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The relationship between prevalence and incidence of dental caries. Some observational consequences.

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Objectives: To investigate the relationship between incidence and prevalence of caries. The principles are illustrated by means of Lexis diagrams, which show the relationship between cases of caries belonging to a population with a certain incidence and natural course of the disease in time. The analysis shows how studies on prevalence yield associations that reflect the determinants of the disease progression just as much as the causes of disease. Also the diagnostic criteria of the disease affect the prevalence estimate. The presence of fluoride changes the course of the disease and the prevalence estimate even with an unchanged incidence rate. This knowledge about incidence and prevalence should be taken into consideration when data from cross-sectional and time-series studies are interpreted. In an example from Norway the prevalence of caries was reduced. During the same period fluoride was made universally available, invasive treatment criteria were changed to less invasive and the time between the regular examinations were extended. These factors affect the estimates of caries made by cross-sectional recordings.

Key words: Cross-sectional estimates, fluoride, incidence, prevalence, treatment criteria

The prevalence and the incidence of a disease are important information about the dynamics of the disease in a population. In light of recent understanding of the causes and the progression of caries (Fejerskov *et al*., 2003; Holst and Schuller, 2000), the relationship between prevalence and incidence of caries can be viewed in a new perspective. The biological process of caries can be regarded as a dynamic process where demineralisation and remineralisation take place all the time. When the oral environment is unfavourable, demineralisation will dominate and result in tissue loss. When conditions are favourable for remineralisation, the progression of a caries lesion may stop, and the process may reverse. The presence of fluoride enhances remineralisation and delays demineralisation. The causes of demineralisation and remineralisation must be sought in the complex nature of nearby and distant explanatory factors causing caries (Holst and Schuller., 2000). The distribution of such causes in a population determines the prevalence and the incidence of caries.

Population based estimates of caries occurrence are not based on measurements of the disease itself. Rather the clinical expression of the demineralisation process is measured and even the treatment of the demineralisation. The DMF index is an example of such measurements. The Missing component and the Filled component of the index was included assuming that they were purely expressions of disease experience (Klein *et al*., 1938). This paper is about how different concepts of caries, fluoride, dental care and dental treatment regimes have affected the DMF estimates, and how DMF estimates have affected the understanding of the prevalence and incidence of caries and caries experience.

During the 1960's and 1970's optimal dental care in the Nordic countries was considered to be regular dental examinations and treatment preferably twice a year. This understanding of good quality dental care was the basis of public dental services for children in these countries (Kostlan 1979). It was good clinical practice to fill a cavity at the earliest sign of caries applying Blacks specifications for cavity preparation. It was considered good clinical practice to fill small cavities if the dentist knew that the interval to the next examination of the same individual would be longer than the recommended half year. Along with better understanding of how caries progresses and with fluoride coverage from toothpaste and other vehicles, the treatment philosophy has changed gradually. Gimmestad *et al*. (2003) showed how invasive treatment strategies were replaced by less invasive strategies in the Public Dental Service of Oslo in Norway. Caries in the enamel was no longer replaced by a filling. As a consequence of the new treatment criteria more initial caries lesions may remineralise before any further loss of tissue.

Data from the Public Dental Service in Norway have shown an improvement in the oral health of children since the 1970's. The percentage of children without caries and the mean DMFT is lower. The incidence of a disease can only be estimated by data at two times under standardised conditions. Most epidemiological surveys and epidemiological information systems from the public dental services are based on cross-sectional data collection. A question can therefore be raised: "How well do cross-sectional data on prevalence reflect the incidence of caries?" Important conditions related to oral health are changing. Fluoride toothpaste is universally used,

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the treatment criteria for restorative intervention have changed, and the length of intervals between regular examinations has increased. The research by Mejare and Mjör (2003) indicates that the progression rate of caries in adolescents is now slower. Since most cross-sectional recording of DMF have been interpreted in prevalence terms, the question above can be rephrased: What is the relationship between prevalence and incidence of caries under changing conditions affecting disease occurrence and each of the DMF indicators separately?

In this work a theoretical model of the relationship between incidence and prevalence of dental caries is applied. The paper is divided into three sections. The first section will briefly summarise the characteristics of caries measurements in observational studies. In the second section the relationship between incidence and prevalence is explored. In the final section the results are discussed and some suggestions for further studies are outlined.

Measuring caries in observational studies

An outcome measure is valid to the degree that there is agreement between the observed and the theoretical dimensions of the phenomenon of interest. Caries and the consequences of the disease were first combined into the DMF index by Klein *et al*. (1938). Since then the index has had an almost universal usage. Several researchers have recognised the limitations of the DMF index (Marcenes and Sheiham, 1993, Whelton and O'Mullane 1997). Holst and Schuller (2000), and Schuller and Holst (2001) underlined that the index should only be used in cross-sectional epidemiology because the index gives rise to confusing interpretations in studies over time. In addition to being difficult to measure validly and reliably, the D indicator may change over time rather as a result of regular dental visits with restorative dental interventions than of changes in the underlying incidence of the disease. The size of a D indicator is determined to a large extend by available and regular dental services. The M indicator and the F indicator are easier to define both theoretically and operationally. However, there are also serious threats to the use of these indicators. Originally the M and F indicator were included as indicators of the severity of caries. A filled tooth was assumed to have been affected by caries. An extracted tooth was considered by Klein *et al*., (1938) to be the ultimate negative outcome of a caries process in the mouth. It is now understood that the F-indicator does not reflect a constant level of caries progression at the time of restoration. Criteria for fillings have been shown to have changed considerably during the last 25 years (Gimmestad *et al*., 2003). Studies have shown that the magnitude of the F and M indicator also indicates availability and regularity of dental services, consumer preferences and economic constraints (Holst *et al*., 1992).

Incidence and prevalence

By definition incidence is the number of new cases per time and population unit. Prevalence is the number of cases at a certain time in a defined population. The relationship between incidence and prevalence can be specified in the following way (Rothman and Greenland, 1998): Incidence x duration = prevalence. The product of new cases per time unit t and the average duration of the disease (mean t per case) equal the total number of cases in a specified time. The more rapid a course of a disease the more the incidence is equal to the prevalence. The longer duration of the natural course of a disease, the more the prevalence deviates from the incidence.

The relationship between the incidence and the prevalence can be illustrated by a Lexis diagram (Figure 1). The Lexis diagram is a time and age coordinate system (Lexis, 1875) The diagram is used in demography and in survival analysis and has useful statistical properties (Pressat, 1961, Keiding, 2005). The y-axis can be the time spent in a study, or as in the present study the natural course of caries measured in time. Events such as death or tooth destruction can be added by placing an appropriate symbol at the end of the line (Francis and Pritchard., 2000). Each diagonal line represents a case and the distance between the diagonal lines expresses the incidence and the slope of the lines the progression time. The closer the lines are the higher the incidence per time unit. The diagrams in Figures 1 and 2 present necessary simplifications. The incidence and progression are drafted as linear phenomena despite the fact that individual cases do not appear with regular intervals and progression varies between individuals and is not linear. Figure 1 illustrates two populations with the same incidence, one with a rapid (a) and one with a slow (b) progression time. The vertical lines indicate cross-sectional data collections. The small circles represent the number of times the cross-sectional study finds a case of caries. Figure 1 (a) and (b) show that the prevalence estimate will be higher in (b) than in (a) even though the incidence is the same. When the incidence is reduced by 50% as in the Figure 2 (c) and (d), the estimate of the prevalence is affected. A disease may change either in incidence or in its natural course or both. When a lower incidence is combined with a slow progression rate, Figure 2 (d), the prevalence estimate may not be very different from the estimate in Figure 1 (a). Cross-sectional based estimates of a disease provide difficulties with regard to valid interpretations of the underlying disease occurrence.

The progression of dental caries

The Lexis diagram is further used to show the progression of dental caries in four distinct stages along the y-axis: Precavitated undetectable, precavitated detectable, cavitated restorable and cavitated unrestorable (Pitts *et al*., 2003) (Figure 3). From the theoretical zero point at the bottom of the vertical axis a precavitated and clinically undetectable lesion may develop. This lesion may remineralise and disappear or progress into the precavitated, detectable stage. The precavitated and detectable lesion may remineralise and not progress, or progress into the next stage: a cavitated restorable lesion. During this stage the cavity may be restored, and the tooth will appear with a filling. If the cavity is not restored, there is a chance that the cavity will remineralise and appear as arrested caries. If not restored or turned into an arrested caries, the caries process progresses and leads to total destruction of the tissues or extraction of the tooth, called cavitated, unrestorable. The cut-off lines between

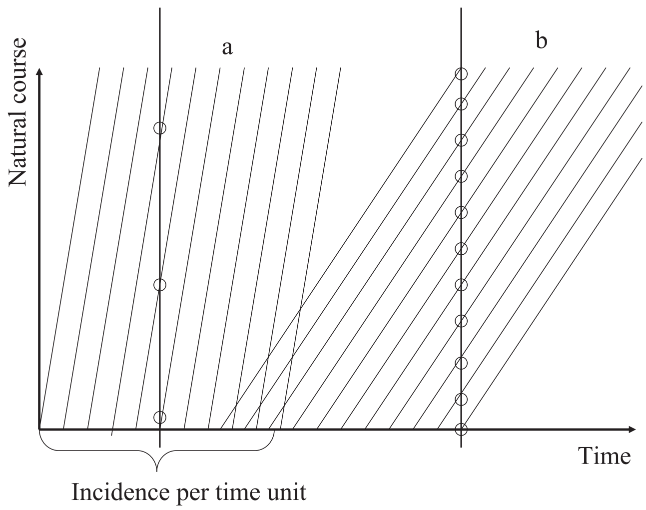

Figure 1. *A Lexis diagram showing the natural course and incidence of a disease and number of cases observed cross-sectionally (the vertical line)*

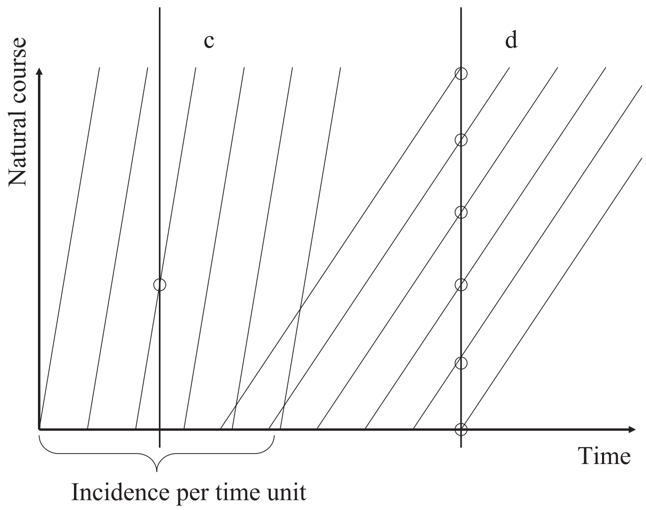

Figure 2. *A Lexis diagram showing the natural course and a 50% reduction in incidence of a disease and number of cases observed cross-sectionally (the vertical line)*

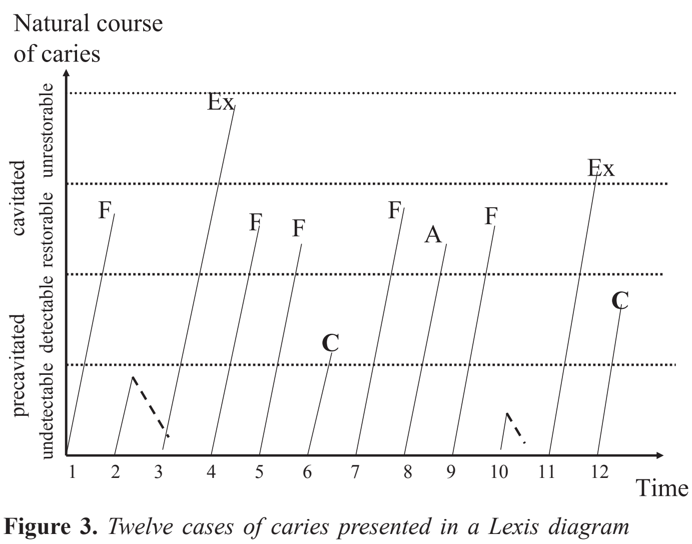

Figure 3. *Twelve cases of caries presented in a Lexis diagram (F=filled, Ex= extracted, A=arrested caries, C=caries)*

the four stages were set arbitrarily, since there is no clear documentation as to the length of natural course in each stage. This does not affect the principles that the figures are meant to illustrate.

Figure 3 shows 12 cases of caries belonging to a population with a fixed incidence. The figure shows the following: Case 1 was filled (F) when the lesion had developed to the cavitated restorable stage. Case 2 developed into a precavitated, undetectable lesion that remineralised. Case 3 was never restored and the tooth was finally extracted (Ex). Case 4 developed to a detectable cavitated lesion and was restored (F). Case 5 developed to a cavitated lesion and was restored (F). Case 6 progressed to the detectable level, whereafter it may remineralise or progress (C). Case 7 was filled at the cavitated restorable level (F). Case 8 progressed into a detectable level and started to remineralise . It may either continue as an arrested caries lesion (A) and may be left as such or filled later. Case 9 progressed until a restoration was made (F). Case 10 remineralised shortly after it developed and disappeared. Case 11 progressed to destruction and extraction (Ex). Case 12 progressed into a precavitated detectable lesion (C). It may progress further, arrest or remineralise.

Figure 4 shows the same incidence and cases of caries in an environment where fluoride is present. Figure 4 illustrates how the caries lesions may progress or not in the presence of fluoride in the biofilm. The presence of fluoride changed the progression rate of caries to a less rapid one. The less rapid progression gave case number three and eleven an opportunity to be restored. Cases 2, 4, 5 and 12 began to remineralise. Fewer cases reached a cavitated level because of the presence of fluoride.

Discussion

The consequences of what has been shown are important when cross-sectional data are collected over time for monitoring oral health in a population. Two important aspects have been illustrated. One is related to choice of the criteria for measuring caries and is illustrated in Figure 3 and 4 horizontally. In some studies crude and in other studies fine criteria are used. Figure 3 and 4 show that the number of observations that will be made is obviously dependent upon the crudeness of the criteria. If caries is observed at the cavitated level there will be one arrested and five restorations according to Figure 3 and one arrested and four fillings according to Figure 4. If caries is observed at the uncavitated, detectable level there will be two more caries lesions on that level according to Figure 3 and three more according to Figure 4. Whether the arrested lesion will be registered as caries, arrested caries or as sound or filled depends also on the criteria used. Thus in a cross-sectional study the number of cases will vary according to the criteria used and the presence of fluoride. This is so even though the incidence of the disease is constant.

The other aspect is related to the fact that a cross-sectional study of prevalence may be misleading in the paradoxical situation in which better survival from a disease and therefore a higher prevalence follows from the action of preventive agents that mitigate the disease once it occurs (Rothman and Greenland 1998). This parallels the mechanisms of fluoride that reduce demineralisation and enhance remineralisation. Even though fewer cases continue to demineralise because of the presence of fluoride, the slower progression time provide more cases of caries cross-sectionally observed. The result may appear to be a nearly unchanged prevalence even though fewer cases reach the cavity level. Depending on the criteria for fillings and the time interval between regular dental examinations, fewer cases will reach the stage of extraction.

Fluoride in itself does not reduce the level of different risk factors. The presence of fluoride does not change the underlying causes of incidence of disease but affects the progression and natural course of caries. Slower progression and longer duration of the natural course of caries may be misinterpreted as a higher prevalence. Causes of the incidence of caries such as sugar has not been included in the presentation. Sugar consumption is a major cause of caries, and sugar consumption may also affect progression time of a caries lesion.

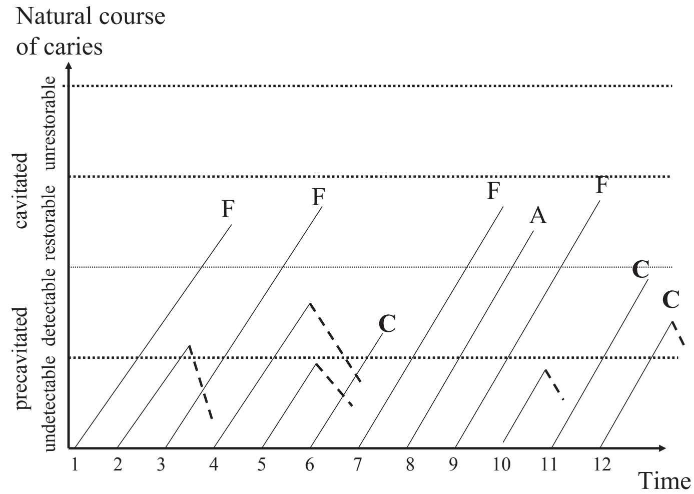

Figure 4. *Twelve cases of caries presented in a Lexis diagram with fluoride present in the environment (F=filled, Ex= extracted, A=arrested caries, C=caries)*

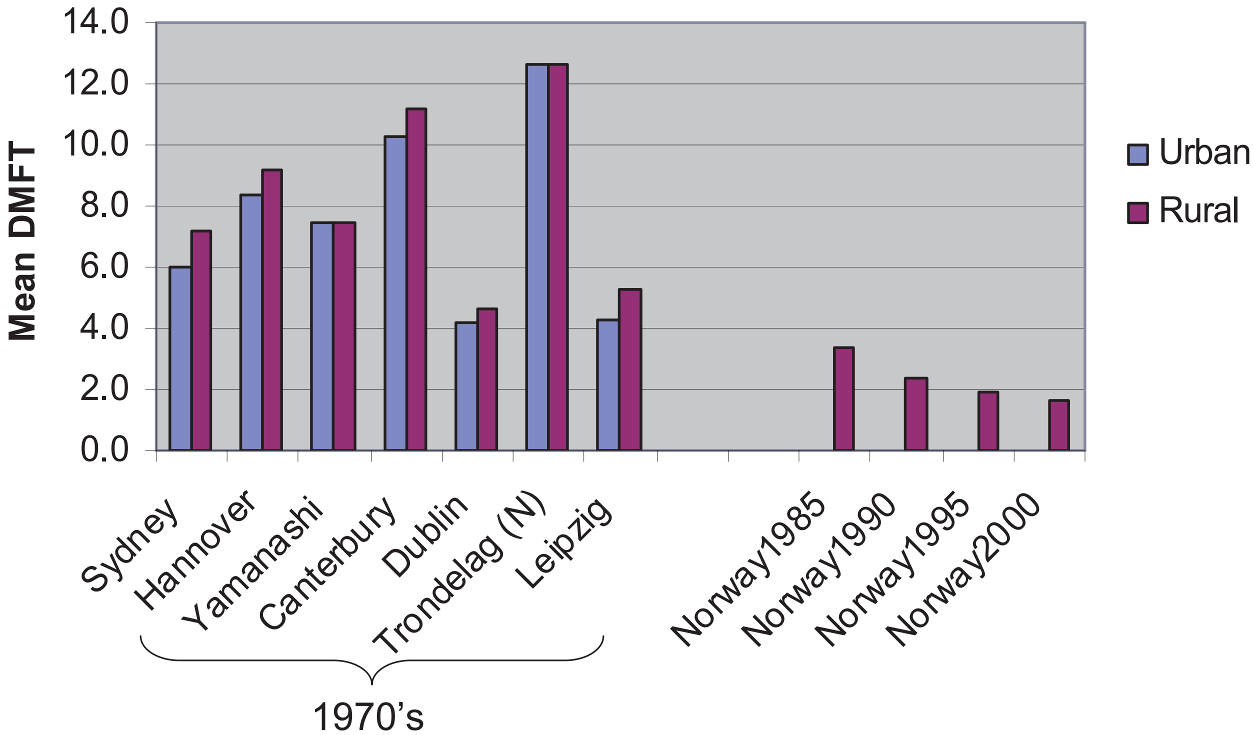

Figure 5. *Average DMFT among 13-14 year olds in seven countries in 1973 [WHO 1984] and national service statistics from all 12 year olds in Norway in 1985, 1990, 1995 and 2000.*

Cross-sectional data from the WHO ICS I study showed that in seven participating countries DMFT levels amongst 13-14 year olds was highest in Norway in the 70s. (Figure 5) (Arnljot *et al* 1985). At that time full coverage by the Public Dental Service and yearly examination of all children had been accomplished, whereas fluoride in toothpaste had become accessible in 1971. Invasive treatment criteria were used in the Public Dental Service. From what has been shown above these factors combined may have resulted in DMF estimates of prevalence that may have been higher than justified by the underlying non-observed caries incidence.

At the time of the WHO ICS I there were no national epidemiological data on caries in children in Norway. Service data from the Public Dental Service comprised the number of filled surfaces per child until 1984. The average number of filled surfaces per child 11 years old levelled off from nearly five surfaces per year in 1968 to 1.2 in 1983 (Birkeland *et al*.,2000). Since 1985 data on the number of DMFT per child in age group 5, 12 and 18 have been collected yearly in the Public Dental Service. The average DMFT of all 12 year Norwegian children are shown in Figure 5 in 1985, 1990, 1995 and 2000. The greatest reduction in DMFT among children in Norway took place in the 1970's (Holst and Schuller, 2000). The above reasoning leads to a bold hypothesis: The reduction in DMF teeth shown by cross-sectional data in Figure 5 is the effect of a reduction in the incidence of caries that appear greater than it really was. This can be further specified:

1. Since prevalence reflects both the incidence rate and the action of preventive agents, studies on prevalence yield associations that reflect the determinants of the disease progression just as much as the causes of disease.
2. A change in the natural course of a disease affects the prevalence estimates made cross-sectionally.
3. The presence of fluoride or other interfering substance changes the natural course of caries. Cross-sectional data of the phenomenon may show a higher prevalence.
4. The criteria for measuring caries affect the observed number of cases and the observed natural course of caries.
5. The criteria for restorative therapy affect the numerical value of DMF index and the size of the components. Invasive criteria will provide a high DMF and possibly a high proportion of F teeth. Non- invasive criteria will provide a lower DMF and lower proportion of F teeth. Applying non-invasive criteria combined with fluoride will reduce the estimated prevalence even though the incidence is unchanged.
6. The time-interval between caries controls affect cross-sectional estimates of caries. Extending the recall intervals from 12 to 24 months in a regular dental care system results in a doubling of the occurrences of new decayed teeth at the time of examination. This may be interpreted as an increase in prevalence even though the incidence is unchanged.

The present study has shown some of the limitations from the use of cross-sectional observational data. It is necessary to take into consideration how different conditions relate to the course of a disease and its treatment, and how they affect prevalence estimates. The limitations of a cross-sectional design may be so serious that longitudinal study designs should be preferred. In longitudinal designs changes in both incidence and rate of progression of the natural course of a disease can be monitored to gain a better understanding of the relationship between the incidence and prevalence of a disease.

References

Arnljot, H., Barmes, D., Cohen, L., Hunter, P. and Ship II. (1985): *Oral Health Care systems. An International Collaborative Study*. Quintessence Publishers Company Ltd 1985. ISBN 1 85097 001 7.

Birkeland, J.M., Haugejorden, O. and Fehr, F.R.v.d.(2000): Some factors associated with the caries decline among Norwegian children and adolescents: Age-specific and cohort analyses. *Caries Research* **34**,109-116.

Fejerskov, O., Nyvad, B. and Kidd E.AM.(2003): *Clinical and histological manifestations of dental caries.* In: Fejerskov, O.and Kidd, EAM [eds]. Dental caries and its management. Pp71-96, Oxford: Blackwell Munksgaard.

Francis, B., Pritchard J.(2000): *Bertin, lexis and the graphical representation of event histories*. http://www.cybergeo.presse.fr/semiogra/brian/franjoh2.htm

Gimmestad, A., Holst, D. and Fylkesnes, K.(2003): Changes in restorative caries treatment in 15-year-olds in Oslo, Norway, 1979-1996. *Community Dentistry and Oral Epidemiology* **31**,246-51.

Holst, D., Petersen, P.E. and Grytten, J.(1992): Health services research in oral health care: an empirical example. *Scandinavian Journal of Dental Research* **100**, 77-80.

Holst, D. and Schuller, A.A.(2000): Oral Health changes in an adult Norwegian population: a cohort analytical approach. *Community Dentistry and Oral Epidemiology* **28**,102-111.

Keiding,N.(2005) *Lexis Diagram*. Armitage P., Colton,T.(Eds) Encyclopedia of Biostatistics. Pp2767-2767. England,Whiley.

Klein, H., Palme, C.E. and Knutson, J.W.(1938): Studies on dental caries. *Public Health Reports* **53**,751-765.

Kostlan, J.(1979): *Oral Health Services in Europe*. World Health Organization, WHO Regional Publications European Series No 5, Copenhagen.

Lexis W. (1875): *Einleitung in der theorie der Bevölkerungsstatistik*. Trübner:Strassburg

Marcenes, W.S. and Sheiham, A.(1993): Composite indicators of dental health: functioning teeth and the number of sound-equivalent teeth [T-health]. *Community Dentistry and Oral Epidemiology* **21**,374-378.

Mejare, I. and Mjör, I.A (2003): Prognosis for caries and restorations. In: Fejerskov, O.and Kidd, EAM [eds]. *Dental caries and its management*. Pp295-302, Oxford: Blackwell Munksgaard.

Pitts, N.B., Fejerskov, O. and Fehr, F.R.v.d.(2003): Caries epidemiology, with special emphasis on diagnostic standards. In: Fejerskov, O.and Kidd, EAM [eds]. *Dental caries and its management*. Pp71-96, Oxford: Blackwell Munksgaard.

Pressat R.(1961). *L'Analyse Démographique*. Presses Universitaires de France: Paris.

Rothman, K.J.and Greenland, S. *Modern epidemiology*. (1998):2. nd edn.USA:Lippincott-Raven.

Schuller, A.A.and Holst, D. (2001) Oral status indicators DMFT and FS-T: reflections on index selection. *European Journal of Oral Sciences* **109**,155-159.

Whelton, H.and O'Mullane, D.M. (1997): *Public health aspects of oral diseases and disorders. Dental caries*. In: Pine, C. [ed]: *Community Oral Health*. Pp 75-81. Oxford: Reed Educational & Professional Publishing.