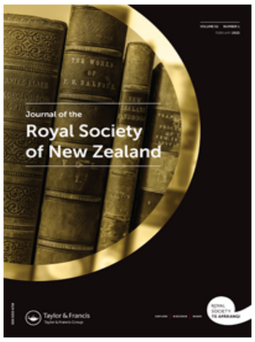

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RESEARCH ARTICLE

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Childhood caries experience in two Aotearoa New Zealand birth cohorts: implications for research, policy and practice

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ABSTRACT

Oral health in Aotearoa New Zealand has improved in the last seven decades, but improvements among young children have stagnated in the last two. Four out of ten 5-year-olds are affected by caries and many pre-schoolers require dental treatment under general anaesthesia. We analysed data from two longitudinal studies, the Dunedin Multidisciplinary Health and Development Study and the Christchurch Health and Development Study. We compared their methods, cohort characteristics and childhood oral health findings and discuss their implications for policy, research, and practice. Age 5 dmft was obtained in the Dunedin Study from clinical examinations, and from School Dental Service records in the Christchurch Study. Findings were consistent with respect to childhood socioeconomic status, exposure to community water fluoridation, and maternal education. Despite overall improvements, caries rates remain relatively unchanged: dmft in these cohorts, measured in the 1970s–1980s, resemble New Zealand's statistics for 5-year-olds in the 2000s. Notwithstanding the steep caries decline observed over the years, the caries distribution has shifted, whereby the greatest severity of disease is now concentrated among a smaller group of the most deprived children. Early childhood caries appears to be a useful indicator of deprivation that should inform interventions for those in greatest need.

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Introduction

Early childhood dental caries (ECC) remains a highly prevalent public health problem, with over 500 million children affected globally (Kassebaum et al. 2017), and involving nearly two in three children at age 5 years (Tinanoff et al. 2019). Dental data in Aotearoa New Zealand has been collected from multiple sources including national surveys, epidemiological surveys, cohort studies and routinely collected data from the School Dental Service (Hollis 1970; Hunter 1984; Fergusson & Horwood 1986; Ministry of Health 2019; Hong et al. 2020). Dental caries prevalence and severity at age 5 were

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first assessed in certain regions in the 1940s (Hewat & Eastcott 1953) and nationally in the 1950s (Department of Health 1956; Department of Health 1975) and have decreased markedly since then, yet four out of ten 5-year-old children are still affected by tooth decay today (Ministry of Health 2019) and a high number of preschool children require treatment under general anesthesia (Thomson 2016; Hunt et al. 2018). Since 1990, the Ministry of Health has collected data on the oral health of children at 5 and 12–13 years of age during each child's routine visit to the Community Oral Health Service (COHS) in each of the 20 District Health Boards (DHBs). Strong socioeconomic gradients and ethnic inequalities exist in caries experience among children and adolescents (Ministry of Health 2010; Ministry of Health 2019).

Age, period and cohort effects—which represent three ways in which health changes over time (Burton-Jeangros et al. 2015)—might have influenced the caries decline in Aotearoa New Zealand. *Age effects* refer to the changes in health as individuals progress and age through life, such as how caries experience is greater in adulthood than in childhood (Broadbent et al. 2013). *Period effects* refer to responses to events experienced by all groups in a population at different times, irrespective of age. For example, after the introduction and widespread use of fluoridated toothpaste in the 1970s in Aotearoa New Zealand, a decrease in caries rates was observed among all age groups (Ministry of Health 2010). *Cohort effects* represent changes in health that can occur over time due to differences in the composition of society as a whole (that is, they are specific to a particular generation); they represent the accumulation of lifetime exposures and the intersection of age and period effects. Caries trajectories—observed among groups of individuals that follow the same developmental course of disease and among whom progression is similar over time—might differ across generations. Caries experience increased with age at the relatively constant average rate of 0.8 permanent tooth surfaces per year in a predominantly white, European New Zealand cohort (Broadbent et al. 2008). However, this rate may differ in other population groups, such as Pacific or Māori peoples, which have experienced a different set of exposures. Understanding age, period and cohort effects in longitudinal research is important to oral epidemiology because these effects will have various implications for public health and policy.

Likewise, longitudinal research is useful when studying the natural history of chronic, cumulative oral diseases such as dental caries, because repeated measures on the same individuals over a period of time provide consistent information about disease experience (Thomson 2004). It also helps identify risk factors and treatment needs that could not otherwise be elucidated using other study designs. Oral health birth cohort studies (OHBCSs) are observational prospective studies that investigate and collect data on oral health and oral health-related characteristics. They are not common in oral epidemiology. They may have been conducted as part of a general birth cohort study or could stand alone as an independent study. Details of the available 15 ongoing long-term OHBCSs worldwide and their main findings have been reported elsewhere (Peres et al. 2020). The systematic comparison of findings and measurements across the different OHBCSs is relevant to research in oral epidemiology because replication and consistency of findings among different study populations enables confidence in the observed associations. Replication increases the robustness of findings, along with their accuracy and credibility (Poulton et al. 2020), and it may be useful in accelerating the transfer of such evidence into policies that could improve people's quality of life.

Two major Aotearoa New Zealand birth cohort studies have assessed population-based samples at multiple time points from birth to the fifth decade of life and so made important contributions to understanding the natural history of oral health conditions and their determinants. These are known as the Dunedin Multidisciplinary Health and Development Study and the Christchurch Health and Development Study (hereafter the Dunedin and Christchurch studies, respectively). For example, the Christchurch Study showed social disadvantage to be associated with lower rates of dental service use at age 5 years (Fergusson et al. 1981; Beautrais et al. 1982; Fergusson et al. 1984) but higher caries experience (Fergusson & Horwood 1986). Both studies have shown that exposure to community water fluoridation (CWF) protects against dental caries (Evans et al. 1980; Evans et al. 1984; Fergusson & Horwood 1986; Shannon et al. 1986). More recently, Dunedin Study findings have shown that caries experience in adulthood is predicted by maternal self-rated oral health (Shearer et al. 2011) and that the caries increment from adolescence through to adulthood is constant (Broadbent et al. 2008; Broadbent et al. 2013), contrary to earlier understanding of the natural history of the condition.

In both cohorts, childhood oral health was assessed more than four decades ago, but their dental findings have not yet been contrasted and compared side-by-side, and it is unclear to what extent the experience of dental caries among participants in these cohorts is similar to that experienced by Aotearoa New Zealand children today. It is possible these data still hold research findings that have not been fully realised for oral health policy in the twenty-first century. Accordingly, this study: (1) compares the methods, strengths and weaknesses, characteristics and childhood oral health findings of these two cohort studies; and (2) discusses the implications of their findings for ongoing research, practice, and policy development.

Material and methods

This report summarises and compares the childhood oral health findings from two Aotearoa New Zealand birth cohort studies: the Dunedin and Christchurch studies. The Dunedin Study is a longitudinal investigation of a population-representative birth cohort of 1037 individuals (91% of eligible births; 52% boys) born between 1 April 1972 and 31 March 1973 in Dunedin, Aotearoa New Zealand (Poulton et al. 2015). Cohort families represent the full socioeconomic status (SES) range of the South Island, and study participants are primarily of European ethnicity (7.5% self-identify as Māori, and 1.5% as Pacific people). Perinatal data was collected at birth, and the cohort for the longitudinal study was defined at age 3 years. The cohort has been assessed again at ages 5, 7, 9, 11, 13, 15, 18, 21, 26, 32, 38, and (most recently) at age 45 years, when 938 (94%) of the 997 living cohort members took part. Written informed consent was obtained, and the New Zealand Health and Disability Ethics Committee approved each assessment phase (Poulton et al. 2020). The study members have been physically examined and interviewed about their mental health and cognition, cardiovascular health, respiratory health, sexual and reproductive health, and psychosocial functioning (Poulton et al. 2015). Oral examinations have been performed at 5, 9, 15, 18, 26, 32, 38, and 45 years of age and clinical data on dental caries, periodontal disease, oral hygiene, enamel defects and other oral health-related components have been collected.

The Christchurch Study is a longitudinal study of a birth cohort of 1265 children who were born in the Christchurch urban region between 15 April and 5 August 1977. These children represented 97% of all children born in all maternity units in the Christchurch urban region during that period. Cohort families represent the full SES range of the South Island. Most participants self-identify as being of European origin, but about 13% report Māori or Pacific ethnicity. Participants were studied at birth, 4 months, annually from age 1 to 16 years, and again at 18, 21, 25, 30, 35, and age 40 years, when 904 (74%) of the 1222 living cohort members participated. Written informed consent was obtained, and each assessment was approved by the Regional Health and Disabilities Ethics Committee. Data on development, wellbeing, self-reported general health, and social circumstances has been collected from several sources (Fergusson et al. 1989). Oral health-related data has been collected at 5, 6, 7, 8, 9, 10, 11, 12, 13, and 40 years of age.

In both studies, maternal information was recorded at the time of birth or at age 5 or 6 years, and family SES was recorded using the Elley-Irving scale of socioeconomic status for Aotearoa New Zealand, which places occupations into six categories ranging from 1 = professional to 6 = unskilled labourer (Elley & Irving 1976).

Childhood oral examinations

Childhood oral health by age 5 years was first assessed in the Dunedin Study (in 1977–78), by four dentists using WHO methods (World Health Organization 1977), within one month of the participant's fifth birthday. Data on dental caries at the tooth and surface levels (buccal, lingual, distal and mesial considered for canines and incisors, and occlusal surface included for premolars and molars), oral hygiene, presence of developmental anomalies and enamel defects, and the number of abscessed and traumatised teeth was collected; details of the examination methods have been reported elsewhere (Evans et al. 1980; Evans et al. 1982; Evans et al. 1984). Additionally, data on service use and oral hygiene practices—such as toothbrushing, parental supervision, use of fluorides, and exposure to CWF—were obtained from parents' reports. At the time of data collection, most children were exposed to CWF since fluoridation commenced there in 1967 (Evans et al. 1984). Among those dentally examined, parents' report on their child's place of residence for each year from birth to age 5 years was checked against maps showing areas with CWF. Children were coded as: All-life = when they lived in a fluoridated area to age 5 years, Part-life = lived at least three months in a fluoridated area, Non-fluoride = never lived in a fluoridated area. Children's consumption of fluoride tablets (at each year from birth to age 5 years) was coded as: None = never consumed, All-life = those who consumed at least daily for four + years, Part-life = consumed for less than four years daily or for four + years but less than daily.

The first phase of dental data collection in the Christchurch Study was carried out in 1982–83. Clinical dental data was obtained from the routinely-collected records of the first and second visits made to a School Dental Service (SDS) clinic at ages 5 or 6 years. The SDS records accounted for the number of visits the child had made to the school dental clinic every year; accordingly, each child could have data from multiple examinations each year, but only the first and second visits were obtained for the present analysis. Also, data on the child's medical history (attendance to the general practitioner, hospital visits and admissions), dental service use (Beautrais et al. 1982), fluoride use (Shannon et al. 1986), and exposure to CWF were collected. At the time of data collection, around a fifth of participants lived in parts of Christchurch with CWF (Waimairi ward) while the remainder lived in unfluoridated parts of the city (Fergusson & Horwood 1986). Details of the examination and methods have been reported elsewhere (Beautrais et al. 1982; Fergusson & Horwood 1986; Shannon et al. 1986). Among those dentally examined, parents' report on their child's place of residence for each year from birth to age 7 years was also checked against maps showing areas with CWF and children were coded as: All-life = children lived in a fluoridated area to age 7 years, Part-life = lived between one and six years in a fluoridated area, Non-fluoride = never lived in a fluoridated area. Children's consumption of fluoride tablets (at each year from birth to age 7) was coded as: None = never consumed, All-life = those who consumed fluoride tablets from birth to age 7 years, Part-life = consumed fluoride tablets from one to six years. In the Christchurch Study, the frequency with which tablets were consumed was not assessed.

Statistical analysis

In both studies, caries experience at age 5 years was summarised using the dmft index (which comprises the number of decayed, missing or filled deciduous teeth due to caries (Klein et al. 1938)). This was computed with data obtained from clinical examinations in the Dunedin Study and from SDS records at ages 5–6 for the Christchurch Study. For analysis, dmft scores were trichotomised: absence of decayed, missing or filled teeth (dmft = 0), moderate caries experience (dmft = 1–4) or high caries experience (dmft ≥ 5). This is consistent with the commonly-used service definition for high dental caries experience in Aotearoa New Zealand and with previous reporting (Broadbent et al. 2004).

Descriptive and bivariate analyses for the outcome variables by socio-demographic characteristics (family social background, sex, and socioeconomic status at birth) were conducted using STATA version 16.1 (StataCorp LLC, College Station, Texas, USA). Chi-square tests were used to examine the statistical significance of associations observed between categorical variables. Mann–Whitney U or Kruskal–Wallis tests where appropriate were used for continuous dependent variables. The threshold for statistical significance was $p < 0.05$.

Results

The methodological characteristics of the cohort studies and details of the childhood oral health assessments are presented in Table 1. The Christchurch Study was initiated five years after the Dunedin Study, and so there is a five-year age difference between participants in the two studies. In each cohort, the number of participants included at baseline represented over 90% of eligible births at that time and consisted of more than 1000 participants with similar gender mixes. Dental clinical data at age 5 years were available for 922 participants (50.3% males) in the Dunedin Study. In the Christchurch Study, 1048 and 925 participants had available dental data from the first (50.4% males) and second (50.2% males) school dental nurse visits, respectively.

More Christchurch than Dunedin Study members had visited the school dental nurse by age 5 years (Table 1). As reported by their parents, over 90% of the children in both

Table 1. Baseline characteristics, methodological aspects of the first oral health assessment and oral health-related characteristics among Dunedin and Christchurch Study participants.

	Dunedin Study	Christchurch Study
Cohort characteristics		
Birth period for cohort	1 April 1972–30 March 1973	1 April–5 August 1977
Participants in the complete birth cohort, N	1037 (91% of eligible births)	1265 (97% of eligible births)
Males, % (N)	51.6 (535)	50.2 (635)
Details of first dental health assessments		
Years of data collection	1977–78	1982–83
Age of participants (years)	5	5–6
Dental sample at baseline, % (N)	89.0 (923)	88.8 (1123)
Males, % (N)	50.3 (464)	50.4 (528) at 1st SDS visit 50.2 (464) at 2nd SDS visit
Participants dentally examined, % (N)	88.9 (922)	82.8 (1048) at 1st SDS visit 73.1 (925) at 2nd SDS visit
Type of dental examiners (N)	Dentists (4)	School dental nurses (N = ?, examined as part of routine care)
Location of dental examination	Research setting in a dental chair with clinical lighting, disposable mirrors, and explorers at the DMHDRU	Conventional setting at the school dental service clinics
Criteria for dental examination	World Health Organization	Clinical judgement of examiners
Method of obtaining self-reported information	Face-to-face interview with parent and completion of questionnaire	Face-to-face interview with parent and school dental nurse's records
Completed dental questionnaire, % (N)	88.9 (922)	87.5 (1107)
Oral health-related characteristics at age 5–6 years		
Visiting a school dental nurse, % (N)	90.2[a] (832)	94.8[a] (1048)
Use of fluoride toothpaste, % (N)[b]	92.0[a] (841)	94.3[a] (1059)
Reporting toothbrushing 2 + times per day, % (N)	51.6 (474)	Not asked
Reporting toothbrushing with fluoride 2 + per day, % (N)	47.3 (436)	Not asked
Simplified Oral Hygiene Index[c] (mean, SD)	1.0 (0.5)	Not available
Exposure to CWF, % (N)		
All-life	80.2 (739)	17.8 (197)
Part-life	10.2 (94)	21.7 (240)
No CWF	9.7 (89)	60.5 (670)
Exposure to fluoride tablets, % (N)		
All-life	5.6 (52)	6.9 (76)
Part-life	8.0 (74)	45.2 (500)
None	86.3 (796)	48.0 (531)

Abbreviations: DMHDRU = The Dunedin Multidisciplinary Health and Development Research Unit, SDS = School Dental Service, CWF = community water fluoridation. [a] Chi2 test, $p < 0.05$. [b] In the Dunedin Study the use of fluoride toothpaste includes parents' responses coded as 'always, mostly, and equally to non-fluoride', whilst in the Christchurch Study use was obtained from parent's report coded as 'yes/no'. [c] Combined debris and calculus indices. Scored surfaces were 55, 65 buccal; 75, 85 lingual; 51, 71 labial.

studies used a fluoridated toothpaste, but fewer than half of the participants in the Dunedin cohort brushed their teeth at least twice a day using a fluoridated toothpaste (or had them brushed by a parent), while toothbrushing frequency was not asked in the Christchurch Study. There were differences in children's exposure to fluoridated water supplies between the two cohorts. Among those dentally examined, a higher proportion of children lived in a fluoridated area from birth to age 5 years in the Dunedin cohort (over 90% including those who lived at least part of their lives in a fluoridated area), while the proportion was just under 40% for the Christchurch cohort. Additionally, over half of Christchurch's cohort were exposed to the use of fluoride tablets.

At age 5, children normally have 20 primary teeth present. In the Dunedin Study, 2.4 of these were caries-affected, while the number was slightly lower in the Christchurch Study, with only 2.2 of the 20 teeth (Table 2). Among the teeth that were caries-affected, over half were untreated and one in 20 had been extracted in the Christchurch Study (first dental visit), while only a quarter were untreated and one in 100 had been extracted in the Dunedin Study. In each case, the balance comprised restored teeth.

No sex differences were found in the proportion of caries-affected children in either study (Table 3), but consistent gradients were observed by SES and exposure to CWF, whereby they were lowest among those study members of high SES groups and those who had been exposed to CWF for life. Similar gradients were also observed for family type, maternal education, and maternal age at the child's birth.

Consistent gradients were also observed in both cohorts in mean dmft score by childhood SES, whereby they were highest in the low SES group and lowest in the high SES

Table 2. Oral health data and mean dmf scores among the Dunedin and Christchurch Study participants at age 5/5–6 years.

	Dunedin Study	**Christchurch Study**[d]
Mean dmfs (SD)	3.7 (5.9)	Not available
Mean dmft (SD)	2.4 (3.1)[a]	1st visit: 2.2 (3.6)[a] 2nd visit: 2.8 (3.9)
Mean dt (SD)	0.6 (1.4)	1st visit: 1.2 (2.1) 2nd visit: 0.8 (1.6)
Mean ft (SD)	1.8 (2.4)	1st visit: 1.0 (2.1) 2nd visit: 1.9 (2.8)
Mean mt (SD)	0.0[b] (0.3)	1st visit: 0.1 (0.6) 2nd visit: 0.1 (0.7)
% caries-affected children (N)	59.1 (545)[c]	1st visit: 45.8 (480)[c] 2nd visit: 54.4 (503)[c]
% with dmft 0 (N)	40.9 (377)	1st visit: 54.2 (568) 2nd visit: 45.6 (422)
% with dmft 1–4 (N)	38.9 (359)	1st visit: 26.6 (279) 2nd visit: 30.0 (277)
% with dmft 5 + (N)	20.2 (186)	1st visit: 19.2 (201) 2nd visit: 24.4 (226)
% with 1 + dt (untreated decay) (N)	28.2 (260)	1st visit: 37.7 (395) 2nd visit: 33.0 (305)
% with 1 + missing teeth due to caries (N)	1.4 (13)[c]	1st visit: 3.3 (35)[c] 2nd visit: 5.6 (52)
% with 1 + filled teeth (N)	50.9 (469)	1st visit: 27.1 (284) 2nd visit: 46.6 (431)

[a]Wilcoxon rank sum test, $p < 0.001$, 'dt' and 'dmft' in the Dunedin Study includes indicated for extraction 'it'. [b] Actual value 0.03. [c] Chi2 test, $p < 0.05$. [d] Data reported obtained from the first and second visits to the School Dental Service.

Table 3. Caries-affected children and mean dmft at ages 5/5–6 by socio-demographic characteristics among Dunedin and Christchurch Study participants.

	Dunedin Study		Christchurch Study			
	% (N)	dmft, (SD)	1st SDS visit, % (N)	dmft, (SD)	2nd SDS visit, % (N)	dmft, (SD)
Sex *(Dud = 922; Chch SDS v1 = 1048, SDS v2 = 925)*						
Female	59.0 (266)	2.3 (3.0)	43.9 (228)	2.1 (3.5)	52.7 (243)	2.6 (3.7)
Male	59.2 (279)	2.5 (3.2)	47.7 (252)	2.3 (3.7)	56.0 (260)	3.0 (4.1)
SES at birth *(Dud = 918; Chch SDS v1 = 1048, SDS v2 = 925)*						
High	50.4 (69)	1.7 (2.4)	31.2 (64)	1.3 (2.5)	39.9 (69)	1.7 (3.0)
Medium	58.7 (345)	2.3 (3.0)	46.1 (263)	2.2 (3.5)	54.4 (280)	2.8 (3.8)
Low	66.3 (128)[a]	3.2 (3.9) [c]	56.3 (153)[a]	2.9 (4.6)[c]	65.0 (154)[a]	3.6 (4.4)[c]
Exposure to CWF *(Dud = 922; Chch SDS v1 = 1048, SDS v2 = 925)*						
All-life	58.1 (429)[a]	2.3 (3.1) [c]	38.0 (71)[a]	1.7 (3.1)[c]	46.2 (78)[a]	2.1 (3.4)[c]
Part-life	55.3 (52)	2.3 (2.9)	49.3 (111)	2.3 (3.7)	59.1 (120)	2.9 (3.8)
No CWF	71.9 (64)	3.5 (3.7)	46.9 (298)	2.3 (3.7)	55.2 (305)	3.0 (4.1)
Maternal age at child's birth *(Dud = 918; Chch SDS v1 = 1048, SDS v2 = 925)*						
≤ 20 yrs	63.5 (92)	2.8 (3.6)	58.1 (86)	2.9 (4.0)	66.7 (90)	3.6 (4.0)
21–25 yrs	56.8 (212)	2.2 (3.0)	48.7 (174)	2.6 (4.0)	57.0 (179)	3.2 (4.3)
26–30 yrs	59.1 (149)	2.3 (2.8)	38.0 (147)	1.7 (3.1)	46.9 (161)	2.3 (3.6)
31–35 yrs	56.0 (56)	2.4 (3.4)	39.3 (44)	1.6 (2.8)	50.0 (47)	2.2 (3.5)
> 35 yrs	68.8 (33)	3.2 (3.4)	65.9 (29)[a]	2.9 (3.3)[c]	66.7 (26)[a]	3.2 (3.5)[c]
Maternal education at birth[b] *(Dud = 920; Chch SDS v1 = 1048, SDS v2 = 925)*						
Primary	59.4 (38)	3.0 (3.0)	50.4 (270)	2.6 (3.8)	59.1 (287)	3.2 (3.7)
Secondary	61.5 (347)	2.6 (3.3)	43.4 (135)	2.0 (3.5)	51.6 (143)	2.5 (3.8)
Tertiary	54.1 (158)	2.0 (2.6) [a]	37.3 (75)[a]	1.6 (2.9)[a]	45.1 (73)[a]	2.0 (3.3)[a]
Family type *(Dud = 915; Chch SDS v1 = 1048, SDS v2 = 925)*						
Single parent family	67.4 (31)	2.5 (2.6)	62.3 (43)	3.8 (4.6)	71.2 (47)	4.3 (4.8)
Two parent family	58.5 (508)	2.4 (3.2)	44.6 (437)[a]	2.1 (3.5)[c]	53.1 (456)[a]	2.7 (3.8)[c]

Abbreviations: Dud = Dunedin Study, Chch = Christchurch Study, SES = socioeconomic status, SDS = School Dental Service, v1/v2 = 1st and 2nd SDS visits, respectively, CWF = community water fluoridation. [a] Chi2 test, $p < 0.05$. [b] In the Dunedin Study, maternal education attainment was recorded when study members were 3 years old.[c] Kruskal-Wallis test, $p < 0.05$. [d] Wilcoxon rank sum test, $p < 0.05$.

group, with the mean score in the former being more than twice that of the latter (Table 3). Similar gradients were observed for exposure to CWF, maternal education, and maternal age at the child's birth, whereby the younger the mother's age, the higher the child's dmft score (except for the oldest mothers aged over 35 years, whereby the child's dmft scores were higher again and resembled those of the younger age group).

Mean dmft among 5-year-old children was 2.4 and 2.2 for the Dunedin and Christchurch birth cohorts, respectively. Contemporary figures for Aotearoa New Zealand as a whole were 3.7 in 1977 and 2.6 in 1982 (Figure 1). Mean dmft at age 5 in these two cohorts is close to national statistics for 5-year-old children in the 2000s. Overall, caries prevalence and mean dmft have decreased proportionally to one another, but have changed little since the 1980s (Figure 2).

Discussion

This study provides a side-by-side comparison of the methodological aspects and early childhood oral health findings of two Aotearoa New Zealand birth cohort studies

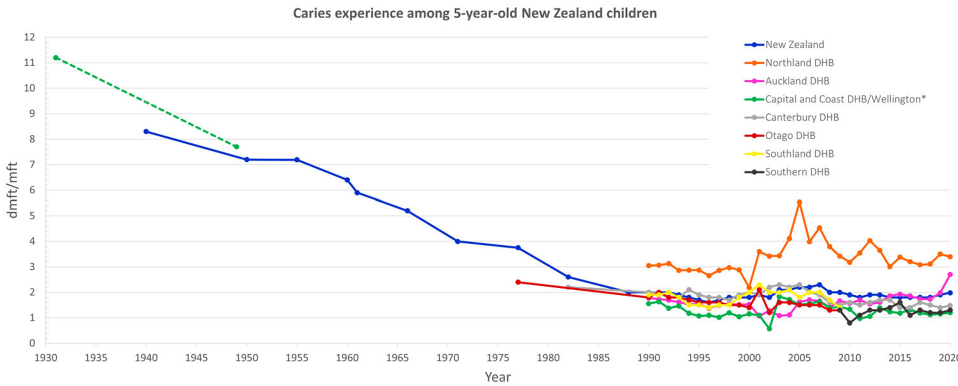

Figure 1. Caries experience among 5-year-old Aotearoa New Zealand children from year 1930 to 2020. *Dashed line represents data for Wellington, solid line represents Capital and Coast DHB data. Abbreviations: DHB = District Health Board, dmft = decayed, missing or filled deciduous teeth due to caries. Data sources: 1930–32† (Hewat et al. 1952), 1940‡ (Hewat et al. 1952 and Department of Health 1956–83; Department of Health 1975), 1948–50† (Hewat & Eastcott 1953), 1950‡ (Department of Health 1956–83, also cited in Colquhoun 1988), 1955† (Department of Health 1956; Department of Health 1975), 1960‡ (Department of Health 1956–83; Hollis 1970), 1961–71 (Department of Health 1956–83), 1977 (Hunter 1984) and separate datapoint for the Dunedin Study (Evans et al. 1980; Evans et al. 1982; Evans et al. 1984), 1982 (Hunter 1984). and separate datapoint for the Christchurch Study (Shannon et al. 1986), 1988 (cited in Colquhoun 1992). From 1990 to 2020 data were retrieved from Ministry of Health—Annual data explorer: New Zealand Health Survey [Data file]. For the period 1990–2005, data were obtained from School Dental Service records (mft was reported until 2001, dmft was reported from 2002 onwards). For the period 2006–20, data wereobtained from Community Oral Health Service (COHS) records (dmft reported). ‡ data point represents average of available values weighted by sample size.

initiated more than 40 years ago. The two studies showed resemblance in caries experience patterns and, despite some improvements, such observed patterns remain relatively unchanged from currently observed caries experience among 5-year-olds in Aotearoa New Zealand.

Considering the first research aim, the studies had some methodological differences, including the examination settings (number of examiners and physical location) and the type of information collected. For example, one distinction was that the Dunedin Study had detailed data to describe caries experience at the tooth surface level (count of caries-affected tooth surfaces as well as teeth), thus changes over time could be investigated at the tooth surface level, while in the Christchurch Study, SDS data was reported only at the tooth level (count of affected teeth only). Another example was the source of the dental data, with data collected by purposively calibrated examiners in the Dunedin Study but from routinely collected SDS clinical records in the Christchurch Study. Children's exposure to CWF and category cut-offs were based on previous reports (Evans et al. 1980; Evans et al. 1984; Fergusson & Horwood 1986), and so were not fully comparable between studies. However, exposure differed between the cohorts, with Dunedin being largely fluoridated and Christchurch being largely not. If such methodological differences had not existed between the two studies, differences in the number of dental fillings or missing teeth would have been unlikely. However, a slight underestimation in caries

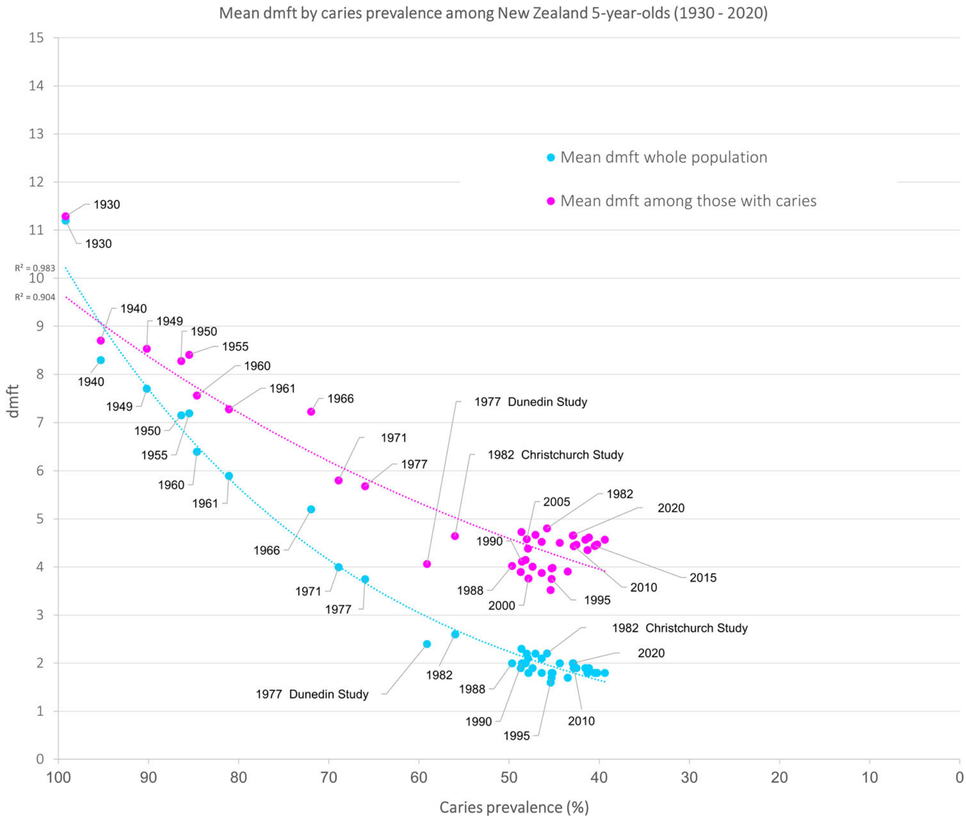

Figure 2. Mean dmft by caries prevalence among New Zealand 5-year-olds from the 1930s to year 2020. For data sources see Figure 1.

detection could have been a possibility in the Dunedin Study because the examination criteria used were based on the presence of cavitation; in the Christchurch Study, caries detection and recording was based on contemporary School Dental Service practices. Additionally, the timing of the examination could have affected the findings. For example, Christchurch Study children could have had dental data from age 6 years, being a year older than their Dunedin counterparts, thereby increasing their time at risk for dental problems (decay, fillings), and so they may have had more accumulated caries experience than they would otherwise have had a year earlier.

Notwithstanding these differences, similarities arise. First, fluoridated toothpaste use was almost universal in both cohorts (although only half of the Dunedin cohort used it as recommended, twice daily), and SDS utilisation rates were similar and resembled the national figure of 90% enrolment in 1982 (Hunter 1984). Secondly, caries experience showed gradients by CWF, SES, maternal education and family type, supporting the premise that social disadvantage is associated with poor oral health (Poulton et al. 2002; Declerck et al. 2008; Wagner et al. 2014). Finally, both cohorts were representative of their source population (Fergusson & Horwood 2001; Poulton et al. 2015).

To address the second research aim, we discuss why early findings from these two cohorts are relevant and have important implications for Aotearoa New Zealand children today. Caries experience declined rapidly from the 1950s through to the 1970s, just before these two cohort studies were initiated. Caries experience in these studies was slightly lower than that of New Zealand as a whole (Hunter 1984). At the time of data collection, CWF in Dunedin had been in place for a decade (Evans et al. 1984) and so, as observed in other cities (Moffat et al. 2017), the lower treatment needs could be due to the number of years exposed to this public health measure. Moreover, mean dmft in the Christchurch Study was lower than that of New Zealand in non-fluoridated regions (Hunter 1984). This could have been due to an under-representation of Māori and Pacific children (among whom caries rates tend to be higher) relative to the wider Aotearoa New Zealand population, the fact that a substantial number of participants lived in a part of Christchurch that did have CWF, and the high proportion of cohort members who used fluoride tablets.

The mean number of fillings among Dunedin Study members was greater than among Christchurch Study members at their first SDS visit, but similar to that seen at the second visit. This could reflect different practices in enrolling children in the SDS between Dunedin and Christchurch, with Dunedin perhaps enrolling children and performing restorative treatment at a younger age. This assumption might also be supported by the fact that, in the 1970s, the SDS had its focus on controlling caries through restorative treatment. Changing untreated decay to filled teeth as soon as caries lesions appeared indicated efficiency and evoked dental fitness (Beautrais et al. 1982), and this resulted in a high proportion of filled teeth (Evans et al. 1980).

How can we draw upon these data for the benefit of New Zealand's children today? Implications for research, public oral health policy, and practice

Our findings have some implications for future oral health research. Studying the natural history of dental caries across the lifespan requires the use of the longitudinal design (Thomson 2004). Caries rates among Māori and Pacific children are greater than among other children in Aotearoa New Zealand (Ministry of Health 2010; Shackleton et al. 2018). Thus, new longitudinal studies should consider oral health among Māori and Pacific communities in order to advance wellbeing and equity towards Pae ora (Healthy futures for Māori) (Ministry of Health 2020a) and Ola Manuia (Pacific Health and Wellbeing Action Plan) (Ministry of Health 2020b). Existing studies, like the ongoing 'Pacific Islands Families Study' (Sundborn et al. 2011; Schluter et al. 2017) or the 'Growing up in New Zealand' cohort (Thornley et al. 2021), could expand the available oral health-related and clinical data (dmft/DMFT) obtained from SDS records, by collecting self-reported or clinical data that would help in identifying critical periods, levels of influence and intervention targets for the persisting inequalities.

There are, however, some technical issues that arise with respect to research, because, even in prospective studies, the data available to address life-course questions are likely to be incomplete (Pickles et al. 2007), and the research questions that originally drove the investigative process can differ from those planned for (or arising from) later data collections. To understand how caries patterns evolve, dental data collection should extend beyond childhood to reveal changes into the adult years. Routinely-collected SDS data used in the Christchurch Study improved our understanding of how childhood caries is associated with risk later in life but could not reveal detail on the 'shape' of the trajectories of caries experience, but new dental data collection could help answer this. If clinical examinations were not viable, historical dental data could be obtained from routinely-collected dental treatment visits, or teeth could be photographed (or digitally scanned) for subsequent evaluation for oral health conditions. Also, as a cumulative condition, dental caries manifests as a continuum of changes in the dental hard tissues. Therefore, to fully recognise its extent, it may be useful to collect data on the different stages of dental caries using more sensitive detection criteria—such as ICDAS (Ismail et al. 2007)—in order to include both cavitated and non-cavitated lesions.

Our findings also suggest several implications for Aotearoa New Zealand public oral health policy. First, the observed patterns of caries experience by SES, maternal education and exposure to fluoride replicated in the two studies remain (alongside ethnicity and deprivation) major determinants of caries occurrence (Ministry of Health 2010; Shackleton et al. 2018). Understanding common risk factors associated with ECC may help identify opportunities for cross-disciplinary interventions to improve oral health and raise awareness among policymakers about advantages of addressing the root causes of a myriad of health issues, with the goal of seeing more investment in education, poverty reduction, and health promotion. Greater government spending on health care and lower private out-of-pocket expenditure are associated with better oral health (Baker et al. 2018) and lower infant mortality (Conley & Springer 2001). As with other chronic conditions, oral health problems are experienced individually, but are fundamentally social and political in nature (Baker et al. 2018). Thus, their control (and prevention) requires initiatives beyond the individual risk level, focused towards the more distal determinants of health. Second, we are living in a society in which energy-dense —high-fat and high-calorie—types of diet are the norm. These low-nutritional-value diets disproportionately affect the more disadvantaged communities because highly processed junk foods are usually easier to find and cheaper to buy (Otero et al. 2015). Under a neoliberal societal regime, there is very limited personal control over the surrounding cariogenic and obesogenic environments (Otero et al. 2015; Thomson 2018). Given the structural inequality behind nutrition, the possibility of subsidising healthy foods might appear as a less regressive measure than applying food taxes (Otero et al. 2015) and might help in reducing the daily intake of sugar, fat, and salt. Encouraging the production of healthier foods could also have a complementary effect at a population level (Caraher & Cowburn 2005). Third, CWF reduces dental caries experience and is a cost-effective public measure promoting health equity (Moore & Poynton 2015; Moore et al. 2017). Therefore, it should be advocated for and expanded to increase population coverage in Aotearoa New Zealand (actual coverage 61% (ESR—Institute of Environmental Science and Research 2021)). Fourth, health promotion strategies such as the 'Baby teeth matter' campaign (Health Promotion Agency 2018)—a social-marketing-based strategy that promotes regular tooth brushing with fluoridated toothpaste among preschoolers and their families—should be strengthened, especially among the most deprived communities. Finally, downstream preventive interventions at the community level, such as school-based toothbrushing programmes (Clark et al. 2019) or supporting breastfeeding (Phantumvanit et al. 2018), may help develop personal skills and influence beneficial behaviour changes.

We discuss some implications for practice. Current Community Oral Health Service (COHS) data indicate that dental caries remains highly prevalent among Aotearoa New Zealand children, having changed little from when participants in the two cohorts were aged 5, despite various clinical and public health efforts over the decades. There is no particular or biological reason within the caries process *per se*, to explain such a plateau, but the disease persists among a sizeable proportion of children. At present, mean dmft scores among 5-year-olds are lower than in past decades, but they also show greater skewness in their distribution. Among the 40% who have experienced caries, mean dmft scores match those of the children in these two birth cohorts back in the 1970s–1980s. This implies that poor oral health becomes a better marker of deprivation and risk nowadays, when experience of oral disease (such as dental caries) is less common. However, there are some exceptions. Recent Ministry of Health data (2020) shows age 5 dmft scores among children from Northland and other northern regions to be markedly higher than the national average of 1.98 (Northland dmft = 3.41, Waitemata dmft = 2.37, Auckland dmft = 2.72, Counties Manukau dmft = 3.20). This points to both ethnic and SES inequalities, potential regional inconsistencies in the delivery of dental care (Gowda et al. 2009), and variations in the delivery of CWF (Ministry of Health 2021). If the disease affected almost every child in Aotearoa New Zealand in the past, the current reality is that the highest burden is concentrated among those who experience the greatest hardship, adversity and social disadvantage. Accordingly, ECC rates have been identified as a responsive population-level marker of socioeconomic inequality and societal stress (Thomson 2018).

How can we then ensure equitable access to dental treatment and prevention for the most in-need children and their whānau? As proposed in the World Health Organization Health Promotion framework (World Health Organization 1986), health services should be reoriented so that timely dental care is facilitated not only on a problem-solving basis (to cover treatment needs) but to prevent future disease and improve overall health. The latter could involve oral health practitioners becoming more engaged in dental public health practice, promoting oral health outside of dental clinics and hospitals, reaching the people of Aotearoa New Zealand in their school environments, neighbourhoods, and workplaces, in ways in which they could relate to and enjoy. Practical examples might be bringing mobile clinics into deprived or isolated suburbs, supplying free toothbrushes and fluoridated toothpaste, building social networks within local communities, and enhancing self-efficacy. Moreover, we could build on ideas from the 'Childsmile' Scottish experience, where community health workers could be trained to undertake 'social prescribing' (Macpherson et al. 2019) adapted to New Zealand's context. This approach involves first identifying and signposting children and families at greater social risk and in need of additional support, and then referring them to engage in physical activity groups, gardening and cooking clubs, debt advice workshops or any other resources commonly provided by community/voluntary organisations—not provided within the healthcare system—that would contribute to optimising their health and wellbeing.

In summary, while some differences in methods (related to study design, case definitions, implementation, and measurement) were found between the Dunedin and Christchurch cohorts, the early oral health findings observed among 5-year-olds were consistent and showed similar patterns. When feasible, existing studies should prioritise clinical data collection because it adds value to future measurement waves and otherwise represents a missing opportunity for direct comparison of oral health outcomes. Notwithstanding the steep caries decline in Aotearoa New Zealand over the decades, and that some improvements have been observed in oral health, the caries distribution has shifted to the extent that the greatest severity of disease is now concentrated among a smaller group of the most deprived children. Early childhood caries appears to be a useful indicator of deprivation that should lead us to target context-based public health actions to reach those who need it the most.

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Authors' contributions

BR analysed the data and drafted the paper. JMB, WMT, JB, LJH, SR and RP 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 datasets are available on request by qualified scientists. 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. We offer secure access on the Duke, Otago, and King's College campuses.

The Christchurch Study datasets are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Ethics approval statement

In the Dunedin Study, study members gave written informed consent, and the New Zealand Health and Disability Ethics Committee approved each assessment phase. In the Christchurch

Study, study members gave written informed consent, and each assessment was approved by the Regional Health and Disabilities Ethics Committee.

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