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Cariogram – a multifactorial risk assessment model for a multifactorial disease

Douglas Bratthall and Gunnel Hänsel Petersson

Department of Cariology, Faculty of Odontology, Malmö University, Malmö, Sweden

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Abstract – This paper reviews some common methods for the assessment of caries risk. It also describes a new way of illustrating the caries risk profile of an individual, the Cariogram. Past caries experience and socioeconomic factors are often used for prediction of caries. As prediction models, the methods are simple, inexpensive and fast. However, they are not risk models, as they do not specify which particular risk factors are operating. Various biological factors can be used for risk assessment. Common ones are bacteria, diet and host factors. Taken separately, these biological factors often have limited predictive values. Socioeconomic factors often have a heavy impact on the biological factors as they can explain why an individual, for example, has a cariogenic diet or neglects oral hygiene. The biological factors are the immediate cause of the cavities. Caries experience is an illustration of how the host copes up with the biological activity. To facilitate the interpretation of biological data, the Cariogram was developed. It is a computer program showing a graphical picture that illustrates a possible overall caries risk scenario. The program contains an algorithm that presents a 'weighted' analysis of the input data, mainly biological factors. It expresses as to what extent different etiological factors of caries affect caries risk. The Cariogram identifies the caries risk factors for the individual and provides examples of preventive and treatment strategies to the clinician.

Key words: caries experience; caries risk; Cariogram; risk factor; risk groups

Douglas Bratthall, Department of Cariology, Faculty of Odontology, Malmö University, SE 205 06 Malmö, Sweden
Tel: +46 40 6658527
e-mail: douglas.bratthall@od.mah.se

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The concept of caries risk assessment is, from one point of view, simple and straightforward. The idea is to: (a) identify those persons who will most likely develop caries and (b) provide these individuals proper preventive and treatment measures to stop the disease. Opponents of this high-risk strategy claim that it is nearly impossible to identify such persons (1), and that extra preventive measures for high-risk individuals will not work anyway (2–4). Some investigators claim that similar measures should be administered to the whole population, regardless of the risk (5). While we understand but do not fully accept this opinion, we illustrate one approach that adds some more facts to the discussion. Before that, we believe it is important to analyze the difference between a 'risk model' and a 'prediction model', and we base the description on Beck's proposals (6).

A risk model is used when it is important to identify one or more risk factors for the disease so that likely points for intervention can be planned. A risk model, therefore, should exclude risk predictors such as past disease, number of teeth, etc., as such factors do not cause further disease. A prediction model, on the contrary, is used when one is mainly interested in identifying who is at high risk. The main goal is to maximize sensitivity and specificity of the prediction, so that any good predictor may be included in the model. The choice of the model depends on the purpose and situation in which the assessment is being made, e.g. if it is a public health matter or a clinical perspective. Questions that may arise are: are we talking about individuals, groups of people or even societies/countries? Which are the data we should collect for caries risk assessment? Which of them are the most important ones? How can we eliminate or reduce the risk factors? The diverse opinions expressed on these issues are clearly illustrated in several studies (1, 7–23).

Broadly speaking, one could define three main approaches for risk assessment, which are based on: (i) past caries experience, (ii) socioeconomic factors and (iii) biological factors.

Past caries experience

One way to predict future caries is to use the past caries experience. In several studies among children and adolescents, it has been found that those individuals who develop lesions early in life or have several lesions tend to develop more lesions during the coming years (18, 23–32). These children are often designated as 'high-risk individuals'. Several variants of the method such as selecting only certain tooth surfaces for the risk assessment exist. As a prediction model, the method is simple, inexpensive and fast. However, it is not a risk model, as it does not specify the particular risk factors that are operating.

Socioeconomic factors

Using socioeconomic factors is another way to select high-risk individuals. Individuals living under severe socioeconomic conditions often tend to develop more lesions than those having a better situation (33–45). Such 'risk individuals' are found in certain districts in a country/area or in certain parts of a city, or belong to certain ethnic or religious groups. It is not a risk model, as it does not specify the biological risk factors.

Biological factors

Various biological factors can be used for risk assessment. In this approach, factors that are actively operating in the caries process are selected, including the factors of the Keyes' three-circle diagram (46), namely bacteria, diet and susceptibility (host) factors. Examination of the oral cavity is needed in order to assess the amount and composition of plaque, as is a dietary record to estimate diet composition and frequency of intakes. Susceptibility factors include, for example, saliva and its protection systems and tooth resistance, often a reflection of fluoride exposure.

This approach can both be looked upon as a 'model for prediction' for future caries, as well as a risk model, as it does specify individual risk factors and it should be possible to use globally. In addition, when risk factors are reduced, the caries risk will be less. However, the model is more time-consuming and if, for example, saliva tests are included, more expensive than the other methods.

The Cariogram

A challenge for the biological factor approach is to correctly summarize the complex picture of the various inter-related caries risk factors, so that it can easily be used by the dental professional routinely in the clinic. A new model for understanding the interactions of various factors was therefore proposed and a graphical model, the Cariogram, was drawn up to illustrate the fact that caries can be controlled by several different means. The Cariogram has similarities with Keyes' circles (46), but differs in that it is possibile to single out the impact of individual risk factors. In recent years, Hänsel Petersson et al. (47–51) performed a series of studies to evaluate the program.

The computer version of the Cariogram presents a graphical picture that illustrates a possible overall caries risk scenario. The program contains an algorithm that presents a 'weighted' analysis of the input data, mainly biological factors (Table 1). Furthermore, it expresses the extent to which different etiological factors of caries affect the caries risk for a particular individual and provides targeted strategies for those individuals. The Cariogram does not specify the particular number of cavities that will or will not occur in the future.

How is a Cariogram created?

The patient is examined and data collected for some factors of direct relevance for caries, including bacteria-, diet-, and susceptibility-related factors. The various factors/variables are given a score according to a predetermined scale and entered in the computer program. According to its built-in formula, the program presents a pie diagram where 'bacteria' appears as a red sector, 'diet' as a dark blue sector and 'susceptibility'-related factors as a light blue sector. In addition, some 'circumstances' are presented as a yellow sector. The four sectors take their shares, and what

Table 1. Caries related factors and the data needed to create a Cariogram

Factor*	Comment	Info/data needed
Caries experience	Past caries experience, including cavities, fillings and missing teeth because of caries. Several new cavities definitely appearing during preceding year should give a high score even if number of fillings is low	DMFT, DMFS, new caries experience in the past 1 year
Related diseases	General disease or conditions associated with dental caries	Medical history, medications
Diet, contents	Estimation of the cariogenicity of the food, in particular sugar contents	Diet history, lactobacillus test count
Diet, frequency	Estimation of number of meals and snacks per day, mean for 'normal days'	Questionnaire results, 24 h recall or dietary recall (3 days)
Plaque amount	Estimation of hygiene, for example according to Silness-Löe Plaque Index (PI). Crowded teeth leading to difficulties in removing plaque interproximally should be taken into account	Plaque index
Mutans streptococci	Estimation of levels of mutans streptococci (*Streptococcus mutans*, *Streptococcus sobrinus*) in saliva, for example using Strip mutans test	Strip mutans test or other laboratory tests giving comparable results
Fluoride programme	Estimation of to what extent fluoride is available in the oral cavity over the coming period of time	Fluoride exposure, interview patient
Saliva secretion	Estimation of amount of saliva, for example using paraffin-stimulated secretion and expressing results as milliliter saliva per minute	Stimulated saliva test – secretion rate
Saliva buffer capacity	Estimation of capacity of saliva to buffer acids, for example using the Dentobuff test	Dentobuff test or other laboratory tests giving comparable results

*For each factor, the examiner has to gather information by interviewing and examining the patient, including some saliva tests. The information is then given a score of a scale ranging from 0 to 3 (0–2 for some factors) according to predetermined criteria. The score '0' is the most favorable value and the maximum score '3' (or '2') indicates a high, unfavorable risk value.

is left appears as a green sector and represents the chance of avoiding caries:

- The dark blue sector 'Diet' is based on a combination of diet contents and diet frequency.
- The red sector 'Bacteria' is based on a combination of amount of plaque and mutans streptococci.
- The light blue sector 'susceptibility' is based on a combination of fluoride programme, saliva secretion and saliva buffer capacity.
- The yellow sector 'Circumstances' is based on a combination of caries experience and related diseases.
- The green sector shows an estimation of the 'Chance of avoiding caries'.

The chance of avoiding caries, and conversely the risk of caries, are expressions for the same process but illustrated inversely. When the chance of avoiding caries is high, the caries risk is small and vice versa. Details of the factors that are included and the data needed to give scores for the Cariogram are presented in Table 1 and an example of a Cariogram in Fig. 1.

Examples of results from studies in which the Cariogram was used

The Cariogram has been evaluated in two large longitudinal studies, one performed in young children (50), and the other in the elderly (51). As they both have been published, we give only some key data here.

The Cariogram in a children's study

The aim of the first study was to evaluate the risk for caries among children and to evaluate the program by comparing the risk model with the actual caries increment over a 2-year period. The final study population consisted of 438 schoolchildren, 10–11 years of age, living in and around a mid-size city situated on the west coast of Sweden. The risk assessment consisted of the following steps: a questionnaire, an interview, estimation of oral hygiene, saliva sampling, reviewing dental records and X-rays and creating a risk profile for each child using the Cariogram. The questionnaire and interview focused on

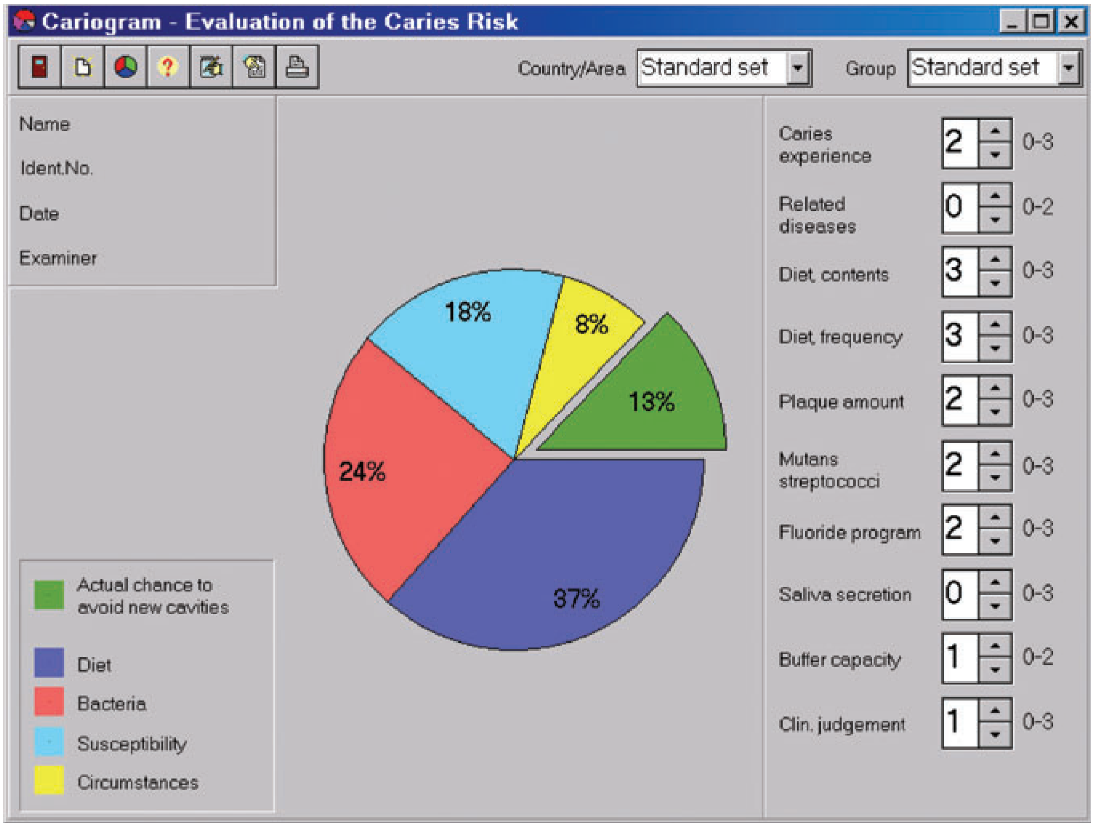

Fig. 1. Example of a Cariogram indicating high caries risk with the 'chance of avoiding caries (new cavities)' estimated to only 13%.

questions about diet, number of meals and snacks per day, the use of fluoride toothpaste and other fluoride supplements. Estimation of oral hygiene was performed using a mirror and an ordinary lamp. Paraffin-stimulated whole saliva was collected to measure saliva secretion rate, buffer capacity, and counts of lactobacilli and mutans streptococci. The caries experience (DMFT/DMFS) together with information about preventive treatment measures, was extracted from the dental records. The values obtained were entered in the Cariogram computer program in order to calculate each child's caries risk profile, expressed as the percent chance of avoiding caries. Re-examination for caries was performed after 2 years and the actual caries increment was calculated. There was a dropout of 46 participants (10.5%).

The children were divided into five groups at baseline according to the assessed percent chance of avoiding caries from the highest risk group, 0–20%, to the lowest predicted risk of 81–100% chance of avoiding caries. The patient's regular dental team took decisions on preventive and restorative dental care during the 2-year study period and the teams were not aware of the results of the study.

Results

The mean DMFT value of the 438 children at baseline was 0.87 ± 1.35 (SD) and the mean DMFT at follow-up for the remaining 392 children was 1.38 ± 1.97. The mean DMFT and DMFS values and increment results for the different Cariogram groups are presented in Table 2. It can be seen that the highest risk group developed almost 10 times more caries (DMFS) compared with the best group (increment 2.58 versus 0.27).

Figure 2 shows the actual caries increment over 2 years. In the low-risk group (81–100% chance of avoiding caries), 83% of the children had not developed any new caries lesions. In the highest risk group (0–20% chance of avoiding caries) 92% developed new caries lesions.

Logistic regression analyses were carried out for the children using DMFS increment (caries/no caries) over 2 years as the response variable. When all independent variables, Cariogram included, were entered in the regression model, only two factors, the Cariogram ($P < 0.001$) and the DMFS at

Table 2. Caries risk expressed as 'percent chance of avoiding caries', number of individuals in percent and mean DMFT at baseline and at follow-up after 2 years. Mean DMFT/DMFS increment over 2 years ($n = 392$)

Percent chance of avoiding caries according to the Cariogram	0–20% 'high risk'	21–40%	41–60%	61–80%	81–100% 'low risk'
Distribution of individuals (%): at baseline	3.6	7.1	13.7	26.7	48.9
Mean DMFT, at baseline	2.63	1.97	1.60	1.13	0.23
Mean DMFT, at follow-up	4.58	3.46	2.65	1.54	0.46
Mean DMFT increment	1.67	1.46	1.07	0.42	0.23
Mean DMFS increment	2.58	2.62	1.47	0.53	0.27

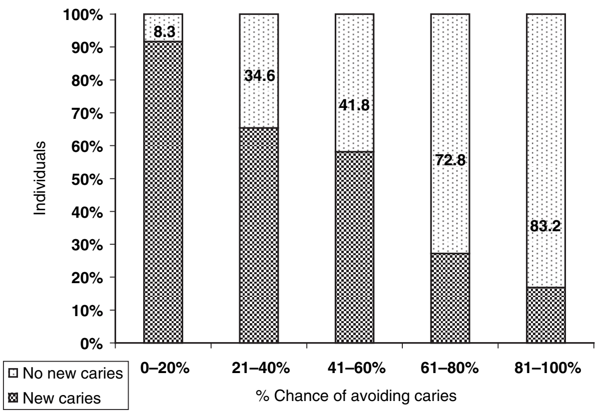

Fig. 2. Actual caries increment, presented as no new caries versus new caries over 2 years according to the caries risk assessments made by the Cariogram. Reprinted from 'Hänsel Petersson et al. (51), by permission of S. Karger AG, Basel.

baseline, i.e. past caries experience ($P = 0.001$) turned out to be significantly associated with caries increment. The Cariogram was the most powerful explanatory variable of caries increment. When the Cariogram was excluded as an independent variable in the model, four factors, i.e. lactobacilli counts, mutans streptococci, diet frequency, and baseline DMFS were associated significantly with caries increment.

The Cariogram in a study with elderly people

The aim of the second study was to evaluate the Cariogram in a group of elderly individuals (51) by comparing the caries risk assessment of the program with the actual caries increment over a 5-year period. The study population consisted of individuals who participated in a 5-year incidence study on coronal and root caries (52, 53). A total of 208 individuals in the age groups of 55, 65 and 75 years were examined. Clinical and radiographic examinations were carried out and changes between the status at baseline and the follow-up examination were recorded in terms of tooth loss, new carious lesions, and restorations at coronal and root surfaces.

The participants were interviewed about their health, intake of medications and dietary habits and food consumption. Questions were asked about frequency of tooth brushing and the use of fluoride dentifrice, rinsing, and tablets, and the percentage surfaces harbouring plaque were calculated during the examinations. Saliva samples were obtained to estimate saliva secretion rate, buffer capacity, mutans streptococci, and lactobacilli. The individuals were divided into four risk groups according to the assessed percent chance of avoiding caries, from the highest risk group (0–20%) to the low/rather low predicted risk (61–100%).

Results

The mean DMFT at baseline for the group that also participated in the follow-up examination 5 years later ($n = 148$) was 23.45 ± 4.19 and the corresponding value for DMFS was 89.53 ± 25.07. The mean Decayed Filled Surfaces (DFS) increment over 5 years, as related to baseline Cariogram predictions, showed that the individuals in the highest risk group demonstrated a mean DFS increment of 9.54, while the lowest risk group had 1.74. The mean DFS increment for the total group was 5.93 ± 9.35.

The number of new lesions at the fifth year examination was related to the Cariogram groups. Fig. 3 shows the results. For example, where the program predicted 0–20%, 18% had no new lesions. For the 61–100% chance of avoiding caries group, 84% had no new lesions.

Figure 4 shows the mean Decayed Filled Root Surfaces (DFRS) increment over 5 years in relation to baseline Cariogram predictions. In the highest risk group, DFRS increment was 4.59 while in the lowest risk group the corresponding value was 0.65.

We conclude that, in both the studies described, the Cariogram was able to sort the individuals

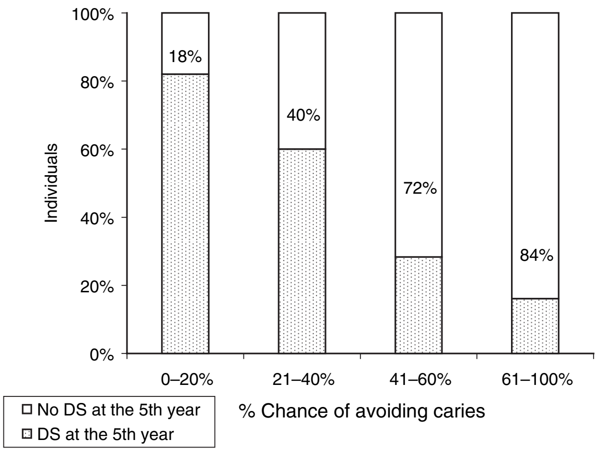

Fig. 3. The percentage of individuals with or without 'Decayed Surfaces' (DS) at the fifth year in the predicted groups according to Cariogram risk assessment, 5 years earlier.

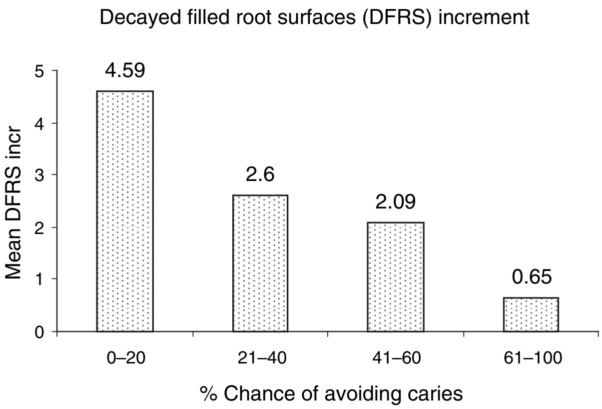

Fig. 4. Mean Decayed Filled Root Surfaces (DFRS) increment over 5 years in relation to baseline Cariogram predictions.

into risk groups that reflected the actual caries outcome, and the results were statistically significant.

Discussion

Dental caries is a multifactorial disease, with several well-known components participating in the disease process, like diet, bacteria, saliva, and fluoride exposure. This paper has described a method, the Cariogram, to facilitate the interpretation of such data by making up the risk profile of an individual. Studies have been referred to where the Cariogram appeared to predict caries development in a statistically significant way. The key point is that the program takes into account several risk factors and tries to evaluate them in a 'weighted' way. The algorithm is based on considerations such as, for example, 'a cariogenic diet is more "dangerous" if there is abundant plaque containing cariogenic bacteria' or 'low saliva secretion rate is particularly dangerous if several other factors are unfavourable'. Thus, the idea is to combine factors that in various studies have been shown to be related to caries incidence.

Searching the internet using a common search engine (Google) for 'risk assessment tool' revealed over 700 references (February 2005). There were tools to determine risk for various cancer forms, osteoporosis, earthquakes, pollution, asthma, bedsores, falls in nursing homes, workplace hazards, viruses (for humans, animals, computers), investments, floods and much more. Where the tools were explained in some detail, one could see that information on various risk factors had to be collected and then the results were either just added or were subjected to a weighted evaluation. Surprisingly, few attempts were made in cariology to develop complex and practical risk assessment tools, while numerous reports have dealt with prediction-based models on one or a few factors only. In presenting the results, statistical methods have been applied using sensitivity/specificity for a particular cut-off point of the test as related to a particular number of cavities to appear over a specified time. Using this approach for a multifactorial disease like caries has, with few exceptions, mostly failed. Actually in our opinion, these 'shallow' types of calculations have set back proper use of caries-related information and tests for many years. Moreover, one should be happy that similar methods were not used when calculating risks of floods and earthquakes!

The Cariogram was originally developed as an educational model, in the first place for discussions within the profession. Later on, the interactive version has found a place in education of dental staff and for education and discussions with patients concerning preventive strategies. The original algorithm has not been changed and data from many more studies from different countries are needed until such decisions are possibly taken. Some frequently asked questions regarding the Cariogram are addressed below.

Is the Cariogram a risk model or a prediction model?

Actually, it is both because it acts as a prediction model that predicts who is at high risk, and it is a risk model identifying the risk factors to facilitate planning of interventions. The risk factors are the dominating factors but past caries experience is also included, although this factor has not been given a particularly heavy weight. The reason is that if risk factors were reduced, it should be reflected in the Cariogram.

Why are social factors not included in the Cariogram?

A number of papers have clearly indicated the importance of social factors for caries risk. Still, the Cariogram does not address these factors directly. The reason is that social factors do not directly act on the tooth surface (if they had, there would be carious lesions everywhere, not just where there are bacteria). Social background can often explain reasons for factors such as neglected oral hygiene and increased sucrose consumption, factors that are already included in the Cariogram. Hence, social factors need not be taken into account separately when constructing the Cariogram.

Is the algorithm of the Cariogram based solely on 'evidence-based' studies?

No, there are too few studies of that kind to make it possible. Therefore, data from many other studies and even case reports have affected the final formula. In addition, the method of using meta-analyses for a multifactorial disease can give misleading results. For example, the impact (weight) for caries incidence of sugar consumption is much higher in a country with limited use of fluoride toothpastes when compared with those countries where fluoride toothpaste, plus other fluoride exposures, are widely used. We have tried to build the Cariogram algorithm on FF&C, in other words, taking into account 'full facts and circumstances'. In doing so, one tries to define the circumstances under which a particular factor should be given high-, medium- or low-risk input.

What is the sensitivity and specificity of the Cariogram?

Calculating such values demands 'cut-off' points and the Cariogram does not have such a point. According to Rodricks (54):

> Risk is the probability that some harmful event will occur… Because it is a probability, risk is expressed as a fraction, without units. It takes values from 0 (absolute certainty that there is no risk, which can never be shown) to 1.0, where there is absolute certainty that a risk will occur. Values between 0 and 1 represent the probability that a risk will occur.

In other words, the Cariogram expresses a probability. For example, '90% chance of avoiding caries' means that most people with that particular combination of risk factors would stay without new cavities. If a person anyway developed caries with that probability, the program was not 'wrong' as it had not said '100%'.

Why use the Cariogram model?

The answer depends on who is asking. For a practicing dentist in an industrialized country, an answer could be: it is a prediction/risk assessment model that can be used in the daily routine of the clinic. It illustrates caries-related factors and suggests actions to take. The tests needed can easily be performed by the dental personnel and evaluated. The model is affordable, user-friendly, and easy to understand by anyone. It can be a tool for motivating the patient and the model can also serve as a support for clinical decision making when selecting preventive strategies for the patient. Kidd (55) states that, 'changing patients' behavior is the cornerstone of preventive treatment. Advice should always be relevant to the individual, who must be made aware of the problem – if they have one'.

How can I get hold of the Cariogram?

Several language versions can be downloaded by everyone from the Internet page: http://www.db.od.mah.se/car/cariogram/cariograminfo.html. Moreover, the English manual is available from that page, free of charge.

In conclusion, this paper has briefly commented on some common methods for the assessment of caries risk: past caries experience, socioeconomic factors and biological factors. Taken separately, several of the individual factors often have limited predictive values, which is why we believe that any factor should be seen in a broader context. The three approaches for risk assessment are inter-related. Socioeconomic factors often have a heavy impact on the biological factors; they can explain why an individual, for example, has a cariogenic diet or neglects oral hygiene. The biological factors are the immediate cause of the cavities. The caries experience is an illustration of how the host has been able to cope with the biological activity. Therefore, there is no contradiction between using socioeconomic and biological factors. The key for effective prevention is to find the best use of this combined knowledge.

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