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Trajectory Patterns of Dental Caries Experience in the Permanent Dentition to the Fourth Decade of Life

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Abstract

Dental caries is a chronic, cumulative disease, but no studies have investigated longitudinal patterns of caries experience. The objective of this study was to identify and describe developmental trajectories of caries experience in the permanent dentition to age 32. Longitudinal caries data for 955 participants in a longstanding birth cohort study were analyzed by trajectory analysis. Three caries experience trajectories were identified by the SAS macro PROC TRAJ; these were categorized as “high” (~ 15%), “medium” (~ 43%), and “low” (~ 42%) DMFS (Decayed, Missing, and Filled Surfaces). All were relatively linear, although the higher trajectories were more “S-shaped”. This effect disappeared following adjustment for the number of unaffected surfaces remaining at each age, suggesting that, among individuals following a similar caries trajectory, caries rate is relatively constant across time.

Keywords

longitudinal study; adult; trajectory analysis; caries

INTRODUCTION

Dental caries is a chronic, cumulative disease, and the caries status of an individual develops over time. Caries occurs at any stage in life, provided that an individual has susceptible teeth (and surfaces) remaining. Biological, behavioral, and environmental factors act upon the dentition throughout life, suggesting that the life-course approach (Ben-Shlomo and Kuh, 2002) is relevant to dental caries epidemiology. However, dental caries epidemiology has rarely been investigated from the life-course perspective (due, in part, to a paucity of appropriate data), and statistical approaches to the analysis of such data have, correspondingly, been seldom discussed in the dental literature. Analyzing differences in the accumulation of caries experience over time among individuals can be challenging, and the interpretation of such data is not always straightforward (Härkänen *et al.*, 2002). In the past, many researchers have defined groups to assist in data analysis on the basis of risk factors or other subjective classifications; however, such an approach may fail to identify important developmental patterns (Nagin, 2005).

Latent class analysis is a statistical approach used to group observations (or variables) into strongly inter-related subgroups (or classes). Latent class analysis is relatively new in health research, and appears to be a useful tool for evaluating complex developmental data. Thus, it

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provides a new and exciting option for identifying, summarizing, and describing the complex patterns of findings often generated by life-course studies. While numerous statistical software applications are available for conducting latent class analysis, not all can deal with longitudinal data.

'Group-based trajectory modeling' is a specialized application of finite mixture modeling, and can simplify longitudinal data by identifying developmental trajectory groups on a likelihood basis. It approaches a set of individual trajectories by grouping those which closely resemble one another (using a probability function). Essentially, the methodology assumes the existence of unobserved (latent) subpopulations. While these groups do not (necessarily) exist *per se*, their identification has applications in both the interpretation and further analysis of longitudinal data. Dealing with a small number of groups of trajectories is less complicated than analyzing several hundred individual trajectories (Nagin, 2005). Presentation of longitudinal findings may be in the form of easily understood graphs and tables, and determinants of group membership can be more readily investigated. Such data may be more accessible for clinicians and other non-researchers.

While trajectory analysis is relatively new (Nagin and Land, 1993), it has already been used extensively in longitudinal social research (Nagin and Tremblay, 2005). In psychology, the term 'developmental trajectory' is used to describe the course of a behavior or outcome over age or time. Such a term (or one such as 'disease trajectory') could also be applied to the progression over time of a cumulative disease, such as dental caries.

Utilizing group-based trajectory analysis, we investigated the natural history of dental caries experience in a birth cohort from childhood until the middle years of life. This research will be particularly useful in determining whether (at the population level) high-risk periods for dental caries exist—a 'critical period' of risk such as, for example, the teenage years (Carlos and Gittelsohn, 1965)—or whether a cumulative increase in caries experience over time is relatively constant, suggesting that risk does not vary with age (Ben-Shlomo and Kuh, 2002).

METHODS

The Dunedin Multidisciplinary Health and Development Study (DMHDS) is a longitudinal study of a birth cohort of children who were born at the Queen Mary Hospital, Dunedin, New Zealand, between 1st April 1972 and 31st March 1973 (Silva and Stanton, 1997). Perinatal data were obtained, and the sample for the longitudinal study was first followed up at age 3 yrs (N = 1037), and again at ages 5, 7, 9, 11, 13, 15, 18, 21, 26, and, most recently, at 32 yrs. The current study uses data collected from dental examinations at ages 5, 9, 15, 18, 26, and 32 yrs. The Otago Ethics Committee granted ethics approval for each assessment phase. Over 90% of the cohort self-identify as being of European origin. Study participants gave informed consent prior to inclusion.

Measurement of Dental Caries

At each age, dental examinations for caries and missing teeth were conducted by calibrated examiners. Before each examination, recording sheets were adjusted to account for teeth that had been missing at the previous assessment. Teeth were examined for dental caries and restorations, with 4 surfaces (buccal, lingual, distal, and mesial) being considered for canines and incisors, and a fifth surface (the occlusal) included for premolars and molars. In a small number of cases where a surface could not be visualized by the examiner, the surface was excluded from the examination (and later analyses). We obtained an estimate of accumulated tooth loss due to caries by observing the presence or absence of each tooth, and by ascertaining the reason for its absence at that age by asking the participant at the time of each examination.

Repeat examinations were not possible, because of the logistical constraints imposed by the tightly scheduled assessment that study participants underwent. Dental examiners were not aware of study participants' socio-economic status (SES) or questionnaire responses at the time of the examinations. Further information on these assessments is available in previous publications (Suckling *et al.*, 1985; Thomson *et al.*, 2000; Broadbent *et al.*, 2006).

Data Analysis

We used surface-level dental examination data to compute DMFS (Decayed, Missing, and Filled Surfaces). For the 'M' component of DMFS, a minimum of 3 surfaces was assigned as having been carious for each extracted tooth (Broadbent and Thomson, 2005). Where more than 3 surfaces (4 or 5) were known to have been carious at the most recent assessment prior to the extraction of the tooth, this number was used. For example, DMFS scores for teeth which were missing at age 26 due to caries were adjusted by their surface status at age 18 (if present), while teeth which were missing due to caries at age 32 were adjusted by their surface status only from age 26. In this study, only teeth which had been lost because of caries are included in the estimations of tooth loss due to caries, and in the 'M' component of DMF scores.

Group-based trajectory analysis was performed with the PROC TRAJ macro in SAS version 9.1 (Jones *et al.*, 2001). To enable a single measure of dental caries experience to be used for the trajectory model, the modified DMFS was used, as described above. The modified measure is preferable in this instance to either DFS or generally accepted DMFS (where each missing tooth is presumed to have been completely decayed prior to extraction), since it is very likely that those measures provide under- and overestimates of true caries experience, respectively (Broadbent and Thomson, 2005). Data analysis was restricted to those study participants for whom dental data were available from at least 3 assessment ages. The PROC TRAJ macro assumes that missing data are missing completely at random, and the model is adjusted so that missing observations do not contribute to the sample size or analytical outcome.

The parameters for the trajectory model were determined on a maximum-likelihood basis by a general *quasi*-Newton method (Dennis *et al.*, 1981; Jones and Nagin, 2005). In the interests of parsimony, a three-group trajectory analysis model was defined (Table). The Bayesian Information Criterion (BIC) is a tool which is often used in model selection; however, in trajectory analysis, the BIC does not always clearly identify a preferred number of groups. Selection of that number must balance the interests of parsimony with the objective of reporting the distinctive developmental patterns in the data. The objective of model selection is not the maximization of some statistic of model fit; rather, it is to summarize the distinctive features of the data in as parsimonious a fashion as possible (Nagin, 2005).

We defined the order of the two resultant groups with the greatest experience of dental caries over time as having cubic trajectories, while the group with the lowest disease experience was allocated a linear trajectory. This combination was determined by visual inspection of the shapes of the trajectory plots, and by adjustment of the parameters to maximize the BIC within the three-group model.

Since it is not yet possible to fit models in PROC TRAJ according to the zero-inflated negative binomial (ZINB) distribution, the zero-inflated Poisson (ZIP) model was used instead as a reasonably acceptable alternative (Lewsey and Thomson, 2004). The degree of zero-inflation for the ZIP model was determined with the BIC. At all ages, the analysis was restricted to the permanent teeth, since the primary teeth constitute a discrete dentition. Age-5 dental data were included, because 46 of the 878 participants at that age had had at least 1 permanent tooth erupted, but none had yet experienced caries. Thus, age 5 served as a 'zero point' for dental caries experience.

Plot data were generated by means of the macro 'TRAJPLOT'. To reinforce the model and trajectory plots produced, we calculated 95% confidence intervals through the macro 'TRAJPLOTNEW'. Standard errors for the mean trajectories were calculated according to a first-order Taylor series expansion (Jones and Nagin, 2005). Plot data were exported into (and plotted in) Intercooled Stata 8.0 (Stata Corporation, College Station, TX, USA). The percentage of caries-affected surfaces was computed at each age within each trajectory group, and this was also plotted.

RESULTS

Participation rates in the Dunedin Study have remained high, with 972 study individuals (96%) participating at age 32 yrs, and 932 (92%) participating in the dental examination. Dental caries data were available for 955 individuals at 3 or more of the 6 dental assessment ages, and the following analyses are restricted to those individuals. The 82 excluded individuals included 48 males (9.0%) and 34 females (6.8%).

The individual caries trajectories were plotted (Fig. 1), and through the trajectory group assignment based on the PROC TRAJ macro, 384 participants (40.2%) were assigned to 'group 1', 427 (44.7%) to 'group 2', and 144 (15.1%) to 'group 3'. These were designated the 'low', 'medium', and 'high' trajectory groups, respectively. When DMFS data by trajectory group were plotted against age, the mean DMFS scores of trajectory groups were seen to diverge with increasing age (Fig. 2). By age 32, the mean DMFS was 5.4 (SD 3.7) in group 1, 18.6 (SD 6.8) in group 2, and 42.3 (SD 12.7) in group 3. On average, 36.9% of tooth surfaces in trajectory group 3 had been affected by caries by age 32. At the group level, the plot of the percent of caries-affected surfaces (of those permanent teeth present in the mouth) revealed no period of rapid increase in DMF (Fig. 3).

The prevalence of tooth loss was greatest in the two higher trajectory groups. None of the participants had lost teeth due to caries by the age of 18 yrs. By age 26, 0.6% of participants in the low DMFS trajectory, 13.2% in the medium DMFS trajectory, and 33.3% in the high trajectory for DMFS had lost teeth due to caries, with a mean 0.0, 0.3, and 0.7 teeth lost, respectively. By age 32 yrs, the prevalence of tooth loss due to caries had increased in all groups, to 5.9% in the low trajectory, 28.4% in the medium, and 53.8% in the high trajectory, with a mean 0.1, 0.7, and 2.2 teeth lost, respectively.

DISCUSSION

The Dunedin Study remains the only dental study to have followed a group of individuals from birth to adulthood. Our use of group-based trajectory analysis appears to be a valid approach to exploring developmental trajectories; the technique has the added advantage of being simple to interpret. The trajectory groupings are a useful statistical device for capturing the essential features of the underlying complex reality of the longitudinal caries data-set.

A possible weakness of this study is that we have chosen to limit our analyses of possible determinants of trajectory group membership (at this stage), and have not yet considered any potential confounding variables. From an analytical standpoint, it is important to remember that the trajectory 'groups' do not exist in the real sense; they are an analytical convenience. Furthermore, several alternative programs are available for estimation of such latent classes (PROC TRAJ, MPlus, and LatentGold), and the outcomes of latent class analyses may differ according to the precise estimation parameters that are specified. PROC TRAJ (which we have used) does not consider growth factor variances within trajectory classes, while the alternative program MPlus does. This consideration is important theoretically, since it may affect the trajectory group membership of a few cases; however, it is unlikely that including such

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variation would materially affect the overall outcome (and associated inferences) of the analysis.

Trajectory analysis appears to be a useful and valid descriptive tool in the investigation of caries experience across the life-course, and can aid in the recognition of patterns (or trajectories) of caries experience over time. In this study, the two higher trajectory plots were S-shaped (or cubic), while the lowest trajectory was linear. Teeth were lost at a proportionally greater rate among participants following higher trajectories, thus decreasing the number of surfaces available and 'at risk' to caries in the mouth over time. The rate of increase in %-DMFS appeared to be linear in all trajectory groups, with no apparent drop-off in the rate of increase in %-DMFS with increasing age. Thus, analysis of our data does not support the commonly held belief among dentists that childhood and adolescence are periods of special risk for dental caries, or that caries 'immunity' may be acquired during late adolescence or early adulthood (Carlos and Gittelsohn, 1965). In this population at least, new caries appears to be occurring at a relatively constant rate, implying that for greatest benefit, caries-preventive measures are necessary at all stages of the life-course.

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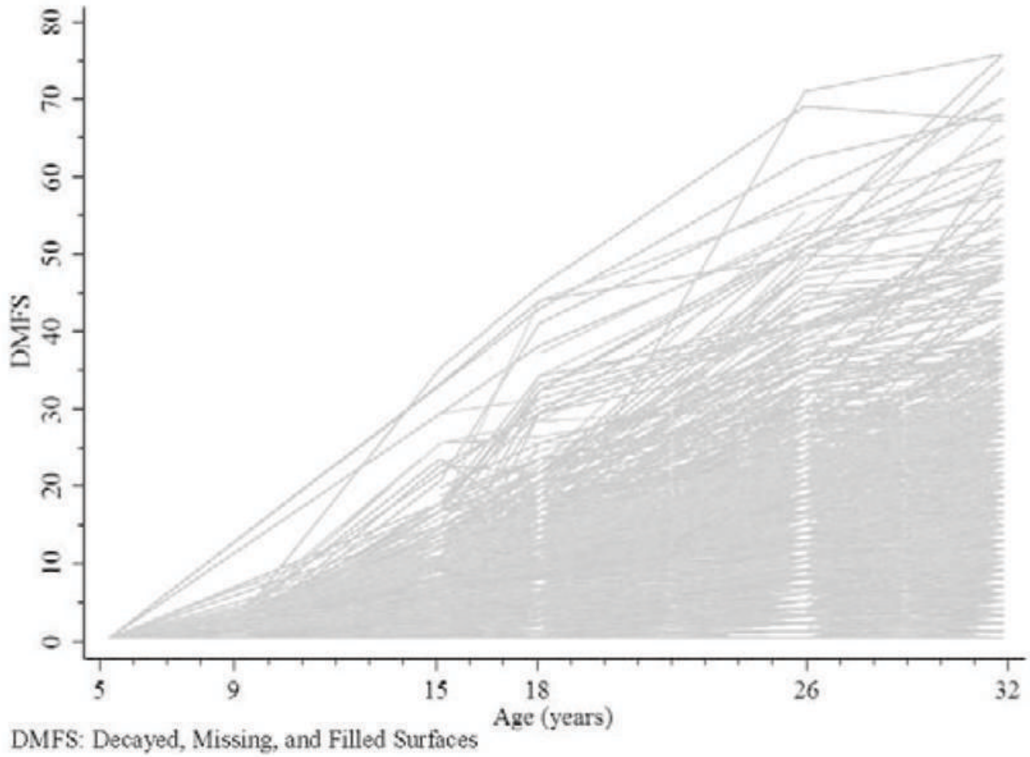

Figure 1.
Simple join of DMFS scores by age (from the Dunedin Multidisciplinary Health and Development Study database).

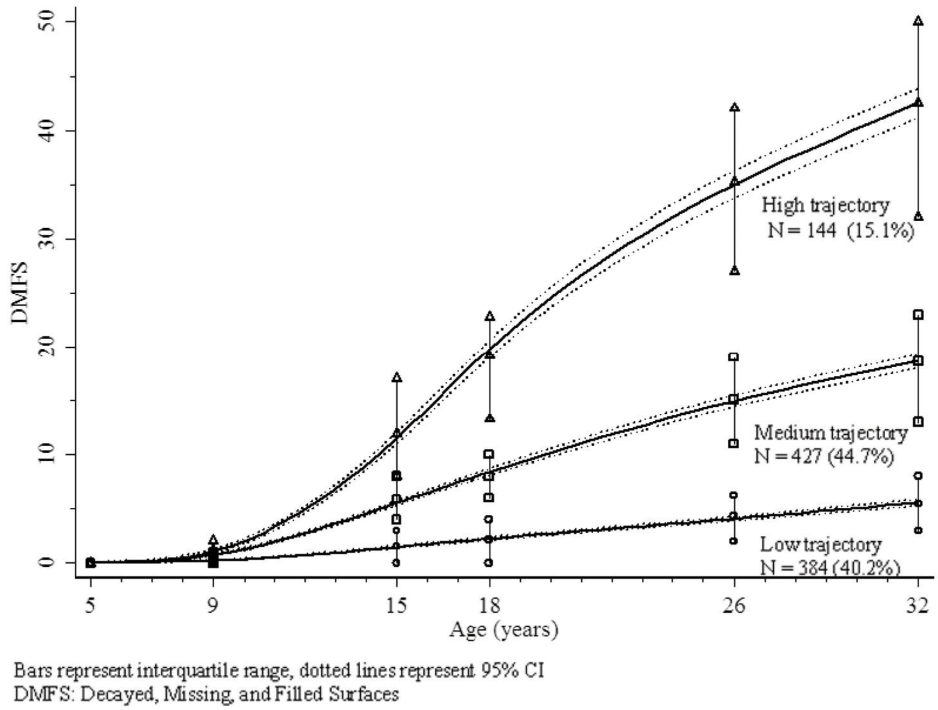

Figure 2.
Trajectory plot of mean DMFS scores for three-group caries trajectory analysis model.

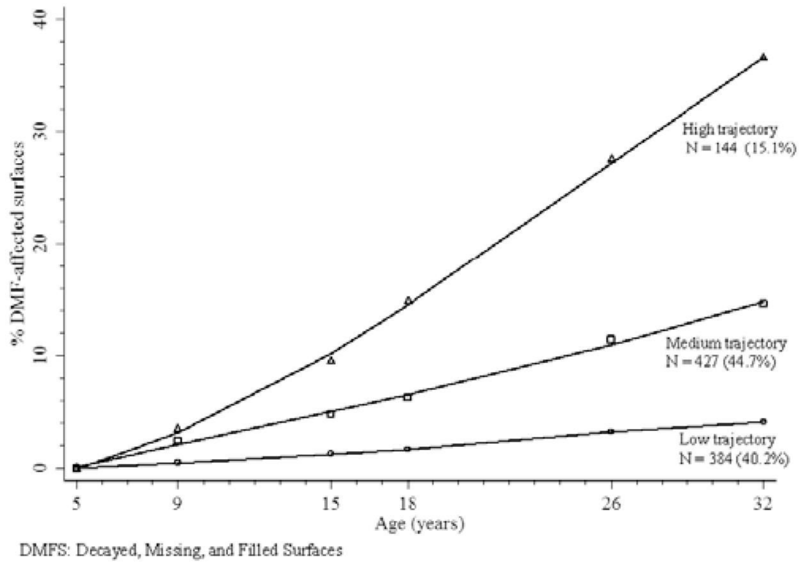

Figure 3.

Plot of mean percentage of at-risk surfaces affected by caries over time for three-group caries trajectory analysis model.

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Table

Trajectory Model Selection Criteria

	BIC*	Percent Change in BIC for +1 Group	AIC
1 group	−19528		−19512
2 groups	−13165	−32.6	−13126
3 groups	−11669	−11.4	−11607
4 groups	−11026	−5.5	−10941
5 groups	−10850	−1.6	−10743
6 groups	−10748	− 0.9	−10618
7 groups	−11401	+6.1	−11248
8 groups	−11339	−0.5	−11163
9 groups	−11378	+0.3	−11180

*BIC, Bayesian Information Criterion; AIC, Akaike Information Criterion.