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Individual caries increments during adolescence in seven Norwegian cohorts born 1996–2002

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Abstract

Background Caries increment during adolescence, including enamel caries, is rarely explored in detail. This study assessed the caries increment during the period from 12 to 18 years. The specific objectives were to examine time trends, increment variability between individuals, and whether baseline caries experience at 12 years or sex had an impact on the caries increment.

Methods The sample included seven birth cohorts (1996–2002; *n* = 23,135) from a general adolescent population in Trøndelag County, Norway. Data was based on dental records from the Public Dental Service. Two caries increment thresholds were examined at the tooth level: the enamel caries increment ($\Delta D_{1-2}T$), and the caries increment at the dentin level, including missing and filled teeth ($\Delta D_{3-5}MFT$). Zero-inflated Poisson models were used to account for the skewed distribution with a high proportion of zero caries increment (31.1% with $\Delta D_{1-2}T = 0$ and 33.4% with $\Delta D_{3-5}MFT = 0$).

Results The mean caries increments for the seven cohorts were $\Delta D_{1-2}T = 3.14$ (95% CI: 3.09–3.19) and $\Delta D_{3-5}MFT = 2.51$ (95% CI: 2.47–2.55). A modest temporal trend of decreasing caries increment across cohorts was observed at both thresholds: $\Delta D_{1-2}T = -0.31$ (95% CI: ±0.13) and $\Delta D_{3-5}MFT = -0.43$ (95% CI: ±0.11). However, this decrease was small compared to the variation in caries increments between individuals. Females had slightly lower mean caries increment than males, but there was no effect of sex on the change across cohorts. Adolescents with high baseline caries experience at 12 years had higher mean caries increments compared to the intermediate or low baseline caries experience groups, and a reduction across cohorts was only seen in the two latter groups.

Conclusions While there was a modest reduction in caries increment across cohorts, this reduction was small compared to the variation in caries increments between individuals. The change across cohorts was the same in females and males. Baseline caries experience at 12 years was a strong predictor of caries increment and the

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reduction across cohorts was only seen among those with lower baseline caries experience, incdicating an increased dental health disparity among Norwegian adolescents.

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Keywords Adolescents, Caries experience, Caries increment, Variation between individuals

Background

The 2019 Global Burden of Disease study found untreated caries in permanent teeth to constitute the most prevalent oral condition, with adolescents and young adults having the highest prevalence [1]. For three decades, from 1990 to 2019, the global burden of caries was relatively stable [2, 3]. Thus, the common view that the prevalence of untreated dental caries declined during this period is not the whole truth [4]. A decline did tend to occur in high-income countries [4], especially in the 12-year-old group, but not in low- and middle-income countries [5]. A recent systematic review and meta-analysis addressing the broader caries status which included enamel caries, concluded that caries continues to constitute a burden among European adolescents [6].

The DMFT/S (Decayed, Missing, and Filled Tooth/Surfaces) index [7], traditionally used in epidemiological studies, is a measure of caries experience that includes both current and past caries in permanent teeth. Thus, repeated cross-sectional studies on caries in adolescents and adults may include past caries experience from childhood. Few studies have followed cohorts from early adolescence, a time coinciding with the eruption of numerous permanent teeth, until the end of the teenage years [8, 9]. As such, by using caries increment as a measure, the number of new caries lesions occurring during the teenage period can be registered without the interference of previous caries experience. A study in Norway assessed mean caries increment calculated from 12 to 18 years across ten birth cohorts [10]. They reported a non-significant reduction in caries increment across the cohorts, and suggested that most of the caries reduction observed in 18-year-olds between 1985 and 2000 may have occurred before age 12 years. In high-income countries, the caries reduction reported among older adolescents [11] is probably a result of both a caries decline at the age of 12 years and a reduction in the caries increment during adolescence. Due to possible differences in dental health policies, services and programs, access to dental care, and cultural factors, findings may not be generally applicable, even among nations with comparable economic and developmental status.

Past caries experience is a predominant predictor of future caries development [12]. Various single cohort studies have found that caries in primary teeth predicted a continuity in caries risk during adolescence [13, 14], and that caries experience in permanent teeth in early adolescence was associated with higher caries experience some years later [8]. These studies underline that caries is unevenly distributed [4]. Because of this skewness, a potential caries reduction observed across cohorts does not necessarily apply to the entire study population.

Given the scarcity of research on the specific caries activity that occurs during adolescence, this study aimed to explore the caries increment occurring between 12- and 18 years in seven birth cohorts. In more detail, this study sought to [1] uncover possible time trends of changes in caries increment across the cohorts [2], examine the increment variability between individuals, and [3] assess whether baseline caries experience at 12 years or sex had an impact on the caries increment.

Methods

Study design, population, and setting

The present study is a sub-study of the research project #Care4YoungTeeth < 3 (the Research Council of Norway, ref. no. 320362) on tailored oral health promotive and preventive strategies for adolescents. The study has a prospective longitudinal design with a sample drawn from Trøndelag County in the central part of Norway. The county covers 13% of Norway and comprises 38 rural and urban municipalities. In 2020, 12–18-year-olds constituted 8.2% (38,279/468,981) of the population in Trøndelag County (Statistics Norway, www.ssb.no). The Public Dental Service (PDS) operated 52 dental clinics in the county in 2022, of which 15 were ambulatory. The drinking water in Norway has little naturally occurring fluoride and is not fluoridated [15].

Norwegian law [16] requires the PDS to provide dental care to all residents under the age of 19 free of charge. Data from 2020 show that, nationally, approximately 97% of the eligible individuals in this age group were enrolled in the PDS [17]. Dental health data on 5-, 12-, and 18-year-olds are reported annually to the Norwegian KOSTRA registry (Municipality-State-Reporting) and are available at Statistics Norway (https://www.ssb.no).

The data on the seven birth cohorts included in the present study, drawn from Trøndelag County PDS records, comprised adolescents born 1996–2002. Altogether 36,349 adolescents were examined by the PDS at 12 years-of-age, 18 years-of-age, or both (Fig. 1d). However, to be able to determine individual caries increments, this study only included adolescents who had visited the PDS at both 12 years-of-age (in 2008–2014)

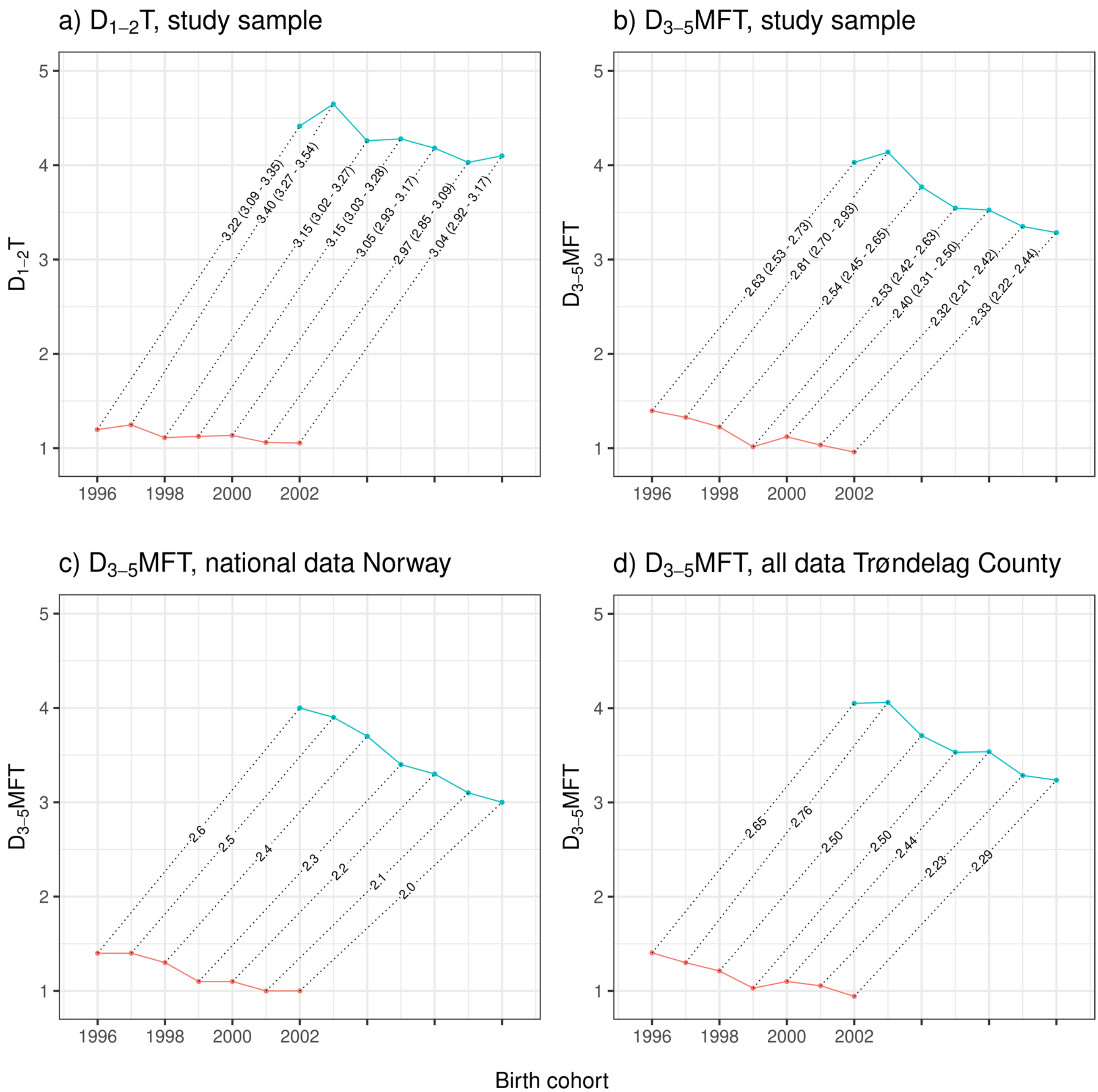

Fig. 1 Mean caries experience and increments for the seven cohorts born 1996–2002. Colored lines and data points show mean caries experience, red at 12 and blue at 18 years of age. Caries increments were measured as the change in caries experience from 12 to 18 years of age, visualized by dotted lines with mean increment values, with **1a** and **b** also reporting corresponding confidence intervals. **1a** and **b** illustrate enamel caries ($D_{1-2}T$) and caries at the dentin level ($D_{3-5}MFT$), respectively, for the study sample ($n = 23{,}135$). **1c** depicts $D_{3-5}MFT$ values on a national level (Norway, n = n/a) and **1d** on a county level (Trøndelag, $n = 36{,}349$)

and 18 years-of-age (in 2014–2020). The entire study sample of 23,135 adolescents constituted about 60% of the 12-year-olds registered as living in Trøndelag County (Statistics Norway, www.ssb.no) (Fig. 1a and b). As dental health statistics are reported on 12- and 18-year-olds, the PDS examines large proportions of individuals at these ages. Still, the difference in coverage percentages is probably due to individually based recall intervals for oral examinations (maximum recommended interval: 24 months) [18]. Other reasons that may have affected coverage percentage include mobility or unwillingness to visit the dental clinic.

The Regional Committees for Medical and Health Research Ethics in Norway reviewed and approved the present study (approval no. 217487/REK Central). The approval included dispensation from informed consent for extracting data from dental health records in the PDS in Trøndelag County. The Norwegian Agency for Shared Services in Education and Research also evaluated the study (ref. no. 726897).

Caries calibration

The PDS have applied a five-graded caries diagnostic tool that has been taught at Norwegian dental schools for decades and is integrated in the PDS electronic dental health record system (Opus Dental™). During the period studied, 2008–2020, the PDS in Trøndelag arranged caries diagnostic training sessions at the dental clinics and at the district or county level. The sessions included radiograph-based caries diagnostic training and case discussion. In the southern part of the county (i.e., former South-Trøndelag County), the sessions were supported by a computer-based training program [19]. This program contained exercises based on radiographs and clinical photos of sound and carious teeth, together with standardized feedback. In 2017, a 1-day caries diagnostic training seminar was arranged for all dentists and dental hygienists ($n \sim 150$) in Trøndelag County. The program featured a theoretical section on caries classification and a training session in which participants annotated bitewing radiographs in smaller groups.

Caries registration

This study is based on actual dental records from the PDS; the data was not generated in a research setting. The PDS conducted regular dental exams at local clinics by dentists and dental hygienists employed by the service. The adolescents were examined in a dental chair equipped with a light source, air-water syringe, and suction. No systematic pre-examining prophylaxis was applied. A dental mirror and a straight probe were used to visually and tactilely identify caries lesions on dry tooth surfaces (using air-water syringe, suction, and dental cotton rolls). Diagnostics were based on a combined clinical and radiographic (bitewing) examination [18].

Registrations used in this study were restricted to permanent teeth (excluding third molars). Each tooth was registered as sound, decayed (enamel and dentin caries), missing, or filled (according to the DMFT index) [7]. Caries lesions, the decay component, were classified using a diagnostic system of five grades [20]. Grades 1 and 2 constituted enamel caries (D_{1-2}) and grades 3–5, dentin caries (D_{3-5}), see Additional file 1: S1 for grade definitions. Caries increments at the tooth level, over the interval age 12–18 years, were calculated at two thresholds: the enamel caries increment ($\Delta D_{1-2}T$) and the caries increment at the dentin level ($\Delta D_{3-5}MFT$). Using the same diagnosis criteria, surface level caries increment at dentin level ($\Delta D_{3-5}MFS$) was also calculated, see Additional file 1: S8. The age and sex of the participants was also retrieved from the PDS records.

Statistical methods

R version 4.1.2 (R Core Team, 2021) was used for the analyses and figure production. The significance level was set to $p < 0.05$ (5%) for all tests. The analysis included only individuals who visited the dentist at both 12 and 18 years of age. This allowed us to assess the variation between individuals. It also enabled appropriate statistical modelling and provided a good visual presentation of effect sizes.

Two thresholds for caries increments were applied: $\Delta D_{1-2}T$ and $\Delta D_{3-5}MFT$. Among the adolescents, some individuals had a negative $\Delta D_{1-2}T$ ($n = 1{,}151$; 5.0%), and some, a negative $\Delta D_{3-5}MFT$ ($n = 103$; 0.4%). These individuals were assigned an increment value of zero to fit into the appropriate distribution for count data. Given that a zero $\Delta D_{3-5}MFT$ score is common in this population, we used zero-inflated Poisson models (ZIP models) [21] and the *glmmTMB* package in R [22]. Details for model selection, use of ZIP models, R syntax, and R summary outputs are presented in Additional file 1: S2 and S3. The results were presented as means and 95% confidence intervals (CIs). The CIs for mean values estimated directly from the dataset, not as a part of the ZIP models, were calculated with bias-corrected and accelerated bootstrap CI (abbreviated to BCa) by using the *boot* [23, 24] and *coxed* [25] packages in R. We also calculated median values and interquartile ranges (IQRs) for these data.

To evaluate whether a potential change in $\Delta D_{3-5}MFT$ across cohorts depended on baseline $D_{3-5}MFT$ or $D_{1-2}T$ at 12 years of age, we created three quartile-based categories: low (0), intermediate (1–2), and high (≥ 3) baseline $D_{3-5}MFT$ or $D_{1-2}T$. For the baseline $D_{3-5}MFT$ model we also estimated the change in caries increment at surface level ($\Delta D_{3-5}MFS$), Additional file 1: Fig. S8.1. In addition, we applied a model using $D_{3-5}MFT$ categories retrieved from Norwegian KOSTRA statistics [26]. These categories differed slightly from the ones we used above: low (0), intermediate (1–4), and high (≥ 5) baseline $D_{3-5}MFT$. A significant interaction between the predictors cohort and baseline caries level would mean that at least two of the three regression lines had different slopes. If this effect was non-significant, we removed it from the model and evaluated whether the mean group values differed, that is, if the elevation of the regression lines differed. We used the same approach to evaluate the effect of sex.

Additional file 1: S4–S9 present the R summary output for each model. Additional file 1: S10 presents an interpretation of outputs. To calculate effect sizes of the variability explained by the ZIP models, we calculated a

Table 1 Caries experience at 12 and 18 years of age including all seven cohorts, birth year 1996–2002 ($n = 23{,}135$)

	$D_{1-2}T$		$D_{3-5}MFT$		Enamel caries proportions
	mean (95% CI)	median (IQR)	mean (95% CI)	median (IQR)	$D_{1-2}T/(D_{1-2}T + D_{3-5}MFT)$
Age 12 years	1.13 (1.11–1.16)	0 (0–2)	1.16 (1.14–1.18)	0 (0–2)	49.3%
Age 18 years	4.27 (4.22–4.33)	3 (1–6)	3.67 (3.62–3.72)	2 (1–6)	53.8%

$D_{1-2}T$: Decayed (grade 1–2: enamel caries) Teeth; $D_{3-5}MFT$: Decayed (grade 3–5: dentin caries), Missing, and Filled Teeth; IQR: Interquartile range; CI: Confidence interval

pseudo R-squared value using the *r2_zero-inflated* function in the *performance* package [27].

Results

Caries experience

This prospective cohort study included a sample of 23,135 adolescents (birth year 1996–2002), of which 48.8% were females. At 12 years of age, the adolescents displayed a mean $D_{3-5}MFT$ (caries experience at the dentin level) of 1.16 (95% CI: 1.14–1.18) and at 18 years the mean $D_{3-5}MFT$ was 3.67 (95% CI: 3.62–3.72). Enamel caries constituted about half of the total caries experience both at age 12 (49.3%) and at age 18 (53.8%), Table 1.

Caries increment

In the present study, a caries increment is the measured difference in $D_{1-2}T$ or $D_{3-5}MFT$ between 12 and 18 years of age, denoted $\Delta D_{1-2}T$ and $\Delta D_{3-5}MFT$, respectively. Figure 1 displays mean caries increments (dotted lines) for the study sample (Fig. 1a and b), at county level (Fig. 1d), and national level (Fig. 1c). As seen in the figure, selecting only adolescents for whom it was possible to calculate individual increment values (Fig. 1b), did not strongly bias the increment compared to when all individuals were included (Fig. 1d). Furthermore, the $\Delta D_{3-5}MFT$ data for our study sample (Fig. 1b) and for Trøndelag County (Fig. 1d) were similar to national $\Delta D_{3-5}MFT$ data (Fig. 1c), although the reduction in increments across cohorts was less in Trøndelag than at the national level (Fig. 1d vs. 1c). The subsequent results and plots were based on individual caries increment measures as the response variable. The mean caries increments for the study sample were $\Delta D_{1-2}T = 3.14$ (95% CI: 3.09–3.19) and $\Delta D_{3-5}MFT = 2.51$ (95% CI: 2.47–2.55). The proportion of individuals with zero increment, that is, $\Delta D_{1-2}T = 0$ or $\Delta D_{3-5}MFT = 0$, were 31.1% and 33.4%, respectively. Figure 2 shows a decrease in caries increment across the seven study cohorts. This decrease was significant for both $\Delta D_{1-2}T$ (Fig. 2a; chi-square = 79.38; df = 1; $p < 0.001$) and $\Delta D_{3-5}MFT$ (Fig. 2b; chi-square = 45.33; df = 1; $p < 0.001$). Additional file 1: S4 include parameter estimates for the model lines in Fig. 2a and b. The predicted mean reduction in increment from the 1996 to

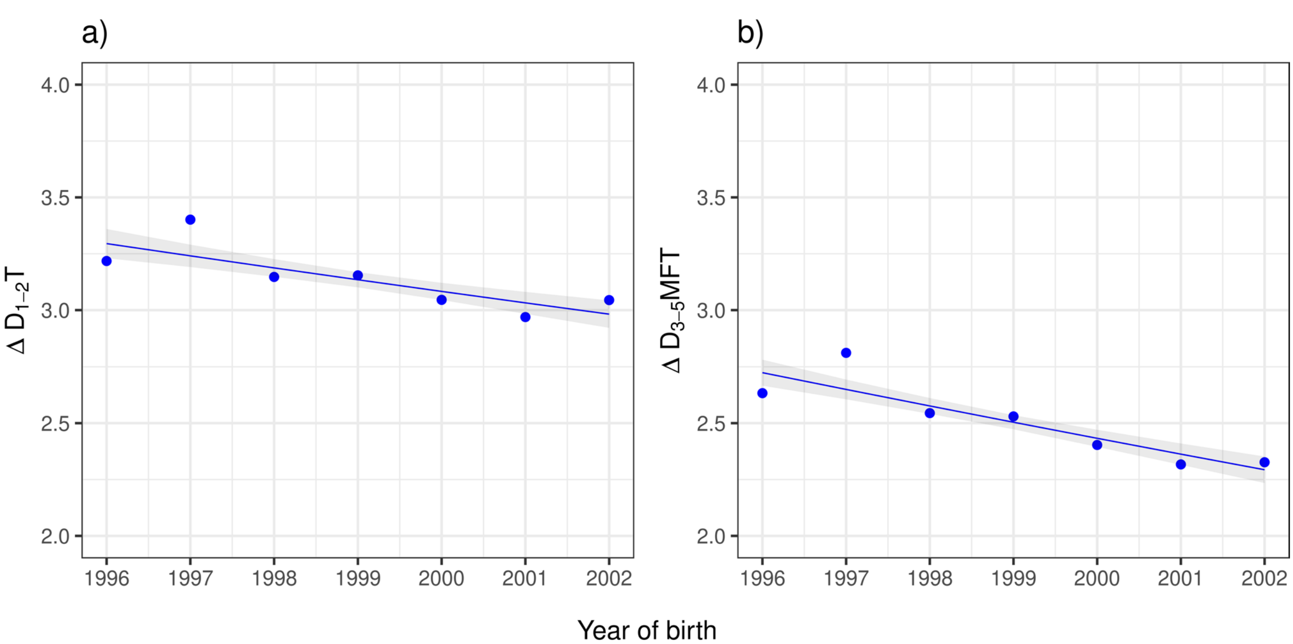

Fig. 2 Mean caries increments between ages 12 and 18 years for enamel caries ($\Delta D_{1-2}T$, **2a**) and for caries at the dentin level ($\Delta D_{3-5}MFT$, **2b**) in the seven birth cohorts born 1996–2002, $n = 23{,}135$. The data points represent the arithmetic means of the individual increments. The lines are predicted means from zero-inflated Poisson regression models based on individual increments. The shaded areas represent corresponding 95% confidence intervals

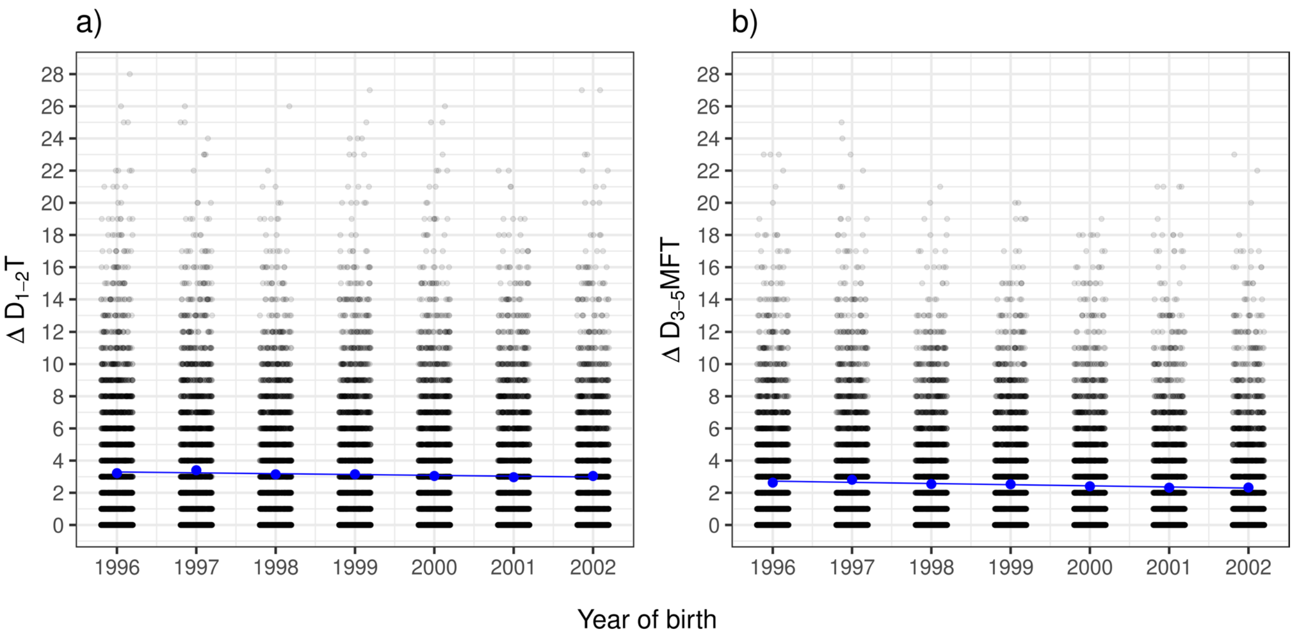

Fig. 3 Individual caries increments between ages 12 and 18 years for enamel caries ($\Delta D_{1-2}T$, **3a**) and for caries at the dentin level ($\Delta D_{3-5}MFT$, **3b**) in the seven birth cohorts born 1996–2002, $n = 23{,}135$. The blue data points are the arithmetic means of the individual increments. The blue lines are predicted values from zero-inflated Poisson regression models based on the same individual increments; that is, the blue lines and data points are the same as in Fig. 2. The small, scattered data points represent individual caries increments. To better visualise the density of observations in each cohort and at each increment value, a slight random horizontal displacement and 90% transparency were applied to the raw data points

Table 2 Caries increment at the dentin level ($\Delta D_{3-5}MFT$) for the seven birth cohorts born 1996–2002 ($n = 23{,}135$), stratified by sex and baseline caries experience ($D_{3-5}MFT$ or $D_{1-2}T$) at age 12 years.

	Study sample	ΔD_{3-5}MFT	
	%	mean (95% CI)	median (IQR)
Total sample	100	2.51 (2.47–2.55)	1 (0–4)
Sex			
Females	48.8	2.45 (2.39–2.50)	1 (0–4)
Males	51.2	2.57 (2.51–2.63)	1 (0–4)
Baseline D_{3-5}MFT*			
Low	53.4	1.77 (1.72–1.81)	1 (0–3)
Intermediate	28.9	2.98 (2.90–3.05)	2 (1–4)
High	17.7	3.99 (3.89–4.10)	3 (1–6)
Baseline D_{1-2}T*			
Low	54.4	1.84 (1.79–1.88)	1 (0–3)
Intermediate	29.1	2.81 (2.73–2.88)	2 (0–4)
High	16.5	4.22 (4.10–4.35)	3 (1–6)

ΔD_{3-5}MFT: caries increment at dentin level; IQR: interquartile range; CI: confidence interval

*Baseline caries experience at age 12 years

the 2002 cohort was $\Delta D_{1-2}T$ = -0.31 (95% CI: ±0.13) and $\Delta D_{3-5}MFT$ = -0.43 (95% CI: ±0.11).

Variation between individuals

Despite a statistically significant reduction in mean caries increment across the cohorts, the reduction was small compared to the variation in caries increments between individuals. Figure 3 illustrates the large variability in the raw data compared with the slope of the regression lines. Furthermore, the adjusted pseudo R-squared value for the $\Delta D_{1-2}T$ regression model was 0.001 and for the $\Delta D_{3-5}MFT$ model, 0.002. This suggests that only a small proportion of the variability could be explained by the reduction in caries increments across cohorts (model lines in Figs. 2 and 3).

Impact of baseline caries experience

The mean caries increments including all cohorts differed depending on baseline caries experience ($D_{3-5}MFT$) at age 12 years: $\Delta D_{3-5}MFT_{High}$ = 3.99 (95% CI: 3.89–4.10), $\Delta D_{3-5}MFT_{Intermediate}$ = 2.98 (95% CI: 2.90–3.05), and $\Delta D_{3-5}MFT_{Low}$ = 1.77 (95% CI: 1.72–1.81) in Table 2. These results are supported by the model where the overall $\Delta D_{3-5}MFT$ was significantly larger for the high group compared to the two other groups, where both the conditional and the zero-inflated part of the model go in the same direction. For the conditional part of the model, the $\Delta D_{3-5}MFT$ in the high group was significantly larger than in the two other groups (high vs. intermediate, $z = 19.62$, $p < 0.001$; high vs. low, $z = 7.43$, $p < 0.001$). Similarly, for the zero-inflation part of the model, the probability of an extra zero for the high group was less than for the two other groups (high vs. intermediate, $z = 30.34$, $p < 0.001$; high vs. low, $z = 12.12$, $p < 0.001$). The same pattern was revealed when comparing the intermediate vs. low

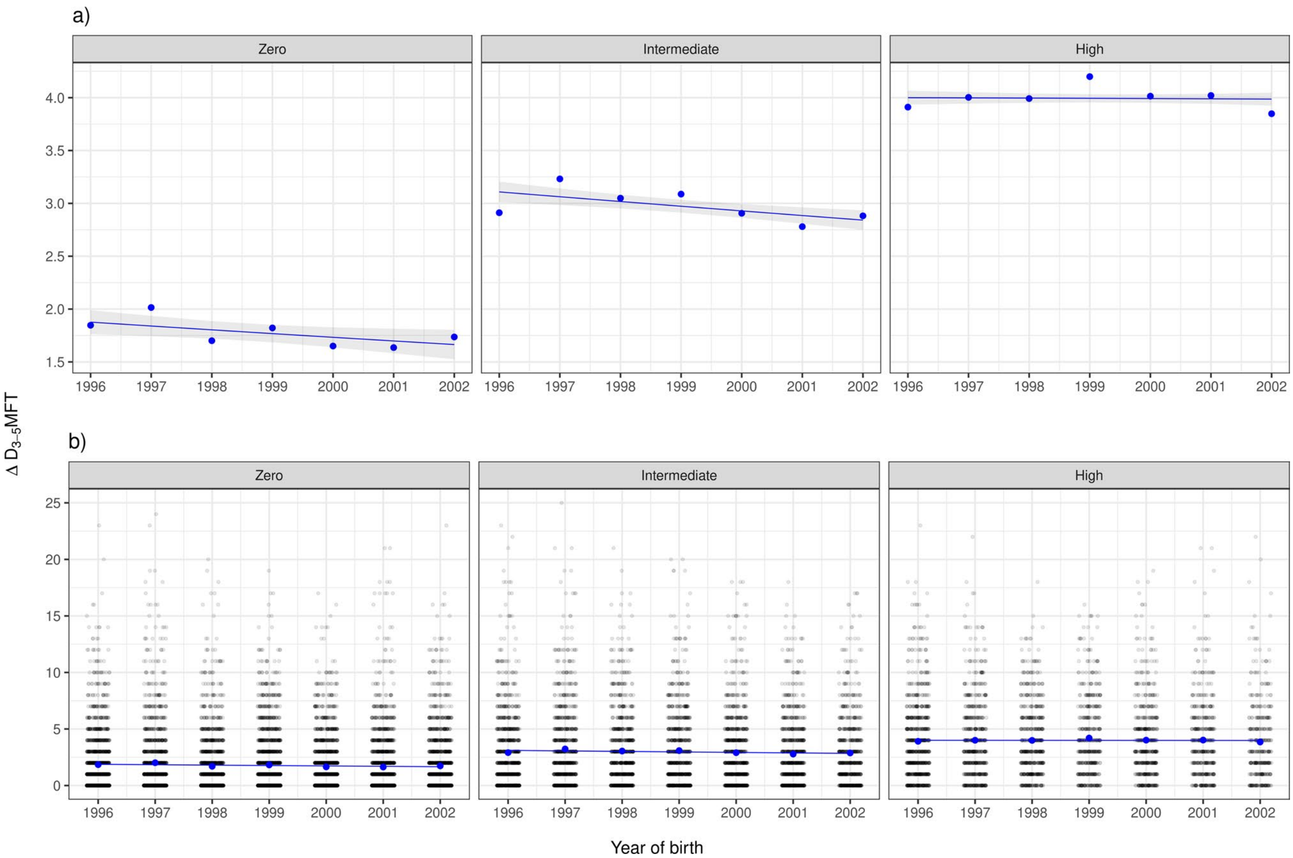

Fig. 4 The effect of baseline caries experience at 12 years of age. Caries increment at the dentin level (ΔD_{3-5}MFT) between ages 12 and 18 years for the seven birth cohorts born 1996–2002 (n = 23,135) according to baseline caries experience at the dentin level (i.e., D_{3-5}MFT at 12 years of age). Baseline caries categories were low, intermediate, and high, representing 0, 1–2, and ≥ 3 D_{3-5}MFT, respectively. **4a** shows mean caries experience at the dentin level (D_{3-5}MFT) as points; the lines represent predicted values from a zero-inflated Poisson regression model, including the interaction between cohort (year of birth) and baseline caries experience. Shaded areas represent 95% confidence intervals for the regression lines. **4b** shows the same data as **4a**, but with the addition of the individual caries increments. To better visualise the density of observations in each cohort and at each increment value, a slight random horizontal displacement and 90% transparency were applied to the raw data points

groups. Similar results were found for baseline enamel caries (D_{1-2}T), Table 2.

Evaluation of whether any change in ΔD_{3-5}MFT across birth cohorts depended on baseline D_{3-5}MFT at 12 years (Fig. 4) revealed a significant interaction between cohort (year of birth) and baseline D_{3-5}MFT (chi-square = 7.61; df = 2, p = 0.022). The interaction means that at least two of the three regression lines have different slopes. Treatment contrasts of the conditional model (Additional file 1: S5) revealed that both the low and the intermediate baseline D_{3-5}MFT groups have significantly stronger reductions in caries increments across the birth cohorts than the high baseline D_{3-5}MFT group (high vs. intermediate: z = 2.28, p = 0.023; high vs. low: z = 2.55, p = 0.011). Similar patterns were found with caries increments at surface level (ΔD_{3-5}MFS) (Additional file 1: S8 and Fig. S8.1) and for baseline D_{1-2}T (Additional file 1: S6 and Fig. S6.1). Categorization of the low, intermediate, and high groups was based on quartile values and gave the following distribution of individuals for the three groups: 53.4%, 28.9%, and 17.7%, respectively. Based on the KOSTRA categories, the distribution was 53.4%, 41.6%, and 5.0%, respectively. Using the KOSTRA categories gave even more extreme results for the high group with a tendency of an increase in the caries increment across birth cohorts: ΔD_{3-5}MFT = 0.10 (95% CI: ±0.13). Further details for the KOSTRA model are available in Additional file 1: S7 and Fig. S7.1.

The differences between the elevation (mean) and the slope of the regression lines for the three baseline caries groups were small compared to the variation between individuals (Fig. 4b). Nevertheless, the adjusted pseudo R-squared was 0.079, which means that it increased 39.5 times compared to the model using only the cohort as a predictor. Considering the difference in elevation of the three regression lines compared to the variability of the raw data (Fig. 4b), the variability explained by the model was considered both biologically and statistically significant.

The effect of sex

The mean caries increment for the study sample was lower in females than in males, $\Delta D_{3-5}MFT_{Female}$= 2.45 (95% CI: 2.39–2.50) and $\Delta D_{3-5}MFT_{Male}$= 2.57 (95% CI: 2.51–2.63), Table 2. This was supported by the model where females had a lower ΔD_{3-5}MFT compared to males (Additional file 1: Fig. S9.1; chi-square = 79.92, df = 2, $p < 0.001$). Please note that this is not the same as having lower caries experience in general.

The analysis of the effect of sex on ΔD_{3-5}MFT revealed no interaction between sex and birth cohort (Additional file 1: S9 and Fig. S9.1; chi-square = 4.64, df = 2, $p = 0.098$). In other words, the regression lines for females and males had the same slope. Similar to the model using only the cohort as a predictor the adjusted pseudo R-squared value was low (0.002) due to the large variability between individuals compared to the effect of sex.

Discussion

Across birth cohorts from 1996 to 2002, a modest decline was observed in the caries increment between ages 12 and 18 years. Furthermore, compared to the group with high baseline caries experience (D_{3-5}MFT and D_{1-2}T at 12 years) both the intermediate and low baseline caries groups, showed stronger reductions in ΔD_{3-5}MFT across the birth cohorts. Overall mean ΔD_{3-5}MFT was higher in the high baseline D_{3-5}MFT and D_{1-2}T groups compared to the low and intermediate groups. Females had slightly lower caries increments compared to males, but there was no effect of sex on the change in increments across cohorts. Notably, the effect of cohort or sex on caries increments was small compared to the variability in increments between individuals.

Innovative aspects of this study are that, instead of presenting temporal trends in caries experience during the 12–18-year period using data from repeated cross-sectional studies, we adopted a longitudinal design comprising seven birth cohorts, and we were able to report individual caries increments. Another innovative aspect was our investigation of the enamel caries increment during adolescence as a separate component.

Compared to the number of studies targeting early childhood caries, fewer have restricted their analyses to caries in adolescence, and only sporadic studies have included data on enamel caries. Furthermore, some of the previous studies have used surface level caries (DMFS) [28, 29], which cannot be compared to the DMFT values in the present study. Of the studies reporting DMFT values, some originated decades ago and are also not fully comparable [30, 31]. David et al. reported relatively high D_{3-5}MFT scores at age 12 years (1.9) and 18 years (6.1) in Norway [30] based on examinations in 1993 and 1999. The Källestål & Wall study [31] reported a DMFT of 1.48 (enamel caries not included) in 12-year-olds from examinations conducted before 2000. In contrast, the more recent Splieth et al. study [32] in Germany, also with examinations of 12-year-olds reported the DMFT (enamel caries not included) and enamel caries experience to be 0.44 and 0.52, respectively. These values lie below our findings of D_{1-2}T = 1.13 and D_{3-5}MFT = 1.16 at age 12 years. One explanation for the low scores in the German study might be that the exam did not include radiographs. The André Kramer et al. study in Sweden [33] took radiographs when indicated (i.e., when surfaces could not be visually inspected or based on risk assessment) and reported a DFT (D: manifest caries that clearly extended into the dentin), of 0.7 in 12-year-olds and 2.5 in 18–19-year-olds. The study was conducted in 2007–2009 and had caries values lower than our findings at both 12 and 18 years of age. Consistent with recent literature [6], findings in the present study revealed that enamel caries comprised approximately half of the caries load at 12 and at 18 years. This finding indicates a preventive opportunity during adolescence, as caries can be arrested at the enamel level, thereby avoiding the need for restorative treatment.

Compared to the change in caries increment across cohorts, the variation in caries increments between individuals, both ΔD_{1-2}T and ΔD_{3-5}MFT, was large. This demonstrates the importance of recognizing variation between individuals and not only mean values in different groups or across cohorts, when evaluating caries increments. The work of reducing caries increments in the teenage years can progress only when we understand the factors underlying this large variation between individuals. In addition, even though the modest caries increment reduction across cohorts has limited clinical significance in the short time span that this study covers, a sustained decrease will eventually enhance dental health in the population overall. Our study shows that caries experience up to 12 years of age explains some of the variation, which means that caries-preventive measures before the teenage years should be considered. This is in line with the literature; Warren et al. [34] identified a wide range in the caries increment from the age of 13 to 17, where one group had virtually no caries incidence and another group experienced high caries incidence.

Past caries experience is a powerful caries predictor [12]. A recent study by Brusius et al. [35] found that adolescents with past caries experience at the cavity level at 12 years had a two-fold higher risk of caries increment at 14–15 years than those with no caries experience. These findings correspond to the higher mean ΔD_{3-5}MFT in the high baseline D_{3-5}MFT group compared to the low and intermediate baseline caries experience groups in our study. Even though the potential for improvement is larger in adolescents with overall higher increment levels, the recorded modest reduction in caries increment across cohorts in our study, was driven by adolescents with no (low) or low–medium (intermediate) caries experience at baseline (12 years). The group of adolescents with a high caries experience at baseline experienced no reduction in caries increment across cohorts. This is in line with the Swedish National Public Health Report [36], which found that the mean caries experience among the most severely affected 12-year-olds was higher in 2005 than in 1997, although we investigated a slightly different time period. In our study the effect sizes for these differences across cohorts are relatively small. However, if this pattern prevails over time, it implies increased dental health disparities. Our findings reflect a polarization of caries disease, where children who experience caries are also more likely to maintain a higher caries burden throughout adolescence. It is widely acknowledged that dental caries is unequally distributed and there are persistent reports of a socioeconomic gradient, with subgroups of the population being disproportionately affected [37, 38]. The World Health Organisation (WHO) presents a framework of determinants for oral health [39] which conceptualizes how oral health is influenced by environmental, political, and socioeconomic, as well as commercial determinants. These structural determinants have an impact on individuals' socioeconomic status and the conditions under which we live. This will in turn influence our opportunities and choices, and the behaviors we adopt [4, 39]. Within this framework, interventions can be implemented at all levels to reduce inequalities in dental health [40]. Interventions on the broader political and social levels are potentially more efficient, but more challenging to implement than clinical preventive interventions [4]. Our findings show that a polarization in the caries burden was present already at 12 years of age, highlighting that interventions at any level should be implemented from early childhood and onwards.

Sex has been investigated as a possible caries predictor during adolescence. Karlsson et al. [28] showed in their follow-up study that although females had a higher caries risk than males at baseline (12 years), by the age of 17, their risk was lower than for males. Likewise, André Kramer et al. [33] found that 16–19-year-old females had a lower caries risk than males, while among 12-year-olds and younger (7–12 years), females had a higher risk. Our results found a similar trend, as the mean caries increment from 12 to 18 years of age was slightly lower for females than males. However, it should be noted that in our material, the effect size of this difference was small, and sex did not affect the change in increments across cohorts.

The modest reduction in caries increments across cohorts and other findings in our study may have been influenced by dental health policies and interventions. In 2018, the national guidelines "Dental health services for children 0–20-year-olds" were published [18]. Even though this was in the last part of the time span covered by our study, the work with these guidelines started years earlier and involved the PDS throughout the country, which may have induced an increased awareness of dental care for children and adolescents. The guidelines highlight the use of motivational interviewing (MI) [41], a method applied to activate the patients' motivation, in working with oral health behaviour change. During the period 2012–2015, the PDS in Trøndelag arranged a course in motivational interviewing for dental health personnel with two times one-day training sessions. One would expect an increased adoption of motivational interviewing following this training may have affected our findings. A study conducted in 2022 in Trøndelag PDS [42] reported that 78% of dental hygienists and 50% of dentists used motivational interviewing with their adolescent patients. The same study revealed that their experience in using the method varied and they also suggested that external conditions in some adolescents' lives, made it difficult to change oral behaviours. This may also be reflected in our findings, with some individuals carrying a larger caries burden at 12 years of age, and the lack of careis increment reduction across cohorts found in this group during adolescence. These individuals may need an intervention approach addressing the social determinants of dental health.

Strengths of the present study include the large population-based sample and thorough statistical methods, including the use of models that accounted for the skewed distribution. Tests of the robustness of the findings revealed similar caries increment reductions both when selecting only participants that enabled calculation of individual values and when using data that included all individuals. Following current recommendations in oral epidemiology [43], we also investigated enamel caries increment. Weaknesses of the study include a high number of examiners, suboptimal examiner training in caries diagnostics before and during the study period, and no assessment of examiner reliability. Studies based on dental records would benefit from regular calibration sessions with standardized reability measurements being fully implemented in the dental services. Furthermore, in cohorts with many examiners caries registrations of under- and over-estimates are inevitable, regardless of whether the diagnostic tool has been used for years and is well incorporated. Nevertheless, systematic bias is reduced when there is many examiners, and for large studies Hausen et al. [44] have indicated that caries data in public health records are not decisively inferior to those obtained from examinations by trained and calibrated examiners. In the present sample population, negative caries increments for enamel caries and at dentin level were recorded in 5.0% and 0.4% of the individuals, respectively. These negative increments can be explained by the relatively long timespan between baseline and follow-up registration that opens to both inter- and intra-examiner disagreement. As for enamel caries observed at 12 years, it may have undergone regression or complete healing or have further progressed into the dentin layer at 18 years. Reversal of the caries increment at the dentin level may partly be explained by the concept of minimally invasive dentistry where caries in the outermost layer of dentin is treated non-operatively, as non- and minimally invasive treatment strategies are well adopted among Norwegian dentists [45]. Hence, by well-controlled brushing with fluoride toothpaste caries may be arrested and later registered as enamel caries.

Conclusions

In this Norwegian adolescent population, there was modest temporal reduction in enamel caries increment and in caries increment at the dentin level across seven birth cohorts (1996–2002). However, this reduction was small compared to the variation in caries increment between individuals. Females had a slightly lower mean caries increment compared to males, but the change across cohorts was the same for both sexes. Adolescents with high baseline caries experience at 12 years had the highest mean caries increment and a reduction in caries increments across cohorts was only found in those with low and intermediate baseline caries experience. If this reflects a continuing trend, it suggests an increasing disparity in dental health among Norwegian adolescents.

Abbreviations

DMFT/S	Decayed, Missing, and Filled Tooth/Surfaces
PDS	Public Dental Service
KOSTRA	Municipality-State-Reporting (Norwegian: Kommune-Stat-Rapportering)
ZIP	Zero-inflated Poisson
CI	Confidence interval
IQR	Interquartile range
WHO	World Health Organization

Supplementary Information

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Supplementary Material 1: Supplementary information on caries grade diagnosis system, description of the statistical modelling, and R summary outputs for the final models used and presented in the main manuscript. In addition, presentation of different models exploring the possible effect of baseline caries experience at 12 years or sex on the caries increment.

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Author contributions

All authors contributed to the concept and design of the study. BH managed the data acquisition and KHMJ conducted the statistical analysis. All authors contributed to interpretation and discussion of the findings. KHMJ, MSS, RKE, TB, and HH wrote the manuscript. All authors contributed to a critical review and revision of the manuscript, gave their final approval, and agreed to the submission.

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Data availability

Caries data at the national and county level from the KOSTRA statistics are available at Statistics Norway (https://www.ssb.no/). Caries data at the individual level were extracted from dental records held by the Public Dental Service, Trøndelag County, Norway. These datasets are not publicly available due to a lack of informed consent and ethical approval for public data sharing. Further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

The Regional Committees for Medical and Health Research Ethics in Norway reviewed and approved the present study protocol (approval no. 217487/REK Central). The approval included dispensation from informed consent for extracting caries data from dental health records in the PDS in Trøndelag County. The Norwegian Agency for Shared Services in Education and Research also evaluated the study (ref. no. 726897). This study was performed in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

Co-author Abhijit Sen is a member of the BMC Oral Health Editorial Board and hence has a competing interest as defined by BMC. The other authors declare that they have no competing interests.

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