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Differential Unmet Needs and Experience of Restorative Dental Care in Trajectories of Dental Caries Experience: A Birth Cohort Study

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Dental caries susceptibility · Birth cohort · Life course perspective · Epidemiologic studies · Public health dentistry

Abstract
Dental caries is a chronic and cumulative disease but little has been reported on the continuity of the disease and its treatment through life. Group-based multi-trajectory modeling was used to identify developmental trajectories of untreated carious tooth surfaces (DS), restored tooth surfaces (FS), and teeth extracted due to caries (MT) from ages 9 to 45 years in a New Zealand longitudinal birth cohort, the Dunedin Multidisciplinary Health and Development Study (n = 975). Associations between early-life risk factors and trajectory group membership were examined by specifying the probability of group membership according to a multinomial logit model. Six trajectory groups were identified and labeled: "low caries rate"; "moderate caries rate, maintained"; "moderate caries rate, unmaintained"; "high caries rate, restored"; "high caries rate, tooth loss"; and "high caries rate, untreated caries". The two moderate-caries-rate groups differed in count of FS. The three high-caries-rate groups differed in the relative proportion of accumulated DS, FS, and MT. Early childhood risk factors associated with less favorable trajectories included higher dmfs scores at age 5, lack of exposure to community water fluoridation during the first 5 years of life, lower childhood IQ, and low childhood socioeconomic status. Parent self-ratings of their own or their child's oral health as "poor" were associated with less favorable caries experience trajectories. Children who had clinical signs of dental caries together with a parent rating of child's oral health as poor were more likely to follow a less favorable caries trajectory. Higher deciduous dentition caries experience at age 5 years was associated with less favorable caries trajectories, as were children whose parents gave "poor" ratings of their own or their child's oral health. These findings highlight the considerable intergenerational continuity in dental caries experience from early childhood to midlife. Subjective measures of child oral health are informative and might aid as predictors of adult caries experience in cases where childhood dental clinical data were not available.

Introduction

Although dental caries rates among children in New Zealand (NZ) have been declining over the past 4 decades [Ruiz et al., 2022], it remains a problem among the most disadvantaged groups in NZ [New Zealand Ministry of

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Health [2010]; Shackleton et al. [2018] and globally [Peres et al., 2019]. Such persisting inequality indicates a need for a different approach toward prevention and treatment. Given the multifactorial etiology and complex nature of dental caries, there is no universal solution for its management. It has been advocated that complex approaches – that include structural [Thomson et al., 2004], universal, and individual strategies [Macpherson et al., 2019] – must be employed.

To address oral health inequalities, an understanding of the life-course perspective is essential. The life-course model provides a framework under which strategies to address inequality can be designed and tested [Nicolau and Marcenes, 2012; Peres et al., 2020]. Disadvantage starts before birth and accumulates throughout life [Marmot, 2010]. The early-life environment has profound effects on individuals' subsequent life-course trajectories and their future experience of disease [Poulton et al., 2002; Peres et al., 2011, 2019]. This means that any action to ameliorate health inequalities should start early and be followed throughout life. Given that dental caries is a chronic, cumulative condition, the life-course model offers the ideal scenario for understanding its determinants and early-life predictors of tooth decay.

Previous reports from a representative NZ birth cohort study described the natural history of dental caries from birth into adult life. In that work, group-based trajectory modeling was used to identify developmental trajectories of caries experience into early adulthood [Broadbent et al., 2008, 2013]. Those findings suggested that individuals could be assigned to three caries experience patterns of change – or trajectories – and that the caries increment was relatively constant through to the fourth decade of life [Broadbent et al., 2013]. To date, it remains unclear whether characterizing trajectories of caries experience – by examining the past and present disease components – could also inform about unmet needs or access to care. The latter would be important for understanding whether some aspects of oral health inequalities are more related to experience of disease or to treatment of disease.

In the interest of understanding permanent dentition caries trajectories and their association with some early-life predictors in a longitudinal study of New Zealanders, the aims of this study were to: (1) describe the combined developmental trajectories of caries experience and its management by modeling untreated carious tooth surfaces (DS), restored tooth surfaces (FS), and teeth extracted due to caries (MT) from childhood to mid-adulthood (ages 9–45 years); and (2) identify early childhood oral health risk factors associated with trajectory group membership.

Materials and Methods

Participants

Participants were members of the Dunedin Multidisciplinary Health and Development Study (DMHDS), a longitudinal investigation of a population-representative birth cohort of 1,037 individuals (91% of eligible births; 52% boys) who were born between April 1972 and March 1973 in Dunedin, New Zealand. The cohort represented the full range of socioeconomic status (SES) of NZ's South Island, and is primarily NZ/European white (93%), matching South Island demographics [Poulton et al., 2015]. Assessments were carried out at birth and ages 3, 5, 7, 9, 11, 13, 15, 18, 21, 26, 32, 38, and most recently (completed April 2019) 45 years, when 94% (n = 938) of the 997 participants still alive took part [Poulton et al, 2020]. Study members have been assessed on physical and mental health domains, social circumstances, development, and well-being. Oral examinations were conducted at 5 (first dental assessment), 9, 15, 18, 26, 32, 38, and 45 years of age, with clinical data on dental caries, periodontal disease, oral hygiene, enamel defects, and other oral health-related components (parent's ratings, service use, toothbrushing, and snacking behaviors) were collected accordingly. For a detailed description of oral health examinations, see online supplementary Tables S1 and S2 (for all online suppl. material, see https://doi.org/10.1159/000530378).

Outcome Measures

The present study uses dental data collected at ages 5, 9, 15, 18, 26, 32, 38, and 45 years. At each age, dental examinations were conducted by dentists according to WHO methods [World Health Organization, 1977]. Teeth were examined for dental caries and restorations, with four surfaces being considered for canines and incisors, and five surfaces for premolars and molars. Caries experience was summarized using the dmf/DMF index at the surface and tooth levels [Klein et al., 1938]. Further details on previous dental examinations have been reported elsewhere [Evans et al., 1980; Broadbent et al., 2008; Hong et al., 2020]. The three primary outcome measures in this study were DS, FS, and MT from ages 9 to 45 years (age-5 DMF data were not available because no participants had caries in permanent teeth at that age).

Early-Life Risk Factors (Childhood Predictors of Trajectory Group Membership)

Deciduous dentition caries experience at age 5 years was summarized using the dmfs index. For some analyses, Study members were classified as caries-free (dmft = 0), moderate caries experience (dmft = 1–4), or high caries experience (dmft≥5). Oral hygiene was measured at age 5 years using the Simplified Oral Hygiene Index modified for deciduous teeth [Greene and Vermillion, 1964], and these scores were z-standardized.

Parents were asked whether their child's frequency of toothbrushing with fluoridated toothpaste was at least twice a day, and whether this was supervised. Additionally, they were asked whether their child had yet visited the school dental service for dental check-up. "Cariogenic snacking" was characterized as "present" if Study members consumed cariogenic snacks at least 5 nights per week, and "not present" if it was less frequent. Fluoridation exposure based on household address data was used to allocate children to one of three categories for residence in a fluoridated area: (1) their whole lives (birth to age 5 years); (2) part of their lives (at least 3 months); or (3) never.

Parents' ratings of their own and the child's oral health were recorded when Study members were 5 years old. Parents were asked to assess their child's dental health. For analysis, responses were trichotomized into "Very Good/Moderately good," "Average," and "Moderately poor/Very poor/Don't know." They were also asked about their own oral health using the question "If you have your natural teeth, how would you grade your own dental health?" For analysis, responses were trichotomized into "Excellent/Fairly good," "Average," and "Fairly poor/Very poor/Don't know/Edentulous."

Childhood SES was estimated as the average of the highest level of either parent using the Elley-Irving scale of occupational SES [Elley and Irving, 1976], which had been assessed at birth and at ages 3, 5, 7, 9, 11, 13, and 15 years. Individual scores were allocated to high, medium, and low SES categories. Childhood IQ was assessed using the Wechsler Intelligence Scale for Children–Revised (WISC–R) [Wechsler, 1974], administered to the participants at ages 7, 9, and 11 years. The IQ variable used for the current analyses was the averaged measure of IQs determined at these three ages, standardized to population norms with a mean of 100, and a standard deviation of 15 [Caspi et al., 2020]. For a detailed description of these early-life risk factors, see online supplementary material.

Data Analysis

Group-based multi-trajectory modeling [Nagin et al., 2018] was used to identify caries experience developmental trajectories using multiple indicators: DS, FS, and MT – all of which are distinct features of the DMF index (count of decayed, missing, or filled surfaces/teeth) – from ages 9 to 45 years. This statistical tool allows identifying latent clusters of individuals following similar trajectories across multiple indicators of an outcome of interest [Nagin et al., 2018] and monitor their patterns of change within the course of a disease or phenomenon. Analyses used Stata/SE 17.0 (StataCorp LLC, College Station, TX, USA) and the *traj* plug-in [Jones and Nagin, 2013] and were restricted to participants for whom dental data were available from at least three assessment ages (n = 975). For the three models (DS, FS, and MT), the censored normal distribution was used, with censors set at values beyond the range of observed data values. As recommended [Nagin, 2005], a two-stage process was conducted for model selection. The first stage focused on the choice of the number of groups to include in the model; the second focused on determining the preferred order of the polynomials specifying the shape of each trajectory. In the former, we fitted models with between 3 and 8 groups and used model-fit-statistics and content knowledge to select the final model. We did not test beyond 8 groups, in order to preserve parsimony. In the latter, we used cubic, quadratic, and linear polynomial orders to fit the DS, FS, and MT models, respectively. We compared models' Akaike's information criterion, Bayesian information criterion, sample size-adjusted Bayesian information criterion, and Entropy. Given how the latter are calculated for these models, larger – more positive – values indicate better fitting models [Nagin and Odgers, 2010]. Subsequently, model adequacy was assessed based on recommended criteria considering average probabilities of group membership for individuals assigned to each group, the odds of correct classification, and reasonably tight confidence intervals around the estimated group membership probabilities. See online supplementary Tables S3 and S4 for model selection details.

We examined associations between early-life risk factors (time-stable covariates) and the probability of following a particular trajectory. The childhood risk factors included in the final multivariable model were those associated ($p < 0.05$) with trajectory group membership in the bivariate models. The association of early-life risk factors with trajectory group membership was examined by specifying the probability of trajectory group membership modeled with a multinomial logit function. Parameter estimates from the models without any predictors were used as the starting values for the trajectory parameters in the model with the predictors (including early-life risk factors). Subsequently, the model-predicted values were checked so that they did not differ substantively across the models with and without the time-stable early-life predictors.

We then examined two alternative models. Probability of group membership was regressed again on the early-life risk factors, but age-5 caries experience was substituted by parent's ratings of child's oral health or parent's self-rated oral health, in order to examine associations between these subjective measures of oral health at age 5 years and subsequent trajectory group membership. Reporting of data complied with STROBE guidelines.

Results

Identifying Permanent Dentition Caries Trajectory Groups

Caries trajectories were calculated for 975 study participants. The selected trajectory model included six trajectory groups, with trajectories following a cubic function for DS, a quadratic function for FS, and a linear function for MT. Figure 1 shows the plotted trajectories of permanent dentition caries experience into mid-adulthood, with 95% confidence intervals.

The findings reveal several patterns. The first group accounted for 43.9% of the cohort (n = 431), and was labeled "low caries rate" group. They did better across the three measures (DS, FS, and MT) than those who followed any other trajectory, with low untreated caries, restored surfaces, and teeth missing due to caries. The second and third groups were similar in their (moderate) caries rates, with the most caries experience observed around ages 26 and 32 years. What distinguished these two groups was the number of fillings, whereby in the "moderate caries rate, maintained" group (24.6% of participants, n = 240) there was a rising number of restored surfaces that roughly doubled the count of FS in the "moderate caries rate, unmaintained" group (20.0%, n = 194). These groups were labeled "maintained" and "unmaintained," to reflect their differential experience of restorative dental care. The last three groups had high caries rates; however, they differed in the relative proportion of dental caries that had been treated with dental restorations (FS), extractions (MT), or remained untreated (DS). The fourth group

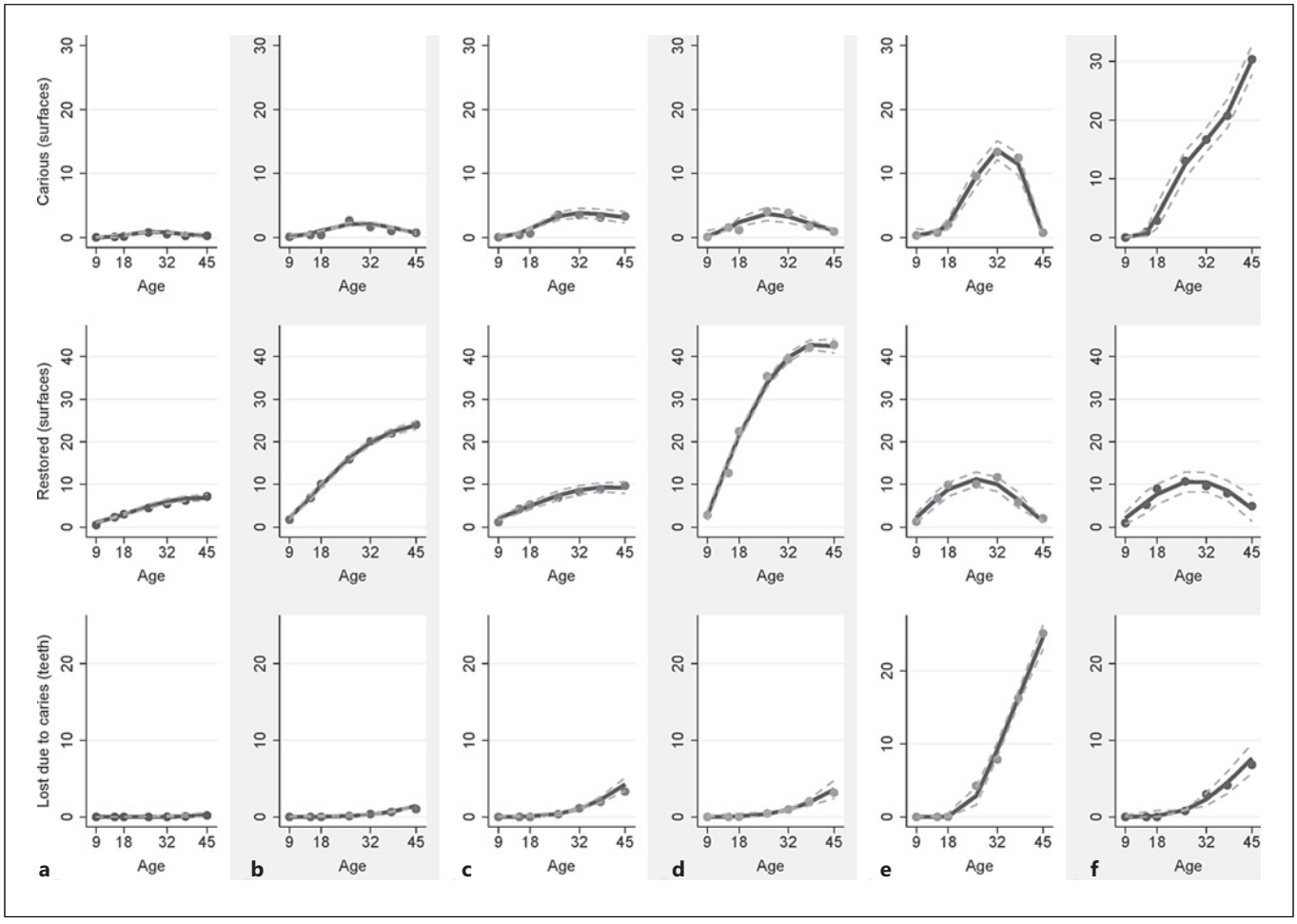

Fig. 1. Multi-trajectory model for permanent dentition caries (n = 975). Panels (**a–f**) show the six groups (viewed vertically) and the % group membership or proportion assigned to that group. **a** Group 1: Low caries rate (43.9%). **b** Group 2: Moderate caries rate, maintained (24.6%). **c** Group 3: Moderate caries rate, unmaintained (20.0%). **d** Group 4: High caries rate, restored (5.9%). **e** Group 5: High caries rate, tooth loss (3.3%). **f** Group 6: High caries rate, untreated caries (2.2%).

(5.9%, n = 57), labeled "high caries rate, restored," is characterized by a distinctly increasing number of restored surfaces. The fifth group (3.2%, n = 31), labeled "high caries rate, tooth loss," showed declining trajectories of DS and FS from age 32 years which corresponded with an increasing trajectory of missing teeth due to caries. The last group (2.2%, n = 22) labeled "high caries rate, untreated caries" showed an increasing trajectory of DS that might have not yet peaked by age 45 years.

Early-Life Risk Factors for Permanent Dentition Caries Trajectories (Predictors of Trajectory Group Membership)

Profiles of early-life characteristics for the trajectory groups identified – based on posterior probability – are reported in Table 1. For example, of the Study members who as children had been exposed to community water fluoridation (CWF) for their entire lives (birth to age 5 years), around 46% were assigned to the "low caries rate" group, and only 10% to the "high caries rate" groups. Furthermore, among those who as children were categorized as high SES, nearly 60% were assigned to the "low caries rate" group and fewer than 10% to the "high caries rate" groups. Of all potential early-life risk factors examined in bivariate analyses (online suppl. Table S5), deciduous dentition dental caries experience, z-standardized plaque score, and children's exposure to CWF by age 5 years were associated with less favorable permanent dentition caries trajectories ($p < 0.05$). Low-SES children were more likely (than medium- or high-SES children)

Table 1. Permanent dentition caries trajectory profiles based on posterior probabilities* for group assignment (% indicates row percentage)

Variable	Group					
	low caries rate	moderate caries rate, maintained	moderate caries rate, unmaintained	high caries rate, restored	high caries rate, tooth loss	high caries rate, untreated caries
Caries experience at age 5 years (%)						
Caries free	55.9	17.0	19.6	2.8	1.7	3.1
dmft 1–4	41.2	28.2	20.6	5.3	3.2	1.5
dmft 5+	24.2	36.3	18.7	13.7	4.9	2.2
Presence of untreated caries (%)						
0 dt	48.6	21.9	20.3	4.8	2.2	2.2
1+ dt	31.2	34.0	18.6	9.1	4.7	2.4
dmfs (SD)	2.2 (4.0)	5.4 (7.3)	4.1 (6.9)	6.8 (6.0)	4.2 (4.0)	3.7 (6.8)
dmft (SD)	1.6 (2.4)	3.4 (3.6)	2.5 (3.4)	4.4 (3.5)	3.1 (2.7)	2.2 (3.5)
Z-standardized plaque score at age 5 years (SD)	−0.1 (1.0)	−0.2 (0.9)	0.1 (1.0)	0.3 (1.0)	0.6 (1.3)	0.5 (1.2)
Toothbrushing with fluoride toothpaste at age 5 years (%)						
2+ daily	44.4	25.2	20.4	4.1	2.9	3.1
< twice/day	43.0	25.5	19.2	7.8	3.0	1.5
Toothbrushing supervision at age 5 years (%)						
Child brushes alone (no supervision)	36.1	23.7	28.3	5.9	4.1	1.8
Occasionally supervised	45.4	26.1	16.9	7.1	2.4	2.1
Usually/always supervised	47.5	25.4	16.9	4.2	3.0	3.0
Child use of dental services at age 5 years (%)						
Visited SDS for dental check-up	43.2	26.9	20.1	5.7	2.0	2.0
Did not visit SDS for dental check-up	44.4	22.8	19.2	6.5	4.4	2.7
Cariogenic snack (nights/week) at age 5 years (%)						
0–4	44.7	26.2	18.5	5.5	2.8	2.3
5+	42.1	22.5	22.5	7.2	3.3	2.4
CWF during first 5 years of life (%)						
All-life	45.8	23.0	21.3	5.5	2.6	1.8
Part-life	39.8	34.1	12.5	5.7	3.4	4.5
No CWF	29.9	35.6	14.9	10.3	5.7	3.4
Parent's ratings of child's oral health at age 5 years (%)						
Very good/Moderately good	49.3	21.9	20.7	4.5	1.8	1.8
Average	35.7	30.7	17.8	8.3	4.6	2.9
Moderately poor/Very poor/DK	28.9	32.5	19.3	9.6	6.0	3.6
Parent's self-reported oral health at age 5 years (%)						
Excellent/Fairly good	53.9	19.6	20.7	3.2	0.7	1.8
Average	44.1	26.4	19.5	5.4	2.7	1.8
Fairly poor/Very poor/ Edentulous/DK	32.2	30.0	19.1	9.7	5.6	3.4
Sex (%)						
Female	47.9	24.1	16.1	6.9	4.4	0.6
Male	40.6	25.2	23.5	4.8	2.0	3.8
Childhood SES (birth to age 15 years, %)						
High	58.0	24.8	10.2	5.7	0.0	1.3
Medium	45.3	25.5	19.5	5.7	2.4	1.6
Low	29.9	21.3	28.9	6.6	8.1	5.1

Table 1 (continued)

Variable	Group					
	low caries rate	moderate caries rate, maintained	moderate caries rate, unmaintained	high caries rate, restored	high caries rate, tooth loss	high caries rate, untreated caries
Standardized childhood IQ[a]	103.5 (13.4)	101.1 (13.5)	95.4 (15.0)	98.9 (12.8)	91.3 (16.3)	94.6 (14.8)

SDS, school dental service; CWF, community water fluoridation; DK, don't know; SES, socioeconomic status based on the average of the highest occupation level of either parent assessed repeatedly for each participant at 3, 5, 7, 9, 11, and 15 years of age. [a]The Wechsler Intelligence Scale for Children–Revised (WISC–R) was administered to the participants at ages 7, 9, and 11 years. *Posterior probability assigns participants to the group that most likely generated their data.

to follow an unfavorable caries trajectory. By contrast, children with a higher IQ were more likely to follow the "low caries rate" trajectory. Toothbrushing practices were not included in the final model because they exhibited specific associations only with trajectory group membership, whereby children who were occasionally and usually supervised during toothbrushing were less likely than children that brushed alone to be assigned to the "moderate caries, unmaintained" group (relative to the "low caries rate" group).

In the final model including early-life risk factors (Table 2), higher dmfs scores at age 5, lack of exposure to CWF during the first 5 years of life, lower childhood IQ, and low childhood SES were associated with less favorable permanent caries experience trajectories. Men were more likely than women to be assigned to the "moderate caries rate, unmaintained" and the "high caries rate, untreated caries" groups. Higher childhood IQ was associated with lower odds of being assigned to any unfavorable trajectory.

Children whose parents gave "poor" ratings of their own or their child's oral health were more likely to follow the less favorable trajectories (Table 3). Additionally, children having clinical signs of dental caries (dmft>0) – combined with a parent rating their child's oral health as poor – were more likely to follow less favorable permanent caries experience trajectories (online suppl. Table S6).

Discussion

This study investigated the longitudinal trajectories of DS, FS, and MT in the permanent dentition from childhood into middle age. Using group-based multitrajectory modeling, we identified six trajectory groups. Three main findings emerge from our data. First, there is continuity in disease experience, whereby higher caries experience at age 5 years was associated with higher caries experience by midlife. Second, early-life risk factors associated with less favorable trajectories included a higher dmfs score at age 5 years, lack of exposure to CWF during the first 5 years of life, lower childhood IQ, and low childhood SES. Third, poor parental self-ratings of oral health and of child's oral health predicted membership of less favorable trajectories.

Limitations of this study should be considered. Some of these have been previously discussed, such as the lack of radiographs [Broadbent et al., 2013] and the need to interpret trajectory analysis findings about specific groups with caution [Murray et al., 2022]. Our modeling includes one group comprising only 2% of participants and our analyses were likely underpowered to detect associations involving that group; however, those data showed a unique trajectory characterized by untreated caries. The study has also some notable strengths. First, it used a population-based cohort followed from birth with a high participation rate (94%) after 5 decades, and caries experience was measured under standardized protocols using appropriate data quality control procedures. Participants are primarily of NZ European ethnicity and the findings can be generalized to similar populations.

To our knowledge, this is the first study to model trajectories of the components of the DMF index, providing insights about caries and its treatment over the lifecourse. The groups were described according to rates of caries and its management. The group with "low caries rate" (44% of the cohort) was characterized by generally negligible levels of untreated decay and tooth loss with few restored surfaces by midlife. The groups labeled "moderate caries rate, maintained" and "moderate caries rate, unmaintained" (25% and 20% of the cohort, respectively) had similar rates of caries but differed markedly in the number of restored surfaces, reflecting better access to restorative

Table 2. Associations between early-life risk factors and permanent dentition caries trajectory groups ($n = 877$ observations used in the trajectory model)

Risk factor	Permanent dentition caries trajectory groups									
	moderate caries rate, maintained[a] OR (95% CI)	*p*	moderate caries rate, unmaintained[a] OR (95% CI)	*p*	high caries rate, restored[a] OR (95% CI)	*p*	high caries rate, tooth loss[a] OR (95% CI)	*p*	high caries rate, untreated caries[a] OR (95% CI)	*p*
dmfs at age 5	1.16 (1.11, 1.21)	<0.001	1.13 (1.07, 1.18)	<0.001	1.17 (1.11, 1.23)	<0.001	1.09 (1.00, 1.18)	0.038	1.08 (0.98, 1.19)	0.115
Z-standardized plaque score	0.79 (0.65, 0.97)	0.026	1.03 (0.82, 1.29)	0.827	1.25 (0.93, 1.69)	0.142	1.46 (0.99, 2.14)	0.054	1.31 (0.86, 2.00)	0.206
CWF during first 5 years of life										
All-life	Ref									
Part-life	1.76 (0.98, 3.14)	0.057	0.75 (0.31, 1.81)	0.525	1.14 (0.39, 3.34)	0.805	1.43 (0.35, 5.81)	0.616	3.26 (0.92, 11.60)	0.068
No CWF	2.29 (1.25, 4.21)	0.008	1.01 (0.42, 2.39)	0.991	2.55 (1.06, 6.13)	0.037	3.28 (1.04, 10.36)	0.043	3.27 (0.76, 13.98)	0.110
Sex										
Female	Ref									
Male	1.41 (0.97, 2.05)	0.075	2.17 (1.36, 3.47)	0.001	0.86 (0.47, 1.60)	0.644	0.73 (0.29, 1.83)	0.503	11.52 (2.31, 57.62)	0.003
Childhood SES[b]										
High/ Medium	Ref									
Low	1.21 (0.71, 2.05)	0.479	2.42 (1.41, 4.17)	0.001	1.23 (0.56, 2.69)	0.605	4.34 (1.74, 10.85)	0.002	3.54 (1.20, 10.45)	0.022
Standardized childhood IQ[c]	0.98 (0.97, 1.00)	0.034	0.95 (0.93, 0.96)	<0.001	0.98 (0.96, 1.00)	0.109	0.95 (0.92, 0.99)	0.004	0.96 (0.92, 0.99)	0.021

OR, odds ratio; CI, confidence interval; CWF, community water fluoridation. [a]Comparison group = Low caries rate trajectory group [b]Socioeconomic status based on the average of the highest occupation level of either parent assessed repeatedly for each participant at 3, 5, 7, 9, 11, and 15 years of age [c]The Wechsler Intelligence Scale for Children–Revised (WISC–R) was administered to the participants at ages 7, 9, and 11 years.

care in the "maintained" group. The remaining groups were characterized by some form of sharply increasing caries experience to midlife. One group, "high caries rate, restored" (6% of the cohort) had the highest number of fillings of all groups. The "high caries rate, tooth loss" group (3% of the cohort) showed a sharp increase in untreated caries up to age 32 years; this then fell, concomitant with a sharp increase in tooth loss. The last group, "high caries rate, untreated caries" (2% of the cohort) was characterized by steadily increasing tooth loss and untreated caries even after age 32 years. The decline in untreated caries occurring in groups four and five was consistent with the increase in fillings and tooth loss, respectively. However, the steady increase in untreated caries in the final group appears to have not yet reached its zenith. This suggests that they are currently experiencing active disease and have not received timely or appropriate care for it. This last group might also reflect a particular type of high-caries-risk individual, and it remains of interest to examine whether some identifiable set of characteristics or outcomes at age 45 years – such as low SES, unemployment, or alcohol/drug addiction – could be associated with these group differences. Within the modeling strategy, formal criteria and usability were considered to decide on the preferred number of groups [Nagin and Odgers, 2010]. Increasing from a five- to a six-group model revealed novel features of the data and not just repetition of the fifth's group trajectory shape with different rates. However, caution should be exercised when making inferences about the final group, due to its small size.

Higher dmfs scores at age 5, lack of exposure to CWF during the first 5 years of life, lower childhood IQ, and low childhood SES were associated with membership of

Table 3. Associations between early-life risk factors and permanent dentition caries trajectory groups (alternative models 1 and 2 include self-reported measures of child oral health at age 5 years; n = 877 obs. were used in each trajectory model)

Risk factor	Permanent dentition caries trajectory groups									
	moderate caries rate, maintained[a] OR (95% CI)	p	moderate caries rate, unmaintained[a] OR (95% CI)	p	high caries rate, restored[a] OR (95% CI)	p	high caries rate, tooth loss[a] OR (95% CI)	p	high caries rate, untreated caries[a] OR (95% CI)	p
Alternative model 1										
Parent's self-rated oral health										
Excellent/ Fairly good	Ref									
Average	1.79 (1.15, 2.77)	0.010	1.05 (0.61, 1.79)	0.859	1.97 (0.84, 4.63)	0.120	3.11 (0.63, 15.36)	0.164	0.97 (0.26, 3.65)	0.965
Fairly poor/ Very poor/ Edentulous/ DK	2.92 (1.80, 4.74)	<0.001	1.26 (0.70, 2.27)	0.450	4.46 (1.91, 10.41)	0.001	7.27 (1.52, 34.70)	0.013	2.08 (0.60, 7.16)	0.247
Z-standardized plaque score	0.83 (0.68, 1.01)	0.066	1.08 (0.86, 1.35)	0.513	1.29 (0.96, 1.73)	0.089	1.42 (0.96, 2.11)	0.082	1.28 (0.3 1.97)	0.266
CWF during first 5 years of life										
All-life	Ref									
Part-life	1.85 (1.05, 3.27)	0.034	0.77 (0.32, 1.84)	0.557	1.27 (0.44, 3.69)	0.655	1.64 (0.39, 6.94)	0.498	3.59 (1.00, 12.86)	0.050
No CWF	2.40 (1.33, 4.35)	0.004	1.11 (0.47, 2.60)	0.811	2.59 (1.09, 6.16)	0.032	2.87 (0.91, 9.07)	0.073	3.30 (0.78, 13.95)	0.104
Sex										
Female	Ref									
Male	1.43 (0.99, 2.07)	0.055	2.19 (1.37, 3.49)	0.001	0.85 (0.46, 1.57)	0.602	0.66 (0.26, 1.65)	0.372	11.67 (2.40, 56.69)	0.002
Childhood SES										
High/ Medium	Ref									
Low	1.16 (0.69, 1.95)	0.581	2.54 (1.48, 4.37)	0.001	1.14 (0.53, 2.48)	0.732	3.42 (1.34, 8.71)	0.010	3.26 (1.09, 9.73)	0.035
Standardized childhood IQ	0.99 (0.97, 1.00)	0.039	0.95 (0.93, 0.96)	<0.001	0.98 (0.96, 1.01)	0.130	0.96 (0.92, 0.99)	0.007	0.96 (0.92, 1.00)	0.027
Alternative model 2										
Parent's ratings of child's oral health										
Very good/ Moderately good	Ref									
Average	2.23 (1.47, 3.37)	<0.001	1.49 (0.88, 2.54)	0.138	2.81 (1.45, 5.45)	0.002	3.13 (1.21, 8.10)	0.019	1.91 (0.63, 5.81)	0.255
Moderately poor/Very poor/DK	2.62 (1.38, 4.97)	0.003	1.53 (0.69, 3.37)	0.295	3.32 (1.30, 8.48)	0.012	4.29 (1.25, 14.69)	0.021	2.21 (0.51, 9.54)	0.290
Z-standardized plaque score	0.86 (0.70, 1.04)	0.121	1.08 (0.86, 1.35)	0.496	1.36 (1.01, 1.82)	0.040	1.50 (1.01, 2.22)	0.044	1.32 (0.86, 2.03)	0.196
CWF during first 5 years of life										
All-life	Ref									
Part-life	1.69 (0.95, 2.99)	0.073	0.73 (0.30, 1.76)	0.479	1.12 (0.39, 3.24)	0.837	1.34 (0.33, 5.39)	0.681	3.34 (0.94, 11.89)	0.063
No CWF	2.93 (2.33, 3.53)	<0.001	1.24 (0.53, 2.91)	0.613	3.41 (1.43, 8.12)	0.006	3.87 (1.23, 12.21)	0.021	3.84 (0.92, 15.98)	0.065

Table 3 (continued)

Risk factor	Permanent dentition caries trajectory groups									
	moderate caries rate, maintained[a] OR (95% CI)	*p*	moderate caries rate, unmaintained[a] OR (95% CI)	*p*	high caries rate, restored[a] OR (95% CI)	*p*	high caries rate, tooth loss[a] OR (95% CI)	*p*	high caries rate, untreated caries[a] OR (95% CI)	*p*
Sex										
Female	Ref									
Male	1.52 (1.61, 5.32)	0.025	2.32 (1.46, 3.71)	<0.001	0.91 (0.50, 1.68)	0.768	0.69 (0.27, 1.76)	0.440	11.87 (2.46, 57.33)	0.002
Childhood SES[b]										
High/ Medium	Ref									
Low	1.30 (0.78, 2.18)	0.312	2.53 (1.48, 4.33)	0.001	1.32 (0.61, 2.84)	0.478	4.03 (1.61, 10.08)	0.003	3.58 (1.21, 10.58)	0.021
Standardized childhood IQ[c]	0.98 (0.97, 1.00)	0.039	0.95 (0.93, 0.96)	<0.001	0.98 (0.96, 1.01)	0.126	0.96 (0.92, 0.99)	0.006	0.96 (0.92, 0.99)	0.026

OR, odds ratio; CI, confidence interval; DK, don't know; CWF, community water fluoridation; SES, socioeconomic status (birth to age 15 years). [a]Comparison group = Low caries rate trajectory group. [b]Socioeconomic status based on the average of the highest occupation level of either parent assessed repeatedly for each participant at 3, 5, 7, 9, 11, and 15 years of age.

less favorable trajectories, which represent the groups with the highest burden of disease and the poorest access to dental care. Previous longitudinal studies have shown deciduous dentition caries experience to be associated with caries experience in the permanent dentition [Broadbent et al., 2008, 2013; Peres et al., 2009]. This study further confirms such findings but adds further context with respect to continuity in access to dental treatment and unmet need for dental care. Through its components, the dmf/DMF index – which represents past and present disease – can inform how much of that disease has been treated. Moreover, the increasing number of decayed surfaces with age in the "moderate caries rate, unmaintained" trajectory group represents unmet treatment need. The high number of FS observed in the "moderate caries rate, maintained" group likely reflects better access to dental care. Interpreting the increasing number of teeth lost due to caries in the "high caries rate, tooth loss" group is less straightforward, because it could represent the endpoint of the dental restorative cycle (by which point a tooth can no longer be saved), or as the only treatment option for deeply carious teeth that have not previously been restored, or carious teeth being removed for financial reasons that could otherwise be restored.

Social inequalities exist in a wide range of objective (number of caries lesions, restorations, and missing teeth) and subjective (self-rated oral health) aspects of oral health [Guarnizo-Herreño et al., 2014; Mejia et al., 2018]. Social inequalities in oral disease experience represent differential rates of disease. For example, there are SES gradients in periodontal disease, edentulism, and untreated decay among adults [Thomson et al., 2004; Schwendicke et al., 2015]. Similar gradients are observed for caries experience and untreated dental decay among children [Shackleton et al., 2018; Shen et al., 2021]. Oral health inequalities also manifest as uneven access to opportunity and health care. Examples include lower use of dental services among lower SES adults, or higher rates of dental treatments provided under general anesthesia among lower SES children [Thomson, 2016]. Our findings showed that Study members who were children of low SES parents were more likely to follow an unmaintained or a high caries rate trajectory (featuring tooth loss and untreated decay). The latter highlights not only differential rates of disease but also inequalities in care for that disease. Consistent with these observations, findings from an Australian population survey of adult oral health showed that the lower the household income, the greater the proportion of untreated decay and need for dental treatment, suggesting that, more than differentials in overall levels of accumulated disease (represented by the DMFT score), the greatest social inequalities arose from differences in its management (DMFT components) [Mejia et al., 2014].

Dental plaque, lack of exposure to fluoridated water supplies, and high sugar intake are known risk factors for early childhood caries [Pitts et al., 2017; Ha et al., 2021]. In

the current study, lack of exposure to CWF during the first 5 years of life was associated with higher odds of being in the less favorable groups. Early Dunedin Study findings showed that, at age 5 years, caries experience was higher among children who lived in areas exposed to CWF than among those who were not, and that it was more beneficial for those of low SES [Evans et al., 1984]. This finding has been replicated not only in a co-existing NZ birth cohort [Fergusson and Horwood, 1986] but across decades [Kamel et al., 2013; Schluter et al., 2020; Ha et al., 2021] and among many populations [Rugg-Gunn et al., 2016]. CWF has been shown to be one of the most effective public health measures in reducing not only overall caries experience but also inequalities in oral health, and more than any more targeted approaches [Shen et al., 2021]. Such evidence should not be dismissed and should lead to support for expanding CWF in countries where oral health inequalities persist.

Children whose parents had given "poor" ratings of their own oral health were more likely to follow the less favorable trajectories. These associations between parents' self-reported oral health and their children's adult trajectories provide further evidence of intergenerational continuity in oral health. Intergenerational factors – maternal experience of disease and family beliefs and behaviors – are important influences on child tooth decay. Previous age-5 years Dunedin Study findings showed consistent gradients in caries experience at age 32 years by categories of maternal self-rated oral health. Poor maternal self-rated oral health indicated risk for poor oral health among their children as they reached adulthood [Shearer et al., 2011]. As suggested in that earlier work – and in line with the current findings – asking mothers of young children about their own oral health is likely to assist in identifying children who will be most likely to experience severe caries in adulthood.

Children whose parents gave "poor" ratings of their child's oral health were also more likely to follow the less favorable trajectories, as were the children who had a combination of signs of dental decay with a parental rating of their oral health as poor. Subjective ratings of oral health can be used as valid surrogates of permanent caries experience [Thomson et al., 2012] or used as a caries risk assessment tool in the case were no clinical dental data (dmfs/dmft) are available. Some studies have shown modest associations between parents' ratings and children's oral disease status [Divaris et al., 2012; Akinkugbe et al., 2020]. Such findings might be explained by the fact that subjective health ratings – subject to personal and sociocultural factors – can taint by either magnifying or diminishing the individual perceptions of health and well-being [Jylhä, 2009]. However, recent findings of a large representative cross-sectional study of oral health of Australian schoolchildren aged 5–14 years found that more positive parental ratings and longer lifetime exposure to CWF were associated with lower caries experience in childhood. The researchers discussed that subjective ratings are not comparable to objective clinical ratings, and neither should they be judged as "right" or "wrong"; rather, they should be considered complementary information and as a different – perhaps more important to a person – dimension of health [Foley et al., 2021]. Subjective ratings are useful even when not perfectly concordant with physical health, because they embody broader concepts and can capture changes in both the explicit and the implicit components of a variable being measured [Jahedi and Méndez, 2014].

In this respect, the use of parents' ratings as a proxy for child oral health lends support to the validity of the "Lift the Lip" initiative [Centre for Oral Health Strategy, 2010]. This is a screening and caries risk assessment tool developed in Western Australia to increase awareness among families and so help prevent child decay. Non-dental health professionals are asked to regularly check children's teeth for signs of early caries and eruption abnormalities. In NZ, the "Lift the Lip" initiative was implemented within the "Well Child Tamariki Ora Programme" provided for all NZ toddlers and preschoolers and aims to detect children at risk for future oral health problems [New Zealand Dental Association, 2008]. As part of the programme health professionals are asked to lift the lip and examine the gums and teeth to detect any visible decay before children reach school age. If any is detected, the child is referred to a dental therapist or dentist for appropriate management. After the screening, parents are again encouraged to lift the lip regularly at home to check for signs of disease and to enable timely access to dental care. Our findings showed that the observed associations improved slightly when dmfs was added to parents' ratings of child oral health (Table 3 and online suppl. Table S4), supporting the use of subjective ratings to complement clinical data in determining how future disease is more likely to happen.

Good oral health in childhood lays the foundation for good oral health as an adult [Thomson et al., 2004]. The longitudinal associations between deciduous dentition caries experience at age 5 years and permanent dentition caries trajectories at age 45 were expected. Given its multifactorial, chronic nature, future research and more attention should be paid to early-life circumstances in order to minimize exposure to risk factors and maximize the long-term benefits of putting our attention into child oral health, without forgetting that risk factors commonly cluster and are deeply embedded in societal structure.

In conclusion, deciduous dentition caries experience at age 5 years was associated with higher permanent dentition caries experience by midlife, and children whose parents gave "poor" ratings of their own or their child's oral health

were more likely to follow the less favorable permanent caries experience trajectories. These findings highlight the considerable (and intergenerational) continuity in dental caries experience from early childhood to midlife. Subjective measures of child oral health are informative and might be useful as alternative predictors of adult caries experience in cases where childhood dental clinical data were not available.

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Statement of Ethics

Written informed consent was obtained from parents when participants were 3, 5, 7, 9, 11, and 13 years old, from both participants and their parents at age 15 years, and from participants in the remaining assessment ages (18 through to 45 years). Each assessment for the Study was approved by the appropriate Ethics Committee (most recently the NZ Health and Disability Ethics Committee: 17/STH/25/AM05). Research was conducted ethically in accordance with the Declaration of Helsinki.

Conflict of Interest Statement

The authors report no conflicts of interest related to this study.

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Author Contributions

B.R. analyzed the data, interpreted the findings, and drafted the paper. J.M.B. collected data, analyzed the data, interpreted the findings, and critically reviewed of the manuscript. C.L.H. collected data, supported data analysis, and critically reviewed the manuscript, W.M.T., S.R., and R.P. provided critical intellectual input in data interpretation and revising the paper. All authors have read and approved the final version of this manuscript and agree to be accountable for all aspects of the work.

Data Availability Statement

The Dunedin Study datasets reported in the current article are not publicly available due to a lack of informed consent and ethical approval for public data sharing. The Dunedin Study dataset requests involve a concept paper describing the purpose of the data access, ethical approval at the applicant's university, and provision for secure data access. Further inquiries can be directed to the director of the Dunedin Study.

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