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Income at birth and tooth loss due to dental caries in adulthood: The 1982 Pelotas birth cohort

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Abstract

Objective: To estimate the effect of income at birth on adulthood tooth loss due to dental caries in 539 adults from the 1982 Pelotas birth cohort.

Methods: Family income was collected at birth. Tooth loss was clinically assessed when individuals were aged 31. Dental visit and oral hygiene at age 25 were considered mediators. Confounders included maternal skin color, and individual's skin color, sex, and income in adulthood. Marginal structural modeling was used to estimate the controlled direct effect of income at birth on tooth loss due to dental caries that was neither mediated by the use of dental service nor oral hygiene.

Results: Forty-three percent of the individuals of low income at birth lost one/two teeth, and 23% lost three or more; among those non-poor, the prevalence was 30% and 14%, respectively. Poor individuals at birth had a 70% higher risk for missing teeth in adulthood than those non-poor. The risk of losing one/two (risk ratio 1.68) and three or more teeth (risk ratio 3.84) was also higher among those of low income at birth.

Conclusions: Economic disadvantage at birth had an effect on tooth loss due to dental caries at age 31 not mediated by individual risk factors.

KEYWORDS

cohort studies, edentulism, epidemiology, income, oral health

1 | INTRODUCTION

In life-course epidemiology, the critical period theory considers the time window as a key factor (Nicolau, Thomson, Steele, & Allison, 2007). Thus, according to this theory, exposures that occurred early in life will program the development of adult conditions (Barker, 1998). Evidence suggests that childhood socioeconomic position (SEP) directly impacts on health outcomes in adulthood (Kuh & Ben-Shlomo, 2004), such as diabetes, stroke, and cardiovascular diseases (Nandi, Glymour, Kawachi, & VanderWeele, 2012). In oral health, adverse early-life SEP has been associated with oral cancer, caries, and periodontitis (Krishna Rao et al., 2015; Peres, Peres, Thomson, et al., 2011; Schuch et al., 2019).

Tooth loss is a public health problem that negatively affects the quality of life (Kassebaum et al., 2014; Peres et al., 2019; Thomson, 2012), and has been associated with adverse health outcomes such as malnutrition, hypertension, and obesity (De Marchi, Hugo, Hilgert, & Padilha, 2012; Nascimento et al., 2016; Peres, Tsakos, Barbato, Silva, & Peres, 2012). Severe tooth loss affected 2% of the world population and was ranked in the 36th position among the most prevalent chronic diseases that affect life expectation (Marcenes et al., 2013). This condition is influenced by several factors, including educational level, family income, oral hygiene habits, dietary habits, and access and utilization of dental care services (Barbato, Peres, Hofelmann, & Peres, 2015; Thomson, Poulton, Kruger, & Boyd, 2000). In a meta-analysis, we found that individuals of low income had greater odds of losing teeth (Seerig, Nascimento, Peres, Horta, & Demarco, 2015).

Despite the rising evidence on the topic, there are still gaps that need to be filled in. The available source of evidence is mainly originated from high-income countries (Blane, Netuveli, & Stone, 2007), and as the patterns of socioeconomic inequalities differ from high- to the low–middle-income countries, the effects of early-life SEP on adult health outcomes may differ significantly according to the setting where the study was conducted (Lima-Costa, De Oliveira, Macinko, & Marmot, 2012). In light of the preceding discussion and based on the critical period model, we hypothesize that relative poverty at birth has a direct effect on tooth loss in adulthood, independent of adult socioeconomic conditions. In order to identify possible causal pathways, we developed a directed acyclic graph (DAG; Figure 1). As oral hygiene and dental services mediate the association between income and tooth loss, collider bias might be created if conventional regression is employed (Robins & Greenland, 1992). Furthermore, as adult income is affected by family income at birth, additional bias might occur (Robins & Greenland, 1992). In order to overcome these issues, marginal structural modeling, which accounts for time-dependent confounders and mediators, can be employed under a counterfactual framework (Robins, Hernan, & Brumback, 2000). Accordingly, the aim of this study was to estimate the controlled direct effect of family income at birth on adult tooth loss due to dental caries not mediated by oral habits occurring in later life using marginal structural modeling.

2 | METHODS

As this a human observational longitudinal study, the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used to guide the reporting of the study. The study was performed in accordance with the Declaration of Helsinki; all follow-up assessments were approved by the Ethics Committee of the Federal University of Pelotas (IRB#19551713.9.0000.5317), and a signed consent form was collected either from the parents of participating children or the adult participants.

2.1 | The 1982 Pelotas birth cohort

In 1982, all maternity hospitals of the city of Pelotas were visited daily. All live births whose mothers lived in the urban area of the city were examined and their mothers interviewed. These individuals have been followed up for several times during the life course (Horta et al., 2015). In 1997, 900 individuals were randomly selected for the Oral Health Study (OHS)-97, and in 2006 (OHS-06) and 2013 (OHS-13), they were contacted for new oral examinations. Information regarding dental caries, missing teeth, and periodontal disease among others was elicited. In 2013, six dentists previously trained and calibrated performed oral examination at the individuals' home. Examiners underwent theoretical and practical training on 20 individuals with similar age but not enrolled in the cohort. Examiner reliability was assessed using weighted kappa, which ranged from 0.89 to 0.95 for tooth loss.

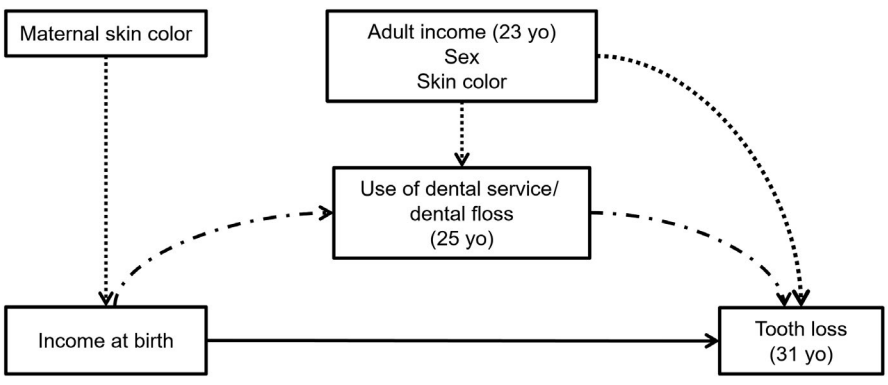

FIGURE 1 Directed acyclic graph (DAG) of possible pathways between income at birth and tooth loss due to dental caries in adulthood

Methodological details of the Oral Health Studies nested to the 1982 Pelotas birth cohort can be found elsewhere (Peres, Peres, Demarco, et al., 2011).

2.2 | Outcome: tooth loss at age 31

Tooth loss was assessed through a full-mouth examination. Only teeth lost due to dental caries were considered for this study. In order to assure that, we used the code 4 of the DMF index, and in the absence of evident signs of multiple caries lesions, participants were asked, during the clinical examination, the reason for tooth loss (e.g., presence of pain or abscess prior to extraction). In cases of doubt, we used data from the previous dental examinations (e.g., presence of dental caries). Thus, teeth lost for other reasons (code 5 of the DMF index), such as periodontal disease, trauma, or due to orthodontic treatment, were not included in the outcome variables.

Two different variables were defined as the outcome:

1. Number of missing teeth: Discrete variable that considered the number of missing teeth;
2. Categories of missing teeth: Three categories were created from the discrete variable. The reference category comprised those individuals that have never lost a tooth until the age of 31; the next category included those individuals that have lost at most two teeth; and finally, the last category comprised individuals that have lost 3 or more teeth. These categories were created based on the mean number of missing teeth.

2.3 | Exposure: family income at birth

The main exposure for this study was family income at birth. Family income was collected at birth through a face-to-face interview and categorized according to the Brazilian minimum wage units (the mid-year value of the minimum wage in 1982 was 16 608 *cruzeiros*) in five categories: less than 1 minimum wage unit (21.9% of the entire cohort), 1.1–3 units (47.4%), 3.1–6 (18.5%), 6.1–10 units (6.5%), and more than 10 units (5.7%). Unfortunately, information on income was not collected as a continuous variable. Thus, due to the unequal numbers of individuals in each income category, a principal component analysis was conducted in order to classify family income into tertiles (Barros et al., 2006). For this study, the exposure was included as a binary variable; thus, the middle and last tertiles were merged into the category "Non-poor"; while the first tertile comprised the category "Poor."

2.4 | Mediators and confounders

Maternal skin color was considered as a baseline confounder. This variable was dichotomized into "white"/"brown and black." Adult income was collected as a continuous variable and later categorized into tertiles. Self-reported individuals' skin color at age 23 ("white"/"brown and black") and gender were also included as confounders in the model.

The mediator "dental service utilization in the last year" was collected as a binary variable "Yes"/"No." Dental flossing at age 25 ("do you often floss your teeth?") was also collected as a binary variable "Yes/No."

For a better understanding of the relationship between those variables in the model, Figure 1 displays possible causal pathways assumed in order to estimate the controlled direct effect of income at birth on adult tooth loss not mediated by dental service or use of dental floss.

2.5 | Statistical analyses

In order to estimate the controlled direct effect (CDE) of income at birth on tooth loss in adulthood that was not mediated by dental service utilization and use of dental floss at age 25, marginal structural modeling was used. As hypothesized in the DAG, adult income, influenced by family income at birth, confounded the mediator-outcome relation. According to VanderWeele, (2009), the presence of a causal intermediate that confounds the mediator-outcome relation allows the estimation of the controlled direct effect of the exposure on the outcome. As the controlled direct effect may be equal to natural direct effect in the absence of an interaction between exposure and mediator, multiplicative interaction was tested (De Stavola & Daniel, 2012). This interaction was examined, including the cross-product term in the analytical model. As no interaction was detected, the cross-product term was omitted in the subsequent analyses (Tables S1 and S2).

Stabilized weights were calculated for exposure (1) and mediators (2) in separate according to the following formulas:

$$\mathrm{SW}_i^x = \frac{P\left(X=x\right)}{P\left(X=x|C_1\right)}, \tag{1}$$

$$\mathrm{SW}_i^m = \frac{P(M_x=m_x|E=e)}{P(M_x=m_x|E=e,M_y=m_y,C_3,C_2,C_1,)}. \tag{2}$$

Stabilized weight for each model is given by $\mathrm{SW}=\mathrm{SW}_i^x * \mathrm{SW}_i^m$. Stabilized weights were calculated separately for the two mediators (dental service use and dental floss) (M_x, M_y) for the two outcome models that considered individual mediators. For calculating the weight of each mediator, the other one was included as confounder of the *mediator-outcome* relation. For the marginal structural model that adjusted for both mediators, the final stabilized weight was obtained by multiplying the stabilized weights of family income at birth, dental service use, and dental floss.

The distribution stabilized weights were as follows: final stabilized weight: mean = 1.01; range = 0.22–5.24; IQR = 0.64–1.18; "Dental service use" stabilized weight: mean = 1.00; range = 0.33–3.40; IQR = 0.77–1.10; "Dental floss" stabilized weight: mean = 1.01;

range = 0.26–4.52; IQR = 0.75–1.13. All analyses were conducted in the software Stata 13.0 (StataCorp.).

2.6 | Sensitivity analyses

2.6.1 | Unmeasured confounder

In order to test the assumption of no unmeasured confounder (U), a sensitivity analysis was performed. For conducting this analysis, we assumed that the relative excess risk due to interaction between X and U is equal to 0. The parameters of U, such as γ (conditional increase in risk for tooth loss), P1 (prevalence in those exposed to the mediators), and P2 (prevalence in those non-exposed to the mediators), were specified. We used the following model given by VanderWeele (2010) to calculate the bias introduced by U that could invalidate the controlled direct effect:

$$\text{Bias CDE}^{\text{RR}}_{x,x^*|c}(m) = \frac{1+(\gamma-1)\,(\text{P1})}{1+(\gamma-1)\,(\text{P2})}.$$

3 | RESULTS

In the Oral Health Study-13 (OHS-13), 539 individuals were examined, representing 60.1% of those examined in the OHS-97. Socioeconomic and demographic indicators of the participants enrolled in the OHS-13 were comparable to those of the original cohort study (data not shown). About 51% of the sample lost at least one tooth; 34% lost at most two teeth, whereas 17% lost three or more teeth. The mean number of missing teeth was 1.25. Among those of low income at birth, the prevalence of 1 or 2 lost teeth was 43%, while the prevalence of losing more than 3 teeth was 23%, while among those non-poor at birth the prevalence was 30% and 14%, respectively.

Table 1 displays the descriptive analysis. The crude analyses indicated that low income at birth, brown/black maternal skin color, no use of dental floss at age 25, and low income at age 23 increased the risk of tooth loss in adulthood.

Table 2 presents the controlled direct effect of income at birth on tooth loss not mediated by dental service use (Model A), dental floss (Model B), and by both mediators (Model C). Model A shows that individuals considered "poor" at birth presented 73% higher risk of losing 1 or 2 teeth (risk ratio [RR] 1.73; 95% CI 1.02–2.95), and 3 times higher risk of having 3 or more missing teeth (RR 3.13; 95% CI 1.67–5.90) compared with those that were "non-poor" at birth. The counterfactual relative risk for missing teeth was 61% higher among those "poor" compared to those who presented a better economic condition at birth (RR 1.61; 95% CI 1.19–2.20). When the effect was controlled for dental floss at age 25, individuals that were "poor" at birth presented 93% greater risk for having 1 or 2 teeth lost at age 31 (RR 1.93; 95% CI 1.12–3.32), and almost 4 times higher risk for missing 3 or more teeth (RR 3.84; 95% CI 2.03–7.26). Considering the

TABLE 1 Distribution of sociodemographic variables, life course socioeconomic measures, among participants enrolled in the 1982 Pelotas birth cohort and crude risk ratio estimates with 95% confidence intervals. Pelotas, Brazil. (n = 539)

	Total sample	Categories of teeth lost				Number of teeth lost	
	Percentage	1–2 teeth (%)	Crude RR (95% CI)	≥3 teeth (%)	Crude RR (95% CI)	Mean number	Crude RR (95% CI)
Income at birth							
Non-poor	70.2	30.3	1.0	14.2	1.0	1.05	1.0
Poor	29.8	42.8	2.3 (1.5–3.5)	23.3	2.7 (1.6–4.5)	1.73	1.6 (1.3–2.2)
Mother's skin color							
White		31.7	1.0	16.3	1.0	1.17	1.0
Brown/Black		45.9	2.2 (1.3–3.7)	20.0	1.9 (1.0–3.6)	1.65	1.4 (1.0–1.9)
Sex							
Male	50.6	36.6	1.0	15.4	1.0	1.10	1.0
Female	49.4	33.2	0.8 (0.6–1.2)	18.4	1.1 (0.7–1.8)	1.40	1.3 (1.0–1.6)
Income at age 23							
Non-poor	70.7	31.8	1.0	13.4	1.0	1.05	1.0
Poor	29.3	37.2	1.6 (1.1–2.4)	23.0	2.4 (1.5–3.9)	1.59	1.5 (1.2–2.0)
Dental service utilization in the last year at age 25							
No	41.9	37.8	1.0	17.1	1.0	1.37	1.0
Yes	58.1	30.9	0.7 (0.5–1.1)	16.7	0.8 (0.5–1.4)	1.18	0.9 (0.7–1.1)
Dental floss at age 25							
Yes	29.0	36.0	1.0	11.8	1.0	1.06	1.0
No	71.0	32.3	1.0 (0.6–1.5)	18.93	1.7 (0.9–3.2)	1.36	1.2 (1.0–1.7)

TABLE 2 Controlled direct effect of income at birth on tooth loss at age 31 from the Marginal Structural Models. Model A: Controlled only for "Dental visit at age 25"; Model B: Controlled only for "Use of dental floss at age 25"; Model C: Controlled for both mediators. Pelotas, Brazil

	Lost teeth[a] (RR)		
Income at birth	1–2	≥3	Number of teeth[b] (RR)
A			
Non-poor	1.00	1.00	1.00
Poor	1.73 (1.02–2.95)	3.13 (1.67–5.90)	1.62 (1.19–2.20)
Dental visit at age 25			
No	1.00	1.00	1.00
Yes	0.90 (0.53–1.53)	1.16 (0.66–2.13)	0.95 (0.70–1.30)
B			
Non-poor	1.00	1.00	1.00
Poor	1.93 (1.12–3.32)	3.84 (2.03–7.26)	1.78 (1.30–2.40)
Dental floss at age 25			
No	1.00	1.00	1.00
Yes	0.74 (0.46–1.18)	1.95 (0.94–3.96)	1.28 (0.91–1.81)
C			
Non-poor	1.00	1.00	1.00
Poor	1.68 (1.00–2.92)	3.78 (1.97–7.26)	1.71 (1.25–2.33)

[a]Multinomial logistic regression.
[b]Negative binomial regression.

number of teeth lost, those "poor" at birth presented 78% increased risk for losing teeth than those "non-poor" at birth (RR 1.78; 95% CI 1.30–2.40). Finally, Model C presents the direct effect controlled for both mediators simultaneously. Individuals that were born in a disadvantaged family showed 68% higher risk for losing 1 or 2 teeth (RR 1.68; 95% CI 1.00–2.92), while the risk was almost 4 times higher when the outcome was set as losing more than 3 teeth (RR 3.84; 95% CI 1.97–7.26). Individuals "poor" at birth had 70% greater risk of losing teeth than those "non-poor" (RR 1.71; 95% CI 1.25–2.33).

Sensitivity analysis for unmeasured confounder U is presented in Table S3. This table presents hypothetical scenarios where the controlled direct effect of income at birth on tooth loss would be eliminated. Considering the prevalence among exposed and non-exposed to mediators combined with the strong association between U and outcome, no unmeasured variable seems to eliminate the CDE.

4 | DISCUSSION

This study presents evidence that individuals of low socioeconomic position at birth presented a higher risk of losing teeth due to dental caries in adulthood. Our findings support our previous hypothesis that low income at birth has a long-term effect on tooth loss due to dental caries in adulthood independent of adult socioeconomic circumstances. Our findings are corroborated by previous studies, which showed that disadvantaged economic conditions in childhood impact on general and oral health conditions in adulthood (Nandi et al., 2012; Schuch et al., 2019).

In a previous study conducted in this cohort, Peres, Peres, Thomson, et al. (2011) found that poor individuals at birth had a higher risk of having more unsound teeth at age 24. According to the authors, subjects that experienced poverty in early life had less access to oral hygiene items (such as dental floss) so as to dental care service, which led to neglected oral hygiene habits in childhood (Oliveira et al., 2013). Since habits developed in early life influence habits in adulthood, it is expected that neglected habits established in childhood will follow a similar pattern during the life course (Sheiham et al., 2011). In addition, dental caries is a cumulative disease whose neglected treatment will eventually lead to tooth extraction. The combination of those factors might have predisposed individuals to dental caries in adulthood; the only cause to tooth loss considered for our study.

Our findings shed light on the importance of public health interventions to prevent dental caries and tooth loss. We demonstrate that there is a direct effect of income at birth on tooth loss in adulthood that is not mediated by adulthood individual risk factors. In our analysis, the two risk factors that are most directly related to the outcome were the use of dental services and oral hygiene, which was accounted for using the information on dental flossing. Our decision to use dental flossing as a proxy for oral hygiene attempts to circumvent report bias, as individuals tend to report a higher frequency of toothbrushing due to social desirability, and therefore, such a measure may not accurately reflect the oral hygiene habits. Based on ours and similar findings (Peres, Nascimento, Peres, Demarco, & Menezes, 2018), we advocate that solving oral health inequalities is beyond the capacities of individual measures since individual risk factors by themselves are not able to compensate the effect of income inequalities on oral health. Public health strategies need to be implemented, focusing on the societal and commercial determinants of health. Policies such as optimal community water

fluoridation programs, regulation of the marketing, and promotion of sugary foods to children and taxes on sugar-sweetened beverages are paramount to prevent dental caries and tooth loss and to reduce oral health socioeconomic inequalities (Watt, 2007).

In a recent study, Celeste, Eyjolfsdottir, Lennartsson, and Fritzell (2020) found that SEP affects oral health cumulatively over the life course and through a chain of risks. Thus, the authors refuted the hypothesis that early-life SEP results exclusively from an adverse SEP at birth, but rather from a combination of several detrimental exposures over the life. However, prior to a direct comparison between our findings and those from Celeste and colleagues, we should examine some methodological differences that might have influenced the controversial results. Firstly, Celeste and et al. used self-reported oral health status, and despite the use of tooth loss as the main outcome, information originated from a single question, which accounted neither for the reason of tooth loss nor for the number of teeth lost. Secondly, in the study by Celeste and colleagues, it is possible to observe a direct effect of early-life SEP on young/mid-adulthood (34–49 years), similarly to our findings. However, it seems that tooth loss in older individuals results from a combination of early-life and adult SEP, rather than just from the direct effect of early-life SEP. Finally, our study was conducted in Brazil, a low–middle-income country, while Celeste's study was carried out in Sweden, a high-income country. Given that the patterns of social inequalities are extremely different between these two countries, we expect that the effect of SEP may differ significantly according to the countries' characteristics.

The results of this study should be considered in the context of some limitations. Firstly, the way family income was collected in 1982 was not a continuous measure. It is well established in the literature that a misclassification error can occur in the presence of a variable categorization (VanderWeele, Chen, & Ahsan, 2011). In this study, the variable income was treated as categorical and binary, as in previous reports from this cohort (Barros et al., 2006; Correa et al., 2010). Secondly, the use of a DMF-S to assess tooth loss might have underestimated our results. This index classifies a highly destroyed tooth by dental caries (residual tooth root) as a "present decayed tooth" in the oral cavity, even when the tooth extraction is strongly recommended. Finally, we did not have data on sugar consumption, which is closely related to dental caries, tooth loss, and SEP. However, we believe that the different components of SEP used in this study accounted for the information on sugar consumption. Additionally, fluoridated toothpaste and water are universally consumed in the city, irrespective of the SEP.

Regardless of the limitations, some strengths of this study should be highlighted. The present study was carried out in a birth cohort followed up several times since birth (Horta et al., 2015). Birth cohorts are adequate to measure the impact of early-life exposures on the development of chronic diseases in adulthood (Thomson et al., 2004), as it makes early-life measures less susceptible to recall bias and provides robustness to the findings. Furthermore, the high rate of follow-up ensured the internal validity of this study. It is also important to emphasize that data regarding tooth loss are originated from a clinical examination performed by trained and calibrated dentists. Finally, estimates obtained from the marginal structural modeling provide a possibility that a causal relationship between income at birth and tooth loss in adulthood exists. The conditions required by the marginal structural model in order to provide robust estimates are satisfied in our study. The sensitivity analysis suggests that the effect of a possible unmeasured confounder U must be strongly associated with the outcome (γ = 3 or γ = 4) and present a great prevalence difference among those exposed and non-exposed to both mediators to eliminate the controlled direct effect of the exposure on the outcomes. The hypothetical scenarios created in the sensitivity analysis that nullify the effect are unlikely; hence, we could assume that early-life income affects tooth loss in adulthood. Assumptions such as positivity and correct model specification are essential for weight estimation. This may be violated if the mean value of stabilized weight is far from 1.00. Since the means of stabilized weights in this study were 1.00, the aforementioned assumption can be considered to be satisfied. Finally, the assumption of "no interaction" implies that the effect measure is equal across all levels of mediator.

In conclusion, those individuals of low income at birth had higher risk of losing teeth in adulthood, independent of adult income, use of dental service, and oral hygiene. Our findings reinforce the relevance of developing public policies to reduce the existing early-life socioeconomic vulnerability, especially in low- and middle-income countries.

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AUTHOR CONTRIBUTION

Gustavo Giacomelli Nascimento: Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing-original draft; Writing-review & editing. **Lenise M. Seerig:** Data curation; Investigation; Methodology; Writing-original draft; Writing-review & editing. **Helena S Schuch:** Investigation; Methodology; Writing-review & editing. **Bernardo L. Horta:** Conceptualization; Methodology; Project administration; Writing-review & editing. **Karen Glazer Peres:** Conceptualization; Funding acquisition; Methodology; Writing-review & editing. **Marco Aurélio Peres:** Conceptualization; Funding acquisition; Project administration; Writing-review & editing. **Marcos Britto Correa:** Funding acquisition; Methodology; Writing-review & editing. **Flavio Fernando**

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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