Association between grandparent co-residence, socioeconomic status and dental caries among early school-aged children in Japan: A population-based prospective study

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Globally many children are living with grandparents, and it has been suggested that grandparent co-residence may be associated with dental caries in infants and toddlers possibly through passive parenting style, accompanied by children's cariogenic behaviors such as feeding sugary sweets. However, little is known about this association in schoolchildren, adjusted for socioeconomic status. Therefore, this study investigates the association between grandparent co-residence, socioeconomic status, and dental caries among schoolchildren. All caregivers of first-grade children (age 6–7 years) in Adachi City, Tokyo, were administered a questionnaire about children's grandparent co-residence status and oral health-related behaviors, and responses were linked with dental examination records conducted by school dentists (N = 3,578). Multilevel Poisson regression analysis was applied to examine the association between grandparent co-residence, socioeconomic status, and dental caries status for each individual tooth, adjusting for potential covariates. The percentage of dental caries experience was higher among children living with grandparents (48.9%) than among children living without grandparents (44.0%). The risk for caries, however, did not differ according to grandparent co-residence status when tooth type, child's age and sex, and parental socio-economic status and structure were adjusted (PR, 1.13; 95%CI, 0.90, 1.42). The association between grandparent co-residence and dental caries among early school-aged children in urban Japan was confounded by socioeconomic status.

Dental caries is the most widespread chronic disease, affecting a vast majority of schoolchildren and nearly all adults in most industrialized countries. In Japan, the most recent national school surveillance data indicate that approximately half of primary schoolchildren have one or more dental caries. Dental caries can have serious and lasting complications such as pain and tooth loss, as well as reduction in children's abilities to eat, speak and learn. In light of dental caries prevention, it is important to initiate interventions to prevent caries at an early age. Identifying the key risk factors is among the first steps towards developing an effective intervention.

It is well-known that one of the determinants of dental caries among children is socioeconomic environments. To date, research has largely focused on parents as they play the major role in dietary and oral hygiene behavioural acquisition in young children. The study showed that parental socio-economic status, such as low maternal educational level and low household income level, and family structure, such as family size, single parent, and presence of an older sibling at home, are associated with increased risk of dental caries development. In line with this endeavour of the association between social environment and paediatric dental caries, several studies reported that children aged 1.6 years old and 3 years old living with or looked after by grandparents were more likely to have dental caries particularly in urban children. However, the results are not consistent in

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older children and few studies have adjusted for parental socioeconomic status, which might confound the association between grandparent co-residence and dental caries of children.

In recent years, research interest has grown towards the role of grandparents in dental caries development among children as a primary or a secondary caregiver\(^1^9,2^0\). Today, grandparent co-residence is common not only in developing countries but also worldwide (e.g., 12% in the United States in 2015\(^2^1\), and 20% in Japan in 2016\(^2^2\)). Grandparents are more involved in childrearing, not just because of extended longevity but also due to family structural changes (e.g., rises in lone-parent households) and socioeconomic trends (e.g., increases in financial difficulties)\(^2^3–2^5\). It was reported that grandparents hold poor knowledge of nutritional and oral hygiene requirements for children\(^2^6,2^7\), and children aged 1.6 years old and 3 years old living with or looked after by grandparents have been suggested to have increased risk of dental caries 14–17, particularly in urban children 18. However, the results are not always consistent in 4–5 year-old children\(^1^6\), and the effects in children who are more independent in self-care and whose deciduous teeth start to shed while permanent teeth start to grow (around 6–7 years old) are unknown. Also, previous studies that compared the risk of dental caries between children who live with grandparents and those who do not did not adjust for the effects of fragile family socio-economic and structural characteristics, which are important confounding factors, and hence making it difficult to interpret the results.

The Adachi Child Health Impact of Living Difficulty (A-CHILD) study\(^2^8–3^3\) is a population-based prospective cohort data of children in Adachi City, Tokyo, Japan. A-CHILD study has information on health and living conditions, including detailed clinical oral data assessed by school dentists and family socio-economic characteristics and structure of school-aged children. The present study uses the A-CHILD study data and examines the association of grandparent co-residence, parental socioeconomic status, dental caries of children in a prospective cohort of first-grade Japanese children.

**Results**

Table 1 shows the characteristics of the sample. The percentage of the children living with grandparents was 9.3%. Overall, 44.4% of the participants had at least one dental caries with the mean (SD) of 1.68 (2.58), with a range from 0 to 14 for dft and 0–4 for DMFT, in the second-grade (the distributions of dft and DMFT are shown in Supplementary Fig. 1). The percentage of dental caries experience was higher among children living with grandparents (48.9%) than among children living without grandparents (44.0%). Demographic and family characteristics of children who live with and who do not live with grandparents are presented in Table 1. Compared with children who do not live with grandparents, children who do were more likely to live in households with

|                          | All (n = 3,578) | Grandparent co-residence |
|--------------------------|-----------------|--------------------------|
|                          | n | %  | n | %  | n | %  | p  |
| Sex                      |   |    |   |    |   |    |    |
| Male                     | 1,814 | 50.7 | 1,640 | 50.5 | 174 | 52.6 | 0.48 |
| Female                   | 1,754 | 49.0 | 1,597 | 49.2 | 157 | 47.4 |
| Unknown                  | 10 | 0.3 | 10 | 0.3 | 0 | 0.0 |
| Age (month)              | 85.2 | 2.4 | 85.2 | 2.6 | 85.2 | 25.7 | 0.71 |
| Living arrangement with parents |               | <0.001 |               |   |
| Living with two parents  | 3,265 | 91.3 | 3,020 | 93.0 | 245 | 74.0 |
| Lone-parent household    | 310 | 8.7 | 224 | 6.9 | 86 | 26.0 |
| Missing                  | 3 | 0.1 | 3 | 0.1 | 0 | 0.0 |
| Maternal education       |               | <0.001 |               |   |
| Highschool graduate or less | 1,235 | 34.5 | 1,093 | 33.7 | 142 | 42.9 |
| Some college             | 1,504 | 42.0 | 1,379 | 42.5 | 125 | 37.8 |
| College or University graduate | 753 | 21.0 | 703 | 21.7 | 50 | 15.1 |
| Other                    | 23 | 0.6 | 17 | 0.5 | 6 | 1.8 |
| Missing                  | 63 | 1.8 | 55 | 1.7 | 8 | 2.4 |
| Household income (yen)   |               | 0.010 |               |   |
| <3 million               | 376 | 10.5 | 329 | 10.1 | 47 | 14.2 |
| 3 million – <6 million   | 1,434 | 40.1 | 1,309 | 40.3 | 125 | 37.8 |
| 6 million – <10 million  | 1,118 | 31.2 | 1,028 | 31.7 | 90 | 27.2 |
| 10 million and above     | 310 | 8.7 | 285 | 8.8 | 25 | 7.6 |
| Missing                  | 340 | 9.5 | 296 | 9.1 | 44 | 13.3 |
| Birth order              |               | 0.12 |               |   |
| Middle or last-born      | 1,896 | 53.0 | 1,734 | 53.4 | 162 | 48.9 |
| First-born or only child | 1,682 | 47.0 | 1,513 | 46.6 | 169 | 51.1 |

**Table 1.** Baseline demographics and family characteristics of the participants by grandparent co-residence (n = 3,578). p value is derived from Chi-square test for all except where at least one column had less than 10 samples, then Fisher's exact test as performed.
Table 2. Prevalence and adjusted prevalence ratios (APR) and 95% confidence intervals (95%CI) for dietary and oral-hygiene behaviors in children by co-residence with grandparents (n = 3,578). APR = Adjusted Prevalence Ratio derived from a model that included all the variables presented in the table (i.e., grandparent co-residence, age, sex, birth order, living arrangement with parents, mother’s educational attainment and household economic status).

| Parental control over snack intake (not given/eat at certain time) | Sugar-sweetened beverage intake (≥1 time/day) | Tooth brushing (twice or more/day) | Supervised tooth brushing practice (yes) |
|---|---|---|---|
| % | APR | 95%CI | % | APR | 95%CI | % | APR | 95%CI | % | APR | 95%CI |
| **Grandparent co-residence** | | | | | | | | | | | | |
| Yes | 63.2 | 0.74 | (0.63–0.87) | 25.4 | 1.09 | (0.87–1.37) | 71.9 | 0.96 | (0.90–1.04) | 82.2 | 0.99 | (0.93–1.04) |
| No | 74.5 | ref | | 20.1 | ref | | 77.1 | ref | | 85.8 | ref | |
| Child’s age (months) | | | | | | | | | | | | |
| 1 to 3 | 1.00 | (0.98–1.01) | 0.99 | (0.97–1.01) | 7.0 | (0.99–1.01) | 8.9 | (0.99–1.00) |
| **Child’s sex** | | | | | | | | | | | | |
| Male | 72.7 | ref | | 21.5 | ref | | 75.3 | ref | | 86.4 | ref | |
| Female | 74.3 | 1.09 | (0.97–1.22) | 19.7 | 0.90 | (0.78–1.03) | 77.9 | 1.04 | (1.00–1.07) | 84.4 | 0.98 | (0.96–1.01) |
| **Mother’s educational attainment** | | | | | | | | | | | | |
| Highschool graduate or less | 64.3 | ref | | 27.8 | ref | | 73.4 | ref | | 81.3 | ref | |
| Some college | 77.2 | 1.51 | (1.33–1.72) | 18.3 | 0.70 | (0.60–0.81) | 79.2 | 1.06 | (1.02–1.11) | 87.2 | 1.05 | (1.01–1.08) |
| College or University graduate | 82.1 | 1.94 | (1.52–2.48) | 13.2 | 0.53 | (0.42–0.66) | 77.4 | 1.04 | (0.98–1.09) | 88.8 | 1.05 | (1.01–1.09) |
| Other | 79.0 | 2.15 | (1.81–2.57) | 15.8 | 0.64 | (0.53–0.77) | 60.9 | 0.85 | (0.61–1.19) | 90.9 | 1.10 | (0.86–1.27) |
| **Household economic status** | | | | | | | | | | | | |
| <3 million | 67.3 | ref | | 26.2 | ref | | 72.1 | ref | | 80.1 | ref | |
| 3 million – <6 million | 73.9 | 1.27 | (1.03–1.55) | 22.5 | 0.88 | (0.69–1.12) | 75.8 | 1.03 | (0.95–1.11) | 84.5 | 1.02 | (0.96–1.09) |
| 6 million – <10 million | 77.3 | 1.32 | (1.06–1.64) | 16.5 | 0.73 | (0.56–0.95) | 79.9 | 1.08 | (0.99–1.17) | 87.4 | 1.05 | (0.99–1.11) |
| 10 million and above | 74.3 | 1.09 | (0.82–1.45) | 15.6 | 0.73 | (0.51–1.06) | 79.7 | 1.08 | (0.98–1.19) | 91.3 | 1.10 | (1.03–1.17) |
| **Living arrangement with parents** | | | | | | | | | | | | |
| Lone-parent household | 73.9 | 1.10 | (0.89–1.37) | 20.1 | 1.01 | (0.78–1.31) | 77.1 | 0.96 | (0.87–1.04) | 86.4 | 0.92 | (0.86–0.99) |
| Living with both parents | 68.1 | ref | | 26.1 | ref | | 70.9 | ref | | 76.1 | ref | |
| **Birth order** | | | | | | | | | | | | |
| First-born or only child | 77.2 | 0.79 | (0.71–0.89) | 21.5 | 1.03 | (0.90–1.18) | 73.3 | 0.92 | (0.89–0.96) | 80.7 | 0.90 | (0.88–0.93) |

Table 2 presents the comparison of dietary and oral hygiene behaviours by grandparent co-residence status. Children who live with grandparents received less parental control over snack intake and supervised tooth brushing practice and less frequently brushed tooth while consumed more sugar-sweetened beverages than those who do not live with grandparents. After adjustment for demographic and family characteristics, prevalence of parental control over snack intake were lower for children who live with grandparents than for those who do not live with grandparents (adjusted PR: 0.74, 95%CI: 0.63, 0.87). However, there was no significant differences between the groups with respect to prevalence of daily sugar-sweetened beverage intake (adjusted PR: 1.09, 95%CI: 0.87, 1.37), frequency of tooth brushing (adjusted PR: 0.96, 95%CI: 0.90, 1.04) and supervised tooth brushing practice (adjusted PR: 0.99, 95%CI: 0.93, 1.04).
Table 3. Outcome prevalence of teeth by tooth type and position (n of individual teeth [level 1] = 80,897; n [level 2] = 3,578). Note: In total, 7 deciduous teeth was recorded as missing teeth due to caries but they were not coded as dental caries following the standard procedure of the school health checkups. In total, 181 cases were identified where deciduous tooth and its permanent successor were growing in the same position. Although 1 permanent successor was identified as decayed, missing or filled, it is likely that permanent successors were just grown and we dropped permanent successors from the analysis in Table 4 and not presented in all teeth category in this table.

Discussion
Our results showed that the association between grandparent co-residence and dental caries experience was explained by parental SES, namely, low maternal education and low household income. The lower parental SES contributed to the reduced prevalence of parental control over snack intake, frequent tooth-brushing and tooth-brushing supervision, the increased prevalence of daily sugar-sweetened beverage intake, and the increased risk of dental caries in the second-grade. To the best of our knowledge, this is the first population-based study which showed that the association between grandparent co-residence and dental caries experience in school-aged children could be confounded by their common cause, low parental SES. To utilize our unique data on tooth-level outcomes, we employed multilevel modelling and adjusted for tooth types and tooth positions that differ for dental caries risk.

Our findings are inconsistent with earlier studies that reported the association between grandparent co-residence and caries among deciduous teeth also disappeared when adjusted for parental SES (Adjusted PR: 1.15, 95%CI: 0.92, 1.45) (Supplementary Table 2) and no association was observed between grandparent co-residence and caries among permanent teeth (Crude PR: 1.22, 95%CI: 0.72, 2.05) (Supplementary Table 3).
Nonetheless, this study has limitations. First, we lacked data on who was providing food and tooth-brushing the children. Although grandparent co-residence reflects the opportunity structure that facilitates grandparent-grandchild interactions, children from nuclear families might have also received care from grandparents who live nearby leading to underestimation of the grandparents' effects at home. Second, a majority of the questionnaires were filled out by parents, and it is possible that grandparents influenced on health behaviours of children during parental absence without being noticed. Third, our sample size limited statistical power to perform sub-group analysis among grandparent co-residence households such as by grandparents' sex, age, health and working status, and relational characteristics (i.e., paternal or maternal). Future studies that directly investigate grandparent childcare and their influence on child health status in diverse family types are needed to understand the influence of grandparents on grandchildren’s health behaviours and health more. Finally, we examined the second-grade children who have just erupted the first molars and have not developed full sets of permanent teeth. As caries rises rapidly to the maximum rate approximately two to three years post-eruption.40

| Outcome                                      | Crude PR | 95%CI | Model I PR | 95%CI | Model II PR | 95%CI | Model III PR | 95%CI | Model IV PR | 95%CI |
|----------------------------------------------|----------|-------|------------|-------|-------------|-------|--------------|-------|-------------|-------|
| Grandparent co-residence                     |          |       |            |       |             |       |              |       |             |       |
| Yes                                          | 1.28     | (1.03–1.60) | 1.29     | (1.03–1.61) | 1.15     | (0.92–1.45) | 1.13     | (0.90–1.42) | 1.06     | (0.85–1.33) |
| No                                           | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Tooth type                                   |          |       |            |       |             |       |              |       |             |       |
| Deciduous tooth                              | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Permanent tooth                              | 0.09     | (0.08–0.97) | 0.09     | (0.08–0.10) | 0.09     | (0.08–0.10) | 0.09     | (0.08–0.10) | 0.09     | (0.08–0.10) |
| Sex                                          |          |       |            |       |             |       |              |       |             |       |
| Male                                         | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Female                                       | 0.85     | (0.74–0.97) | 0.90     | (0.78–1.03) | 0.89     | (0.78–1.02) | 0.87     | (0.76–0.99) | 0.90     | (0.78–1.02) |
| Age (month)                                  | 1.00     | (0.98–1.02) | 1.00     | (0.98–1.02) | 1.00     | (0.98–1.02) | 1.00     | (0.98–1.02) | 1.00     | (0.98–1.02) |
| Maternal education                           |          |       |            |       |             |       |              |       |             |       |
| Highschool graduate or less                  | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Some college                                 | 0.73     | (0.63–0.85) | 0.76     | (0.66–0.89) | 0.79     | (0.68–0.92) | 0.88     | (0.76–1.03) |         |       |
| College or University graduate               | 0.50     | (0.41–0.60) | 0.53     | (0.43–0.64) | 0.57     | (0.47–0.70) | 0.67     | (0.55–0.81) |         |       |
| Other                                        | 0.66     | (0.28–1.56) | 0.67     | (0.28–1.60) | 0.64     | (0.27–1.53) | 0.71     | (0.30–1.69) |         |       |
| Household income (yen)                       |          |       |            |       |             |       |              |       |             |       |
| <3 million                                   | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| 3 million ~ <6 million                       | 0.72     | (0.58–0.90) | 0.83     | (0.65–1.06) | 0.81     | (0.64–1.04) | 0.85     | (0.66–1.08) |         |       |
| 6 million ~ <10 million                      | 0.51     | (0.40–0.64) | 0.63     | (0.48–0.81) | 0.61     | (0.47–0.79) | 0.66     | (0.51–0.85) |         |       |
| 10 million and above                         | 0.63     | (0.47–0.85) | 0.87     | (0.63–1.21) | 0.82     | (0.59–1.14) | 0.89     | (0.65–1.23) |         |       |
| Living arrangement with parents              |          |       |            |       |             |       |              |       |             |       |
| Living with two parents                      | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Lone-parent household                        | 1.61     | (1.29–2.01) | 1.20     | (0.92–1.56) | 1.22     | (0.94–1.58) | 1.20     | (0.93–1.56) |         |       |
| Birth order                                  |          |       |            |       |             |       |              |       |             |       |
| First-born or only child                     | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Middle or last-born                          | 1.73     | (1.51–1.97) | 1.69     | (1.48–1.93) | 1.58     | (1.39–1.81) |         |       |         |       |
| Parental control over snack intake           |          |       |            |       |             |       |              |       |             |       |
| Controlled by parent(s)                     | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Eating at any time                           | 1.96     | (1.69–2.28) |         |       | 1.56     | (1.33–1.82) |         |       |         |       |
| Sugar-sweetened beverage intake              |          |       |            |       |             |       |              |       |             |       |
| <1 times/day                                 | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| 1 time or more/day                           | 1.89     | (1.61–2.22) |         |       | 1.58     | (1.34–1.86) |         |       |         |       |
| Tooth brushing                               |          |       |            |       |             |       |              |       |             |       |
| <2 times/day                                 | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| 2 times or more/day                          | 0.64     | (0.55–0.74) |         |       | 0.79     | (0.68–0.92) |         |       |         |       |
| Supervised tooth brushing practice           |          |       |            |       |             |       |              |       |             |       |
| No                                           | ref      |       | ref        |       | ref         |       | ref          |       | ref         |       |
| Yes                                          | 0.65     | (0.55–0.78) |         |       | 0.86     | (0.71–1.03) |         |       |         |       |

Table 4. Multilevel poisson regression analysis of dental caries experience (decayed or filled primary teeth and Decayed, Missing, or Filled permanent teeth) in the second grade (n of individual teeth [level 1] = 80,897; n [level 2] = 3,578) by grandparent co-residence. PR = Prevalence Ratio; APR = Adjusted Prevalence Ratio (Model I adjusted for tooth type and demographics; Model II further adjusted for parental SES; Model III further adjusted for birth order; Model IV further adjusted for health behaviors).
we may have underestimated the effects of grandparent co-residence. Future studies investigating the older children are required before concluding the effects of grandparent co-residence on school-age children.

Although our result indicated that grandparent co-residence was not the “direct cause” of dental caries, the finding has important implication in dental caries prevention. Several caries prevention strategies such as fluoride mouthrinse in school and supporting dental sealant in dental clinic has been implemented in some municipalities; however, children with lower family SES are still more likely to develop dental caries. An intervention study has shown that grandparents could be empowered as caregivers and contribute to decrease childhood behavioural problems. For high-risk households, they are considered as a valuable resource to promote children’s health and well-beings by serving as role models and providing instrumental support to parents in the home setting.

Training and supervising grandparents with educational handbooks and classes about importance and strategies to prevent childhood dental caries could potentially reduce their grandchildren’s risk of dental caries. Future studies should be conducted with such interventions and compare dental caries experience of infants and children whose co-residing grandparents received the proposed intervention with a similar high-risk group.

In conclusion, our findings indicate that grandparent co-residence reflects low maternal education and low income, which are associated with the increased risk of dental caries in the early school-age children in urban Japan. The current findings can be useful information to consider effective interventions to promote dental caries prevention among families raising elementary school age children.

Methods

We followed the STROBE guideline for the analysis of cohort data.

Study sample. All the parents/guardians of the first-grade children attending public school in Adachi City, Tokyo, Japan (student n = 5,355; school n = 69) were invited to participate in the study in 2015 (response rate: 80.1%) and in 2016 for a follow-up (response rate: 81.4%). In total, 3,711 parents/guardians filled out the survey in both years and agreed to link their responses with school health data. We excluded children who did not participate in the school dental health check-ups in 2016 (n = 23) and children who changed grandparent co-residence status during the follow-up (n = 100), resulting in a final sample of 3,578 children. The study was approved by the research ethics committees at the National Centre for Child Health and Development, and Tokyo Medical and Dental University, and performed in accordance with the Declaration of Helsinki and the Japan’s Ethical Guidelines for Epidemiological Research established by the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Health, Labour and Welfare. All the caregivers (a parent or legal guardian) provided written informed consent for study participation.

Measurements. Information about grandparent co-residence, which was defined as at least one grandparent is listed as a household member, was asked via the questionnaire in the first grade (6–7 years). Dietary and oral hygiene behaviours were also asked in the same questionnaire and the responses were dichotomized according to recommendations by the American Academy of Pediatric Dentistry: (1) parental control over snack intake (letting the child eat freely vs. placing the time to eat/not giving at all), (2) sugar-sweetened beverage intake (2 times or more per day/1 time a day, vs. 4–6 times a week/2–3 times a week/once a week/a few times a month/not at all), (3) tooth brushing (twice or more per day vs. once a day/not every day/unknown) and (4) supervised tooth brushing practice (yes or no).

For the outcome, we evaluated dental caries status in the second grade (7–8 years) for individual tooth. School dentists examined all the children with a plane mouth mirror under standardized lighting in a classroom as a part of annual oral health examination conducted according to the School Health and Safety Act. The dentists followed the standard procedures and guidelines to record any visible caries. We defined having dental caries as the deciduous tooth being decayed or filled (dft) or permanent tooth being decayed, missing or filled (DMFT) and determined the status for each tooth. If children having both deciduous teeth and permanent teeth in the same position, we used the permanent teeth status. With respect to tooth position, we classified teeth into 14 categories (i.e., upper central incisor, upper lateral incisor, upper canine, upper first molar in deciduous teeth/first premolar in permanent teeth, upper second molar in deciduous teeth/second premolar in permanent teeth, upper first molar in permanent teeth, upper second molar in permanent teeth, lower central incisor, lower lateral incisor, lower canine, lower first molar in deciduous teeth/first premolar in permanent teeth, lower second molar in deciduous teeth/second premolar in permanent teeth, lower first molar in permanent teeth, lower second molar in permanent teeth) according to Logan & Kronfeld, assuming that caries risk between left and right side within upper or lower arches is equal.

With respect to potential covariates, we measured basic demographics (child’s sex and age in months) and family structure (living arrangement with parents: dual-parent household vs. lone-parent household; birth order: middle or last-born vs. first-born or only child) from the same household composition question used to identify grandparent co-residence. Those who were not living with father or mother for reasons such as divorce, separation, death, not married and living apart for work, were classified into one group as lone-parent household. We also measured family socio-economic status by maternal education (junior high school graduate, high school graduate, some college or college graduate, university graduate, other) and annual household income (presented 10 categories with JPY500,000 intervals, starting with <JPY500,000 and ending in JPY10,000,000 and over to the participants and set the lowest household income as less than JPY3,000,000 or USD20,235 as of March 18th, 2019).

Statistical analysis. First, we compared the baseline demographic and family environmental characteristics of children who live with grandparent and those who do not, using t-test for continuous independent variables and chi-square test for categorical independent variables. Next, we calculated the prevalence ratio (PR) of dietary and oral hygiene behaviours in the first grade (6–7 years) by grandparent co-residence, using Poisson model and
adjusted for the demographic and family environmental characteristics. Finally, we employed multilevel Poisson regression model to investigate whether grandparent co-residency is associated with dental caries status for each tooth (1 = decayed or filled teeth/Decayed, Missing or Filled Teeth, 0 = sound teeth) in the second grade (7–8 years), nested within individuals. We chose this method over the single-level analysis method because our study participants were in transition from primary to permanent dentition, thus the likelihood of dental caries experience is considerably affected by the existing teeth’s position within the mouth. We built crude and other four models where the first model adjusted for tooth type and demographics, the second model further adjusted for parental SES, the third model further adjusted for birth order and the final model further adjusted for health behaviours. The third and final models were built in order to explore the potential mechanisms behind the association between grandparent co-residence and dental caries. STATA 14.0 was used to perform all the analyses.

Data Availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References
1. Kassebaum, N. J. et al. Global, Regional, and National Prevalence, Incidence, and Disability-Adjusted Life Years for Oral Conditions for 195 Countries, 1990–2015: A Systematic Analysis for the Global Burden of Diseases, Injuries, and Risk Factors. J Dent Res 96, 380–387, https://doi.org/10.1177/0022034517693566 (2017).
2. Japanese Ministry of Education, Culture, Sports, Science and Technology. (2018).
3. Withen, W. F. International implications of “oral health in America: a report of the Surgeon General”. Quintessence Int 31, 697 (2000).
4. Fisher-Owens, S. A. et al. Influences on children’s oral health: a conceptual model. Pediatrics 120, e510–520, https://doi.org/10.1542/ peds.2006-3084 (2007).
5. Shearer, D. M. & Thomson, W. M. Intergenerational continuity in oral health: a review. Community Dent Oral Epidemiol 38, 479–486, https://doi.org/10.1111/j.1600-0528.2010.00560.x (2010).
6. Ntouva, A., Tsakos, G. & Watt, R. G. Sugars consumption in a low-income sample of British young people and adults. Br Dent J 215, E2, https://doi.org/10.1036/sj.bdj.2013.655 (2013).
7. Vereecken, C. A., De Henauw, S. & Maes, L. Adolescents’ food habits: results of the Health Behaviour in School-aged Children survey. Br J Nutr 94, 423–431 (2005).
8. Maes, L., Vereecken, C., Vanobbergen, J. & Honkala, S. Tooth brushing and social characteristics of families in 32 countries. Int Dent J 56, 159–167 (2006).
9. Dye, B. A. & Thornton-Evans, G. Trends in Oral Health by Poverty Status as Measured by Healthy People 2010 Objectives. Public Health Reports 125, 817–830 (2010).
10. Mattila, A. K., Pohjola, V., Suominen, A. L., Joukamaa, M. & Lahti, S. Difficulties in emotional regulation: association with poorer oral health-related quality of life in the general population. Eur J Oral Sci 120, 224–231, https://doi.org/10.1111/1600-0722.2012.00953.x (2012).
11. Pitts, N. B. et al. Dental caries. Nat Rev Dis Primers 3, 17030, https://doi.org/10.1038/nrdp.2017.30 (2017).
12. Suljana, A. & Punnan, P. K. Family related factors associated with caries prevalence in the primary dentition of five-year-old children. J Indian Soc Pedod Prev Dent 33, 83–87, https://doi.org/10.4103/0970-4388.155108 (2015).
13. Borowska-Struginska, B. et al. Prenatal and familial factors of caries in first permanent molars in schoolchildren living in urban area of Lodz, Poland. Homo 67, 226–234, https://doi.org/10.1016/j.jch.2015.12.002 (2016).
14. Kojima, K. F. & Niwa, M. M. Relationship between caries prevalence and factors influencing dental health care in infants – comparison between male and female of 3-year-old children. Ţigâta 84, 588–600 (1997).
15. Himode, D. S. et al. Analysis of factors influencing the caries prevalence of deciduous teeth in children of three years old. J Dental Health 38, 631–640 (1988).
16. Yamamoto, M. T., Nakamura, A., Matsuoka, G., Haniooka, N. & Caries, T. prevalence and caries risk factors in children aged 3 to 5 years: cross-sectional study. J Dent Health 63, 15–20 (2013).
17. Aida, J., Ando, Y., Oosaka, M., Niimi, K. & Morita, M. Contributions of social context to inequality in dental caries: a multilevel analysis of Japanese 3-year-old children. Community Dent Oral Epidemiol 36, 149–156, https://doi.org/10.1111/j.1600-0528.2007.00380.x (2008).
18. Ohsuka, K. et al. Analysis of risk factors for dental caries in infants: a comparison between urban and rural areas. Environ Health Prev Med 14, 103–110, https://doi.org/10.1007/s12199-008-0065-6 (2009).
19. Chambers, S. A., Rowa-Dewar, N., Radley, A. & Dobbie, F. A systematic review of grandparents’ influence on grandchildren’s cancer risk factors. PLoS One 12, e0185420, https://doi.org/10.1371/journal.pone.0185420 (2017).
20. Karthigesu, S. P., Chisholm, J. S. & Coall, D. A. Do grandparents influence parents’ decision to vaccinate their children? A systematic review. Vaccine 36, 7456–7462, https://doi.org/10.1016/j.vaccine.2018.10.017 (2018).
21. Glaser, K. et al. Trends in the prevalence of grandparents living with grandchild(ren) in selected European countries and the United States. Eur J Ageing 15, 237–250, https://doi.org/10.1007/s10433-018-0474-3 (2018).
22. National Institution for Youth Education. (2018).
23. Taylor, A. P. J. et al. The Return of the Multi-Generational Family Household. 5 (PewResearchCenter, 2010).
24. Pilkauskas, N. V. & Martinson, M. L. Three-Generation Family Households in Early Childhood: Comparisons between the United States, the United Kingdom, and Australia. Demogr Res 30, 1639–1652, https://doi.org/10.4051/demres.2014.30.60 (2014).
25. Liu, E. E. H. Multi-generation households in Australian cities. 10–11 (Australian Housing and Urban Research Institute, Melbourne, 2012).
26. Speirs, K. E. B. Z., Zorumenov, Y., Anderson, E. A. & Finkbeiner, N. Grandmothers’ involvement in preschool-aged children’s consumption of fruits and vegetables. An exploratory study. ICAN: Infant, Child & Adolescent Nutrition. 1, 332–337 (2009).
27. Oberoi, J., Kathariya, R., Pandi, A., Garg, I. & Raikar, S. Dental knowledge and awareness among grandparents. World J Clin Pediatr 5, 112–117, https://doi.org/10.5409/wjcp.v5.i1.112 (2016).
28. Nawa, N. & Fujiwara, T. Association between social capital and second dose of measles vaccination in Japan: Results from the A-CHILDS study. Vaccine, https://doi.org/10.1016/j.vaccine.2018.12.037 (2019).
29. Doi, S., Fujiwara, T., Isumi, A., Ochi, M. & Kato, T. Relationship Between Leaving Children at Home Alone and Their Mental Health: Results From the A-CHILDS Study in Japan. Front Psychiatry 9, 192, https://doi.org/10.3389/fpsyg.2018.00192 (2018).
30. Doi, S., Fujiwara, T., Ochi, M., Isumi, A. & Kato, T. Association of sleep habits with behavior problems and resilience of 6- to 7-year-old children: results from the A-CHILDS study. Sleep Med 45, 62–68, https://doi.org/10.1016/j.sleep.2017.12.015 (2018).
31. Tani, Y., Fujiwara, T., Ochi, M., Isumi, A. & Kato, T. Does Eating Vegetables at Start of Meal Prevent Childhood Overweight in Japan? A-CHILDS Study. Front Pediatr 6, 134, https://doi.org/10.3389/fped.2018.00134 (2018).
32. Kizuki, M., Ochi, M., Isumi, A., Kato, T. & Fujiwara, T. Parental Time of Returning Home From Work and Child Mental Health Among First-Year Primary School Students in Japan: Result From A-CHILD Study. Front Pediatr 6, 179, https://doi.org/10.3389/fped.2018.00179 (2018).
33. Matsuyama, Y., Fujiwara, T., Ochi, M., Isumi, A. & Kato, T. Self-control and dental caries among elementary school children in Japan. Community Dent Oral Epidemiol 46, 465–471, https://doi.org/10.1111/cdeo.12387 (2018).
34. The Japanese Society of Pedodontics. The chronology of deciduous and permanent dentition in Japanese children. The Japanese Society of Pedodontics. Shini Shikogaku Zasshi 26, 1–18 (1988).
35. Dunifon, R. E., Zio-Guest, K. M. & Kopko, K. Grandparent coresidence and family well-being: implications for research and policy. The ANNALS of the American Academy of Political and Social Science 654, 110–126 (2014).
36. Pitts, N. C. B. & Anderson, T. Children’s dental health survey 2013. Report 2: dental disease and damage in children England, Wales and Northern Ireland., 106 (The Health and Social Care Information Centre, 2013).
37. Mattila, M. L., Rautava, P., Sillanpaa, M. & Paunio, P. Caries in five-year-old children and associations with family-related factors. J Dent Res 79, 875–881, https://doi.org/10.1177/0022034500790031501 (2000).
38. Sahoo, K. et al. Childhood obesity: causes and consequences. J Family Med Prim Care 4, 187–192, https://doi.org/10.4103/2249-4863.154628 (2015).
39. Dunifon, R. E. The influence of grandparents on the lives of children and adolescents. Child Development Perspectives 7, 55–60 (2013).
40. Carlos, I. P. & Gittelsohn, A. M. Longitudinal studies of the natural history of caries. II. A life-table study of caries incidence in the permanent teeth. Arch Oral Biol 10, 739–751 (1965).
41. Matsuyama, Y. et al. School-Based Fluoride Mouth-Rinse Program Dissemination Associated With Decreasing Dental Caries Inequalities Between Japanese Prefectures: An Ecological Study. Journal of epidemiology 26, 563–571, https://doi.org/10.2188/jea.JE20150255 (2016).
42. Aida, J. et al. Trajectory of social inequalities in the treatment of dental caries among preschool children in Japan. Community dentistry and oral epidemiology 45, 407–412, https://doi.org/10.1111/cdeo.12304 (2017).
43. Chan, K. et al. The Effectiveness of Interventions for Grandparents Raising Grandchildren: A Meta-Analysis. Research on Social Work Practice, 1–11 (2018).
44. Neergaard, J. A. A proposal for a foster grandmother intervention program to prevent child abuse. Public Health Rep 105, 89–93 (1990).
45. American Academy of Pediatric Dentistry Clinical Affairs. Policy on Dietary Recommendations for Infants, Children, and Adolescents. Pediatr Dent 39, 64–66 (2017).
46. Policy on Early Childhood Caries (ECC): Classifications, Consequences, and Preventive Strategies. Pediatr Dent 39, 59–61 (2017).
47. Japanese School Health Association. (2016).
48. Logan, W. H. G. & Kronfeld, R. Development of the human jaws and surrounding structures from birth to the age of fifteen years. The Journal of the American Dental Association 20, 379–427 (1933).
49. Gunsolley, J. C., Williams, D. A. & Schenkein, H. A. Variance Component Modeling of Attachment Level Measurements. J Clin Periodontol 21, 289–295, https://doi.org/10.1111/j.1600-051X.1994.tb00320.x (1994).
50. Burnside, G., Pine, C. M. & Williamson, P. R. The application of multilevel modelling to dental caries data. Stat Med 26, 4139–4149, https://doi.org/10.1002/sim.2859 (2007).

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Author Contributions
A.M. and T.F. conceived this study, and A.I., S.D., M.O. and T.F. collected data. A.M. analyzed and wrote the first draft, and A.M., Y.M. and T.F. finalized the manuscript. All authors were involved in writing the paper and had final approval of the submitted and published versions.

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