Tooth-by-tooth survival analysis of the first caries attack in different age cohorts and health centers in Finland

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The aims of this study were to test the hypothesis that existing patient records serve as a source of data for survival analysis of dental health and to develop a system for routinely conducted survival analysis of dental health from tooth eruption to first caries attack. Patient records for three cohorts were collected from four towns in Finland: Oulu, Turku, Kuopio, and Kemi. The study population comprised 2103 children born and living in these towns. The Kaplan-Meier curves for dental caries were drawn separately for each tooth and for the maxilla and mandible (for each age cohort). Placements of the first restoration of all teeth in each age cohort were investigated. The 1960 cohort had an extremely high post-eruptive morbidity in all teeth. The 1970 cohort had relatively high immediate post-eruptive morbidity in both molars, but much lower than that of the 1960 cohort. The filling increment rates for second molars were lower than those of the first molars in the 1970 cohort. Characteristic of the 1980 cohort was a rapid increase in the caries increment of the premolars and second molars 4 years after eruption. The results indicate a big difference in tooth-by-tooth dental health in Finland. A huge decline in caries attack was seen from the 1960 cohort to the 1980 cohort, but a deterioration of dental health in premolars and second molars is clearly seen in the 1980 cohort in the 1990s. □ *Dental caries; dental health; survival analysis*

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In a previous study, tooth-specific caries risk was determined using a sophisticated survival model and Bayesian intensity methods in the statistical analysis of risk intensity (1). The Bayesian intensity models are not the only possible methods for analyzing survival data (2, 3); frequentist methods can be used, but interpretation of the results needs a good knowledge of treating left-, interval-, or right-censored multivariate data (1). Another drawback of these sophisticated statistical methods is that the computational burden in estimation is heavy, such that further practical approaches are needed. We therefore conducted this study of the retrospective analysis of the outcome of caries on different teeth. We analyze the first caries attack on different teeth using Kaplan-Meier survival methods in order to find out if the tooth-specific caries risk was realized in practice in the same teeth.

Survival analysis requires independent data, i.e. each tooth in a subject is independent of the other teeth and each subject has a number of teeth that may possibly become carious (statistical term 'fail') some years post-eruption (dental age) or some years after birth (chronological age). Hence, the teeth in each individual contribute with several observations, which will be dependent from each other and of the interindividual variation. To tackle the problem of dependence, one statistical solution is to estimate the survival curves or the cumulative intensity curves of each tooth of each individual. But because this leads to a large number of curves, a summary of 'cumulative intensity curves' is needed. There are numerous statistical ways of doing this, the simplest being to present a mean of the plots of each tooth with the statistical Kaplan-Meier method.

Tooth-by-tooth survival curves from tooth eruption (origo) to first caries attack of a group of individuals give detailed information about the changes in dental health in different stages of development of the dentition (4, 5). To test the hypothesis that patient documents may be used retrospectively for survival analysis of dental health using methods that do not demand heavy computational capacity, this study was undertaken in three different age cohorts at different health centers in Finland. The aims were: 1) to use records to obtain tooth-by-tooth survival analyses of dental health; and 2) to develop a system for survival analyses of tooth eruption and the first caries attack based on dental age and chronological age using data collected in the course of normal dental treatment.

Materials and methods

Data were collected from four towns in Finland: Oulu, Turku, Kuopio, and Kemi. Patient records were collected for three cohorts: children born in 1960–63 (1960 cohort, $n = 193$), children born in 1970–71 (1970 cohort, $n = 955$), and children born in 1980–81 (1980 cohort, $n = 955$). The children were randomly selected from the files of the health center or a total sample of the age cohort was used.

The primary criterion for inclusion in the analysis was that the subjects had to be citizens born and living in the town in question. The oral health records were copied so

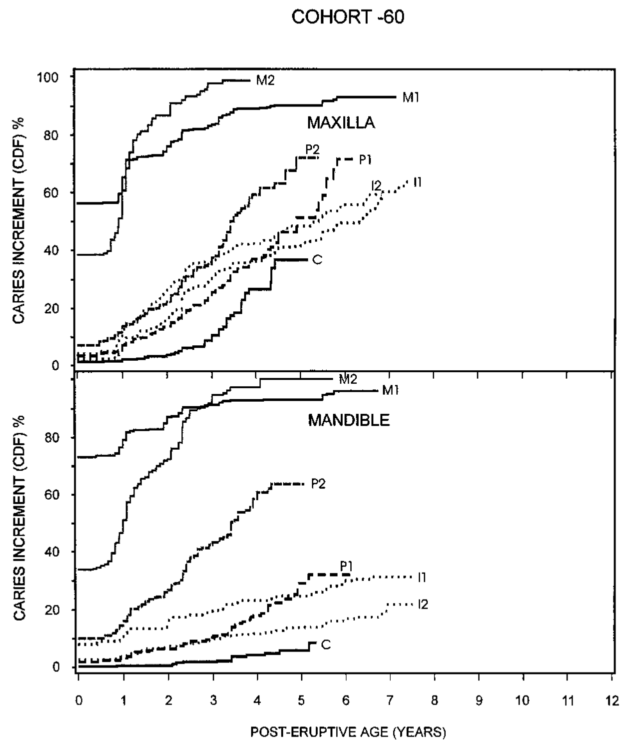

Fig. 1. Caries increment curves for each tooth in the maxilla and mandible of the 1960 cohort. The X-axis represents the post-eruptive age and the Y-axis the tooth-specific cumulative caries increment. M1 = first molar, M2 = second molar, P1 = first premolar, P2 = second premolar, C = canine, I1 = first incisor, I2 = second incisor.

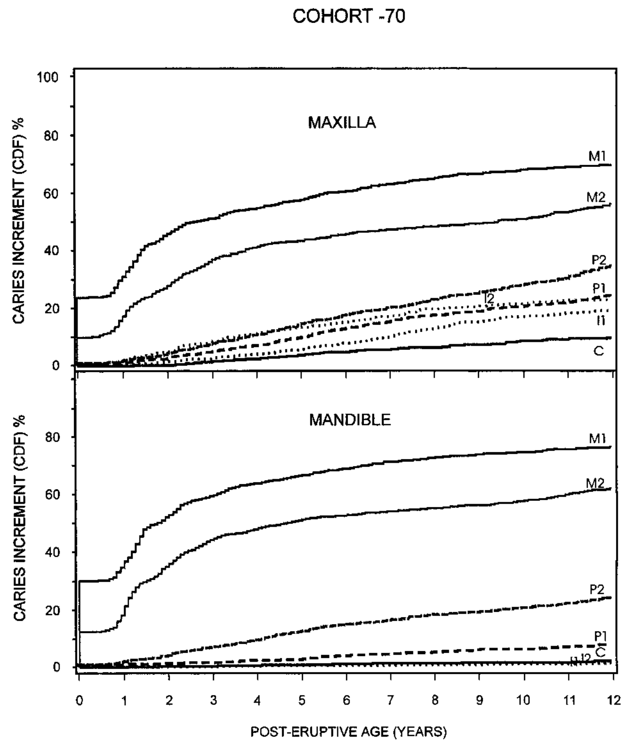

Fig. 2. Caries increment curves for each tooth in the maxilla and mandible of the 1970 cohort. Abbreviations as in Fig. 1.

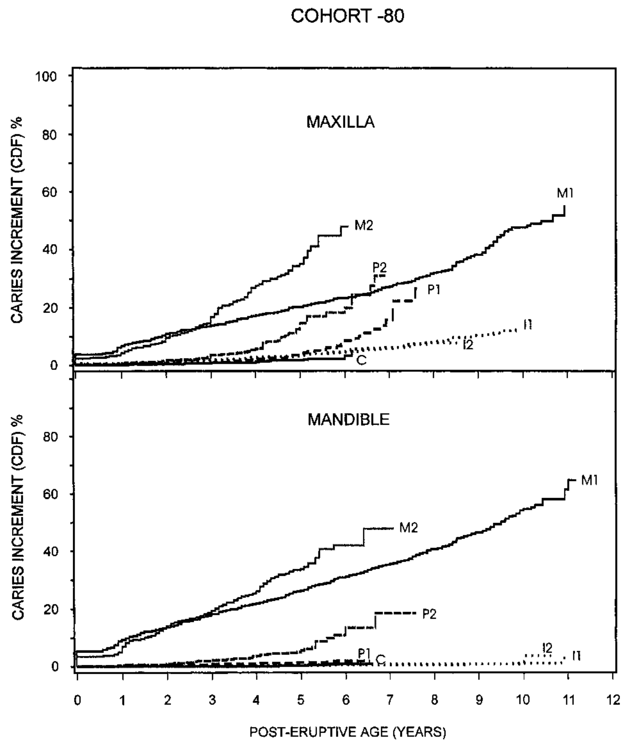

Fig. 3. Caries increment curves drawn for the 1980 cohort for maxilla and mandible and for each tooth separately. Abbreviations as in Fig. 1.

that the children could not be identified (the last names and social security codes were rendered). The study material consisted of 369 children from Oulu, 200 from Turku, and 386 from Kuopio in the 1980 cohort and 281 children from Oulu, 268 from Turku, and 406 from Kuopio in the 1970 cohort. The 1960 cohort consisted of 193 children born in Kemi only, because patient records were not available from the other towns. Kemi is a smaller town than the others and the sample is a representative proportion of the age cohort.

Prevention-oriented dental care with annual examinations came into effect throughout Finland in the 1970s. Dental records of patients born in 1960 were therefore available in Kemi only, not in the other towns. We believed it important to have a picture of the subjects born in the 1960s for comparing with the Carlos & Gittelsohn study (1965), so we also included the 1960 cohort.

The subjects were examined annually and treated in the muncipal health centers free of charge by dentists from birth until at least 19–20 years of age. Caries is normally recorded in annual examinations, and restoration is undertaken if a lesion has reached dentin. This information is documented in standard patient records, along with information on preventive measures, fluoride therapies, use of bitewings, and other procedures.

Caries data collected from the Finnish Public Health

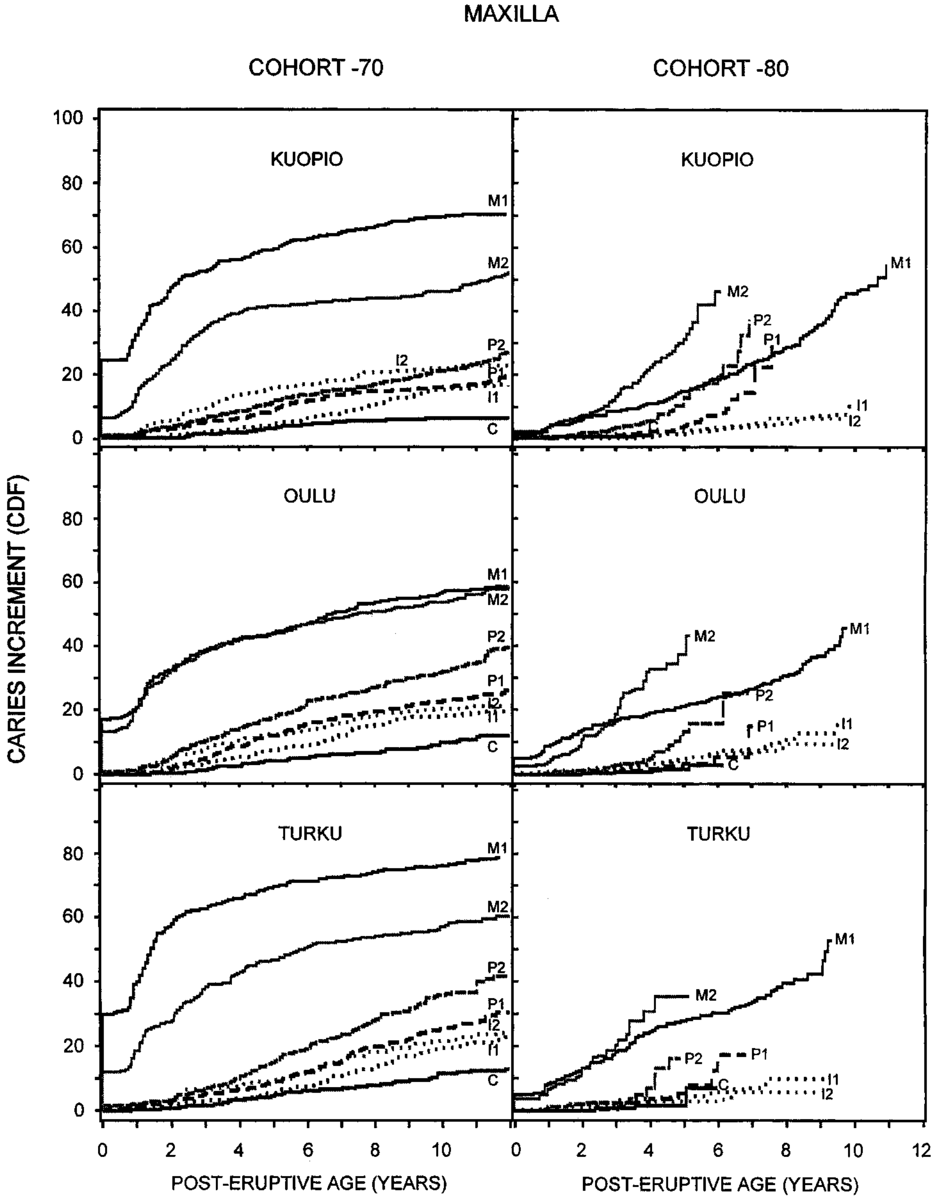

Fig. 4. Caries increment curves for maxilla. Increment curves are drawn for the 1970 and 1980 cohorts for three different study towns. Each tooth is drawn separately in the same way as above. Abbreviations as in Fig. 1.

records have proved to be almost equal to the data from examinations conducted by trained examiners (6).

Observations were made on every tooth (excluding the third molars) from birth to 19–20+ years. Timing of the eruption of each individual tooth, placement of the first fillings due to caries on each tooth surface, and tooth extractions was recorded. Extractions for orthodontic indications were excluded from the present analysis. Up to the age of 16 years the normal interval between examinations was 10–13 months, thereafter an acceptable interval was 18 months; if the observation intervals were longer than 18 months the subject was censored. At least one dental examination was carried out in the 1990s.

Timing of the eruption of each individual tooth for boys and girls was recorded and determined to an accuracy of 1 month. The failure time of a tooth was determined as the time from tooth eruption to the point at which a dentist made a decision, based on the WHO criteria, to fill a caries lesion which had reached dentin (4).

A computer was set up to handle all the data with SAS statistical software. Kaplan-Meier curves for each individual tooth were drawn. Differences between groups were tested using the t test and one-way Anova. A difference was considered to be statistically significant if the P value was <0.05.

Results

Because of the dependent data, Kaplan-Meier curves for dental caries were drawn separately for each tooth for maxilla and mandible and for each age cohort and both genders. No differences were observed between left and right sides or between boys and girls, and therefore the data were combined in the figures. To avoid pseudo replication of the n value (the number of teeth), the statistical analyses of the possible differences between teeth and cohorts were performed between individual teeth, not between tooth groups.

The 1960 cohort had an extremely high (40–75%) morbidity in molars during the year of eruption. The rate of caries attack on molars was not prominent thereafter (Fig. 1). The 1970 cohort, too, had a relatively high immediate post-eruptive morbidity. The difference in morbidity between molars remained the same from eruption to the end of the study period in the 1970 cohort and, in percentage points, was about the same as in the 1960 cohort. The filling increment rates of first restorations due to caries for second molars were lower than those of the first molars and both were lower compared to the 1960 cohort, where both molars failed almost at the same rate (Fig. 2).

A characteristic feature in the 1980 cohort was slow caries attack in first 3 post-eruptive years in all teeth and a rapid increase in caries increment of the premolars and second molars 3–4 years after eruption. Some years after eruption, the caries increment in premolars exceeded the rate of caries increment in the first molars (Fig. 3). Note the upward bending of the curves of the teeth of the second phase of mixed dentition, erupted in the 1990s.

There were no differences in tooth-by-tooth curves at the different health centers (Kuopio, Oulu, and Turku) analyzed (Fig. 4).

Discussion

When tooth-specific caries risk was analyzed with a survival method and Bayesian intensity methods in 3 age cohorts born in the 1960s, 1970s, and 1980s, an overall decrease of caries was seen in the younger cohorts (1). Analyses of the 1960 and 1970 cohorts revealed that the risk in molar teeth was highest immediately after eruption, but in the youngest cohort the risks in individual teeth were so low that no such dependencies on tooth age could be established (1). The shapes of the Kaplan-Meier curves in the present study suggest that the risk of caries on individual teeth became true in the Kaplan-Meier 'outcome' curves, which was as expected on the basis of the risk analysis (1).

In their classic work, Carlos & Gittelsohn (1965) first studied the effect of exposure time on caries risk for individual teeth by applying a life-table analysis of dental health to each tooth (7). Their 'exposure time' is in fact the 'survival time' of that tooth as being sound from eruption to clinical caries.

The greatest difference between the estimated probabilities of survival in the Carlos & Gittelsohn study and in the Finnish studies (1, 4, 5) is the observation that the first and second permanent molars and premolars were in considerably worse condition in the USA during the 1960s than in Finland during the 1970s. This might have been due to a long-term change, but it may also have been due to the more advanced program of prevention conducted in Finland during the past two decades. Also extractions may have been more common in the 1960s than in the 1980s in Finland in general, but this study analyzed the first filling due to caries only and omitted all extracted teeth. In the 1980 cohort, the rate for the first molar (maxilla), age 9–11 after eruption, i.e. age 15–17 years, versus the rate for the second molar from 5 to 7 years after eruption, i.e. age 16–18 years, were not markedly different. This shows that caries committed teeth in the 1980 cohort some years after eruption, whereas the year of eruption determined dental health in the 1960 and 1970 cohorts. This points to the different timing of preventive treatments in different age cohorts.

The shapes of the curves were about equal at each health center in both the 1970 and 1980 cohorts, indicating that the national recommendations of preventive dentistry resulted in about the same outcome at each health center (Fig. 4). It is of special interest that the shape of the curves for individual teeth in Kuopio with fluoridated drinking water was about the same as in the other two health centers in two other towns of equal size in Finland – an observation also reported earlier (8, 9).

In this context, we point to two important aspects: 1) although the data set is created in the course of normal dental treatment, this type of material has been observed as being not decisively inferior to those obtained from examinations by calibrated examiners, because the filling component of DMF determines the outcome of teens (6); 2) in this case, these data sets were collected manually and thereby individually controlled from patient records on paper. Now we have developed a fully automatic system in which the data for Kaplan-Meier curves are collected directly from digital patient records. These curves give similar curves as manually collected and controlled curves do. Thus, tooth-by-tooth curves can also be drawn automatically if digital patient records are available.

In conclusion, the results of the present study indicate a huge difference in tooth-by-tooth dental health in 3 age cohorts of young adults in Finland. The great decline in caries attack between the cohorts is partly compensated in the most contemporary cohort, in which a deterioration of dental health in premolars and second molars is clearly seen as an upward bending of the Kaplan-Meier curves for these teeth.

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