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ORIGINAL ARTICLE

# Computed online determination of life-long mean index values for carious, extracted, and/or filled permanent teeth

MARJUT KORHONEN,[1,2], SINIKKA SALO[3], JORMA SUNI[4] & MARKKU LARMAS[1,5]

[1]*Institute of Dentistry, University of Oulu, Oulu, Finland,* [2]*Health Center of Oulu, Oulu, Finland,* [3]*Health Center of Kemi, Kemi, Finland,* [4]*Health Center of Vantaa, Vantaa, Finland and* [5]*Oulu University Hospital, Oulu, Finland*

**Abstract**

***Objective***. The purpose of this study was to develop and test a data-mining system for the online determination of mean DS, M, and FS or DMFS values per subject at different ages from electronic patient records at two health centers to see if there are north–south differences in oral health in Finland. ***Material and methods***. The mean index values were determined at two health centers using the codes of dental charts and progress notes of electronic dental records during the digital era of more than 10 years in a total of 153,619 subjects of all ages. Extracted teeth, as well as sound, carious, and restored tooth surfaces, were recorded from the dental charts. Treatments were then additionally registered from progress notes of the records when performed. ***Results.*** The cumulative DS and FS values were similar in subjects under the age of 20 years at both health centers. In adults, caries was more abundant in northern Finland, where there was a higher number of restored surfaces (>40) registered, compared to only 30 in southern Finland at the age of 40 years. A high increase in the number of extractions began at age 45 in the north compared to age 70 in the south. These changes were clearly reflected in the DMFS index. ***Conclusions.*** Online determination of health parameters is a feasible methodology. The results revealed that north–south regional differences in dental health still occur in adults in Finland, but not in subjects younger than 20 years of age.

**Key Words:** *Database, dental caries, dental record, extracted teeth, restored teeth*

## Introduction

In caries epidemiology since the 1930s, decayed (D), missing (M), or filled (F) permanent teeth or surfaces have been taken as measures of caries prevalence, with the presumption that restorations or extractions of teeth are consequences of dental caries only. All the index parameters thereby describe both past and present caries experience [1]. The index is useful in describing worldwide caries prevalence in a young population when oral health surveys have been conducted in accordance with the recommended basic methods of the World Health Organization [2]. Combining D, M, or F values within one index figure was meant not only for epidemiological purposes but also for evaluating treatment need due to caries in children and adolescents [1]. In addition, the relationship between prevalence and incidence of dental caries has to be considered when interpreting data from cross-sectional and time-series studies [3].

The index has several serious drawbacks when used in epidemiological studies, however, especially in older adults. The main problem is that its components are not equal entities [4]. Caries does not necessarily lead to a restoration, nor have all extracted or restored teeth been carious. Caries can also affect restored teeth, but these secondary carious attacks on restored surfaces do not affect the total index value. Extracted teeth are not always carious, although they count under dental caries in the index. When computing DMFS in adults, a missing tooth makes it necessary to arbitrarily allocate a number of surfaces as having been decayed. Therefore methods by which to adjust for misclassification of the M-component have been developed [4–6]. Also, the computation of caries increments requires the adoption of specific analytic conventions for handling examiner misclassification, teeth lost due to caries, and multiple events such as caries initiation and progression [7].

Correspondence: Markku Larmas, Institute of Dentistry, University of Oulu, P.O. Box 5281, FIN-90014 University of Oulu, Finland. Tel: +358 04 516 7516. Fax: +358 8 537 5503. E-mail: markku.larmas@oulu.fi

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In clinical practice, the dental chart (tooth and surface specific data) is coded at the first patient examination and thereafter the treatment provided is recorded. In an electronic patient record, the date of birth of the subject, the date of examination, and the dates of individual treatment procedures are normally recorded. The exact dates of these events or procedures are therefore available and can be determined from any digital dental record.

The aim of our study was to test whether automatic data-tabulation from the files of a dental health database is possible. The methodology was tested using digital dental records from two health centers in Finland, one in the southern part of the country (at Vantaa) and one in the north (at Kemi). If the procedure works correctly in these general dental practices, then they form a practice-based research network [8] of more than 100 dental offices. The following working hypotheses could be tested: 1) cumulative reversible and irreversible D gives different profiles of caries attacks in these health centers; 2) the cumulative number of restorations due to dental caries gives life-long cumulative number of caries attacks; 3) cumulative FS is not a sum of the cumulative DS; and 4) the different restoration and preventive strategies of health centers and patient attitudes to dental services will result in different profiles in the numbers of extracted teeth in the elderly population.

## Material and methods

The Committee of Ethical Affairs of Oulu University Hospital and the Health Centers involved granted permission for this study to be conducted. Vantaa is a town with 180,000 inhabitants in the south of Finland, while Kemi (24,000) is located in the north. An electronic patient record system (Denting, KemiTT Center, Kemi, Finland) has been in use at the center at Kemi since 1989, and at Vantaa (Winhit, Novogroup, Helsinki, Finland) since 1994. A total of 63,378 male (46.4%) and 73,231 female (53.6%) subjects visited a health center in Vantaa and 7939 males (46.7%) and 9071 females (53.3%) a health center in Kemi.

An intermediate file containing the following information was compiled from the digital patient documents: date of birth, gender, cavitated carious lesions and restorations on each tooth surface, and extracted or missing teeth. The dates of restorations and extractions performed during the treatment were also compiled from the progress notes. This resulted in 3,371,120 observations in Vantaa and 473,229 in Kemi being included in the data set.

An inclusion criterion in this analysis was that each subject had to have visited the health center for a dental examination at least once during the time period that digital records were in use. Subjects with only sporadic or emergency visits were not included. The follow-up time was therefore between one day and the entire time period.

Each subject was followed until a certain period of time, and was censored if the event (caries onset, restoration, extraction) did not occur at completion of the follow-up (right-censored). We applied interval-censoring on the left side of the time scale with all the parameters when information from the first examination session was recorded from the dental chart. This meant that if the tooth was recorded as being carious, filled, or extracted at that first examination, it was recorded as having caries onset, restoration, or extraction on that date regardless of the exact date. In this case, the birth of the subject was considered the first event. Right-side censoring was used so that the follow-up was censored at the last examination/treatment visit.

In the irreversible caries registration, all carious lesions in the dentition were always counted as D. Another possibility was that when the decay was restored or a carious tooth extracted after being recorded "carious" in the examination, it was deducted from the DS index and recorded as a restored surface (FS) or as an extracted tooth (M) on the day that these treatments were conducted. Extracted sound teeth (e.g. extracted for orthodontic or periodontal reasons) were registered as M only.

Both decays and restorations were counted as surface specific, each tooth having five surfaces. A mean number of reversible D-surfaces, irreversible D-surfaces, F-surfaces, or M-teeth and surfaces as well as DMFS estimates were counted as a function of the age of the subject with 1 day precision so long as the subject was in follow-up.

In order to control the database system, some age cohorts of 1 year were also individually aggregated into an intermediate file. Thereafter, Kaplan-Meier curves of caries onsets, restorations, and extractions were drawn for these age cohorts with SAS to check whether codes were recorded before the "digital era" of the health center, which should not have occurred.

The mean DMFS values were counted for each day using the actual N value. The determining component of the index (D, F, or M) was indicated and the MS value was obtained counting the registered M-value by 5. The difference between genders and different surfaces was tested using statistical software (SAS, Cary, N.C., USA). The significance was determined by *t*-test for each age cohort of 1 year and by Mann-Whitney for the whole follow-up.

## Results

Four age cohorts (born in 1975, 1980, 1985, or 1990) were compiled and the mean cumulative F values were plotted (Figure 1). Since the electronic patient record began at the health center in 1989, the

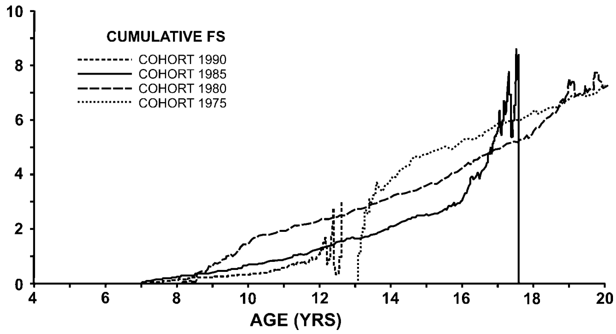


Figure 1. The outcome of the data-mining procedure for age cohorts born in 1990, 1985, 1980, and 1975 at the health center in Kemi. Kaplan-Meier estimates for restored surfaces indicate that no restored surfaces were registered before the digital era and that the cumulative values fluctuated at the end of the digital era owing to a reduction in the number of subjects followed.

age cohort born in 1975 was 13 years old at onset of the digital era. Before the digital era, the dates of restoration treatments were recorded on paper and were not transferred to digital form, but the restorations were still in the oral cavity and in the dental charts and were therefore compiled. With the age cohorts born in 1990, restoration treatments started at 7 years of age, when the first permanent teeth erupted. The follow-up at that health center was terminated when the subjects were 12, 17, or 20 years of age.

At both health centers, caries affected males more frequently than it affected females, the difference being significant ($p < 0.001$ $t$-test of age cohort, $\leq 0.001$ Mann-Whitney). The life-long non-cumulative DS values showed two peaks at about DS 2 (around 25–30 years) and at DS 3 (about ages 55–60) for males in Kemi. These were slightly lower for females (Figure 2A). At DS 1.0–1.5 they were the same ages for both males and females in Vantaa (Figure 2B). The cumulative irreversible DS did not exceed 6 at either health center (data not shown).

The cumulative FS curve has a bell-shape character, with a maximum of 40 for females and males at ages 35–40 at Kemi (Figure 2C). At Vantaa, the maximum was FS 31 at age 42 years for males and females (Figure 2D), after which it leveled and then slowly decreased. The number of restored surfaces at Vantaa was above FS 16 up to age 75 for females and up to age 90 for males, but at Kemi a level below FS 10 could be seen already at age 60. At both health centers, the shape and level of the FS curve were the same under age 25.

The number of extracted teeth increased steadily from a level of 3–4 teeth from age 45 onwards at both health centers and leveled at 25–28 teeth from age 60 onwards at Kemi (Figure 2E). At Vantaa, the mean number of extracted teeth/subject was about 10 less than that at Kemi after age 60 (Figure 2F). The number of teeth at Kemi at age 45 was equal to that at Vantaa at age 90 (Figure 2E, F).

DMFS values revealed that Kemi reached 100 surfaces at age 60 and around age 90 at Vantaa (Figure 3). Caries dominated the DMFS index under age 10, followed by restored surfaces and MS values at 44 years at Kemi and 49 at Vantaa (Figure 3).

## Discussion

Database compiling was observed to be a convenient way of analyzing the normal electronic patient record files from the health centers and for scientific purposes in a practice-based research fashion to compare observations made in real-life conditions on findings of epidemiological studies [8,9].

Because electronic patient records were taken into practice at a certain time at both health centers, no information could be analyzed from patients who attended for dental care at these health centers before that "digital era". This was, indeed, the case with all the tens of age cohorts tested. Some mistakes were observed, e.g. sometimes missing teeth were coded to be different at different examinations, but all these evident mistakes could easily be cleaned up from the file, and their proportion (less than 100) of the millions of codes was minimal.

The mean DMF values of certain age cohorts are normally counted. In the present case, age cohorts are replaced by individuals, so each parameter remained as determined as long as the subject was in follow-up. In practice, this means that some subjects were followed only at the first examination. If treatment or examinations were not performed thereafter, then the values and the subjects gave their contribution to that mean value per subject on that day only. The DMFS curve therefore fluctuates. The low number of subjects at the end of the follow-up resulted in fluctuation of the mean value at right (Figure 1). On the other hand, some subjects were followed during the whole digital era of that health center, and their contribution to the mean values is long lasting. This system for determination of the mean value was adopted from the principles of survival analysis methods and was found to be suitable for obtaining maximum benefit in the practice-based research fashion on the daily cross-sections. Counting the mean value of birth cohorts afterwards with 1–5 years' interval, which is the present practice, would be possible but was found impractical.

The north–south phenomenon reported to occur in the prevalence of dental caries, indicating that dental caries is more abundant in the north in the northern hemisphere [10], still occurs in Finland, but only in adults. New carious lesions (the reversible D values) were almost twice as high at Kemi as at Vantaa before ages 55–60, but after that time new caries lesions almost completely disappeared at Kemi, not due to disappearance of caries but because extractions dominated dental treatment

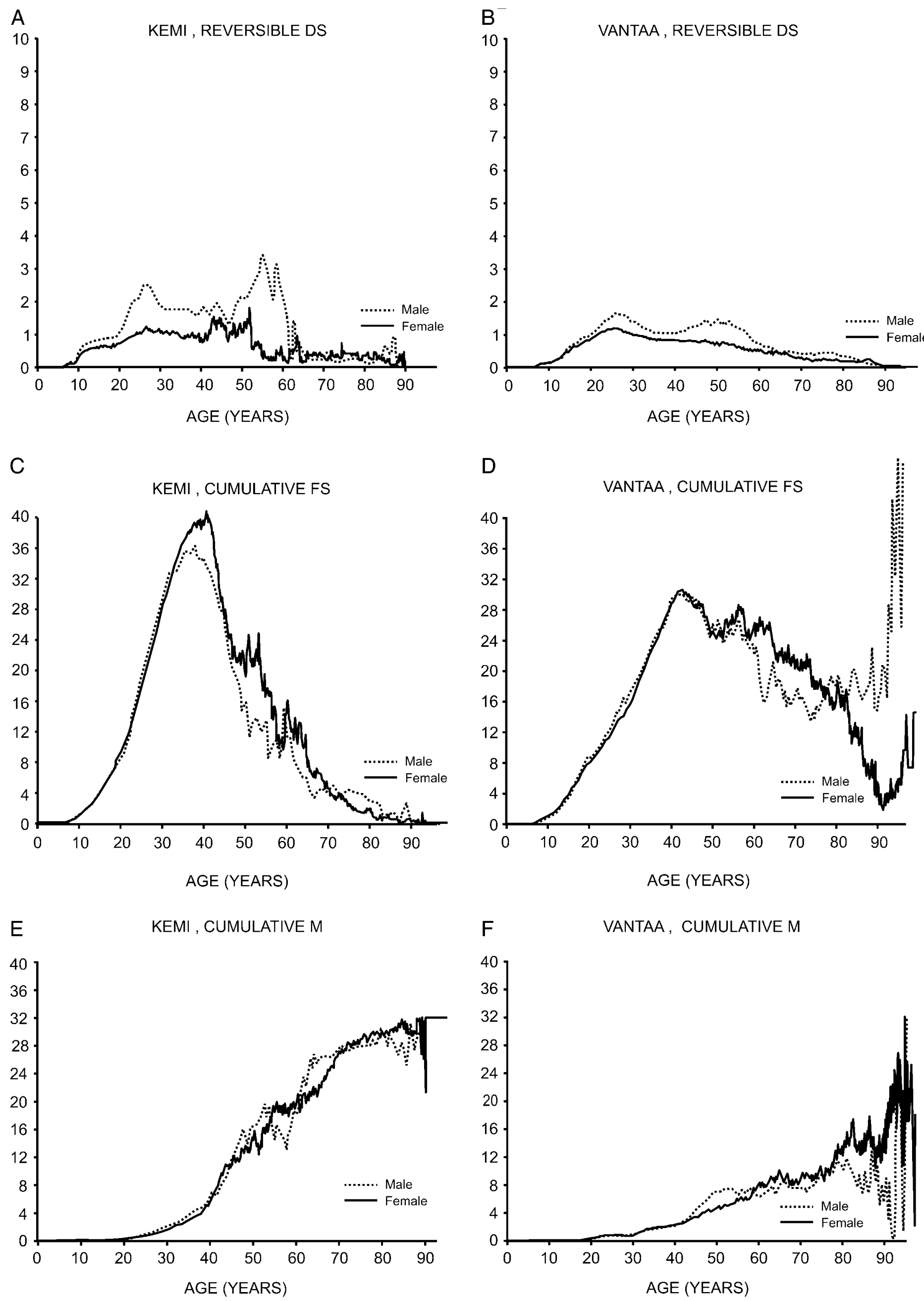


Figure 2. The reversible mean DS values for males and females at the health centers in Kemi (A) and Vantaa (B), the mean FS values for Kemi (D) and Vantaa (F), and the mean number of extracted teeth in Kemi (E) and Vantaa (F) as a function of age.

(Figure 2E). This resulted in a similar north–south phenomenon reported earlier for tooth loss in Australia [11].

The life-long irreversible DS should be close to life-long cumulative FS value if restorations are made due to caries. This really was the case under age 20 at both health centers. Thereafter, the cumulative F value considerably exceeded the cumulative D value. However, this does not mean that restorations of non-carious teeth were frequent. The outcome was due to the interval-censorship treatment used on the left side of the time scale. Most of the restorations made in the 1980s and earlier were still in the oral cavity at the first examination in the 1990s and were thus obtained from the dental chart, whereas most carious lesions diagnosed before the "digital era" were restored and therefore not recorded as caries in the dental chart, but as restorations in the digital dental records. The database system was treating caries leading to restoration as reversible only, which is also the situation in real life.

In conclusion, the results clearly demonstrate that differences in caries incidence or prevalence between the health centers no longer exist in cohorts under age 20 in Finland, but after that age the need for caries treatment is almost twice as high in the north as in the south. This has resulted in subjects in the north ages 30–40 having on average 5–10 surfaces

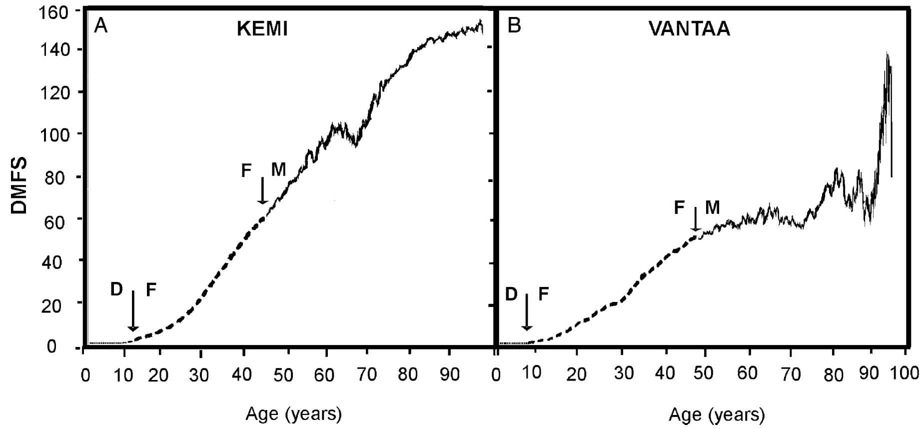


Figure 3. The mean DMFS value counted for each day from 0 to 99 years of age. The arrows show the age when DS turns to FS (broken line) and FS to MS (solid line).

per subject more restorations than in the south. Thereafter, extraction treatments (of restored teeth) are more abundant in the north than in the south, and the geographic variation of tooth loss still occurs in Finland. There are great differences in the dental health of adults and of the elderly in DMFS scores. This novel system enables the follow-up of these changes even on an online basis. The combination of D, M, and F values to one index value is certainly outdated today.

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