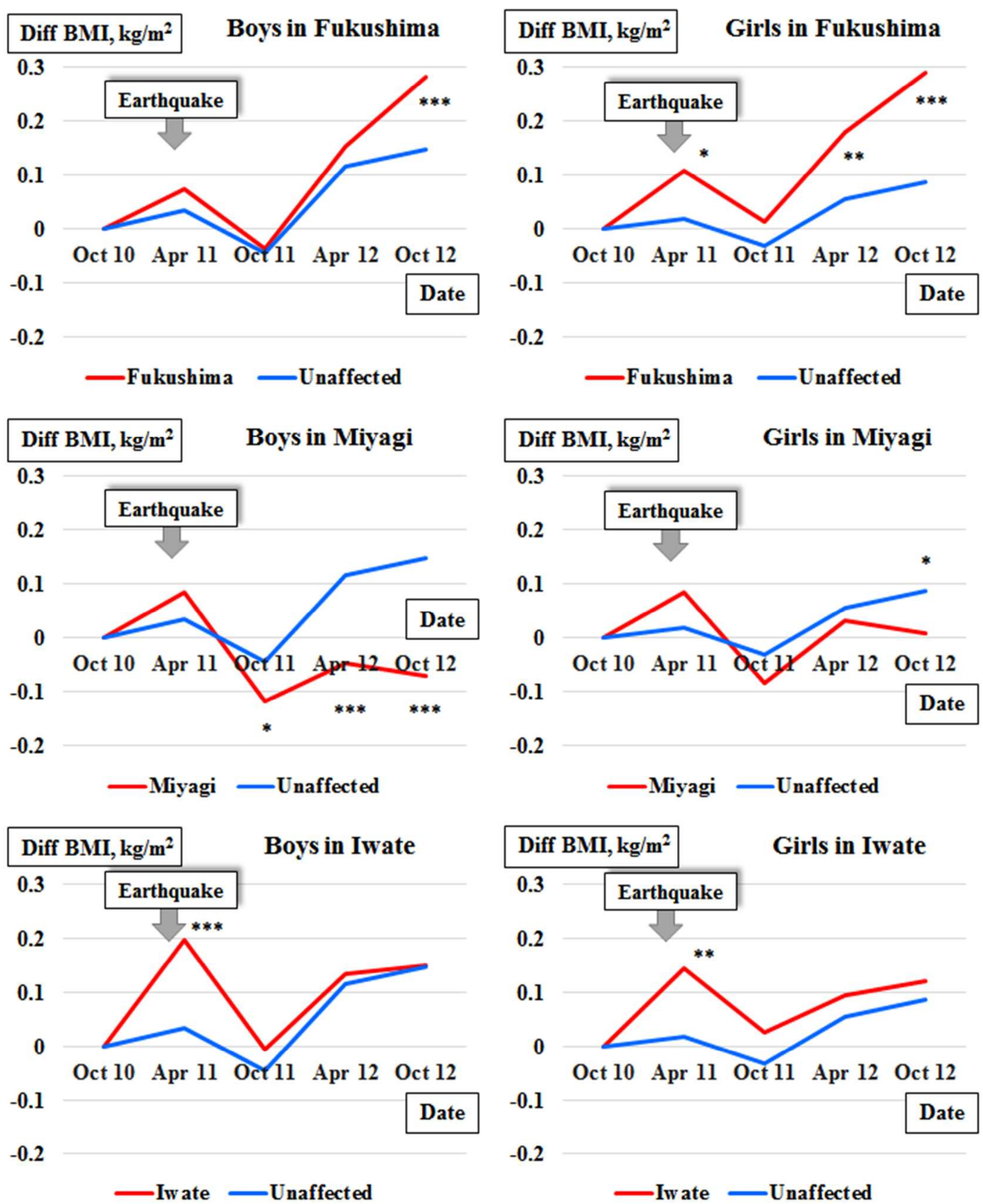
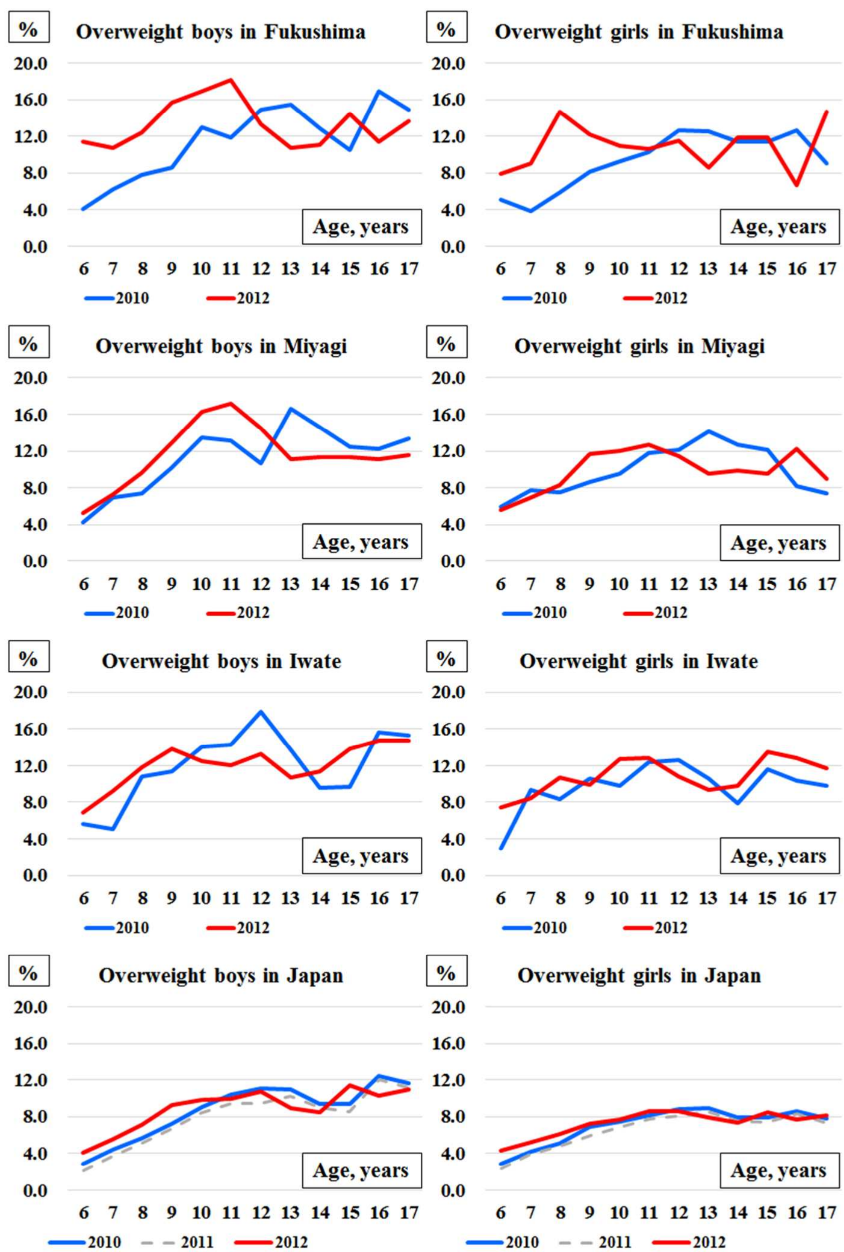
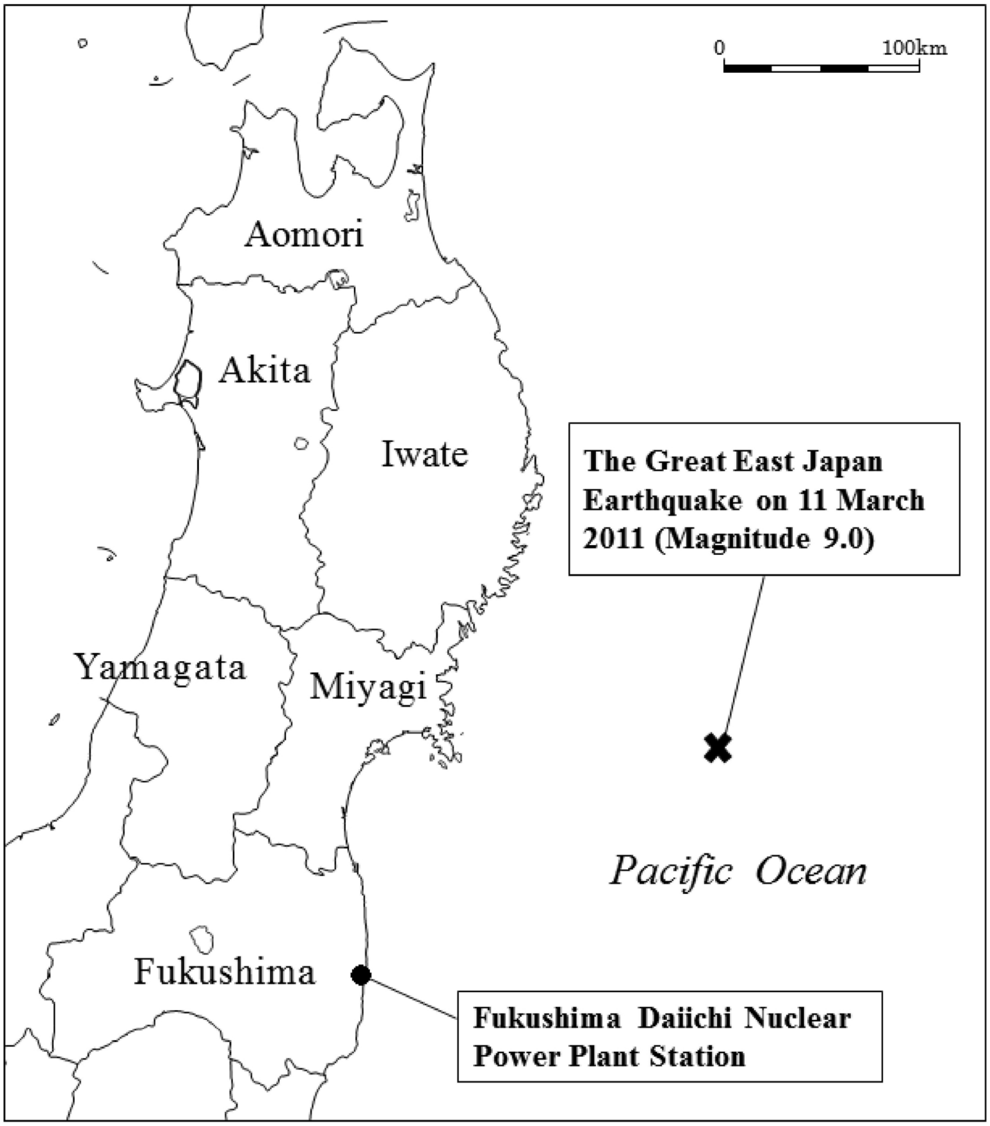
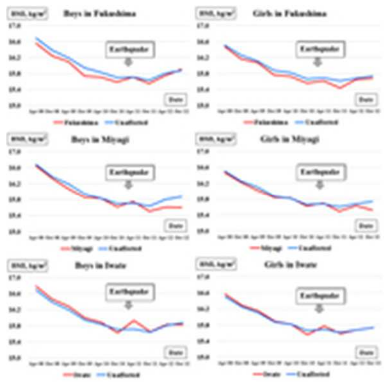


Figure 4 Prevalence of overweight children in Fukushima, Miyagi and Iwate Prefectures and throughout Japan in 2010 versus 2012 from the School Health Statistics Research of Japan. The term ‘overweight’ was defined as weighing 20% or more than standard weight in accordance with the guidelines of The Japanese Society for Pediatric Endocrinology.

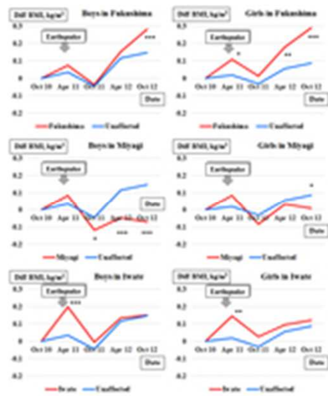




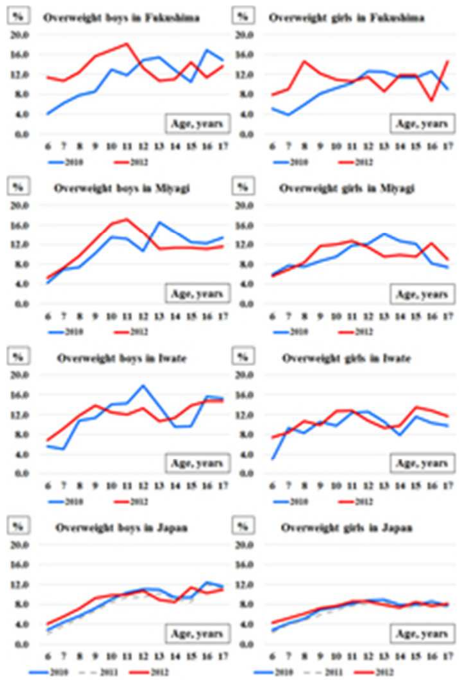
Affected and unaffected areas in northeast Japan.
185x210mm (300 x 300 DPI)



Mean body mass indices (BMIs) of nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan.
8x8mm (600 x 600 DPI)



Estimated changes in body mass index (diff BMI) after October 2010 among nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan. Statistical tests evaluated the P values of the interaction terms in the model. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.
6x8mm (600 x 600 DPI)



Prevalence of overweight children in Fukushima, Miyagi and Iwate Prefectures and throughout Japan in 2010 versus 2012 from the School Health Statistics Research of Japan. The term 'overweight' was defined as weighing 20% or more than standard weight in accordance with the guidelines of The Japanese Society for Pediatric Endocrinology.
9x14mm (600 x 600 DPI)

Supplementary

Supplementary Table 1 Estimated mean body mass indices for children residing in the affected Fukushima, Miyagi and Iwate Prefectures and in unaffected areas also located in northeast Japan

Time point	Boys: Fukushima (n = 646)	Boys: Miyagi (n = 904)	Boys: Iwate (n = 483)	Boys: Unaffected* (n = 1707)	Girls: Fukushima (n = 597)	Girls: Miyagi (n = 854)	Girls: Iwate (n = 458)	Girls: Unaffected* (n = 1658)
April 2008	16.34	16.45	16.43	16.38	16.21	16.33	16.26	16.38
October 2008	16.08	16.17	16.23	16.14	15.97	16.12	16.11	16.14
April 2009	15.97	15.99	16.05	16.00	15.96	15.90	15.95	16.00
October 2009	15.73	15.83	15.85	15.83	15.78	15.79	15.79	15.83
April 2010	15.73	15.81	15.76	15.78	15.73	15.76	15.73	15.78
October 2010	15.63	15.65	15.57	15.64	15.66	15.62	15.56	15.64
April 2011	15.73	15.74	15.75	15.64	15.74	15.70	15.69	15.64
October 2011	15.63	15.54	15.59	15.56	15.61	15.52	15.58	15.56
April 2012	15.78	15.61	15.70	15.71	15.82	15.61	15.61	15.71
October 2012	15.88	15.62	15.74	15.73	15.91	15.59	15.64	15.73

All values are reported as kg/m^2.

2

*Unaffected refers to three unaffected prefectures of northeast Japan (Yamagata, Akita and Aomori).

Supplementary Table 2 Estimated changes in mean body mass index of preschool children after the Great East Japan Earthquake in the affected (Fukushima, Miyagi and Iwate) prefectures and unaffected prefectures in northeast Japan

Time point	**Affected prefecture**	**Unaffected areas***	**Interaction term vs. unaffected areas***	***P* value for interaction term**
Fukushima, boys (n = 646)				
October 2010	0	0	0	—
April 2011	+0.074	+0.036	+0.040	0.29
October 2011	−0.035	−0.043	+0.011	0.78
April 2012	+0.154	+0.116	+0.041	0.28
October 2012	+0.282	+0.148	+0.137	0.0003
Fukushima, girls (n = 597)				
October 2010	0	0	0	—
April 2011	+0.110	+0.021	+0.087	0.02
October 2011	+0.014	-0.030	+0.042	0.27
April 2012	+0.180	+0.056	+0.122	0.0013

4

October 2012	+0.290	+0.088	+0.200	<0.0001
Miyagi, boys (n = 904)				
October 2010	0	0	0	—
April 2011	+0.086	+0.036	+0.048	0.14
October 2011	–0.117	–0.043	–0.076	0.02
April 2012	–0.047	+0.116	–0.165	<0.0001
October 2012	–0.069	+0.148	–0.218	<0.0001
Miyagi, girls (n = 854)				
October 2010	0	0	0	—
April 2011	+0.085	+0.021	+0.061	0.06
October 2011	–0.084	–0.030	–0.057	0.08
April 2012	+0.033	+0.056	–0.026	0.42
October 2012	+0.009	+0.088	–0.082	0.011
Iwate, boys (n = 483)				
October 2010	0	0	0	—
April 2011	+0.200	+0.036	+0.165	<0.0001
October 2011	–0.004	–0.043	+0.040	0.32
April 2012	+0.135	+0.116	+0.020	0.62

5

October 2012	+0.152	+0.148	+0.006	0.88
Iwate, girls (n = 458)				
October 2010	0	0	0	—
April 2011	+0.146	+0.021	+0.124	0.002
October 2011	+0.028	−0.030	+0.057	0.15
April 2012	+0.095	+0.056	+0.038	0.33
October 2012	+0.123	+0.088	+0.034	0.40

All values are reported as kg/m^2.

*Unaffected refers to Yamagata, Akita and Aomori Prefectures in northeast Japan.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3	Line 39
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3	Line 37–59
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6	Line 77–86
Objectives	3	State specific objectives, including any prespecified hypotheses	6	Line 86–89
Methods				
Study design	4	Present key elements of study design early in the paper	8	Line 121–123
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6–7	Line 93–96, 113–117
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7	Line 96–99
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case		NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8	Line 126–130
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8	Line 123–126
Bias	9	Describe any efforts to address potential sources of bias	8	Line 129–130
Study size	10	Explain how the study size was arrived at	9–10	Line 162–166, 177–183

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8	Line 123–126
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8, 17	Line 126–140, 339–344
		(*b*) Describe any methods used to examine subgroups and interactions	8	Line 132–139
		(*c*) Explain how missing data were addressed	7	Line 107–110
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		NA
		(*e*) Describe any sensitivity analyses		NA
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9–10	Line 162–166, 177–183
		(b) Give reasons for non-participation at each stage	6–7	Line 93–96
		(c) Consider use of a flow diagram		NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11	Table 1
		(b) Indicate number of participants with missing data for each variable of interest		NA
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	8	Line 123–126
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Supplementary	Supplementary Table 1
		Case-control study—Report numbers in each exposure category, or summary measures of exposure		NA
		Cross-sectional study—Report numbers of outcome events or summary measures		NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11–12	Line 199–209
		(*b*) Report category boundaries when continuous variables were categorized	28 (Figure 4, legend)	Line 553–554
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful		

		time period		NA
Continued on next page Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		NA
Discussion				
Key results	18	Summarise key results with reference to study objectives	12–13	Line 226–239
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17–18	Line 328–354
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	15	Line 278–300
Generalisability	21	Discuss the generalisability (external validity) of the study results	17–18	Line 344–354
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20	Line 390–395

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Impact of the great east Japan earthquake on the body mass index of preschool children: a nationwide nursery school survey

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2015-010978.R1
Article Type:	Research
Date Submitted by the Author:	08-Mar-2016
Complete List of Authors:	Yokomichi, Hiroshi; University of Yamanashi, Department of Health Sciences Zheng, Wei; Peking University, Department of Social Medicine and Health Education Matsubara, Hiroko; Tohoku University, Department of Disaster Public Health Ishikuro, Mami; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Kikuya, Masahiro; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Isojima, Tsuyoshi; The University of Tokyo, Department of Pediatrics Yokoya, Susumu; National Center for Child Health and Development, Center for Clinical Research Data Tanaka, Toshiaki; Japanese Association for Human Auxology Kato, Noriko; National Institute of Public Health of Japan, Department of Health Promotion Chida, Shoichi; Iwate Medical University, Department of Pediatrics Ono, Atsushi; Fukushima Medical University, Department of Pediatrics Hosoya, Mitsuaki; Fukushima Medical University, Department of Pediatrics Tanaka, Soichiro; Tohoku University, Department of Pediatrics Kuriyama, Shinichi; Tohoku University, Department of Disaster Public Health; Tohoku Medical Megabank Organization, Department of Preventive Medicine and Epidemiology Kure, Shigeo; Tohoku University, Department of Pediatrics Yamagata, Zentaro; University of Yamanashi, Department of Health Sciences
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Paediatrics, Emergency medicine, Nutrition and metabolism, Diabetes and endocrinology, Public health
Keywords:	body mass index, earthquake, Fukushima nuclear accident, preschool child, growth

Impact of the great east Japan earthquake on the body mass index of preschool children: a nationwide nursery school survey

Hiroshi Yokomichi[1], Wei Zheng[2], Hiroko Matsubara[3], Mami Ishikuro[4], Masahiro Kikuya[4], Tsuyoshi Isojima[5], Susumu Yokoya[6], Toshiaki Tanaka[7], Noriko Kato[8], Shoichi Chida[9], Atsushi Ono[10], Mitsuaki Hosoya[10], Soichiro Tanaka[11], Shinichi Kuriyama[3,4], Shigeo Kure[11] and Zentaro Yamagata[1]

[1]Department of Health Sciences, University of Yamanashi, Yamanashi, Japan

[2]Department of Social Medicine and Health Education, Peking University, Beijing, China

[3]Department of Disaster Public Health, International Research Institute of Disaster Science, Tohoku University, Miyagi, Japan

[4]Department of Preventive Medicine and Epidemiology, Tohoku Medical Megabank Organization, Miyagi, Japan

[5]Department of Pediatrics, The University of Tokyo, Tokyo, Japan

[6]Center for Clinical Research Data, National Center for Child Health and Development, Tokyo, Japan

[7]Japanese Association for Human Auxology, Tokyo, Japan

[8]Department of Health Promotion, National Institute of Public Health of Japan, Saitama, Japan

[9]Department of Pediatrics, Iwate Medical University, Iwate, Japan

[10]Department of Pediatrics, Fukushima Medical University, Fukushima, Japan

[11]Department of Pediatrics, Tohoku University, Miyagi, Japan

Corresponding author:

Hiroshi Yokomichi

1110 Shimokato, Chuo City, Yamanashi, 4093898, Japan

E-mail: hyokomichi@yamanashi.ac.jp

Tel: +81-(0)55-273-9566

Keywords: body mass index; earthquake; Fukushima nuclear accident; preschool child; growth

Word count: 4203

ABSTRACT

Objective: To evaluate the impact of the 2011 great east Japan earthquake on body mass index (BMI) of preschool children.

Design: Retrospective cohort study and ecological study.

Setting: Affected prefectures (Fukushima, Miyagi and Iwate) and unaffected prefectures in northeast Japan.

Participants: The cohort study assessed 2033 and 1707 boys and 1909 and 1658 girls in three affected prefectures and unaffected prefectures, respectively, all aged 3–4 years at the time of the earthquake. The ecological study examined random samples of school children from the affected prefectures.

Primary and secondary outcome measures: The cohort study compared post-disaster changes in BMIs and the prevalence of overweight and obese children. The ecological study evaluated post-disaster changes in the prevalence of overweight children.

Results: One month after the earthquake, significantly increased BMIs were observed among girls (+0.087 kg/m^2 vs. unaffected prefectures) in Fukushima and boys and girls (+0.165 kg/m^2 and +0.124 kg/m^2, respectively vs. unaffected prefectures) in Iwate. Nineteen months after the earthquake, significantly increased BMIs were detected among boys and girls (+0.137 kg/m^2 and +0.200 kg/m^2, respectively vs. unaffected prefectures) in Fukushima, whereas significantly decreased BMIs were observed among boys and girls (−0.218 kg/m^2 and −0.082 kg/m^2, respectively vs. unaffected prefectures) in Miyagi. One month after the earthquake, Fukushima, Miyagi and Iwate had slightly increased prevalence of overweight boys, whereas Fukushima had slightly decreased prevalence of overweight girls, compared with the unaffected prefectures. The ecological study detected increases in the prevalence of overweight boys and girls in Fukushima who were 6–11 and 6–10 years of age, respectively.

Conclusion: These results suggest that in the affected prefectures, preschool children gained weight immediately after the earthquake. The long term impact of the earthquake on early childhood growth was more variable among the affected prefectures, possibly as a result of different speeds of recovery.

Word count: 297 words

Strengths and limitations of this study

- The study analysed a unique dataset on child body mass index before and after a disaster.
- The study establishes a reference group for comparison as children mature.
- The study data were limited to nursery school records.
- The cohort of affected participants did not include those who died or relocated.
- The information on previous diets and physical activities was lacking.

INTRODUCTION

The great east Japan earthquake of 2011, with a magnitude of 9.0,[1] was the fourth largest earthquake ever recorded and the largest in Japan.[2] This earthquake together with the subsequent tsunami[3] and the nuclear power plant accident in Fukushima[4] caused immense damage to the Pacific coast of northeast Japan.[5] The disaster resulted in a significant human and property toll: 19,466 people were killed, 6,152 were injured, 124,663 houses were destroyed and 274,638 homes were damaged.[6] The tragedy also affected daily life in the region, disrupting the normal eating and exercise habits of the inhabitants of Fukushima, Miyagi and Iwate prefectures (Figure 1).[7] Experts in child growth have been very concerned about the short- and long-term detrimental health effects of the earthquake and associated events on young children.[8, 9] In particular, schoolteachers and local paediatricians have focused on assessing potential weight gain among the children because the affected children mainly consumed high-carbohydrate diets after the earthquake and were not allowed to play outdoors to avoid exposure to radiation from the damaged nuclear power plant.[10] Despite this warning about potential child obesity, there have been no reliable analyses on children's body weight since the earthquake. In addition, to the best of our knowledge, no study has investigated weight changes among resident children affected by other large natural disasters. The present study was driven by the question of whether the body mass indices (BMIs) of the children in each affected prefecture had changed relative to the BMIs of comparable but unaffected children. Furthermore, this report compared the prevalence of overweight and obese children between affected and unaffected areas in a cohort and an ecological designs.

METHODS

Study participants and measurements

On 27 August 2012, the Ministry of Health, Labour and Welfare of Japan sent a letter to nursery schools across Japan (some of which were undestroyed and still in operation in affected prefectures) through domestic administrators requesting the recipients' participation in the Nationwide Nursery School Survey on Child Health.[11] Nursery school records on student height and weight in the affected and unaffected prefectures of northeast Japan were collected for the participating children born between 2 April 2006 and 1 April 2007 (Japanese fiscal year 2006). Thus, the children evaluated were 4–5 years old during the month of the first primary outcome evaluation (April 2011) and were 6–7 years old when data collection was completed in 2013. Participating children were weighed in their underwear and without shoes. Measurements were based on weight scales and stadiometres, which are legally required equipment at all Japanese nursery schools and kindergartens that undergo half-yearly standardisation by certified measurers.[12] The children were biannually assessed in April and October, and the nursery schoolteachers mailed the records on each child's height and weight to Tohoku University. Accordingly, we defined the half-yearly time points as every April and October from 2008 to 2012. The study participants were children who attended nursery schools that responded to the letter of request. Missing data included that for children who did not attend the participating nursery schools, moved out of the prefectures or died. Because there are no published data of year 2011 for the exact number of the children born in fiscal year 2006 in each prefecture, the approximate proportion of participants among the resident children was calculated according to the number of the first grade primary school students in fiscal year 2012.[13]

Comparison of BMI changes

First, to gain an overview of the trends in children's BMIs, we represented the mean BMIs of children living in the affected prefectures facing the Pacific Ocean (i.e. Fukushima, Miyagi

Yokomichi H et al.

and Iwate prefectures) and then separately the children living on the other side of northeast Japan in unaffected prefectures (i.e. Yamagata, Akita and Aomori prefectures) according to a fixed-effects model that estimates chronological means.[14, 15] For the representations, we separately generated 4 models with an explanatory variable of the time points for the three affected prefectures and the pooled unaffected prefectures. According to the estimated coefficients, we graphically plotted the mean BMIs for the affected prefectures and the unaffected prefectures. Second, for the primary comparisons of interest using a retrospective cohort design, we compared the BMI changes among the children from affected versus unaffected prefectures. Because of the difficulty in comparing BMIs of growing children between different areas, the BMI changes after the earthquake were evaluated from a reference baseline time point of October 2010, the last measured time point prior to the date of the earthquake (11 March 2011), through April 2011, October 2011, April 2012 and October 2012. We compared the BMI changes of children in each affected prefecture with those in the unaffected prefectures using a repeated-measures ANOVA model for mean changes from baseline[16] (diff BMI) for a difference-in-difference analysis of longitudinal data.[15] A binary explanatory variable was set for whether children lived in an affected or unaffected area, and the analyses were adjusted using a covariate of age in month. The following fixed-effects model was employed:

$$\mathit{diff\ BMI}_{ijk} = (\text{Time point})_i + (\text{Time point*Area group})_{ij} + (\text{Age in month})_k + \varepsilon_{ijk}$$

$$\varepsilon_{ijk} \sim N(0, \sigma^2)$$

where i represents index time points of October 2010, April 2011, October 2011, April 2012 or October 2012; j represents indices for each affected prefecture or unaffected area; and k represents indices for individuals. $(\text{Time point})_i$ equals zero when i equals October 2010 (the reference baseline time point). $(\text{Time point*Area group})_{ij}$ represents for an interaction term between $(\text{Time point})_i$ and $(\text{Area group})_j$, and equals zero at any time points when j equals unaffected area. (Age in month)$_k$ is a covariate of adjustment for child age. ε_{ijk} represents the random effect of the error term in the model.

Consequently, we applied three models for comparison of BMI changes within the three affected prefectures with a single reference for the unaffected prefectures. According to the coefficients in the model, we also graphically plotted the BMI changes and then statistically evaluated the differences in BMI change between each affected prefecture and the unaffected prefectures with the statistical significance of the interaction term. All statistical analyses were performed with sex stratification using SAS statistical software (version 9.4, SAS Institute, Cary, NC, USA). Descriptive statistics are reported as means and standard deviations (SDs)/standard errors (SEs). All reported P values are from 2-sided analyses, with P values <0.05 considered statistically significant.

Comparison in the prevalence of overweight and obese children

For the secondary comparisons, the prevalence of overweight and obese children was compared between the affected and unaffected prefectures from October 2010 to 2011. Overweight and obesity were diagnosed according to the child growth standards of the World Health Organization.[17] Because these diagnostic standards essentially change when children reach the age of 61 months, these secondary outcome comparisons were restricted to the data until October 2011 when almost half of the children were 60 months of age or younger. Although the difference in the changes in prevalence (i.e. proportions) between affected and unaffected prefectures is of interest, there is no published statistical test for such difference-in-difference analysis in proportional data. Instead, we applied Fisher's exact test to evaluate the difference in the prevalence of overweight and obese children between affected and unaffected prefectures, which were stratified according to date.

172 In addition, for an ecological study design, the prevalence of overweight boys and girls in the affected prefectures and throughout Japan were assessed for 6–17-year-old children attending primary, junior high and high schools using the descriptive data provided through the School Health Statistics Research of Japan.[18] The investigation by the School Health Statistics Research, which selects examined schools in a stratified random sampling under Japanese law,[19] is conducted annually from April to June. Because of widespread school dysfunction immediately after the disaster in March 2011, the examination could not be conducted in the three affected prefectures in 2011. Therefore, we compared the prevalence of overweight children from the 2012 examination with the prevalence from the 2010 examination for the three prefectures and across Japan to determine whether or not the prevalence had increased after the earthquake. The sources for nation-wide data comprised 4.8% of all Japanese schoolchildren in 2010 and 4.9% in 2012. In both 2010 and 2012, 270,720 primary school children aged 6−11 years, 225,600 junior high school students aged 12−14 years and 126,900 high school students aged 15−17 years were included. With these data, the definition of being overweight was weighing 20% or greater than a standard weight, where percent overweight = (measured weight − standard weight) × 100/standard weight for each given age, sex and height in accordance with the guidelines of The Japanese Society for Pediatric Endocrinology.[20, 21]

RESULTS

Comparison of BMI changes

The data for the affected children on approximately 8.8% of resident children were collected from 646 boys and 597 girls who attended 97 nursery schools in Fukushima, 904 boys and 854 girls from 132 nursery schools in Miyagi and 483 boys and 458 girls from 81 nursery schools in Iwate. The data for the unaffected children on approximately 12.3% of resident

197 children were collected from 307 boys and 285 girls attending 42 nursery schools in Yamagata, 762 boys and 739 girls from 88 nursery schools in Akita and 638 boys and 634 girls from 108 nursery schools in Aomori.

Table 1 shows the baseline anthropometrics in October 2010. Figure 2 and Supplementary Table 1 present the estimated BMIs from April 2008 to October 2012 graphically and numerically, respectively. For the primary comparisons, Figure 3 and Table 2 illustrate the estimated changes in BMI from October 2010 to October 2012 graphically and numerically, respectively, for children residing in each affected prefecture in comparison with those residing in the unaffected prefectures.

Table 1 Baseline characteristics of participating boys and girls in October 2010 in northeast Japan

Anthropometric measurements	Affected prefectures		Unaffected prefectures	
	Boys (n = 2033)	Girls (n = 1909)	Boys (n = 1707)	Girls (n = 1658)
Age, years	4.1 (0.3)	4.1 (0.3)	4.1 (0.3)	4.1 (0.3)
Height, cm	100.6 (4.3)	99.6 (4.1)	100.8 (4.2)	100.0 (4.2)
Weight, kg	15.9 (2.0)	15.5 (1.9)	16.0 (1.9)	15.6 (2.0)
Body mass index, kg/m^2	15.7 (1.2)	15.6 (1.3)	15.6 (1.2)	15.6 (1.3)

All values are presented as mean (standard deviation).

Table 2 Estimated changes in mean body mass index of preschool children after the great east Japan earthquake in the affected (Fukushima, Miyagi and Iwate) prefectures and unaffected

Yokomichi H et al.

214 prefectures in northeast Japan

Time point	Affected prefecture	Unaffected areas*	Interaction term vs. unaffected areas*	*P* value for interaction term
Fukushima, boys (n = 646)				
October 2010	0	0	0	—
April 2011	+0.074	+0.036	+0.040	0.29
October 2011	−0.035	−0.043	+0.011	0.78
April 2012	+0.154	+0.116	+0.041	0.28
October 2012	+0.282	+0.148	+0.137	0.0003
Fukushima, girls (n = 597)				
October 2010	0	0	0	—
April 2011	+0.110	+0.021	+0.087	0.023
October 2011	+0.014	-0.030	+0.042	0.27
April 2012	+0.180	+0.056	+0.122	0.0013
October 2012	+0.290	+0.088	+0.200	<0.0001
Miyagi, boys (n = 904)				
October 2010	0	0	0	—
April 2011	+0.086	+0.036	+0.048	0.14
October 2011	−0.117	−0.043	−0.076	0.018
April 2012	−0.047	+0.116	−0.165	<0.0001
October 2012	−0.069	+0.148	−0.218	<0.0001
Miyagi, girls (n = 854)				
October 2010	0	0	0	—

April 2011	+0.085	+0.021	+0.061	0.057
October 2011	−0.084	−0.030	−0.057	0.077
April 2012	+0.033	+0.056	−0.026	0.42
October 2012	+0.009	+0.088	−0.082	0.011
Iwate, boys (n = 483)				
October 2010	0	0	0	—
April 2011	+0.200	+0.036	+0.165	<0.0001
October 2011	−0.004	−0.043	+0.040	0.32
April 2012	+0.135	+0.116	+0.020	0.62
October 2012	+0.152	+0.148	+0.006	0.88
Iwate, girls (n = 458)				
October 2010	0	0	0	—
April 2011	+0.146	+0.021	+0.124	0.0019
October 2011	+0.028	−0.030	+0.057	0.15
April 2012	+0.095	+0.056	+0.038	0.33
October 2012	+0.123	+0.088	+0.034	0.40

All values are reported as kg/m^2.

*Unaffected refers to Yamagata, Akita and Aomori prefectures in northeast Japan.

Compared to the unaffected prefectures, the observed change in BMI in Fukushima prefecture was significantly higher among boys in October 2012 (+0.137 kg/m^2, P=0.0003) and among girls in April 2011 (+0.087 kg/m^2, P=0.023), April 2012 (+0.122 kg/m^2, P=0.0013) and October 2012 (+0.200 kg/m^2, P<0.0001).

Compared to the unaffected prefectures, the observed change in BMI in Miyagi prefecture was significantly lower among boys in October 2011 (−0.076 kg/m^2, P=0.018), April 2012 (−0.165 kg/m^2, P<0.0001) and October 2012 (−0.218 kg/m^2, P<0.0001) and among girls in October 2012 (−0.082 kg/m^2, P=0.011).

Compared to the unaffected prefectures, the observed change in BMI in Iwate prefecture was significantly higher among boys in April 2011 (+0.165 kg/m^2, P<0.0001) and among girls in April 2011 (+0.124 kg/m^2, P=0.0019).

Comparison of the prevalence of overweight and obese children

Figure 4 shows the secondary comparisons of the prevalence of overweight and obese children in Fukushima, Miyagi and Iwate prefectures with the pooled population of the unaffected prefectures. Compared with the unaffected prefectures, there was a slight increase in the changes of the prevalence of overweight boys between October 2010 and April 2011 residing in Fukushima, Miyagi and Iwate. In contrast, there was a slight decrease in the change of the prevalence of overweight girls residing in Fukushima. Compared with the unaffected prefectures, a slight increase in the changes of the prevalence of obese individuals between October 2010 and April 2011 was observed among boys in Iwate and among girls in Fukushima, Miyagi and Iwate. In contrast, a slight decrease in the change of the prevalence of obese boys was observed in Miyagi. The ecological study also compared the prevalence of overweight children in the affected prefectures as well as across Japan in both 2010 and 2012 (Supplementary Figure 1). We observed increases in the prevalence of overweight individuals among primary school boys in the 6−11 age group in Fukushima, the 6−12 age group in Miyagi, the 6−9 age group in Iwate and the 6−10 age group across Japan. We also found increases in the prevalence of overweight primary school girls in the 6−10 age group in Fukushima, the 8−11 age group in Miyagi and the 6−11 age group across Japan. Among the girls aged 6−7 years in Miyagi, we also observed a slightly decreased prevalence of overweight children. No noteworthy change in the prevalence of overweight children was observed among primary school girls (6−12 years) in Iwate. In the three affected prefectures and across Japan, there were no consistent trends in the prevalence of overweight individuals among junior high and high school students aged 12−17 years.

DISCUSSION

Main results

Our data on post-disaster BMI changes (Figure 3) showed immediate increases in BMI among the preschool boys and girls residing in each affected prefecture, as if in response to the disaster in March 2011. In addition, there was evidence of a prolonged increase in BMI among the boys and girls residing in Fukushima. On the other hand, in Miyagi, we identified a trend of immediate weight gain with subsequent weight loss in both boys and girls. In Iwate, the BMIs of boys and girls gradually approached those of the children living in unaffected prefectures. The prevalence of obese individuals in the cohort data increased to one month after the earthquake among boys in Iwate and among girls in the three affected prefectures, compared with that in the unaffected prefectures (Figure 4). In the ecological study (Supplementary Figure 1), there were increases from 2010 to 2012 in the prevalence of overweight boys and girls in Fukushima and overweight boys in Miyagi and Iwate in their early primary school years, although the results were inconsistent among girls in Miyagi and Iwate that were also in early primary school years. Although the psychological harm that natural disasters cause to children has been reported,[22] the present results have provided additional evidence of an immediate and potentially prolonged increase in BMI among young children following a major disaster.

Possible explanations

At the time of the 2011 earthquake, electricity, gas lines, water supply lines, sewage systems, railways and traffic transportation were all interrupted.[5] The interruption in daily transportation resulted in severe shortages of meat, fish, egg and vegetables.[23] As typically occurs with disasters, administrative and non-political/non-profit organisations supplied carbohydrates such as rice balls and bread to affected populations.[8, 24] In the three affected prefectures, the priority was to supply meals to the affected children.[25] The affected children are presumed to have gained weight due to the carbohydrate-based diet that was supplied, which may account for the weight gain observed in boys and girls in the three affected prefectures immediately after the earthquake, either with or without statistical significance (Figure 3). Furthermore, school gymnasiums were used as shelters for evacuees, and school playgrounds were opened for provisional housing at that time.[24] In Fukushima, where the nuclear power plant station experienced hydrogen explosions, there were few chances to play outside due to fear of radiation exposure, the lack of available playgrounds and an overall mournful mood among the population. Additionally, on 19 April 2011, the Ministry of Education, Culture, Sports, Science and Technology of Japan issued a notice to all schools in Fukushima that principals needed to restrict the availability of school buildings and playgrounds as long as the schools were exposed to 1 mSv or more of radiation per year.[26] The limited outdoor activity may have been reflected in the prolonged BMI increases observed among children living in Fukushima. In contrast, in Miyagi, city infrastructure, hospitals, school education and corporate activities have been recovering much sooner than in Fukushima.[27, 28] This contrast may in part explain the different trends in weight loss observed among boys and girls living in Miyagi. However, how they lost weight has not been established. In Iwate, one report has described a worsening of the mean plasma glucose and haemoglobin A1c levels in 63 affected patients with diabetes from 109.4 mg/dL (SE, 3.9, 6.08 mmol/L [SE, 0.22]) to 134.3 mg/dL (SE, 7.2, 7.46 mmol/L [SE, 0.40]) and from 5.9 % (SE, 0.2, 6.8 mmol/L [SE, 0.3]) to 6.5 % (SE, 0.2, 7.8 mmol/L [SE, 0.3]), respectively, 4 months after the earthquake.[29] The authors were physicians in charge of following up with these patients and they witnessed unbalanced diets heavy with sweets, canned products and boil-in-the-bag foods provided to the evacuees. The authors have speculated that the worsening of the glycaemic control was partly due to unbalanced diets. As was the case in Fukushima and Miyagi, the reported situation of limited access to an adequate diet in Iwate may partly explain the immediate BMI increases observed among preschool boys and girls after the earthquake. Because Iwate prefecture is relatively far from the epicentre of the earthquake and the damaged nuclear power plant (Figure 1), the daily lives of its inhabitants may have returned to normal sooner than it did for those in Fukushima.[27, 28]

Comparison with previous studies

Extraordinary experiences during major disasters change the lives of inhabitants and lead to an array of physical and mental problems.[30-32] A study from medical examinations has shown a +0.2−0.3 BMI change in a year among Fukushima evacuees.[33] Another report from a cohort in Miyagi has described a +0.25 kg/m^2 BMI change among city officials engaging in post-quake recovery and a −0.09 kg/m^2 BMI change among the general population in 2011 after adjusting for sex and age.[34] Our results comparing children in Fukushima and Miyagi are consistent with these previous reports that investigated changes among adults. As described above, the observed BMI increases immediately after the disaster may be partly attributed to unbalanced diet and elevated hormone levels induced by psychological stresses. At the 1995 Great Hanshin (Kobe) earthquake in Japan (7.3 magnitude on the Richter scale), physicians have also reported worsened glycaemic controls among diabetic patients.[35] The authors, who were members of disaster relief teams, have explained that the exacerbations were partly due to unhealthy high-carbohydrate diets and overeating, in responses to sleeplessness and a fear of hunger. At the 2004 Mid-Niigata earthquake (6.8 magnitude on the Richter scale), a report from health check-up data for overworked male prefectural governmental staff members has described an average +0.2 kg/m^2 yearly BMI increase among victims and an average +0.1 kg/m^2 yearly BMI increase among non-victims.[36] At the 1999 Taiwan earthquake (7.2 magnitude on the Richter scale), a study reported that increased sympathetic hormone levels of leptin and cortisol associated with hyperarousal.[37] Because leptin regulates food intake and body weight,[38] and cortisol is induced by psychological stress,[39] hormonal changes in hypervigilant individuals following major earthquakes may cause disturbances in their appetite and BMI.

Practical implications

Medical attention pertaining to mental health and life-style-related issues must be provided adults and in particular elderly adults with a chronic condition during earthquake recovery.[40] With most natural disasters, the focus has been traditionally placed mainly on the health problems of adults and not on the needs of children. This study sheds new light on the risks that a disaster can pose to childhood growth and their risk of obesity after a disaster. The mean BMI levels among boys in Fukushima and boys and girls in Iwate, all approximately four years old at the time that the earthquake struck, appear to show a relatively earlier adiposity rebound, with both immediate and prolonged weight gain (Figure

2). In paediatrics, adiposity rebound is defined as the point of the minimal BMI that comes at 5–6 years old on average.[41] There is a consensus that early adiposity rebound predicts diabetes and obesity in adulthood,[42, 43] although discussion continues about whether the reason for undesirable outcomes at adult age is due to children's lifestyles,[44] to their foetal lives[45] or to other causal mechanisms.[46] Hence, if earlier adiposity rebound indeed occurs in a subset of children after natural disasters due to lack of diet and exercise, administrative agencies and local paediatricians should pre-emptively address this source of future cardiovascular diseases. Because being physically active during the preschool ages reduces BMI over a long term,[47] in the immediate aftermath of an earthquake, play space availability should be ensured, balanced diets should be supplied, and schools should be reopened at the earliest possible date. Additionally, endocrinological and metabolic abnormalities often appear in preschool children with a 12-month history of being overweight.[48] Indeed, stress experienced in early childhood can persist and cause future neurologic and endocrine-related cardiovascular disease.[49] Thus, paediatricians need to assure long term follow-up and pay close attention to the health of children affected by a disaster.

Limitations and strengths

The present study had several limitations. The primary limitation was the representativeness of the sample populations in affected prefectures of northeast Japan. The registered children with available data attended nursery schools that responded to the letter of request. Therefore, the data did not include children who died; those in destroyed nursery schools, nursery schools without schoolteachers or other deficiencies or those who had moved away from the area. Because data were not available indicating whether the most severely affected children gained or lost weight, the direction and the amount of this bias in BMI were not determined. Conversely, the study design could have specifically focused on children who experienced severe suffering. Because of the study design, the definition of 'affected' children did not identify those who were evacuated to provisional houses or who were physically impacted by the tsunami. Therefore, the observed influence of the disaster on their child growth may have been diminished, and the data may not reflect all children in the affected prefectures. However, if the bias should exist, the effects of the earthquake on BMIs would be attenuated according to the observed data and bias toward the null hypothesis. Thus, we consider that the conclusions from the attenuated results would be held. Additionally, because nursery schools in Japan require that either both parents or a single parent without spouse should be employed, nursery school students may not represent the socio-economic status of all children in the studied prefectures. Therefore, although the comparisons of nursery school students in northeast Japan can be internally valid, it may not be possible to generalise the results to all preschool children who will be affected by another disaster. Second, the lack of information on diet and physical activity may limit the comparability of outcomes between the affected and unaffected prefectures studied. Because the Pacific Ocean side of northeast Japan receives less snow than the opposite side, exercise may be more frequent in the affected prefectures than in the unaffected prefectures. This cultural factor may induce bias toward decreasing BMIs of the affected children residing on the Pacific Ocean side. Considering this negative bias in BMI, the weight gains among children living in Fukushima and Iwate might be larger, and the weight loss observed in Miyagi might be smaller than thought. Because there is no published data for the difference in BMI between growing children residing on the Pacific Ocean side or the other side of northeast Japan, the amount of this potential bias was undetermined. To correct for this potential bias, study initiation with a matching method based on cultural confounders for a quasi-experimental design might have reduced the bias. Even so, we minimised the bias by selecting an unaffected reference group from the northeast Japan, where the diet was considered to be similar to that in the three affected prefectures.[50] Finally, the results were limited with no use of z score (standard deviation score) for BMI,[51-53] which might have more properly adjusted for age. Although the standardisation by z score may be ideal for comparison of raw BMI values, the need for comparison of the BMI changes did not allow us to use the standardisation. Thus, we instead chose to compare BMI changes between two groups and make the simple adjustment of a covariate for months of age in the model.

The assembled longitudinal data would be strengthened by its uniqueness in recording child growth before and after a disaster. Although medical attention to the physical and mental health of people affected by a disaster has recently increased, surveys pertaining to this particular disaster have just begun.[54] A number of studies originating from these surveys should provide evidence to bolster disaster medicine. Another strength of this study is comparison of affected children with the unaffected children, who were considered to have been normally growing. For example, although one report described the health status of Iraqi refugees before immigration to the U.S. with an obesity prevalence of 24.6% and a hypertension prevalence of 15.2%,[55] the lack of information on unaffected Iraqis prevented an estimation of the influence of refugee life on human health. Similarly, the impact of a study that reported a high prevalence of mental disorders in Iraqi children during a war,[56] would be weakened because of the lack an unexposed comparator reference group. The evaluation of BMIs in growing children is usually difficult. However, we believe that an epidemiological answer has been provided to the study question on whether children's BMIs were influenced by the disaster. Furthermore, the phenomenon of an increased prevalence of overweight early-year primary school children in Fukushima has been observed in the ecological study. Although an ecological fallacy may exist, it is interesting that this

416 phenomenon has appeared in Fukushima, where there are reports of delayed reconstruction.

417

418 Conclusion

419 The data from earthquake-stricken northeast Japan have shown an immediate increase in BMI
420 among children living in three affected prefectures. The data have also indicated trends of
421 prolonged BMI increases among children in Fukushima and prolonged BMI decreases among
422 children in Miyagi. These data emphasise the need for attention to and follow-up for affected
423 children after a natural disaster to prevent undesirable health outcomes.

424

Yokomichi H et al.

425 **Acknowledgments** We especially thank Prof. Rafael Perera-Salazar, Dr. Richard Stevens, Dr.
426 Jason Oke, Dr. Jan Verbakel, Dr. Joseph Lee and other biostatistics team members at the
427 Nuffield department of Primary Care Health Sciences in the University of Oxford for their
428 insightful advice, which helped to improve the analysis and discussion of the manuscript.

429 **Contributors** SKure, ZY, WZ and HY conceived and designed the study. WZ and HY
430 analysed the data. HY wrote the draft. HM, MI, MK, TI, SY, TT, NK, SC, AO, MH, ST,
431 SKuriyama and SKure collected the data. All authors interpreted the results and critically
432 reviewed the manuscript for important intellectual content.

433 **Competing interests** None declared.

434 **Funding** This work was supported by the Ministry of Health, Labour and Welfare of Japan as
435 Jisedai-Shitei, Fukkoku H24-007 and Jisedai-Ippan H25-002 and by the Ministry of
436 Education, Culture, Sports, Science and Technology of Japan as Scientific Research (C)
437 15K08730 and Challenging Exploratory Research 15K15221. The Ministry of Health, Labour
438 and Welfare of Japan cooperated the data collection. The funders had no role in study design,
439 analysis, decision to publish or preparation of the manuscript.

440 **Ethics approval** The research was approved by the Ethics Committee of Tohoku University
441 School of Medicine (approval number: 2012-1-125).

442 **Data sharing statement** No additional data are available.

REFERENCES

1. Lin W, Conin M, Moore JC, et al. Stress state in the largest displacement area of the 2011 Tohoku-Oki earthquake. *Science* 2013;339:687–90.

2. Dunbar P, McCullough H, Mungov G, et al. 2011 Tohoku earthquake and tsunami data available from the National Oceanic and Atmospheric Administration/National Geophysical Data Center. *Geomat Nat Hazards Risk* 2011;2:305–23.

3. Maeda T, Furumura T, Sakai Si, et al. Significant tsunami observed at ocean-bottom pressure gauges during the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 2011;63:803–8.

4. Christodouleas JP, Forrest RD, Ainsley CG, et al. Short-term and long-term health risks of nuclear-power-plant accidents. *New Engl J Med* 2011;364:2334–41.

5. Mimura N, Yasuhara K, Kawagoe S, et al. Damage from the great east Japan earthquake and tsunami-a quick report. *Mitig Adapt Strateg Glob Chang* 2011;16:803–18.

6. National Police Agency of Japan. Damage situation and police countermeasures associated with 2011 Tohoku district - off the pacific ocean earthquake. 2015. Available: https://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf (accessed 26 Feb 2016)

7. Yanagihara H, Hatakeyama Y, Iwasaki T. Coordination by registered dieticians for nutritional and dietary support in disaster in Japan. *Western Pac Surv Resp J* 2012;3:46–51.

8. Inoue T, Nakao A, Kuboyama K, et al. Gastrointestinal symptoms and food/nutrition concerns after the great east Japan earthquake in March 2011: survey of evacuees in a temporary shelter. *Prehosp Disaster Med* 2014;29:303–6.

9. Kotozaki Y. The nutritional status of women of the coastal region of the great east Japan earthquake disaster area: three years after. *Integr Mol Med* 2015;2: 106–8.

10. Yoshii H, Saito H, Kikuchi S, et al. Report on maternal anxiety 16 months after the great east Japan earthquake disaster: anxiety over radioactivity. *Glob J Health Sci* 2014;6: 1–10.

11. 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.

12. Ministry of Economy, Trade and Industry of Japan. Measurement Act (English version). 1992. Available: http://www.japaneselawtranslation.go.jp/law/detail/?id=82&vm=02&re=02&new=1 (accessed 26 Feb 2016)

13. Ministry of Education Culture, Sports, Science and Technology of Japan. School Basic Survey. 2012. Available:

http://www.e-stat.go.jp/SG1/estat/NewList.do?tid=000001011528. Japanese. (accessed 26 Feb 2016)

14. Allison PD. Fixed effects regression methods for longitudinal data using SAS. Cary, North Carolina: SAS Institute, 2005.

15. Verbeke G, Molenberghs G. Linear mixed models for longitudinal data. Verlag, New York: Springer 2009.

16. Deiss D, Bolinder J, Riveline J-P, et al. Improved glycemic control in poorly controlled patients with type 1 diabetes using real-time continuous glucose monitoring. *Diabetes Care* 2006;29:2730–2.

17. World Health Organization Multicentre Growth Reference Study Group. World Health Organization child growth standards based on length/height, weight and age. *Acta Pædiatr Suppl* 2006;450:76–85.

18. Ministry of Education, Culture, Sports, Science and Technology of Japan. Annual report of the School Health Statistics Research. 2013. Available: http://www.mext.go.jp/b_menu/toukei/chousa05/hoken/1268826.htm. Japanese. (accessed 26 Feb 2016)

19. Ministry of Communications and Internal Affairs of Japan. Statistics Act (English version). 2007. Available: http://www.japaneselawtranslation.go.jp/law/detail/?id=148&vm=02&re=01&new=1 (accessed 26 Feb 2016)

20. Asayama K, Ozeki T, Sugihara S, et al. Criteria for medical intervention in obese children: a new definition of 'obesity disease'in Japanese children. *Pediatr Int* 2003;45:642–6.

21. The Japanese Society for Pediatric Endocrinology. Obesity in Japanese children. 2015. Available: http://jspe.umin.jp/public/himan.html. Japanese. (accessed 26 Feb 2016)

Yokomichi H et al.

22. Hagan JF. Psychosocial implications of disaster or terrorism on children: a guide for the pediatrician. *Pediatrics* 2005;116:787–95.

23. Tsuboyama-Kasaoka N, Hoshi Y, Onodera K, et al. What factors were important for dietary improvement in emergency shelters after the great east Japan earthquake? *Asia Pac J Clin Nutr* 2014;23:159.

24. Sakamoto M. The rise of NGOs/NPOs in emergency relief in the great east Japan earthquake. *Jpn Soc Innov J* 2012;2:26–35.

25. Tsuboyama-Kasaoka N, Purba MB. Nutrition and earthquakes: experience and recommendations. *Asia Pac J Clin Nutr* 2014;23:505.

26. Minisry of Education, Culture, Sports, Science and Technology of Japan. The tentative way of thinking for judgement about availability of school buildings and playgrounds in Fukushima Prefecture. 2011. Available: http://www.mext.go.jp/a_menu/saigaijohou/syousai/1305173.htm. Japanese. (accessed 26 Feb 2016)

27. Zhou Y. How will the 3.11 earthquake transform the population and labor market in Iwate, Miyagi and Fukushima?: knowledge gained from existing studies of disasters. *Jpn Labor Rev* 2012;9:64–85.

28. National Institute for Resarch Advancement. Recovery and reconstruction indexes from the great east Japan earthquake: current status and issues of 3 affected prefectures. 2013. Available: http://www.nira.or.jp/pdf/1301report.pdf. Japanese. (accessed 26 Feb 2016)

Yokomichi H et al.

526 29. Ogawa S, Ishiki M, Nako K, et al. Effects of the great east Japan earthquake and huge
527 tsunami on glycaemic control and blood pressure in patients with diabetes mellitus.
528 *BMJ Open* 2012;2:e000830.

529 30. Kario K, McEwen BS, Pickering TG. Disasters and the heart: a review of the effects of
530 earthquake-induced stress on cardiovascular disease. *Hypertens Res* 2003;26:355–67.

531 31. Fonseca VA, Smith H, Kuhadiya N, et al. Impact of a natural disaster on diabetes
532 exacerbation of disparities and long-term consequences. *Diabetes Care* 2009;32:1632–
533 8.

534 32. Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after
535 disasters. *Epidemiol Rev* 2005;27:78–91.

536 33. Tsubokura M, Takita M, Matsumura T, et al. Changes in metabolic profiles after the
537 great east Japan earthquake: a retrospective observational study. *BMC Public Health*
538 2013;13:267.

539 34. Konno S, Hozawa A, Munakata M. Blood pressure among public employees after the
540 great east Japan earthquake: the Watari study. *Am J Hypertens* 2013:hpt065.

541 35. Kirizuka K, Nishizaki H, Kohriyama K, et al. Influences of the great Hanshin-Awaji
542 earthquake on glycemic control in diabetic patients. *Diabetes Res Clin Prac*
543 1997;36:193–6.

544 36. Azuma T, Seki N, Tanabe N, et al. Prolonged effects of participation in disaster relief
545 operations after the Mid-Niigata earthquake on increased cardiovascular risk among
546 local governmental staff. *J Hypertens* 2010;28:695–702.

Yokomichi H et al.

547 37. Liao S-C, Lee M-B, Lee Y-J, et al. Hyperleptinemia in subjects with persistent partial
548 posttraumatic stress disorder after a major earthquake. *Psychosom Med* 2004;66:23–8.

549 38. Ahima RS, Prabakaran D, Mantzoros C, et al. Role of leptin in the neuroendocrine
550 response to fasting. *Nature* 1996;382:250–2.

551 39. Dickerson SS, Kemeny ME. Acute stressors and cortisol responses: a theoretical
552 integration and synthesis of laboratory research. *Psychol Bull* 2004;130:355.

553 40. Hasegawa A, Tanigawa K, Ohtsuru A, et al. Health effects of radiation and other health
554 problems in the aftermath of nuclear accidents, with an emphasis on Fukushima. *Lancet*
555 2015;386:479–88.

556 41. Whitaker RC, Pepe MS, Wright JA, et al. Early adiposity rebound and the risk of adult
557 obesity. *Pediatrics* 1998;101:e5.

558 42. Rolland-Cachera M-F, Deheeger M, Bellisle F, et al. Adiposity rebound in children: a
559 simple indicator for predicting obesity. *Am J Clin Nutr* 1984;39:129–35.

560 43. E Eriksson JG, Forsen T, Tuomilehto J, et al. Early adiposity rebound in childhood and
561 risk of type 2 diabetes in adult life. *Diabetologia* 2003;46:190–4.

562 44. Rolland-Cachera M. Obesity among adolescents: evidence for the importance of early
563 nutrition. *Hum Growth Context* 1999:245–58.

564 45. Rolland-Cachera M, Deheeger M, Maillot M, et al. Early adiposity rebound: causes
565 and consequences for obesity in children and adults. *Int J Obes* 2006;30:S11–S17.

566 46. Lumeng JC, Taveras EM, Birch L, et al. Prevention of obesity in infancy and early
567 childhood: a national institutes of health workshop. *JAMA Pediatr* 2015;169:484-90.

568 47. Dunton G, McConnell R, Jerrett M, et al. Organized physical activity in young school
569 children and subsequent 4-year change in body mass index. *Arch Pediatr Adolesc Med*
570 2012;166:713-8.

571 48. Shashaj B, Bedogni G, Graziani MP, et al. Origin of cardiovascular risk in overweight
572 preschool children: a cohort study of cardiometabolic risk factors at the onset of obesity.
573 *JAMA Pediatr* 2014;168:917–24.

574 49. Pervanidou P, Chrousos GP. Stress and obesity/metabolic syndrome in childhood and
575 adolescence. *Int J Pediatr Obes* 2011;6:21–8.

576 50. Homma N, Tateyama C. Regional characteristics from the family income and
577 expdenditure survey of Japan: confirmation from 2006 investigation. *Bull Soc Life Cult*
578 *Niigata* 2009;15:7–14. Japanese.

579 51. Onis M, Onyango AW, Borghi E, et al. Development of a WHO growth reference for
580 school-aged children and adolescents. *Bull World Health Organ* 2007;85:660–7.

581 52. Cole TJ. The LMS method for constructing normalized growth standards. *Eur J Clin*
582 *Nutr* 1990;44:45–60.

583 53. Kato N, Takimoto H, Sudo N. The cubic functions for spline smoothed L, S and M
584 values for BMI reference data of Japanese children. *Clin Pediatr Endocrinol*
585 2011;20:47.

586 54. Suzuki Y, Kim Y. The great east Japan earthquake in 2011; toward sustainable mental
587 health care system. *Epidemiol Psychiatr Sci* 2012;21:7–11.

55. Ramos M, Orozovich P, Moser K, et al. Health of resettled Iraqi refugees—San Diego County, California, October 2007–September 2009. *JAMA* 2011;305:459–61.

56. Al-Jawadi AA, Abdul-Rhman S. Prevalence of childhood and early adolescence mental disorders among children attending primary health care centers in Mosul, Iraq: a cross-sectional study. *BMC Public Health* 2007;7:274.

57. Japan Meteorological Agency. Measured height of tsunami at the 2011 off the Pacific coast of Tohoku Earthquake. 2011. Available: http://www.jma.go.jp/jma/indexe.html. (Accessed 7 Mar 2016)

58. Reconstruction Agency of Japan Cabinet. Transition of the numbers of evacuees suffered from the great east Japan earthquake. 2015. Available: http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-1/20151225_hinansha_suii.pdf. Japanese. (Accessed 26 Feb 2016)

Yokomichi H et al.

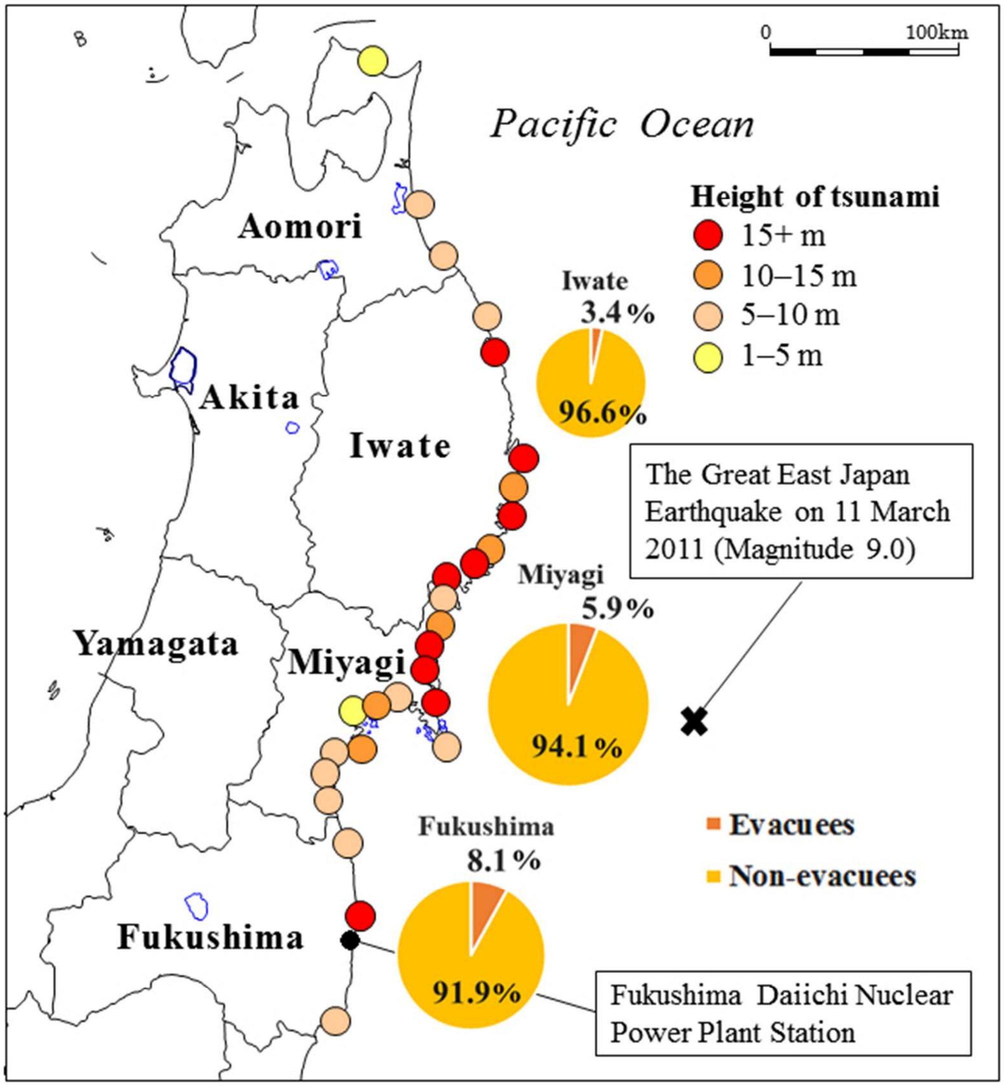
Figure Legends

Figure 1 Affected and unaffected prefectures in northeast Japan.[57] The proportions of evacuees are represented according to the numbers of evacuees in March 2012.[58] The areas of the circles are proportional to the population size.

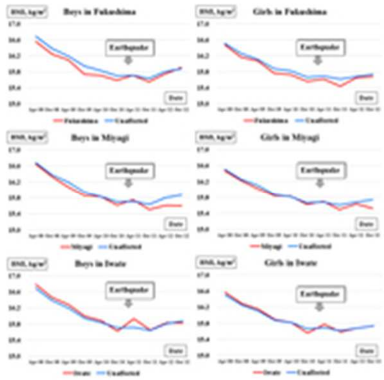
Figure 2 Mean body mass indices (BMIs) of nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan.

Figure 3 Estimated changes in body mass index (Diff BMI) after October 2010 among nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan. Statistical tests evaluated the *P* values of the interaction terms in the model. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

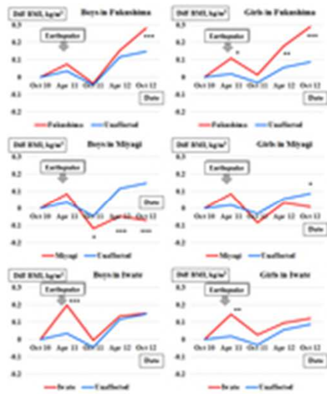
Figure 4 Prevalence of overweight and obese children in Fukushima, Miyagi and Iwate prefectures (red lines) and the unaffected prefectures (blue lines). Solid and dashed lines represent the prevalence of overweight and obese children, respectively. Overweight and obese were diagnosed according to the child growth standards of the World Health Organization.[17] * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.



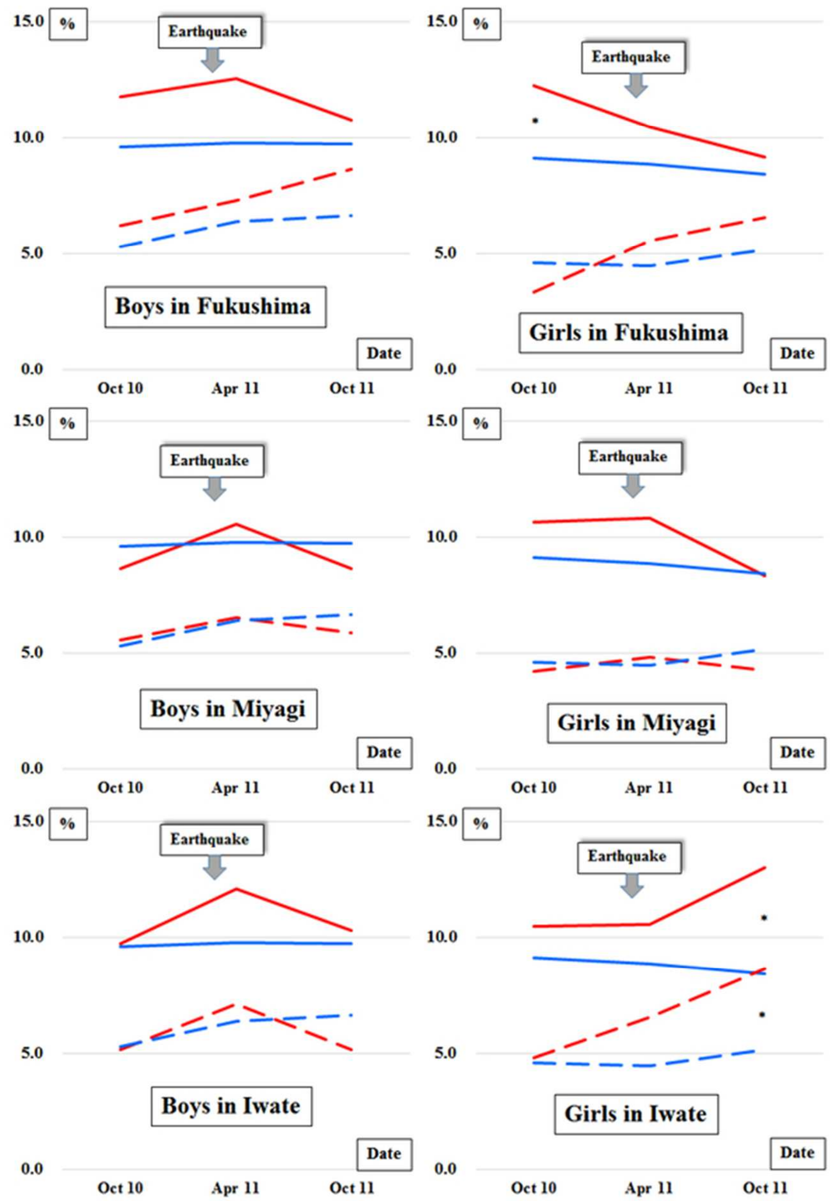
Affected and unaffected prefectures in northeast Japan.[57] The proportions of evacuees are represented according to the numbers of evacuees in March 2012.[58] The areas of the circles are proportional to the population size.
170x184mm (96 x 96 DPI)



Mean body mass indices (BMIs) of nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan.
8x8mm (600 x 600 DPI)



Estimated changes in body mass index (Diff BMI) after October 2010 among nursery school children born between 2 April 2006 and 1 April 2007 in each affected prefecture versus unaffected prefectures in northeast Japan. Statistical tests evaluated the P values of the interaction terms in the model. * *P* < 0.05, ** *P* < 0.01 and *** *P* < 0.001.
6x8mm (600 x 600 DPI)



Prevalence of overweight and obese children in Fukushima, Miyagi and Iwate prefectures (red lines) and the unaffected prefectures (blue lines). Solid and dashed lines represent the prevalence of overweight and obese children, respectively. Overweight and obese were diagnosed according to the child growth standards of the World Health Organization.[17] * *P* < 0.05, ** *P* < 0.01 and *** *P* < 0.001.
25x36mm (600 x 600 DPI)

Supplementary Materials

Supplementary Table 1 Estimated mean body mass indices for children residing in the affected Fukushima, Miyagi and Iwate prefectures and in unaffected areas also located in northeast Japan

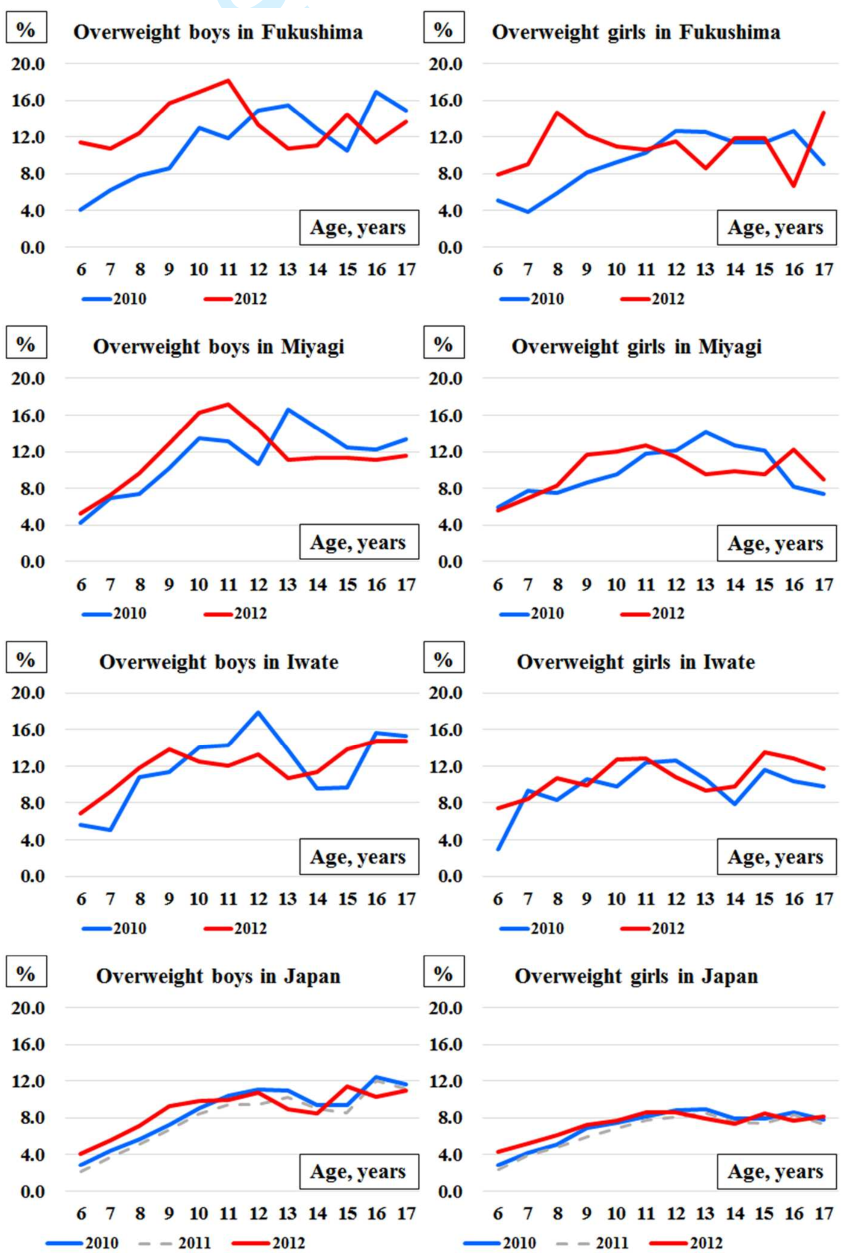
Time point	Boys				Girls			
	Fukushima (n = 646)	Miyagi (n = 904)	Iwate (n = 483)	Unaffected* (n = 1707)	Fukushima (n = 597)	Miyagi (n = 854)	Iwate (n = 458)	Unaffected* (n = 1658)
April 2008	16.34	16.45	16.43	16.38	16.21	16.33	16.26	16.38
October 2008	16.08	16.17	16.23	16.14	15.97	16.12	16.11	16.14
April 2009	15.97	15.99	16.05	16.00	15.96	15.90	15.95	16.00
October 2009	15.73	15.83	15.85	15.83	15.78	15.79	15.79	15.83
April 2010	15.73	15.81	15.76	15.78	15.73	15.76	15.73	15.78
October 2010	15.63	15.65	15.57	15.64	15.66	15.62	15.56	15.64
April 2011	15.73	15.74	15.75	15.64	15.74	15.70	15.69	15.64
October 2011	15.63	15.54	15.59	15.56	15.61	15.52	15.58	15.56
April 2012	15.78	15.61	15.70	15.71	15.82	15.61	15.61	15.71
October 2012	15.88	15.62	15.74	15.73	15.91	15.59	15.64	15.73

All values are reported as kg/m^2.

*Unaffected refers to three unaffected prefectures of northeast Japan (Yamagata, Akita and Aomori).

3

Supplementary Figure 1 Prevalence of overweight children in Fukushima, Miyagi and Iwate prefectures and throughout Japan in 2010 versus 2012 from the School Health Statistics Research of Japan.[18] The term 'overweight' was defined as weighing 20% or more than standard weight in accordance with the guidelines of The Japanese Society for Pediatric Endocrinology.



STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3	Line 39
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3	Line 49–59
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6	Line 74–90
Objectives	3	State specific objectives, including any prespecified hypotheses	6	Line 90–94
Methods				
Study design	4	Present key elements of study design early in the paper	8	Line 139–142
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7	Line 101–106, 111–112
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7	Line 112–114
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case		NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8–9	Line 139–149
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7	Line 106–111
Bias	9	Describe any efforts to address potential sources of bias	9	Line 148
Study size	10	Explain how the study size was arrived at	10–11	Line 182–185, 193–199

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8	Line 135–139
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8–9	Line 131–149
		(*b*) Describe any methods used to examine subgroups and interactions	8	Line 146–147
		(*c*) Explain how missing data were addressed	7	Line 113–114
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		NA
		(*e*) Describe any sensitivity analyses		NA
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10–11	Line 182–185, 193–199
		(b) Give reasons for non-participation at each stage	7	Line 113–114
		(c) Consider use of a flow diagram		NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11	Table 1
		(b) Indicate number of participants with missing data for each variable of interest		NA
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	8	Line 132–135
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Supplementary Materials	Supplementary Table 1
		Case-control study—Report numbers in each exposure category, or summary measures of exposure		NA
		Cross-sectional study—Report numbers of outcome events or summary measures		NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11–13	Table 2
		(*b*) Report category boundaries when continuous variables were categorized	32, Figure 4, legend	Line 615–619

		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		NA
Continued on next page Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		NA
Discussion				
Key results	18	Summarise key results with reference to study objectives	13–14	Line 255–270
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	19–21	Line 359–397
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18–19	Line 334–356
Generalisability	21	Discuss the generalisability (external validity) of the study results	19–20	Line 359–378
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	23	Line 433–437

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.