# Permanent dentition caries through the first half of life

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### IN BRIEF

- Few studies have tracked the oral health of a cohort over time, and none for as long as the Dunedin study or with such a high long-term participation rate in a representative birth cohort.
- Shows how dental caries begins as a childhood disease, but remains important through adolescence and into adulthood.
- Provides hard data to demonstrate the differential susceptibility of the various teeth within the mouth with age.

**Aim** To describe the occurrence of dental caries at the person, tooth and tooth surface level from childhood to early midlife. **Background** No studies have reported on age and caries experience in a population-based sample through the first half of life. **Methods** Prospective cohort study of a complete birth cohort (n = 1,037) born in 1972/73 in Dunedin, New Zealand. Dental examinations were conducted at ages 5, 9, 15, 18, 26, 32 and 38, and participation rates remained high. Surface-level caries data were collected at each age (WHO basic methods). Statistical analyses and graphing of data were undertaken using Intercooled Stata Version 10. **Results** Data are presented on dental caries experience in the permanent dentition at ages 9, 15, 18, 26, 32 and 38. Percentile curves are charted and reported for person-level caries experience. Data are also presented on the number of decayed teeth and tooth surfaces, (including root surfaces at age 38), as a function of the number of teeth and surfaces present, respectively. Across the cohort, the number of tooth surfaces affected by dental caries increased by approximately 0.8 surfaces per year (on average), while the percentage of at-risk tooth surfaces affected by caries increased by approximately 0.5% per year, with negligible variation in that rate throughout the observation period. **Conclusion** These unique data show clearly that dental caries continues as a disease of adulthood, remaining important beyond childhood and adolescence and that rates of dental caries over time remain relatively constant.

#### INTRODUCTION

A recent review has highlighted the universal pattern of permanent-dentition dental caries in populations in terms of the disease's prevalence, incidence frequency distribution and rates of progression.1 The findings confirm an earlier review of caries prediction that found that previous caries experience was the strongest predictor of future caries development.2 Reviews of epidemiological data indicate that caries experience at six years of age (whether that of individuals or groups) predicts caries experience to adulthood.<sup>3,4</sup> This has been substantiated in a long-standing prospective study of a birth cohort born in Dunedin (New Zealand) in 1972/1973.5,6

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Studying the natural history of dental caries experience and treatment is important because it enables identification of the periods in life when risk for the disease is highest; however, there appear to be few longitudinal reports of dental caries experience from childhood through to adulthood. Most published work has featured either children and adolescents7-11 or older people.<sup>12-19</sup> There has been only one population-based study reporting on caries among younger adults, and that reported disease experience from age 26 to 32.20 There persists a perception among dentists that dental caries is (for the most part) active only in the younger population,<sup>21-23</sup> and that the relatively low caries experience found in adolescence is merely being delayed until later in life.24 More recently, reviews of cohort studies of caries in older adults have found this group of the population to also be caries-active.<sup>24-26</sup> Although it was originally thought that high-risk periods for dental caries exist, the more recent availability of life-course data and newer approaches to analysing those data - such as trajectory analysis - have shown that caries appears

to be occurring at a relatively constant rate through life.<sup>5</sup>

There have been many reports confirming the differential susceptibility of the various tooth surfaces, with a hierarchy of caries susceptibility by tooth type and tooth surface existing.1 An Australian study of adults found that caries experience had occurred predominantly in firstmolar teeth, with a greater involvement of the approximal surfaces of posterior teeth in the age group 36-51 years.<sup>24</sup> A four-year longitudinal study of 20,000 US schoolchildren between 5 and 16 years of age found occlusal fissures and buccal pits of first molars to be most susceptible, followed by the occlusal surfaces of second molars, the buccal surfaces of lower second molars and the occlusal surfaces of all second premolars.27 There also appears to be a degree of between-jaw and contralateral symmetry in caries experience.28

Without longer-term prospective cohort studies, it is difficult to determine what is really happening with a chronic, progressive and cumulative disease such as dental caries, and what accurately predicts caries experience in the permanent dentition. It is also difficult to know whether (and how) observed differences in susceptibility of the various tooth surfaces change over time. Accordingly, the aim of the current study was to describe dental caries experience and explore how this occurs at the person, tooth and tooth surface level through the first half of life.

#### METHODS

The Dunedin Multidisciplinary Health and Development Study (DMHDS) is a prospective study of a complete birth cohort (n = 1037; 52% male) born in 1972/73 in Dunedin, New Zealand.<sup>29,30</sup> The general population of New Zealand's South Island is well-represented in the cohort, being primarily of white European ancestry and of the full range of socioeconomic status. Assessments of study members have been conducted at 3, 5, 7, 9, 11, 13, 15, 18, 21, 26, 32 and most recently at 38 years of age, when 95% of the 1,007 living study members were assessed (during 20102012). Dental assessments have been conducted at 5, 9, 15, 18, 26, 32 and 38 years of age. The current study uses dental data on the status of the permanent dentition from all assessments except the assessment at age five. Dental examination methods used at each assessment have been previously reported;31-37 methods relevant to the current investigation are summarised below.

#### **Dental caries examination**

Dental examination for caries and missing teeth were conducted by calibrated examiners. Repeat examinations were not possible because of logistical constraints imposed by the tightly scheduled assessment undergone by study members. Before each examination the data capture forms were adjusted to indicate teeth that had been missing at the previous assessment.

An estimation of accumulated tooth loss due to caries by each age was obtained by observing the presence or absence of each tooth and ascertaining the reason for its absence by asking the study member at that time. Only those teeth that had been lost because of caries are included in estimations of tooth loss due to caries and in the 'M' component of DMF scores. Teeth extracted for reasons other than dental caries (such as impaction or orthodontic treatment) were not included in the computation of tooth loss. Table 1 Participation in the Dunedin multidisciplinary study dental examinations (assessments when no dental examination was conducted are excluded)

Year	Age	Number living	Number seen	Percentage seen	Number dentally examined	Percentage dentally examined	Number of dental examiners
1976	5	1,037	991	95.6	923	89.0	4
1980	9	1,035	955	92.3	683	67.2	1
1987-88	15	1,029	976	94.8	781	75.9	1
1990-91	18	1,027	993	96.7	867	84.4	5
1998-99	26	1,019	980	96.2	932	91.3	3
2004-05	32	1,015	972	95.8	935	91.6	2
2010-12	38	1,007	961	95.4	928	92.4	3

Table 2 Prevalence and severity of dental caries experience by age									
	Age 9	Age 15	Age 18	Age 26	Age 32	Age 38*			
	Number of participants (%)								
1+ teeth DMF-affected	303 (44.4)	638 (81.7)	755 (87.1)	885 (95.0)	906 (96.9)	891 (96.1)			
1+ teeth decayed	32 (4.9)	149 (19.1)	215 (24.8)	595 (63.8)	491 (52.5)	388 (41.8)			
1+ teeth missing	0 (0.0)	0 (0.0)	2 (0.2)	103 (11.1)	222 (23.7)	312 (33.6)			
1+ teeth filled	286 (41.9)	627 (80.3)	745 (85.9)	844 (90.6)	870 (93.0)	853 (91.9)			
Total assessed	683	781	867	932	935	928			
	Mean number of teeth (T) affected (sd)								
DT	0.1 (0.3)	0.3 (0.9)	0.4 (1.0)	2.1 (2.7)	1.7 (2.7)	1.4 (2.8)			
MT	0.0 (0.0)	0.0 (0.0)	0.0 (0.1)	0.3 (1.6)	0.7 (2.3)	1.3 (3.5)			
FT	0.9 (1.3)	3.4 (2.9)	4.6 (3.7)	5.5 (4.1)	6.5 (4.4)	6.8 (4.6)			
DFT	1.0 (1.3)	3.7 (3.2)	5.1 (4.0)	7.6 (4.9)	8.1 (5.0)	8.1 (5.0)			
	Mean number of tooth surfaces (S) affected (sd)								
DS	0.1 (0.3)	0.4 (1.0)	0.5 (1.2)	2.5 (3.8)	2.3 (4.8)	2.5 (7.4)			
MS	0.0 (0.0)	0.0 (0.0)	0.0 (0.4)	1.3 (7.5)	3.4 (11.0)	6.2 (16.6)			
FS	1.1 (1.8)	4.7 (4.7)	6.8 (6.9)	9.8 (9.3)	12.0 (10.6)	13.2 (11.9)			
DFS	1.2 (1.8)	5.1 (5.0)	7.3 (7.2)	12.3 (10.5)	14.3 (11.8)	15.7 (13.6)			
*includes root caries									

Teeth were examined for caries and restorations following World Health Organization methodology.<sup>38,39</sup> Four surfaces were considered for anterior teeth (canines and incisors): buccal, lingual, distal and mesial; while a fifth surface, occlusal, was included for posterior teeth (premolars and molars). Where a surface could not be visualised by the examiner (due to excessive calculus or it being covered by gingival tissue) the surface was excluded from the examination and later analyses.

At early phases of the Dunedin Study (9 and 15) a lack of funding/staffing precluded some participants from being dentally examined, while they were seen for developmental and general health assessments and interviews. The number of examiners at each age is presented in Table 1. One examiner (WMT) conducted nearly all dental examinations at age 26, while most dental examinations at ages 32 and 38 were conducted by the same two (calibrated) examiners (WMT and JMB).<sup>20</sup> A third calibrated examiner (LFP) also conducted a small number of examinations at age 38.<sup>40</sup> Examiners achieved a very high level of intra- and inter-examiner reliability at ICC = 0.99 for DMFS, as has been reported previously.<sup>20,40</sup>

#### Data analysis

Statistical analyses and graphing of data were undertaken using Intercooled Stata

Table 3 Prevalence and severity of dental caries experience by tooth and age								
		Age in years N affected teeth (%)   mean number of surfaces affected among affected teeth (sd)						
	Tooth	Age 9	Age 15	Age 18	Age 26	Age 32	Age 38	
Quadrant 1	8	0 (0.0)   0.0 (0.0)	0 (0.0)   0.0 (0.0)	5 (4.3)   1.0 (0.0)	83 (21.2)   1.7 (1.3)	126 (35.6)   2.6 (1.8)	125 (38.3)   3.1 (1.9)	
	7	0 (0.0)   0.0 (0.0)	144 (19.5)   1.1 (0.4)	291 (33.9)   1.2 (0.5)	462 (50.0)   1.5 (0.9)	531 (57.3)   1.8 (1.2)	535 (58.3)   2.0 (1.4)	
	6	157 (23.2)   1.2 (0.6)	489 (62.6)   1.4 (0.6)	586 (67.9)   1.5 (0.7)	683 (73.6)   1.8 (1.0)	708 (76.1)   1.9 (1.1)	716 (77.7)   2.2 (1.3)	
	5	0 (0.0)   0.0 (0.0)	51 (6.6)   1.6 (0.7)	112 (13.4)   1.8 (0.8)	234 (26.1)   2.1 (1.1)	280 (31.2)   2.4 (1.2)	304 (34.2)   2.8 (1.4)	
	4	0 (0.0)   0.0 (0.0)	31 (4.7)   1.4 (0.5)	67 (9.0)   1.7 (0.6)	185 (23.3)   1.7 (0.9)	206 (26.1)   2.1 (1.2)	221 (28.3)   2.5 (1.5)	
	3	0 (0.0)   0.0 (0.0)	7 (0.9)   1.0 (0.0)	14 (1.6)   1.4 (0.6)	64 (6.9)   1.6 (1.0)	101 (10.8)   1.6 (1.0)	122 (13.2)   1.9 (1.2)	
	2	1 (0.2)   1 (—)	44 (5.8)   1.2 (0.6)	72 (8.5)   1.2 (0.6)	158 (17.4)   1.5 (0.9)	184 (20.2)   1.7 (1.0)	183 (20.4)   2.0 (1.4)	
	1	4 (0.6)   1.8 (1.5)	26 (3.3)   1.2 (0.4)	52 (6.0)   1.4 (0.5)	199 (21.5)   2.0 (1.2)	222 (24.0)   2.1 (1.2)	222 (24.3)   2.2 (1.3)	
Quadrant 2	8	0 (0.0)   0.0 (0.0)	0 (0.0)   0.0 (0.0)	3 (2.6)   1.0 (0.0)	81 (21.3)   1.4 (1.1)	138 (40.4)   2.4 (1.7)	222 (40.0)   3.2 (1.9)	
	7	0 (0.0)   0.0 (0.0)	132 (17.7)   1.1 (0.3)	275 (32.0)   1.2 (0.4)	452 (49.1)   1.5 (1.0)	509 (55.1)   1.8 (1.3)	544 (59.4)   2.2 (1.5)	
	6	158 (23.3)   1.2 (0.7)	468 (59.9)   1.4 (0.6)	575 (66.5)   1.5 (0.7)	678 (72.9)   1.8 (1.0)	709 (76.2)   2.0 (1.2)	708 (76.7)   2.2 (1.4)	
	5	0 (0.0)   0.0 (0.0)	43 (5.6)   1.5 (1.8)	96 (11.5)   1.8 (0.8)	234 (26.1)   2.1 (1.1)	272 (30.3)   2.5 (1.2)	307 (34.4)   2.9 (1.4)	
	4	0 (0.0)   0.0 (0.0)	28 (4.2)   1.3 (0.5)	50 (6.7)   1.7 (0.6)	167 (21.0)   1.8 (1.0)	194 (24.6)   2.2 (1.2)	216 (27.7)   2.6 (1.5)	
	3	0 (0.0)   0.0 (0.0)	7 (0.9)   1.0 (0.0)	16 (1.9)   1.3 (0.5)	74 (8.0)   1.7 (0.9)	109 (11.7)   1.8 (1.0)	127 (13.7)   2.1 (1.3)	
	2	0 (0.0)   0.0 (0.0)	41 (5.4)   1.1 (0.3)	67 (7.9)   1.3 (0.5)	180 (19.9)   1.6 (0.9)	197 (21.7)   1.7 (1.0)	196 (21.9)   2.0 (1.2)	
	1	3 (0.0)   1.0 (0.0)	32 (0.0)   1.3 (0.5)	54 (6.2)   1.4 (0.5)	193 (20.8)   1.8 (1.1)	223 (24.1)   1.9 (1.1)	222 (24.1)   2.1 (1.3)	
Quadrant 3	8	0 (0.0)   0.0 (0.0)	1 (0.0)   1 (—)	10 (6.7)   1.1 (0.3)	85 (21.9)   1.5 (1.1)	123 (34.6)   2.1 (1.6)	150 (46.0)   2.3 (1.7)	
	7	0 (0.0)   0.0 (0.0)	206 (27.6)   1.1 (0.3)	368 (42.7)   1.2 (0.4)	533 (57.7)   1.5 (0.9)	584 (63.1)   1.8 (1.3)	610 (66.5)   2.1 (1.5)	
	6	169 (24.8)   1.2 (0.6)	433 (55.4)   1.5 (0.6)	533 (61.7)   1.6 (0.8)	646 (69.5)   2.0 (1.1)	672 (72.1)   2.2 (1.3)	686 (74.4)   2.5 (1.5)	
	5	0 (0.0)   0.0 (0.0)	40 (5.5)   1.5 (0.7)	78 (9.6)   1.5 (0.7)	179 (20.3)   1.7 (0.9)	216 (24.5)   2.0 (1.1)	254 (29.1)   2.4 (1.4)	
	4	0 (0.0)   0.0 (0.0)	11 (1.5)   1.1 (0.3)	25 (3.1)   1.4 (0.5)	70 (8.1)   1.5 (0.9)	82 (9.5)   1.8 (1.2)	118 (13.8)   2.0 (1.2)	
	3	0 (0.0)   0.0 (0.0)	0 (0.0)   0.0 (0.0)	6 (0.7)   1.0 (0.0)	30 (3.2)   1.5 (1.0)	37 (4.0)   1.6 (1.1)	43 (4.6)   2.3 (1.5)	
	2	1 (0.0)   1 (—)	2 (0.3)   1.5 (0.7)	4 (0.5)   1.5 (0.6)	20 (2.1)   1.6 (1.1)	18 (1.9)   1.8 (1.2)	27 (2.9)   2.5 (1.3)	
	1	0 (0.0)   0.0 (0.0)	3 (0.0)   1.3 (0.6)	5 (0.6)   1.4 (0.5)	22 (2.4)   2 (1.3)	22 (2.4)   2.4 (1.3)	28 (3.0)   2.8 (1.2)	
Quadrant 4	8	0 (0.0)   0.0 (0.0)	0 (0.0)   0.0 (0.0)	13 (9.8)   1.0 (0.0)	89 (22.4)   1.3 (0.9)	136 (37.2)   2.0 (1.5)	149 (43.8)   2.3 (1.7)	
	7	0 (0.0)   0.0 (0.0)	178 (23.8)   1.1 (0.3)	349 (40.5)   1.2 (0.5)	514 (55.6)   1.6 (1.0)	575 (62.1)   1.8 (1.2)	610 (66.4)   2.1 (1.5)	
	6	163 (24.0)   1.2 (0.5)	452 (57.9)   1.5 (0.7)	546 (63.1)   1.6 (0.8)	664 (71.3)   2.0 (1.1)	702 (75.5)   2.2 (1.3)	708 (75.5)   2.5 (1.5)	
	5	0 (0.0)   0.0 (0.0)	36 (4.9)   1.5 (0.7)	77 (9.5)   1.7 (0.8)	179 (20.4)   1.8 (1.0)	227 (25.8)   2.1 (1.2)	257 (25.8)   2.5 (1.4)	
	4	0 (0.0)   0.0 (0.0)	10 (1.4)   1.2 (0.4)	26 (3.2)   1.3 (0.5)	72 (8.3)   1.6 (1.0)	90 (10.4)   1.8 (1.2)	120 (10.4)   2.0 (1.5)	
	3	0 (0.0)   0.0 (0.0)	1 (0.1)   1 (—)	4 (0.5)   1.3 (0.5)	27 (2.9)   1.4 (0.8)	31 (3.3)   1.4 (0.9)	42 (3.3)   2.1 (1.7)	
	2	1 (0.1)   1 (—)	3 (0.4)   1 (0.0)	4 (0.5)   1.3 (0.5)	21 (2.3)   1.8 (1.2)	24 (2.6)   2.0 (1.3)	33 (3.6)   2.5 (1.5)	
	1	1 (0.1)   1 ()	2 (0.3)   2.0 (0.0)	4 (0.5)   1.5 (0.6)	23 (2.5)   1.7 (1.0)	21 (2.3)   1.9 (1.1)	34 (3.7)   2.4 (1.3)	

Version 10.<sup>41</sup> The Lower South Regional Ethics Committee, New Zealand Ministry of Health, granted ethics approval for each phase of this longitudinal study. Study members gave informed consent before participating in each assessment.

#### Data animation

An animated dental chart, showing study participants' mean caries and restorative experience at the tooth and tooth surface level, was developed. Data from years in between each dental assessment were interpolated. Individual frames were drawn for each year of age and animated using open source code into graphic interchange file (GIF) format in order to enable desktop or web-based viewing.

#### RESULTS

Information on the total number of participants assessed at each assessment round

(9, 15, 18, 26, 32 and 38 years) is presented in Table 1. A total of 30 study members were deceased by age 38 years. A total of 957 study members were examined on at least three occasions from age 9 to 38, 984 were examined twice and 1,006 were examined at least once. A total of 922 were also dentally assessed at age five; although a small number of permanent incisors and first molars had erupted by that age, none had yet been affected by tooth decay;<sup>42</sup> so

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these data are not included in this report. Furthermore, because there were no significant sex differences in DMFT scores at any age, the data presented here have not been disaggregated by sex.

The prevalence of dental caries is presented as the number with one or more teeth that were affected by decay, missing, or filled at the time of assessment (DMFaffected). The mean numbers of decayed, missing, and filled teeth and surfaces at each age are presented in Table 2.

DMFT centiles for dental caries experience are presented in Figure 1 and DMFS centiles are presented in Figure 2. Every tenth decile is presented, together with the first, fifth, ninety-fifth and ninety-ninth percentiles. Increasing DMFT follows an asymptotic curve, tangential to the limit of DMFT = 32 (count of the number of teeth in the permanent dentition), while the DMFS centiles followed linear curves.

Data on the number and type of cariesaffected teeth are presented in Table 3, together with the severity of dental caries experience in affected teeth. Dental caries prevalence was greatest at age nine among the first molars and prevalence in those teeth remained the greatest at all ages; however, among caries-affected teeth the severity of dental caries (number of surfaces affected) was greatest in the upper third molars and upper second premolars. The teeth least likely to be affected by caries were the lower incisors and lower canines.

In contrast to the data presented in Table 3, where only caries-affected teeth are included in the computation of caries severity, the data presented in Figure 3 relate to all teeth (including those unaffected by caries). This shows that the severity of dental caries was greatest in the first molar teeth in all quadrants. The least caries experience was observed in the lower incisor and canine teeth, followed by the upper canines, upper incisors and third molars.

Group-based trajectory modelling of DMFS scores to age 32 years was previously conducted,<sup>37</sup> and this has been re-plotted here with extrapolation of data to fit age 38 data (Fig. 4). Supplementary data are presented in the form of an animated figure (Fig. 5 and online supplementary information), showing the change in the proportion of study members' caries-affected teeth and tooth surfaces with increasing age within each trajectory group.





#### DISCUSSION

This study provides a comprehensive summary of dental caries experience in the permanent dentition over time. The findings show that dental caries experience continues throughout the life-course to the late thirties and provide evidence to support the differential susceptibility of the various teeth within the mouth.

Before considering the implications of the data presented in this report, it is important to consider the limitations and strengths of the study. Teeth were not dried before examination and radiographs were not taken, so we are likely to have underestimated the caries experience of this population. Reliability examinations were not conducted: this is an important theoretical consideration, but its actual relevance to the current study's findings is doubtful. It was not possible to calibrate examiners between assessments phases; however, standardised protocols were used at each assessment phase.

Alongside these limitations, this study also has a number of key strengths. The

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Fig. 3 Mean number of DMF-affected tooth surfaces by tooth and age (mean of all teeth, including caries-unaffected teeth)



Dunedin Study remains the best-maintained cohort in the world, with only 5% attrition after almost four decades. Many cross-sectional studies of different agegroups have tried to draw conclusions about dental caries risk at different ages, but neglect to consider the cohort effect. This study has great strength in that it is longitudinal and comprehensive. The high retention rate and population-based nature of the sample gives support to the generalisability of the sample to the source population. Naturally, this study is most relevant in the New Zealand context, as the data collected are on New Zealandborn people; however, it is relevant in a global context because no similar studies have been conducted in other developed countries. Furthermore, oral health in New Zealand is comparable to that in other developed English-speaking nations, such as Australia,<sup>43</sup> as is the pattern of oral health service utilisation in this country.<sup>44</sup>

Between age 32 and 38, we found that mean DFS increased only slightly (from 14.7 to 15.3), while the mean MS and MT nearly doubled in the same period (3.4 to 6.2 and 0.7 to 1.3, respectively). The DMFS finding (15.7 DFS + 6.2 MS by age 38, Table 2) was similar to the DMFS found in Australian recruits aged 36-51 of 24.4 examined in 2002.<sup>24</sup> It is difficult to compare DMFS in different age groups taken ten years apart and in different countries, but these findings appear to be similar. The patterns of dental caries found in Australian dental recruits, as with other studies, showed that caries prevalence was found predominantly in occlusal surfaces, with an increasing prevalence in approximal surfaces of posterior teeth in the 36-51 age group.<sup>24</sup>

Broadbent et al.36 previously reported that a substantial proportion of study members had experienced caries between ages 26 and 32 and found this to be not surprising, due to the increased exposure and time-at-risk of their tooth surfaces. They found that the caries increment was greatest in the posterior and maxillary anterior teeth, a finding which supported reports from other studies.45 In the current study a number of adjustments were made; teeth extracted for reasons other than dental caries were excluded from analyses. The hierarchy of caries susceptibility by tooth type and sites on teeth in all teeth are similar to other findings, but when considering only caries-affected teeth at age 38, the most affected surfaces were found in upper third molars, followed by upper second premolars.

This being the first dental study to have followed a cohort from birth to age 38, it is imperative that this research be continued into the 40s and beyond. There is a need for more longitudinal studies that include collection of comprehensive dental data, for the purposes of confirmation and comparison of results and exploration of generational and regional differences in caries experience.

These unique data show clearly that dental caries continues as a disease of adulthood, remaining important beyond childhood and adolescence, and that rates of dental caries over time remain relatively constant.

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Fig. 5 Animation showing change in the proportion of study members' caries-affected teeth and tooth surfaces with increasing age within each trajectory group. NB animation is available in the online supplementary information associated with this article

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