On Caries Risk Profile and Prevention in an Adult Saudi Population

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Abstract

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Objectives. The aims of this thesis were to evaluate: 1) the caries profile in an adult Saudi population with several dental restorations using a computer-based program (Cariogram), 2) the prevalence of primary and recurrent caries and of filled tooth surfaces in relation to the Cariogram outcome, expressed as "the chance of avoiding caries", 3) the quality of dental restorations and the additional value of using bitewing radiographs, 4) the effect of a "modified fluoride toothpaste technique" on the incidence and progression of approximal caries diagnosed on bitewings and 5) the preventive effect of this toothpaste technique on buccal and lingual enamel caries and to determine the role of patient compliance. ***Material and Methods.*** A total of 175 adults, mean age 30 years, were included. All the individuals were interviewed about their oral health, dietary habits and use of fluoride. Caries was registered both clinically and radiographically. Salivary and microbiological data were obtained using chair-side tests. A risk profile was created using the Cariogram model and the entire population was categorised into various risk groups, based on the Cariogram profile. In 100 adults (as a subgroup from the 175 patients), a total of 803 dental restorations were evaluated, based on the United States Public Health Service (USPHS/Ryge) criteria. Bitewings of Class II restorations were taken to examine the marginal integrity and the anatomic form proximally. Finally, the 175 participants were randomly assigned to either a test (n=88) or a control group (n=87). The test group patients were instructed to use the "modified fluoride toothpaste technique", in which various behavioural factors were standardised in order to improve the caries preventive effect of fluoride toothpaste. The patients in the control group were asked to continue using their regular fluoride toothpaste twice a day without any further instructions. Approximal caries was scored radiographically and enamel buccal/lingual caries clinically at baseline and after 2 years. ***Results.*** The prevalence of initial, total decayed and recurrent caries was high. Significant differences were found between the Cariogram risk groups with respect to these caries indices; the lower the "chance of avoiding caries", the higher the values of the caries indices. The mean "chance of avoiding caries" according to the Cariogram was 31% for the whole population (n=175). Overall, the anatomic form and surface texture obtained unacceptable scores in the majority of the restorations. After adding the radiographic evaluation, the percentage of unacceptable restorations increased by 28% and 17% with regard to marginal integrity and anatomic form respectively. After 2 years, a significant difference was found in the number of new approximal enamel caries between the test group 0.72 (n=54) and the control group 2.27 (n=52) (p<0.001). When all the data were pooled, the test group had a lower incidence of total approximal caries than the control group (p<0.001). The test group also had a lower progression rate of approximal caries (p<0.01). The test group (n=56) had a lower buccal/lingual caries incidence than the control group (n=57) (p<0.05). Both the total progression and the number of arrested buccal/lingual caries were in favour of the test group, but the differences were not statistically significant. The caries reduction in the subgroup with good compliance was significantly higher than in the subgroup with less good compliance. ***Conclusions.*** 1) The Cariogram model was able to identify the caries-related factors contributing to the future caries risk. 2) There was an association between various caries indices and the Cariogram risk groups. 3) The main reason for the unacceptable rating of restorations was recurrent caries. Unacceptable anatomic form and surface texture of the dental restorations were also common and the bitewing radiographs were found to be valuable as an aid to clinical quality evaluation. 4) The "modified fluoride toothpaste technique" reduced the incidence of approximal caries by 66%. 5) The corresponding preventive fraction for buccal/lingual enamel caries was 44% and the patients' compliance appeared to play an important role in this result.

Key Words: Adults. Approximal caries. Bitewing. Caries risk. Cariogram. Dental restorations. Enamel caries. Fluoride toothpaste. Saudi Arabia.

Contents

Original papers

This thesis is based on the following four papers, which will be referred to in the text by their Roman numerals:

I.   Sonbul H, Al-Otaibi M, Birkhed D. Risk profile of adults with several dental restorations using the Cariogram model. Acta Odontol Scand 2008;66:351-357.

II. Sonbul H, Birkhed D. Risk profile and quality of dental restorations: a cross-sectional study. Acta Odontol Scand 2010;68:122-128.

III. Sonbul H, Birkhed D. The preventive effect of a modified fluoride toothpaste technique on approximal caries in adults with high caries prevalence: a 2 -year clinical trial. Swed Dent J 2010;34:9-16.

IV. Sonbul H, Birkhed D. The preventive effect of a modified fluoride toothpaste technique on buccal/lingual enamel caries in adults with high caries prevalence: a 2-year clinical trial. Submitted.

Introduction

$\mathscr{D}$ental caries has been extensively investigated during the last decades, with the focus on pre-school and school children and adolescents [Whelton, 2004; Sheiham, 2005]. However, as the retention of teeth in adult populations increases, dental caries has become a burden for ageing adults. According to the United States National Institutes of Health Consensus Development Panel [2001], more than two-thirds of American adults aged 35 to 44 years have lost at least one tooth due to dental caries. The caries incidence in adult and geriatric populations may vary because of host and environmental factors [Selwitz et al., 2007]. In Sweden, several studies reveal that many elderly people keep their own natural teeth, which may result in an increased risk of developing caries [Lundgren et al., 1997; Fure, 2003, 2004; Österberg et al., 2006; Johanson et al., 2009]. Whelton [2004] has reviewed several studies regarding the risk of caries in adults. It might be concluded that the caries incidence increases with old age, even in adults who have received the benefits of caries prevention in childhood. In this context, dental caries remains a major problem in adults, even in developed countries, such as the United States and Sweden [2001; Hugoson and Koch, 2008].

Global changes in the pattern of dental caries have taken place in recent decades. Data collection on the incidence and progression of coronal and root caries in an age-related study design is important in determining the lifetime pattern of caries [for a review, see Selwitz et al., 2007; Whelton, 2004]. As an example, enamel lesions, particularly on approximal surfaces, should be considered in epidemiological studies to evaluate actual caries prevalence, at both a population and an individual level. Several reports concluded that the true prevalence of caries has often been underestimated due to the exclusion of initial caries from the evaluation [Amarante et al., 1998; Machiulskiene et al., 1998; Poorterman et al., 2002; Moberg Sköld et al., 2005; Hopcraft and Morgan, 2006].

Dental caries results from an ecological imbalance in the equilibrium between tooth minerals and oral biofilms (plaque) [Fejerskov, 2004; Takahashi and Nyvad, 2008]. The biofilm is characterised by microbial activity, resulting in fluctuations in plaque pH. This is a result of both bacterial acid production and buffering action from saliva and the surrounding tooth structure. The tooth surface is therefore in a dynamic equilibrium with its surrounding environment. As the pH falls below a critical value, the demineralisation

of enamel, dentine or cementum occurs, while a gain of mineral (remineralisation) occurs as the pH increases [Manji et al., 1991; Kidd and Fejerskov, 2004]. The process of demineralisation and remineralisation takes place frequently during the day. Over time, this process leads to either caries lesions or the repair and reversal of a lesion [Featherstone, 2004].

Primary caries can occur on different tooth surfaces. On an approximal surface, the lesion starts and forms beneath the contact area between teeth. Caries on an occlusal surface is also a localised phenomenon in pit and fissure. On both occlusal and approximal surfaces, enamel caries is a three-dimensional subsurface demineralisation that spreads along the enamel prisms. Recurrent (secondary) caries is a lesion located at the margin of a dental restoration. From an etiological point of view, recurrent caries does not differ from primary caries. Histologically, it represents a caries lesion adjacent to the margin and there may be signs of demineralisation (wall lesions) along the cavity wall. They could be a consequence of microleakage. However, clinical and microbiological studies indicate that this leakage does not lead to active demineralisation beneath the restoration [for a review, see Kidd and Beighton, 1996; Mjör and Toffenetti, 2000].

Caries risk and related factors

Several factors can influence the microbial metabolic activity in the dental biofilm. These factors include plaque composition and thickness, cariogenic bacteria and diet content and frequency as risk factors. The flow rate, buffer capacity of saliva and presence of fluoride are risk inhibitors providing protection from caries. In addition, previous caries experience, as well as social and behavioural factors, are risk indicators that could indicate the probability of developing caries, but they are not be directly involved in the causal chain [for a review, see Zero et al., 2001; Burt, 2005]. In the present thesis, all these factors are collectively referred to as "caries-related factors".

There are certain locations on the tooth that are prone to caries: the occlusal pit and fissure, the approximal surface cervical to the contact point, buccal or lingual surfaces along the gingival margin and tooth-restoration interfaces. These areas do not differ from the other tooth surfaces with regard to tooth structure, but they are susceptible to caries only because the biofilm tends to stagnate and remain for a prolonged period of time. The biofilm that forms, grows and matures over time does not necessarily lead to clinically

visible caries lesions. Indeed, its presence is a prerequisite for demineralisation and/or remineralisation. The composition of the biofilm itself and the length of time it remains attached and undisturbed are the prime concerns from a cariological point of view [for a review, see Marsh and Nyvad, 2008].

The mutans streptococci (MS) are the major pathogens of dental caries. This is because MS are highly acidogenic and aciduric and they are able to produce extracellular matrix of water-insoluble glucans, which enhances bacterial adhesion to the tooth surface and to other bacteria [Hamada and Slade, 1980; Loesche, 1986]. A systematic review by Tanzer et al. [2001] confirms the major role played by MS in the initiation of dental caries on enamel and root surfaces. However, some studies indicate that the relationship between MS and caries is not absolute and that caries can develop in the absence of these species [Bowden, 1997; Aas et al., 2008]. It has been suggested that other acidogenic and aciduric bacteria, including non-MS and Actinomyces, may also be responsible for caries development [Sansone et al., 1993; van Houte et al., 1994]. When members of the resident flora obtain a selective advantage over other species, the homeostatic balance of the biofilm is disturbed [Marsh, 1999]. This has been explained as an ecological hypothesis [Marsh, 1994]. It is therefore important to describe not only the type or number of bacteria involved in caries but also their activity [Takahashi and Nyvad, 2008]. Even though the presence of lactobacilli (LB) is associated with, but not primarily responsible for, caries development, their increased numbers are found with a high consumption of carbohydrates. The high proportions of MS and LB may be regarded as "biomarkers" of caries development [Nyvad and Kilian, 1990; Chhour et al., 2005] and their count in plaque is positively correlated with their numbers in saliva [Emilson, 1983]and with caries susceptibility [Krasse, 1988; Demers et al., 1990; Powell, 1998].

Fermentable carbohydrates, in particular sucrose, have been shown to be associated with caries initiation and development [Paes Leme et al., 2006]. The bacterial metabolism may be dramatically enhanced by changing nutritional conditions, as the presence of fermentable carbohydrates will lower the plaque pH. Any shift in pH will influence the chemical composition and the bacterial flora inside the biofilm over time [Marsh and Nyvad, 2008]. If a prolonged acidic environment persists, more aciduric bacteria, such as MS and LB, will selectively grow and accumulate and caries lesions will therefore occur or progress. Although diet and oral hygiene maintenance are factors that are indirectly

related to the severity of dental caries, individuals exposed to similar circumstances may vary in their susceptibility to develop caries. Systematic reviews have shown that, with frequent fluoride exposure, the relationship between sugar intake and caries experience is not consistent and controlling the consumption is not always the most important aspect [Burt and Pai, 2001; Zero, 2004]. According to another review, there are no studies in which reduced sugar intake alone affects caries prevalence [Lingström et al., 2003]. However, reducing the frequency of sugar intake could be a means of reducing caries [Sheiham, 2001].

Saliva plays a critical role in the prevention or reversal of the caries process [for a review, see Lenander-Lumikari and Loimaranta, 2000]. It maintains the super-saturation of calcium in plaque. It also neutralises acids, raises the pH and reverses the diffusion rate of calcium and phosphate towards the tooth surface. In the event of extensive challenge, e.g. poor oral hygiene and a low salivary secretion rate, these protective benefits will be disturbed or impaired, placing an individual at high risk of developing caries. It should be noted that various salivary parameters other than bacterial count, e.g. salivary buffer and antimicrobial agents, are of little predictive value as far as caries susceptibility is concerned [Tenovuo, 1997].

The fluoride content in saliva and plaque as a result of using fluoride toothpaste or other fluoride-containing products appears to be more important than the other parameters. It is well known that fluoride has an anti-cariogenic effect that prevents caries and decreases or even reverses the progression of caries lesions. Its mechanisms of action are based on three principles: 1) inhibiting demineralisation, 2) enhancing remineralisation and 3) inhibiting bacterial metabolism [Featherstone, 2000]. Its effect on caries prevalence and incidence is well documented in the literature [Stephen, 1999; Featherstone, 2000; Marinho, 2008]. However, a skewed distribution of caries is evident in epidemiological studies, as a considerable percentage of the population exhibits significantly more caries and runs a high risk of developing new carious lesions, even in fluoridated areas [Whelton, 2004; Selwitz et al., 2007]. This could be attributed to other risk factors that reduce the capability of fluoride to overcome these challenges.

Cariogram

The multi-factorial caries entity makes risk assessment and the prediction of caries development a complex process. The interplay of the caries-related factors can vary over time, between populations, individuals and even within one and the same individual. As a result, dental caries can develop and progress rather rapidly in some individuals compared with others. There is no single test that is able accurately to predict an individual's susceptibility to caries [Reich et al., 1999]. Numerous risk models have been introduced in the literature. However, their predictive outcomes are different and depend on the study population [for a review, see Zero et al., 2001].

A computer-based program (Cariogram) has been developed by Swedish researchers for caries risk assessment [Bratthall, 1996; Bratthall and Hänsel-Petersson, 2003, 2005]. It can be described as a simple tool for a difficult multi-factorial process. Previous studies found that the risk assessment using the Cariogram is in agreement with the opinions of dentists and dental hygienists [Hänsel-Petersson and Bratthall, 2000]. The Cariogram can be used as a prediction or risk model. As a prediction model, the data show a correlation between the Cariogram results and the caries increment over time for children and the elderly [Hänsel-Petersson et al., 2002; Hänsel-Petersson et al., 2003]. Several studies have used the Cariogram as a risk model, where the caries risk was evaluated by identifying the caries-related factors [Tayanin et al., 2005; Ruiz Miravet et al., 2007; Zukanović et al., 2007; Campus et al., 2009]. However, the populations involved in these studies were mostly children and adolescents. It may therefore be of interest to study adult population using the Cariogram model to evaluate the estimated future risk of developing caries and to identify the caries-related factors. It should be noted that the program does not identify the number of cavities that will or will not develop [Bratthall and Hänsel-Petersson, 2005]. One advantage of the Cariogram is its capability to give an individual's total possible risk as a single value expressed as the percentage "chance of avoiding caries", after weighing up all the other caries-related factors in the equation. It is an interactive program that can be used to enhance the patient's motivation by demonstrating how the caries risk can change by modifying the various caries-related factors.

Ten factors are included in the Cariogram model: 1) caries experience, 2) related diseases, 3) salivary flow rate, 4) salivary buffer capacity, 5) plaque amount, 6) diet frequency, 7) diet content, 8) mutans streptococcus count, 9) fluoride programme and 10)

clinical judgement. These ten factors are given a score according to a predetermined scale and are entered in the program. The results are displayed as a pie chart with five different coloured sectors. Four of these sectors represent the extent (in per cent) to which various caries-related factors could affect the fifth one, i.e. the green sector, expressed as "chance of avoiding caries" (for examples, see Appendices 1 & 2). The dark blue sector (Diet) is a combination of diet content and diet frequency; the red sector (Bacteria) is a combination of the amount of plaque and mutans streptococci; the light blue sector (Susceptibility) is a combination of fluoride intake, saliva secretion and saliva buffer capacity; the yellow sector (Circumstances) is a combination of past caries experience and related diseases and, finally, the green sector represents the "chance of avoiding caries". When this latter sector shows a large percentage, the caries risk is probably low and vice versa.

Fluoridated toothpaste

The efficacy of topically applied fluoride in caries prevention has been studied extensively [Groeneveld et al., 1990; Featherstone, 2000; Marinho, 2008]. The decline in caries prevalence in the developed countries over the last four decades is believed to be due to the widespread use of fluoride toothpaste, which is the most common vehicle for delivering fluoride topically [WHO, 1994; Bratthall et al., 1996; Marinho et al., 2003]. Daily toothbrushing with fluoride toothpaste has shown a strong evidence in preventing caries in children and adolescents [Twetman et al., 2003]. It has been documented that fluoride toothpaste reduces the number of new caries lesions over 3 years by 24% [Marinho et al., 2003]. However, no evidence of the effect of fluoride on the prevention of primary caries or recurrent caries in adults is available [WHO 2001; Twetman et al., 2003]. One aspect of the present thesis is therefore to evaluate this effect on a group from an adult population.

A recent Cochrane review [Walsh et al., 2010] confirms the efficacy of fluoride toothpaste in caries prevention, but significantly only for a concentration of >1,000 ppm, and the relative caries preventive effect increases as the fluoride concentration increases. Increased fluoride concentration is accompanied by an increase in plaque fluoride levels [Duckworth and Morgan, 1991]. Furthermore, toothpastes containing 5,000 ppm fluoride have been shown to be more effective at remineralising primary root caries than those containing 1,100 ppm fluoride [Baysan et al., 2001]. In overall terms, a linear correlation

was found between toothpaste fluoride concentrations between 0 and 5,000 ppm and clinical caries efficacy [Tavss et al., 2003].

Many behavioural factors could influence the efficacy of fluoride toothpaste in caries prevention [Davies et al., 2003]. They include the frequency of brushing, the amount of toothpaste applied, the duration of brushing and the time of day. It has been reported that caries increments in individuals who brush only once a day were 20-30% higher than in those who brushed twice a day [O'Mullane et al., 1997]. Julihn et al. [2006] found that irregular toothbrushing at night was strongly associated with a high caries experience. Furthermore, the mean fluoride level in saliva after brushing with a small amount of toothpaste (~0.25 g) was approximately one third of that obtained with a normal amount (~1.0 g) [DenBesten and Ko, 1996]. Another study conducted in adults recommended the application of 1 g or more of the fluoride toothpaste containing 1,000 ppm to increase both the fluoride uptake in the surface enamel and the fluoride concentration in the oral fluid [Koga et al., 2007]. In a recent study, Zero et al. [2010] suggested that both brushing time and toothpaste quantity may be important determinants of both fluoride retention and consequent enamel remineralisation. The question of whether toothbrushing should take place before or after eating is still controversial. Attin et al. [2005] stated: "*Study of the literature gives no clear evidence as to the optimal time-point of tooth brushing (before or after meals). However, in order to eliminate food impaction and to shorten the duration of sucrose impact by tooth cleaning after meals seems to be recommendable*". The use of fluoride toothpaste before "going to bed" has also been supported by Davies et al. [2003]. Another interesting factor is that the post-brushing water rinsing behaviour might affect the availability of fluoride in saliva and dental plaque. Individuals who rinse with large volumes of water have a higher caries incidence than those who rinse with smaller amounts [O'Mullane et al., 1997; Chestnutt et al., 1998].

In a clinical trial, Sjögren et al. [1995] found that the approximal caries in Swedish preschool children was reduced by an average of 26% after using a certain technique called "modified toothpaste technique". Children were instructed to place toothpaste on the teeth prior to brushing and swish the toothpaste foam, together with a sip of water (approximately 10 ml), around the dentition by active cheek movements for 1 minute, before expectorating. In the present thesis, several factors involved in the behaviour of

using the fluoride toothpaste were standardised and the effect on dental caries was then evaluated in a group of adults.

Restorative treatment of caries

The approach of "extension for prevention", described by G.V Black, as a means of caries management has been a cornerstone of 20th century dentistry [Osborne and Summitt, 1998]. This approach, which depends on the "drill and fill" theory, is still utilised and is the favoured method in many countries, even developed ones. Unfortunately, this approach has neither prevented caries nor addressed the challenge of the restoration/re-restoration cycle. Studies have demonstrated that restorations have a limited life span and that the restoration is likely to be replaced many times [Elderton and Nuttall, 1983; Elderton, 1990]. This may lead to repetitive restorative cycles with larger restorations, weaker teeth and an increased risk of more complex treatment [Elderton, 1990; Brantley et al., 1995].

A number of studies have reported that recurrent caries is the most common reason for the replacement of dental restorations [Deligeorgi et al., 2001; Mjör, 2005]. The number of restorations replaced as a result of recurrent caries is higher in general dental practice than in controlled clinical trials [Letzel et al., 1989]. Recurrent caries lesions are most often located at the gingival margins that obscure their detection by direct vision. It is difficult to distinguish marginal discrepancies (e.g. ditching) and discoloration from recurrent lesions. As a result, some dentists replace fillings with staining and minor defects in the belief that these clinical signs are indicative of microleakage that leads to caries [Goldberg, 1981,1990]. However, recurrent caries does not develop as a result of microleakage along the tooth-restoration interface [Mjör, 2005; Sarrett, 2007]. Bacteria may invade larger gaps (>0.4 mm) [Dérand et al., 1991; Kidd et al., 1995; Kidd and Beighton, 1996], but their presence should not be confused with recurrent caries. In fact, only frankly cavitated caries lesions at restoration margins constitute a reliable diagnosis of recurrent caries [Kidd and Beighton, 1996]. Furthermore, taking bitewing radiographs to evaluate teeth with clinically defective restorations could be of value in recurrent caries diagnosis [Hewlett et al., 1993]. However, the type and density of the restorative materials might influence the detection of these lesions [Goshima and Goshima, 1990; Nair et al., 1998].

The success or failure of dental restorations in clinical practice relies on several factors related to the dentist, the patient and the type of dental restoration used [Jokstad et al., 2001]. Numerous studies have assessed the failure rate of different types of dental restoration, particularly in posterior teeth [Manhart et al., 2004; Opdam et al., 2007]. In a Cochrane review, Yengopal et al. [2009] reported that there was no significant difference in the survival rate among different types of restoration used to treat caries. Although dental materials have improved dramatically in the last decade, their physical and mechanical properties differ from those of a tooth and no ideal material currently exists. Some inherent properties, such as marginal ditching in amalgam, the polymerisation shrinkage of composite and the durability of bonding systems, cannot be avoided and they will eventually lead to various discrepancies, prompting caries development.

Although restorative treatment is essential for removing the pathological tissue and restoring form, esthetics and function to the dentition, it does not appear to have a prolonged effect on salivary bacterial populations, including MS [Wright et al., 1992; Gregory et al., 1998]. It was reported that the surfaces most colonised by MS were also those most treated with restorations [Lindquist and Emilson, 1990]. Furthermore, patients with multiple restorations may run a high risk of developing additional caries. The quality of the restorations might deteriorate over time, which in turn influences and increases the risk of developing new caries. It is possible that imperfect restoration margins, rough restoration surfaces, overhang and faulty contours are retentive areas for plaque accumulation. Inadequate cleaning, especially when the margins or fillings are located in difficult areas, is another contributory factor. Iatrogenic damage to the neighbouring tooth is a common side-effect of operative interventions with approximal caries that increases caries progression and the need for restorative treatment in the adjacent tooth [Qvist et al., 1992]. In addition, fillings might obscure caries or makes diagnosis more difficult, resulting in a greater chance of progression. To summarise, placing a restoration neither stops caries nor reduces the likelihood of caries development in the future [WHO 2001; Sheiham, 1997].

Anusavice [2005] has stated that: *"Because there is a wide variability in treatment decisions on when and how to prevent new lesions, on how to arrest the progression of existing lesions, and on when and how to place initial and replacement restorations, the findings from some studies differ significantly from the results of other studies"*. The

decision to place the first restoration in a previously unrestored surface is a crucial event in the life of a tooth, because a permanent restoration, in the true meaning of the word, does not exist. It treats the effect of the disease, not its cause. Consequently, the modern management of caries should entail treating patients according to caries risk assessment and detecting and monitoring early lesions [Deligeorgi et al., 2001; WHO 2001; Fontana and Zero, 2006]. In this context, modifying the risk factors and implementing preventive measures, in conjunction with restorative treatment, should be the ultimate goal in order to prevent new caries, i.e. "primary prevention", while arresting progression at an early stage and increasing the longevity of the already restored tooth is "secondary prevention".

Caries status in Saudi Arabia

The prevalence of dental caries in Saudi Arabia is regarded as high, as it is in many developing countries. However, precise information on the epidemiological patterns of dental caries is limited. The mean DMFT of 12- to 14-year-olds has been reported to be 5.9 [Al-Sadhan, 2006]; the corresponding value in 35- to 44-year-olds is around 9, according to the WHO Oral Health Country/Area Profile Programme (1992). In a cross-sectional study involving 198 adolescents (14-19 years of age), the prevalence of tooth loss due to caries was 41% [Atieh, 2008]. Another study conducted in adults (25 to 55 years of age) reported a range of 6 to 20 in the DMFT score, which increased with age [Almas and Al Jasser, 1996]. Another study involving a random sample of 312 subjects (age groups 6-11, 12-17 and 18-40 years of age) revealed that females, as well as the oldest age group, had higher DMFT scores than males and younger patients [Farsi, 2008]. In a recent large-scale survey, the caries prevalence in the permanent dentition in all age groups was 71% and the mean DMFT score was 4.92; in the 35-44 age group, the DMFT was approximately 9 [Qutub et al., 2008] (Table 1).

Table 1: Prevalence and severity of dental caries in the permanent dentition (DMFT: Decayed, Missing and Filled permanent Teeth) for three age groups (with courtesy from Qutub, 2008).

Age groups (n=1200)		DMFT>0	DMFT		D		M		F	
		%	Mean	SE*	Mean	SE*	Mean	SE*	Mean	SE*
16 yrs	n=400	82.5	4.66	0.19	3.25	0.15	0.28	0.04	1.13	0.11
24-29 yrs	n=400	92.2	7.61	0.27	4.13	0.20	1.13	0.09	2.36	0.16
35-44 yrs	n=400	95.0	9.12	0.30	3.28	0.17	2.97	0.17	2.87	0.16

*SE = standard error

There are few national studies in Saudi Arabia defining the role of caries risk factors in caries incidence [Akpata et al., 1992]. For example, little is known about oral hygiene practices, sugar intake and dental knowledge. Wyne and Khan [1995] reported that 41% of children (4-6 years) did not brush their teeth and 88% were given sweetened snacks. In a recent survey of 10- to 14-year-old children, only 25% of school children brushed their teeth twice a day and 41% consumed carbonated soft drinks every day [Amin and Al-Abad, 2008]. Fewer studies have evaluated diet and oral hygiene habits among adolescents and young adults. In a recent survey, 40-45% of young adults brushed their teeth twice a day [Qutub et al., 2008]. Interestingly, one study revealed that less than half of 130 children (mean age 13 years) had heard about fluoride and only one-third correctly identified the action of fluoride as preventing tooth decay [Wyne et al., 2004].

The dental care system in Saudi Arabia is owned, delivered and financed by the Saudi national government. The dental care is mainly provided at health care clinics and hospitals and to a lesser extent in private practices [Al-Yousuf et al., 2002]. In principle, the government's philosophy is that high-quality dental care should be available for the entire population, regardless of social and educational level, and at no charge. A huge budget has therefore been devoted to dental health care services. In spite of this, the caries incidence has significantly increased in the past decade, in both primary and permanent teeth, in rural and urban areas [Al-Shammery et al., 1998, 1999; Al-Sadhan, 2006], and the caries prevalence remains high, even in areas with a high fluoride level in the water [Al Dosari et al., 2004]. This could be attributed to several factors, including preventive programmes that have not yet been implemented. In addition, the ideology that states that placing restorations is a definitive way of managing dental caries might be the reason for

the high incidence [Guile and Al-Shammary, 1987]. However, several national surveys recommended and raised the importance of the caries risk assessment, oral health education, implementation of community-based preventive measures and the need to develop a national food policy, including controlling sugar intake [Almas and Al Jasser, 1996; Gandeh and Milaat, 2000; Amin and Al-Abad, 2008; Farsi, 2008]. The means of implementing a preventive concept of this kind and the way this priority can be transformed into reality have not yet been determined. In this context, a huge effort is still needed in Saudi Arabia in order to fulfil the goals of the WHO Oral Health Country/Area Profile Programme in lowering the global DMFT [FDI, 1982].

Aims

The present thesis consists of two parts. The first examines the caries prevalence and caries risk profile of an adult Saudi population using the Cariogram model and evaluates the quality of dental restorations (Papers I & II). The second part evaluates the effect of applying the "modified fluoride toothpaste technique" on both approximal and buccal/lingual enamel caries (Papers III & IV). To achieve these general objectives, the aims of this thesis were:

- to evaluate the caries risk profile in a group of Saudi adults with several dental restorations, by assessing various caries-related factors using the Cariogram model,

- to evaluate initial caries, total decayed surfaces, filled surfaces and recurrent caries in relation to the Cariogram data, expressed as the "chance of avoiding caries",

- to evaluate the quality of dental restorations in a group of Saudi adults, emphasising the additional value of bitewing radiographs as an aid to quality evaluations of the restorations,

- to investigate the effect of the "modified fluoride toothpaste technique" on the incidence and progression of approximal caries using bitewing radiographs after 2 years and

- to evaluate the preventive effect of the "modified fluoride toothpaste technique" on buccal/lingual enamel caries clinically after 2 years and to determine the role of patient compliance.

Material and Methods

Study population

In general, the same population was involved in all four papers (I, II, III and IV) (Table 2). All adult patients visiting the Emergency Dental Clinic at the Faculty of Dentistry, King Abdulaziz University, Jeddah, and the Dental Health Clinic of Internal Security, Makkah, Saudi Arabia (see cover page illustration), from February through May 2006, were screened clinically for the following three criteria: 1) $\geq$ 20 teeth, 2) $\geq$ 7 teeth with dental restorations and 3) willingness to participate in the study. One hundred and seventy-five of the 511 patients who were screened fulfilled the criteria and were enrolled in the study. The mean age was 30 years and ranged between 18 and 56 years; the majority were female, 71% (n=125), while 29% (n=50) were male. In Paper II, the entire population (n=175) was invited to participate in the quality evaluation of dental restorations. Only those who were willing to participate in this evaluation were included. A total of 100 of 175 patients (62 females and 38 males; mean age, 29 years) agreed to this evaluation. In Papers III & IV, the 175 patients at baseline were allocated to the test or control group according to a pre-randomised list. The local ethics committee approved all the studies (code number 29/1/1419). Informed consent was obtained from each participant before the examination.

Table 2. The four papers (I-IV) included in the present thesis.

| Paper	Study design	Population (n)	Focus
I		175	Caries risk profile using the Cariogram model
	Cross-sectional		
II		100	Recurrent caries in relation to caries risk and quality evaluation of restorations
III		106	Preventive effect of a "modified fluoride toothpaste technique" on approximal caries
	Longitudinal		
IV		113	Preventive effect of a "modified fluoride toothpaste technique" on buccal/lingual initial caries

Papers I & II

Baseline data

Figures 1 & 2 outline the baseline data collected for Papers I & II, including interviews, bitewing radiographs, photographs, plaque scores, salivary and microbiological factors and caries registration. Only in those who agreed to participate in Paper II was the quality of the restorations additionally examined.
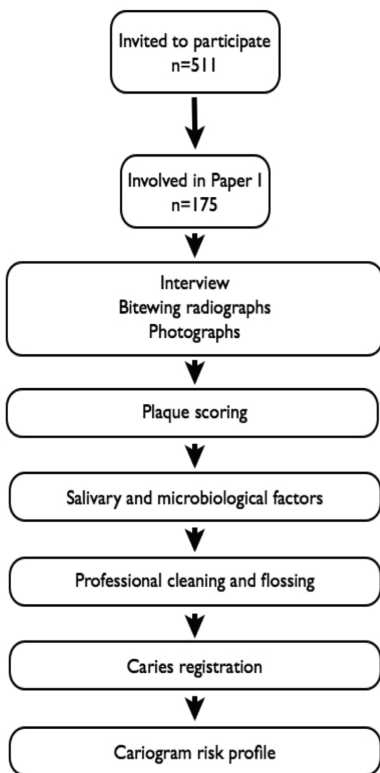
Figure 1. The set-up for Paper I.
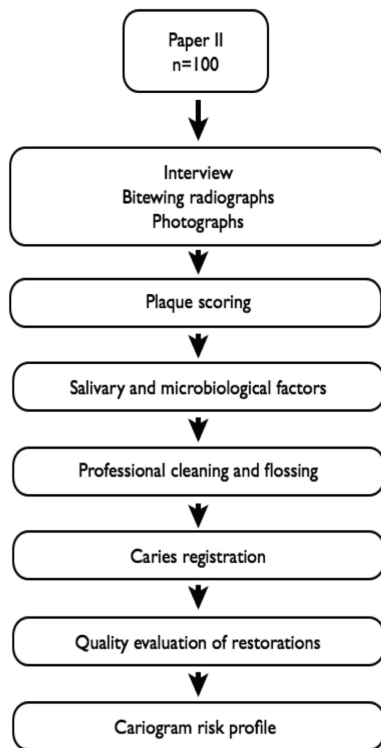
Figure 2. The set-up for Paper II.

Using a standardised structured questionnaire according to the Cariogram manual [Bratthall et al., 2004], all the patients were interviewed, about their medical and dental histories, dietary habits and the use of fluoride. The baseline plaque index (PI) was scored according to Silness and Löe [1964]. Paraffin-stimulated whole saliva was collected and the secretion rate was expressed as ml/min. A chair-side test (CRT Bacteria®, Ivoclar-Vivadent, Schaan, Liechtenstein) was used to evaluate MS and LB counts. The buffer capacity was determined using CRT Buffer® (Buffer Strip, Ivoclar-Vivadent).

Caries registration

Dental caries for the entire dentition, excluding third molars, was recorded clinically by one examiner (H.S.) according to the WHO criteria [1997]. The number of manifest caries (Dm), missing (M) and filled (F) tooth surfaces (S) were scored for each patient and calculated as DmMFS. Tooth surfaces with initial caries (DiS) were registered separately, then combined with Dm as Di+mS and added to DmMFS, resulting in a total number of Di+mMFS.

A dental assistant took four bitewing radiographs of each patient. Approximal caries was scored using the 6-grade scale (0 to 5) according to Gröndahl et al. [1977], illustrated by Mejàre et al. [1998]. Approximal restorations, missing and unreadable surfaces (overlapped or questionable) were scored as 6, 7 and 8 respectively. Recurrent caries as a distinct radiolucency at the approximal gingival margin of the restoration was scored as 9. One examiner (H.S.) evaluated 680 bitewing radiographs using a light desk and a magnifying viewer. All approximal surfaces from the distal surface of the first premolar to the mesial surface of the second molars were included, making a total of 24 surfaces. Scores of 1 to 5 were added to the Di+mS index, apart from scores of 4 and 5 in teeth previously registered as clinically decayed. To validate intra-examiner reliability, 120 radiographs from 35 individuals were re-evaluated after one month by the same examiner (Cohen's kappa value was 0.77).

Caries risk profile (Cariogram)

Since all the patients had several restorations (≥7), the factor "caries experience" was given a score of 3, i.e. worse status than normal for age group. The "clinical judgement" factor was scored as 1, i.e. the risk was evaluated according to the other factors. All the

data were entered according to predetermined scales. Consequently, a pie chart with five coloured sectors that represent (in percentages) the impact of various risk factors related to caries was created for each patient (for examples, see Appendices 1 & 2). The patient's estimated percentage "chance of avoiding caries" was used for the analysis.

In Paper I, the 175 patients were divided into four risk groups according to the percentage "chance of avoiding caries": 1) 0-20% (high risk; n=66), 2) 21-40% (medium risk; n=43), 3) 41-60% (low risk; n=50) and 4) 61-100% (very low risk; n=16). In Paper II, the 100 patients were categorised into three risk groups instead of four: 1) 0-20% (high; n=38), 2) 21-40% (medium; n=28) and 3) 41-100% (low and very low; n=34). This was due to the small number of patients who were assigned to the "very low risk" group according to the Cariogram. The last two risk groups were therefore combined.

Quality evaluation of restorations (Paper II)

A total of 803 restorations in the 100 patients were clinically evaluated according to the United States Public Health Service (USPHS/Ryge) criteria [1980]. Each restoration was evaluated on the following criteria: 1) presence of recurrent caries, 2) marginal integrity, 3) anatomic form, 4) surface texture and 5) colour match. Only frank caries lesions and/or decalcification at the margin of the restoration were registered and marginal staining was excluded. Each criterion was graded as A or B, if clinically "acceptable", and C or D, if "unacceptable" [Ryge and DeVincenzi, 1983; Allander et al., 1989]. Only A, B or C ratings were used for recurrent caries. Fifty-six of the restorations were re-evaluated after 2 weeks; the kappa value was 0.89.

The bitewing radiographs were examined to evaluate the proximal part of Class II restorations with respect to: 1) marginal integrity at the gingival wall, in which the presence or absence of "radiolucency" was recorded, and 2) anatomic form, in which under-contour or over-hang restorations were identified.

Papers III & IV

After 2 years, the follow-up data were collected including plaque scores, enamel caries registration, bitewing radiographs and compliance (Figure 3).
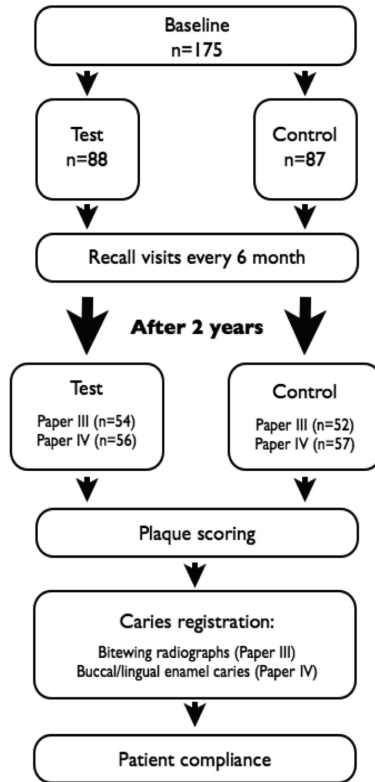
Figure 3. The set-up for Papers III & IV. An explanation of drop-outs is given in Table 3.

Modified fluoride toothpaste technique and compliance

Patients in the test group were instructed to use fluoride toothpaste twice a day based on the "modified fluoride toothpaste technique", originally described by Sjögren et al. [1995]. In the present study, the procedure was slightly modified, increasing the amount of toothpaste from 1 cm to 2 cm (~1 g) and omitting the post-brushing rinsing with water. The technique can be summarised in four steps: 1) 2 cm of the toothpaste was squeezed over wet toothbrush bristles, 2) the patients were asked to brush for approximately 2 min and were told not to expectorate more than necessary, 3) after brushing, the remaining toothpaste foam and saliva "slurry" was swished around in the dentition with active

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movements of the cheeks, lips and tongue, forcing the slurry in between the teeth for about 30 sec before expectorating and 4) no post-brushing water rinsing or eating/drinking for a minimum of 2 hr post-brushing (see Appendix 3). In order to encourage compliance, all the patients were given a pamphlet illustrating all the steps in coloured photographs.

The toothpaste used by patients in the test group was Colgate Maximum Cavity Protection (Colgate, Piscataway, NJ, USA), which contains 1,450 ppm F. Control patients were directed to continue using their regular fluoride toothpaste (also containing 1,450 ppm F) twice a day and were not given any further instructions. The type of fluoride toothpaste was identified prior to the trial.

During the 2-year period, the patients in the test group were recalled every 6 months and the toothpaste technique instructions were reinforced while the patient brushed. At the end of the session, each patient was given another illustrated pamphlet and four tubes of the toothpaste (120 ml). After 2 years, test group patients were monitored by a well-trained dental assistant, while performing the technique, and compliance was assessed. The patients were also interviewed about the regular use of the fluoride toothpaste, frequency of brushing and refraining from eating/drinking for 2 hrs. Compliance in patients who followed the four steps in principle was scored as A, while those who brushed their teeth only once a day and/or rinsed with a sip of water post-brushing were scored as B.

Patients in the control group were also recalled every 6 months, the use of fluoride toothpaste twice a day was emphasised and they were given a toothbrush. At the end of the study, their compliance (i.e. regular use of the fluoride toothpaste and the frequency of brushing) was assessed by the interviewer.

Caries registration

In Paper III, four bitewing radiographs were taken at baseline and after 2 years for approximal caries evaluation. Only approximal surfaces that could be evaluated at both examinations were included in the result. Approximal restored surfaces and recurrent caries were scored. Surfaces that were unreadable at baseline but were scored as sound at follow-up were considered to be caries free at baseline. Any sound surface at baseline that had an enamel or a dentine lesion or had been filled after 2 years was defined in the present study as "caries incidence"; the total "approximal caries incidence" was calculated

after pooling all these data. A change in score from enamel to dentine, from enamel to filled or from filled to recurrent caries was regarded as "approximal caries progression".

In Paper IV, all buccal and lingual surfaces were examined for non-cavitated lesions (enamel caries). The caries diagnostic criteria were modified after those of Nyvad et al. [1999] and only scores for the non-cavitated lesions were used in the present study. Cavitated caries lesions (manifest caries) were registered, regardless of the state of activity. Buccal/lingual surfaces with cervical restorations were recorded as filled.

After 2 years (Paper IV), all the sound buccal/lingual surfaces at baseline that had enamel, manifest caries or had been filled were defined as total "buccal/lingual enamel caries incidence". A change in an enamel surface lesion to surface discontinuity in enamel or a cavity in dentine, or from surface discontinuity in enamel to a cavity in dentine, was defined as "progressed enamel caries". All enamel caries that had been filled was registered. Only decalcification and frank caries lesions at the margin of the restoration were registered as recurrent caries. The summation of all these occurrences was defined as total "buccal/lingual enamel caries progression". Furthermore, all changes from active to inactive caries were collectively referred to as "arrested buccal/lingual caries".

The examiner (H.S.) was masked to patient assignment to test or control group and to compliance results, which were collected by a dental assistant.

Statistical analysis

All the data were analysed using the SPSS statistical package (SPSS Inc., Chicago, IL, USA).

In Paper I, descriptive statistics, including means and standard deviations (SD) of all the caries indices, were calculated for the 175 individuals and for the four Cariogram risk groups. Analysis of variance (ANOVA), followed by Scheffé's test of multiple comparisons, was used to compare the mean numbers of DiS, Di+mS, FS and Di+mMFS between the Cariogram risk groups.

In Paper II, frequency distribution and the percentage of the quality ratings for the 803 restorations were calculated. The percentage of recurrent caries was obtained by dividing the number of restorations diagnosed with recurrent caries by the total number of restorations per patient. ANOVA was used to compare the mean percentage of recurrent caries between the risk groups. When evaluating the difference between clinical

judgement alone and in addition to radiographs, the restoration was regarded as a unit and a paired Z-test was used. A power analysis with an assumption significance level of 1%, SD of 0.5 and a power of 80% to detect a difference of at least 0.15 was performed; a sample size of 260 paired observations was obtained.

In Papers III and IV, Student's t-test was used to compare the test and control groups in terms of caries incidence and progression. Statistical significance tests were performed at individual but not at site level. In Paper IV, the Mann-Whitney U test was used to compare the compliance of patients in the test group in terms of total caries incidence and progression. A power analysis with an assumption significance level of 5%, SD of 3.0 and a power of 90% to detect at least 2.0 differences was performed; a sample size of 48 individuals per group was obtained.

In all the analyses, the level of significance was considered at $p < 0.05$.

Results

Papers I & II

Caries prevalence

The total mean decayed surfaces (Di+mS), MS, FS, DmMFS and total Di+mMFS at baseline are shown in Figure 4. The mean DMFT for the entire population was 11.8. The mean differences in gender were not statistically significant, apart from FS (p<0.05). The mean (SD) of initial caries was 3.5 (3.0), diagnosed clinically, and 5.3 (3.0), diagnosed radiographically. The mean numbers of recurrent caries, clinically and radiographically, were 2.5 (2.9) and 0.9 (1.2) respectively. Around 38% of the total decayed surfaces were diagnosed radiographically.
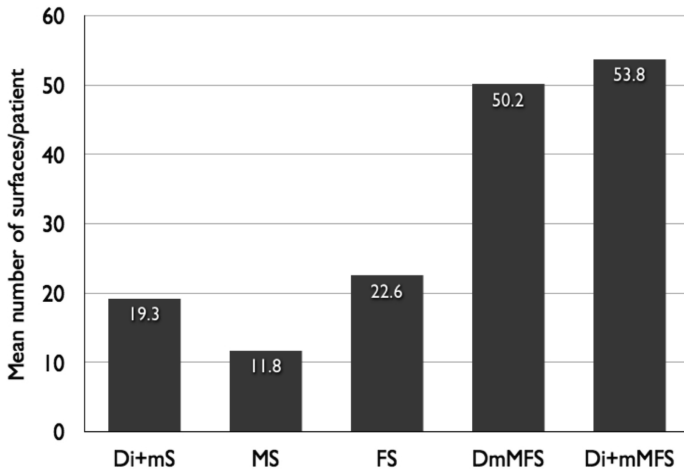
Figure 4. Mean of different caries indices, both clinically and radiographically in the 175 adults.

Caries risk profile (Cariogram)

In Paper I, the mean values of the percentage "chance of avoiding caries" for the four Cariogram risk groups ("high risk" to "very low risk") were 11%, 29%, 49% and 66% respectively. The mean for all 175 patients was 31%.

The LB count ($\geq 10^4$ CFU/ml saliva), i.e. Cariogram score 2 and 3, was observed in 61% of the 175 patients. The corresponding value for the MS count ($\geq 10^5$ CFU/ml saliva) was 75%. Regarding plaque amount, 61% had a PI score between 1.1 and 2, while 8% scored higher than 2. Based on the interview, the percentage of patients using fluoride toothpaste at baseline is presented in Figure 5. No participant used fluoride mouth-rinse solutions or tablets.

Individuals in the "high-risk" group (i.e. 0-20% "chance of avoiding caries") comprised the highest percentage among the other Cariogram risk groups with respect to the caries-related factors. The highest Cariogram scores (i.e. 2 and 3) for LB count, MS count, plaque amount and diet frequency (≥ 6 meals/day) were 33%, 36%, 35% and 19% respectively. Around 16% of the patients never used fluoride.
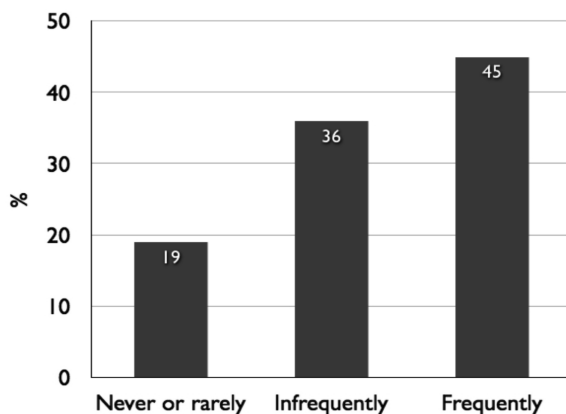
Figure 5. The bar chart represents the percentage of individuals with regard to the use of fluoridated toothpaste (n=175).

When comparing the risk groups with regard to DiS, Di+mS, FS and total Di+mMFS, ANOVA revealed statistically significant differences between the high-risk group and the other three groups regarding Di+mS (p<0.01) and FS (p<0.05). The mean DiS of the high-risk group differed significantly from that of the low-risk group (p<0.05). The mean value for Di+mMFS was similar in the four risk groups (NS).

In Paper II, a significant difference was found when comparing the mean percentage of recurrent caries for the three Cariogram risk groups; the lower the likelihood of new caries being avoided in the near future, the higher the percentage of recurrent caries (p<0.05).

Quality evaluation of restorations (Paper II)

The 803 restorations were distributed as follows: Class I (n=334), Class II (n=281), Class III (n=100), Class IV (n=9), Class V (n=50) and composite veneer (n=29). The majority of restorations were located on the posterior teeth, 625 (78%), and only 178 (22%) on the anterior dentition. The distribution according to the restoration material was amalgam (n=249), composite (n=422) and glass ionomer (n=132).

Regardless of the type of restoration, recurrent caries was diagnosed in 56% of the total restorations. The anatomic form and surface texture showed a high percentage of unacceptable restorations (Figure 6). However, the percentage distribution between ratings A, B, C and D was different for amalgam, composite and glass ionomer. Composite restorations had a lower percentage of C and D ratings than amalgam and glass ionomer, with regard to anatomic form (31%) and surface texture (23%). The majority of glass ionomer restorations (76%) were diagnosed with recurrent caries. The total number of tooth-coloured restorations that were scored as having an acceptable colour match was 347; around 42% of them were diagnosed with recurrent caries.

Figure 7 shows the percentage distribution of the Class II restorations (n=281) in terms of marginal integrity and anatomic form, both clinically and radiographically. Overall, gingival marginal "radiolucency" was detected in 125 (44%) of the Class II restorations, while 101 (36%) had an under-/over-contour proximally. The frequency of clinically unacceptable restorations was 102 (36%) and 174 (62%) with regard to marginal integrity and anatomic form respectively. However, when the bitewing evaluation was added, the corresponding values increased to 180 (64%) and 221 (79%) respectively (p<0.001) (see examples in Appendix 4).
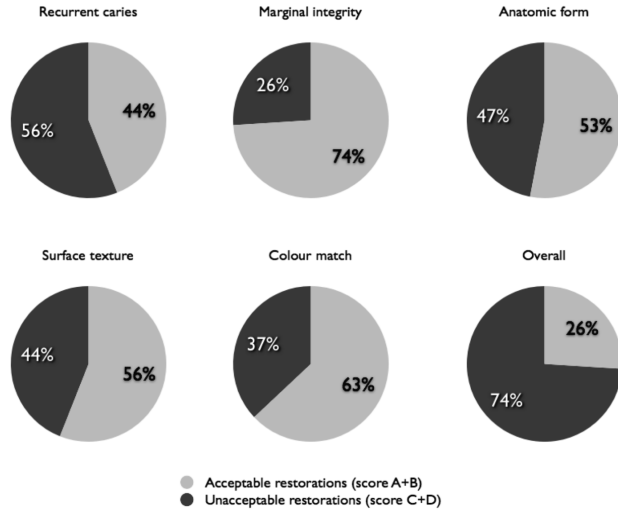
Figure 6. Percentage distribution of acceptable (score A+B) and unacceptable (score C+D) restorations according to USPHS/Ryge criteria in 803 restorations (n=554 for colour match).
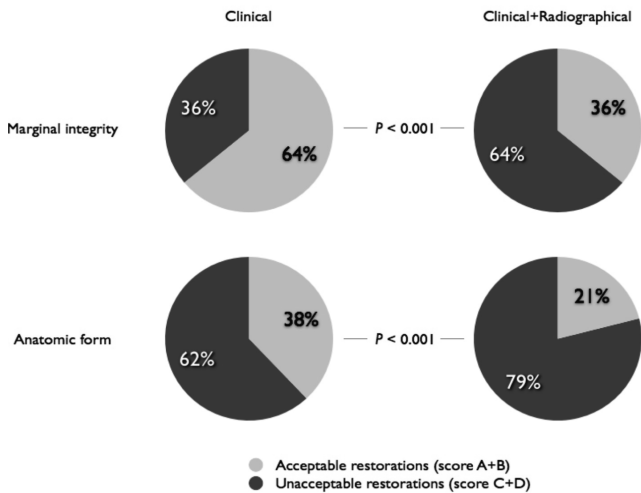
Figure 7. Percentage distribution of Class II fillings (n=281), when scored only clinically and in addition to bitewings in terms of marginal integrity and anatomical form. The significant differences are shown.

Papers III & IV

Drop-outs

One hundred and six patients completed the study in Paper III and 113 in Paper IV (Table 3). Unwillingness to participate in follow-up recall visits was the primary reason for voluntary withdrawal in both groups.

    Despite the large number of drop-outs, there was no significant difference in the mean baseline approximal DFS and total DFS values between the test and control groups in Paper III and IV respectively.

Table 3. Number of patients in Papers III and IV (n=175) and the reasons for drop-outs.

	Test		Control		Total	
	Paper III	Paper IV	Paper III	Paper IV	Paper III	Paper IV
Start of the study	88		87		175	
Drop-outs	34	32	35	30	69	62
Radiographic failure (unreadable/not taken)	2		5		7	
Can not be contacted or moved	17		13		30	
Withdrew from study	15		17		32	
End of the study (2 years)	54	56	52	57	106	113

Plaque index and use of fluoride toothpaste

After 2 years, the plaque score had improved in both groups (p<0.01). Based on the interview, all the patients in both the test and control groups used the fluoride toothpaste regularly (Figure 8). Around 92% of the patients in both groups reported that they brushed their teeth twice a day using fluoride toothpaste; 8% brushed their teeth once daily.
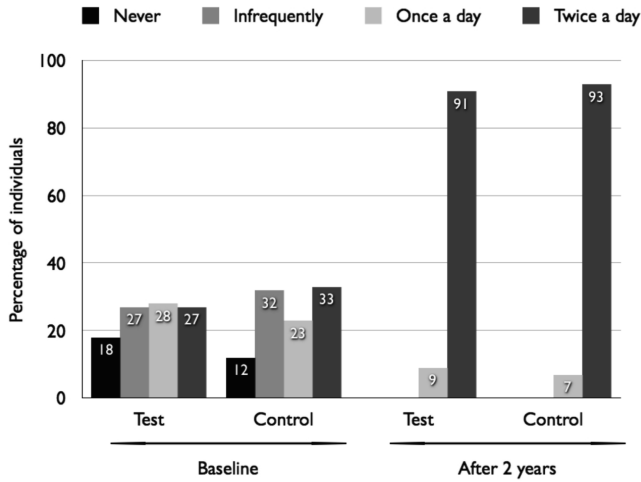
Figure 8. Percentage distribution of individuals in the test (n=56) and control groups (n=57) with regard to the use of fluoride toothpaste at baseline and after 2 years.

Caries incidence and progression

In Paper III, a significant difference was found when comparing the mean of new approximal enamel caries in the test group, 0.72 (0.94), and the control group, 2.27 (2.17) ($p < 0.001$). When all the data were pooled, the test group had a lower total approximal caries incidence of 1.15 (1.49) compared with 3.37 (2.57) in the control group ($p < 0.001$) (Figure 9). The preventive fraction was 66%, i.e. the difference in caries incidence between the test and control groups expressed as a percentage of the incidence in the control group.

After 2 years, the mean approximal recurrent caries in the test and control groups was 0.26 and 0.46 (NS) respectively. Overall, the test group displayed a lower total progression rate of approximal caries ($p < 0.01$). After excluding the approximal enamel caries that had been filled from the total progression, the difference between the two groups was not statistically significant.

In Paper IV, a significant difference was found when comparing the total buccal/lingual enamel caries incidence in the test group, 0.57, and the control group, 1.01 ($p < 0.05$) (Figure 9). The preventive fraction was 44%. However, there was no statistically significant difference in the mean number of the total enamel caries progression and

arrested enamel caries on buccal/lingual surfaces (see examples in Appendices 5 & 6). At the end of the study, the mean number of buccal/lingual enamel caries that had been filled in the test and control groups was 1.63 and 1.75 (NS) respectively. There was no significant difference between the test and control groups with regard to diagnosed recurrent caries.

Figure 9 also shows the combined total caries incidence (approximal and buccal/lingual enamel caries) in the patients involved in Papers III & IV. Patients in the test group had a higher caries reduction, approximately 2.5 times higher, than the control group.
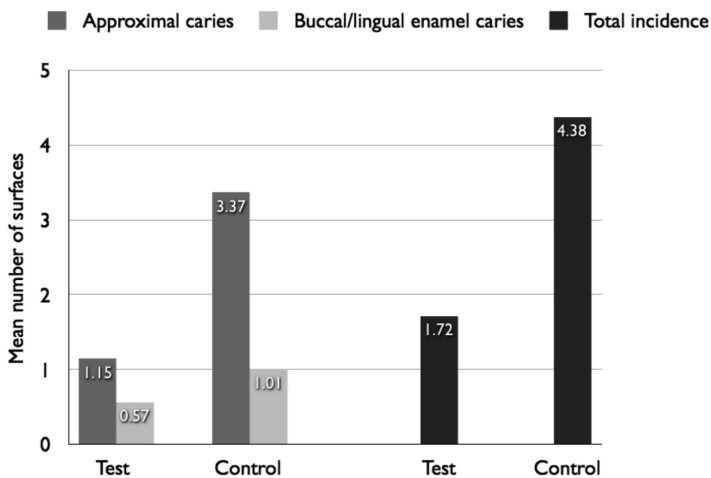
Figure 9. The total caries incidence in the test and control group of approximal (Paper III) and buccal/lingual surfaces (Paper IV), separated and combined after 2 years.

Test group compliance

In Papers III and IV, patient compliance was assessed at the end of the trial by monitoring the patients as they brushed and by the interview. In Paper III (n=54), around 85% had refrained from post-brushing water rinsing, while the rest had either rinsed with a sip of water and/or failed to avoid eating or drinking for 2 hours after toothbrushing. Around 94% brushed their teeth for $\geq$ 1.5 min. The percentage of patients using approximately $\geq$ 1.5 cm of the toothpaste was 96%. In Paper IV (n=56), patients who scored as A (good compliance) had a lower total buccal/lingual enamel caries incidence than those who were scored as B (less good compliance) (p<0.01).

Discussion

Caries risk profile (Cariogram)

The Cariogram is regarded as a useful tool for caries risk assessment and prediction and has been used and validated for both children and elderly individuals [Hänsel-Petersson et al., 2002, 2003]. Young or middle-aged adults (18-33 years old) have rarely been studied. In the present thesis, the mean age of the individuals was 30 years. The Cariogram was used as a model to estimate the risk of developing caries for the study population and to identify the various caries-related factors contributing to that risk.

The main finding in Paper I was that the majority of the patients had a high caries risk; the high- and medium-risk groups among the 175 patients (62%) had a less than 40% "chance of avoiding caries" according to the Cariogram. If the entire population is considered, the mean Cariogram value was only 31%, which is considered to be a low value, i.e. a high caries risk. Of the various caries-related factors included in the Cariogram model, four (LB, MS, plaque index and use of fluoride) obtained high Cariogram scores (i.e. 2 and 3) in the majority of patients. Regarding the high-risk group, the diet frequency score was also considered high and was therefore identified as an additional warning signal. In addition, it should be noted that many of these patients did not use fluoride. This reflects less motivation and awareness of dental care than the other Cariogram risk groups, making them more likely to run a high risk of developing caries.

In overall terms, the caries-related factors identified by the Cariogram could explain both the high caries prevalence in the study population and the probability of a high risk of developing caries. Consequently, action should be taken to modify these factors, on both a population and an individual level, to increase the percentage "chance of avoiding caries" in the future. All the patients in the present study were informed of their estimated caries risk profile (Cariogram outcome) and were encouraged to improve their oral health accordingly.

Cariogram and caries experience

When the patients were divided into four Cariogram risk groups, there were statistically significant differences between various caries components, such as Di+mS and DiS, and the risk groups. Neither of these two indices is specifically included in the Cariogram

model, but they are generally involved in the "caries experience" factor, i.e. DMFT or DMFS. The various caries indices were therefore analysed independently in the risk groups and the results revealed that the high-risk group differed significantly from the others. The Cariogram identified that this group had the highest total decayed component (Di+mS) compared with the other risk groups. One finding that might be somewhat confusing is that the high-risk group had the smallest number of FS, which differed from the other three risk groups. The reason might be that these patients had a high numbers of recurrent caries, which were counted as decayed and not as filled surfaces. This speculation was confirmed in Paper II, where the high-risk group had the highest percentage of recurrent caries compared with the other risk groups.

The total caries experience, i.e. DMFS, has been documented as a strong predictor for future caries [Reich et al., 1999; Zero et al., 2001; Fontana and Zero, 2006]. For this reason, the identification of individuals with a high caries risk is relatively accurate where children and adolescents are concerned and when sufficient baseline data are available. However, in daily practice, an examination only depicts the historical background of caries not the current caries risk of the patient. In adults, the total DMFS value could be overestimated because of the high FS components. The existing DMFS is less sensitive for predicting future caries in adults compared with children [Reich et al., 1999]. It is therefore probably unwise to use the total DMFS as the sole indication of caries risk without weighing the other caries-related factors. It could be of interest to use the Cariogram model in which the current total patient DMFS is readily involved and weighed with other caries-related factors. This will assist the dentist in implementing the optimum caries treatment and evaluating its outcome.

This interpretation was supported by the results of Paper I, where the mean DMFS values were almost equal in the four risk groups, although they might differ in terms of caries risk. In this context, it is important to emphasise that the high caries experience score of the study population does not influence the percentage "chance of avoiding caries". In the Cariogram, the caries experience factor is regarded as a risk marker that might indicate the increased probability of new caries, but it is not a part of the causal chain that lead to caries development. It therefore has less weight than the other risk factors in the built-in algorithm [Bratthall and Hänsel-Petersson, 2005]. This is probably due to the fact that the Cariogram model was originally developed to predict future caries

lesions. As a result, the other risk factors involved in the causal chain were given more weight by the program developer.

Initial caries is likely to have a profound effect as far as the caries risk estimation is concerned. When the total initial caries was added to the total decayed index, the high-risk group differed significantly from all the other Cariogram risk groups and not only from the low-risk group. Adding approximal caries lesions, diagnosed by bitewing radiographs, to the decayed surfaces index might be beneficial for actual caries prevalence estimation [Anderson et al., 2005]. In patients with several dental restorations, as in the present study, the detection of approximal caries by bitewing radiograph is important. According to Powell [1998], approximal tooth surfaces become better predictors of future disease, thereby underlining the importance of the bitewing radiographs. In Paper I, 38% of the total caries diagnosed via bitewing radiographs. This is in agreement with Hopcraft and Morgan [2005] survey, in which more than twice as many additional approximal lesions were detected by bitewing radiographs than by clinical examination in adults aged 17-30 years.

Recurrent caries

One important outcome in Paper II is that, the lower the likelihood of new caries being avoided in the near future, the higher the percentage of recurrent caries. Regardless of the restoration material, recurrent caries was diagnosed in more than half the total restorations. Such a high percentage indicates that these restorations were initially placed without any attempt to evaluate the patient's caries risk. Presumably, these restorations will be replaced for the same reason in the future. Mjör [2005] reported that 50% of restorations in adults were replaced because of recurrent caries. Powell et al. [2000] showed that patients who had restorations placed due to caries had significantly higher MS, resulting in a higher potential for continued caries activity than those who had received no restorations. Furthermore, Sunnegårdh-Grönberg et al. [2009] found that restorations in high caries risk patients had a shorter longevity than those in low- or moderate-risk groups. One recent study demonstrated that the rate of restoration failure due to caries could be reduced in the long term by changing the level of overall caries risk factors [Miyamoto et al., 2007]. In Saudi Arabia, where the caries prevalence has been reported to be high, the placement of dental restorations as the only means of treating caries should be

discouraged. It is imperative to implement national preventive programmes based on risk assessments in various age groups in Saudi Arabia.

The management of caries needs to be based on the patient's risk of developing caries in order to be most health and cost effective [Reich et al., 1999]. In this context, the Cariogram could be of great benefit in daily clinical practice when it comes to evaluating the patient's caries profile. Indeed, this pedagogic model would help allocate patients to the right caries risk category and to identify the caries-related factors that could be modified accordingly. The treatment plan for patients would therefore be more preventive and conservative in design and would not just treat the patients with more fillings, thereby exposing them to further risk [Fontana and Zero, 2006]. This would preserve the tooth structure, increase the longevity of restorations and interrupt the restoration/replacement cycle due to caries.

Quality of dental restorations

Quality evaluations of dental fillings in a cross-sectional design like the present study have to be interpreted with caution. Several similar studies reported that the age of failed restorations has been found to be lower than that reported in controlled clinical trials [Mjör, 1997; Burke et al., 1999, 2001]. Although they are not rated highly in the hierarchy of acceptable evidence, cross-sectional studies involving a large number of fillings and practitioners might shed light on factors influencing the performance of restorations in routine practice situations. In the present study, no attempt was made to compare filling materials in terms of longevity or age at failure. However, an overview of the quality of different filling materials was given and related to the estimated caries risk evaluated by the Cariogram.

In the present survey, the anatomic form and surface texture showed a high percentage of unacceptable restorations. Composite restorations received more acceptable ratings for these two criteria than amalgam and glass ionomer. This is probably because composite restorations in general have improved dramatically during the last decade. In addition, the light-cured composite can be adjusted and polished the day it is placed, in contrast to glass ionomer and amalgam. Restorations with a deteriorated contour, i.e. under- or over-contoured, and rough surfaces, especially adjacent to gingival margins, could favour bacterial growth and plaque maturation. The roughness of intra-oral hard surfaces, e.g.

fillings, will promote plaque formation and maturation, making the tooth surface more vulnerable to caries [Quirynen and Bollen, 1995; Bollen et al., 1997]. This kind of unfavourable quality could have a profound effect, particularly in high-risk patients, as in the present study.

In the present survey, the majority of glass ionomer restorations were diagnosed with recurrent caries, in spite of the release of fluoride, a finding reported in other studies [Randall and Wilson, 1999; Manhart et al., 2004; Wiegand et al., 2007]. For this reason, the fluoride-releasing property of glass ionomer should not be relied upon as a means of preventing caries, while ignoring other caries-related factors.

Matching tooth-coloured restorations is regarded as a critical factor by clinicians and patients from an aesthetic point of view. However, 42% of the tooth-coloured fillings with an acceptable colour match had recurrent caries in the present study (Paper II). Miyamoto et al. [2007] demonstrated that previously restored teeth experienced an increased rate of recurrent caries compared with unrestored teeth. Accordingly, placing or replacing fillings solely for aesthetic reasons should not be undertaken without seriously considering the patient's risk.

The value of bitewing radiographs in addition to clinical quality evaluations in Class II restorations was confirmed in the present study. The unacceptable ratings for proximal marginal integrity and anatomic form increased by 28% and 17% respectively, when restorations were evaluated with bitewing radiographs. It is unlikely that the presence of radiolucency and/or failed anatomic form at the gingival wall of Class II restorations will be detected by clinical examination alone. However, the clinical interpretation of this radiolucency could be crucial. For example, it could be due to the failure of proper condensation with an amalgam, while, in a composite, a thick layer of adhesive could appear to be radiolucent in a radiograph, or it could be a recurrent caries lesion that was not observed on clinical evaluation. Regardless of the cause, this "radiolucency" is regarded as a potential factor for developing caries, particularly in high-risk patients. Mjör [2005] reported that the gingival wall in Class II restorations is the most common site of recurrent caries. Furthermore, proximal overhangs, even minute ones, are predisposed to plaque accumulation and the development of recurrent caries [Mjör and Gordan, 2002; Mjör, 2005]. A number of studies have used bitewing radiographs in the quality evaluation of restorations, emphasising their extra diagnostic value [Poorterman et al., 1999,2000;

Levin et al., 2007]. The information from bitewings could therefore refine the clinical quality evaluation of the restorations. However, the decision on whether or not to expose patients to radiation should be based on the dentist's clinical judgement and should not be performed as a routine procedure.

Caries prevention using the modified fluoride toothpaste technique

The main finding in the second part of the present thesis was that "the modified fluoride toothpaste technique" had a preventive effect on approximal caries and enamel caries located on buccal/lingual surfaces. The difference in caries incidence between the test and control groups could be due to many factors involved in this technique, such as the amount of toothpaste applied and the duration of brushing. However, the influence of avoiding post-brushing water rinsing and refraining from eating or drinking for two hours after brushing could be of interest. As a result, the prolonged availability of a high level of fluoride could be attained. This improves the chance of fluoride being incorporated into the enamel and dentine, thereby rendering the surface more resistant to acidic challenge [ten Cate, 1999]. Studies have shown that the cariostatic effect of topical fluoride is partly related to the sustained presence or release of low fluoride concentrations in the oral environment [Featherstone, 1999; Ellwood et al., 2008]. By avoiding water rinsing, particularly in adults, the salivary fluoride level can remain high up to 2 hrs post-brushing [Issa and Toumba, 2004]. A prolonged low concentration of fluoride in saliva and plaque might enhance the rate of remineralisation [Featherstone et al., 1990]. Furthermore, [Sjögren and Birkhed, 1993] reported that adult patients with high caries activity rinsed with water after brushing more frequently than those with low caries activity. Zero [2006] stated that "*In addition to the inherent properties of a fluoride dentifrice product, biological and behavioral factors can modify its anticaries effectiveness. All of these factors interplay in what can be described as the 'application' phase (the initial interaction of relatively high concentrations of fluoride with the tooth surface and plaque), and the 'retention' phase (the fluoride remaining in the mouth after brushing that is retained in saliva, plaque and plaque fluid, the tooth surface, and oral soft tissue reservoirs)*". By optimising the behavioural factors, as was the intention in our study, the

"modified fluoride toothpaste technique" fulfilled these two phases described by Zero [2006].

In Paper III, the most profound difference was found in the incidence of new approximal enamel caries. The preventive fraction in the present study was around 66%. This percentage is higher than that reported by Sjögren et al. [1995] and is probably due to differences in the study population and patient compliance. The patients involved in the present trial were all adults with a high caries prevalence, which might accentuate the preventive effect of fluoride toothpaste. Marinho et al. [2003] found that the effect of fluoride toothpaste increased with higher baseline levels of DMFS. In a review of fluoride toothpastes, strong evidence of a preventive effect was found in the young permanent dentition, while there was incomplete evidence in the primary dentition [Twetman et al., 2003]. This might indicate that the "modified fluoride toothpaste technique" could have a greater preventive effect in adults than in children, particularly in those with a high caries prevalence. Moreover, a recent study showed that the fluoride concentration in interdental saliva and plaque was higher without post-brushing water rinsing [Nordström and Birkhed, 2009]. Since the toothbrush does not reach the approximal area, slurry rinsing through active cheek movements could result in the rapid transport of fluoride into the interdental plaque [Sjögren et al., 1996]. This could affect the metabolic activity of the bacterial flora, enhance remineralisation and inhibit the demineralisation of approximal tooth surfaces [Tenuta et al., 2009].

There is, however, some controversy regarding the effect of post-brushing water rinsing per se on caries development. The difference between the mean caries increments with and without rinsing was only 0.8 DS in a longitudinal clinical trial and had no statistical significance [Machiulskiene et al., 2002]. In that study, however, the population was not comprised of caries-prone individuals, as in the present trial. In addition, there was no information as to whether the children were instructed not to eat or drink post-brushing. This might be an important factor when it comes to maintaining a high fluoride level in the oral cavity after refraining from water rinsing, as Sjögren and Birkhed [1994] found that eating/drinking directly after brushing reduced the fluoride concentration considerably.

Prevention of recurrent caries

In Papers III and IV, many restorations on the approximal and buccal/lingual surfaces respectively had recurrent caries at the end of the trial and the frequency was higher in the control group than in the test group. Although the differences were not significant, recurrent caries does not differ from primary caries with regard to aetiology. In this context, it might be true to say that fluoride apparently prevents recurrent caries development. A recent in situ study demonstrated that fluoride toothpaste might maintain a high level of fluoride in the biofilm, thereby reducing demineralisation and caries progression adjacent to restorations [Cenci et al., 2008]. Moreover, recurrent caries is one of the most common reasons for the failure of dental fillings [Mjör, 2005]. Consequently, the investigated "modified fluoride toothpaste technique" might be beneficial in preventing recurrent caries or at least interrupting its progression. This could eventually improve filling longevity.

Compliance

It should be pointed out that the 6-month recall visits played a major role in improving the oral hygiene of both test and control patients by the end of the study. In Papers III and IV, the plaque reduction was more or less the same in both groups and all the patients used fluoride toothpaste regularly. Nevertheless, the test group had a lower incidence of both approximal and enamel buccal/lingual caries than the control group. The "modified fluoride toothpaste technique" might therefore be the factor that contributed to the caries reduction in the test group. Another interesting observation was that the majority of test group patients complied with the instructions, indicating that the technique is easy for adults to learn.

Frequency of toothbrushing, as well as post-rinsing behaviour, are probably the most important as far as caries prevention is concerned. Patients in the test group who brushed their teeth only once a day and/or rinsed with a sip of water post-brushing were therefore scored as having "less good compliance". The buccal/lingual enamel caries incidence was significantly higher in these patients than in those with "good compliance". This is in agreement with other reports that showed an association between caries incidence and the frequency of brushing and post-brushing behaviour [O'Mullane et al., 1997; Chestnutt et al., 1998].

It is important to remember the efforts made at the recall visits to emphasise the "modified fluoride toothpaste technique" instructions. These recall visits clearly encouraged patient compliance, as shown by the final results of the study (Paper III). However, the most common complaint from patients who wanted to rinse after brushing was that they did not like the strong taste of the toothpaste slurry that was left after brushing.

The amount of fluoride that might be swallowed as a result of the "modified fluoride toothpaste technique" is less critical in an adult compared with a child. Up to 20% of toothpaste was swallowed when no water rinsing took place post-brushing [Sjögren et al., 1994]. This corresponds to 0.3 mg F/brushing, when using 1 g of a toothpaste with 1,500 ppm F; this amount corresponds to one cup of tea (~1 dL) containing 3 mg F/L [Wu and Wei, 2009]. From a toxicological point of view, this is regarded as negligible for an adult.

Caries progression

According to the present thesis, the "modified fluoride toothpaste technique" in general did not have a pronounced effect on caries progression, compared with the development of new lesions. Although the presence of fluoride enhances the remineralisation process, it has been reported that the effect is more apparent in the demineralisation of enamel rather than the remineralisation [ten Cate et al., 1995].

In Paper III, the number of approximal enamel lesions that progressed into the dentine was somewhat higher in the control group, although the difference was not statistically significant. The reason could be that the rate of approximal caries progression per se is slow in young adults [Mejàre et al., 1999; Mejàre et al., 2004]. A 2-year trial is therefore not long enough to evaluate caries progression, particularly in adults. Moreover, in a group of patients with a large number of FS, such as those in the present trial, including enamel lesions that were filled during the trial when calculating progression might be disputed. It was difficult to trace whether they had first progressed into the dentine. The total progression was therefore re-calculated, excluding this event, but the differences between the control and test groups were not statistically significant.

In Paper IV, the clinical examination of the buccal and lingual enamel caries was dependent on visual and tactile criteria. Although these criteria provide much more information about caries lesion transition patterns in the clinical trials [Baelum et al.,

2003; Hausen et al., 2007; Lima et al., 2008], however, they do not provide much data on the depth or degree of mineral loss at microscopic level. The clinical depth of the lesions could influence the efficacy of fluoride toothpaste [ten Cate et al., 2006]. Consequently, methods that measure the degree of mineral loss and the depth of the lesion should be used in order better to evaluate the possible effect of the "modified fluoride toothpaste technique" on progression.

The number of arrested buccal/lingual enamel caries was similar in both groups. This could be attributed to the fact that the buccal enamel caries is accessible to the mechanical action of the toothbrush bristles that might lead to the abrasion of the superficial layer of the lesion. An effect of this kind has been reported in clinical studies [Holmen et al., 1987; Årtun and Thylstrup, 1989].

Many enamel caries were filled at the end of the trial (Papers III and IV). This somewhat "aggressive" approach should be discouraged and replaced by promoting the conservative management of enamel caries, including the use of fluoride toothpaste, and pursuing caries risk assessment. Moreover, it is apparent that the dentists did not fully appreciate the importance of arresting early caries. In dental practice, the diagnosis of early caries lesions should therefore include detecting the lesion, estimating its depth and degree of demineralisation and, most importantly, making a decision regarding its activity [Nyvad and Fejerskov, 1997]. Lesion surface texture alterations are associated with changes in the progression rate of caries. Active non-cavitated enamel lesions are dull and rough, while inactive non-cavitated enamel lesions are shiny and smooth [for a review, see Thylstrup et al., 1994]. These clinical changes have been reported to provide a reliable, valid indication of caries activity [Nyvad et al., 1999, 2003]. Consequently, using the combined information obtained from the tactile sensation, visual appearance and lesion location could indicate the caries activity of early lesions. Accordingly, treatment decisions can be more conservative and appropriately determined [Fontana and Zero, 2006; Mjör et al., 2008].

Conclusions

- The Cariogram evaluated the caries risk profile in the present adult population and the caries-related factors contributing to the risk were identified.

- There was an association between many caries indices (total decayed surfaces, filled surfaces and recurrent caries) and the Cariogram risk groups but not with the total DMFS.

- The main reason for the unacceptable rating of restorations was recurrent caries. Unacceptable anatomic form and surface texture were also common. Bitewing radiographs were found to be an important aid when evaluating proximal marginal integrity and anatomic form.

- The "modified fluoride toothpaste technique" had a preventive effect on approximal caries in this adult Saudi population with a high caries prevalence. It reduced the incidence of approximal caries by around 66%.

- Using this fluoride toothpaste technique resulted in a preventive fraction for buccal/lingual enamel caries of approximately 44%. Patient compliance appeared to play an important role in this result.

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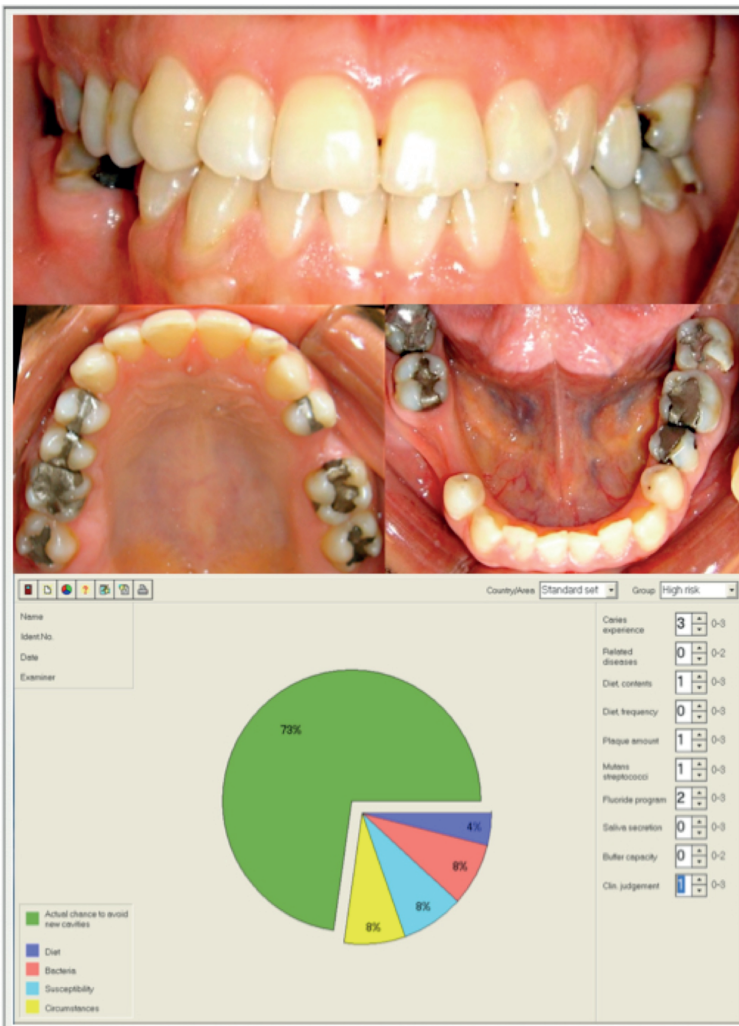
Appendices
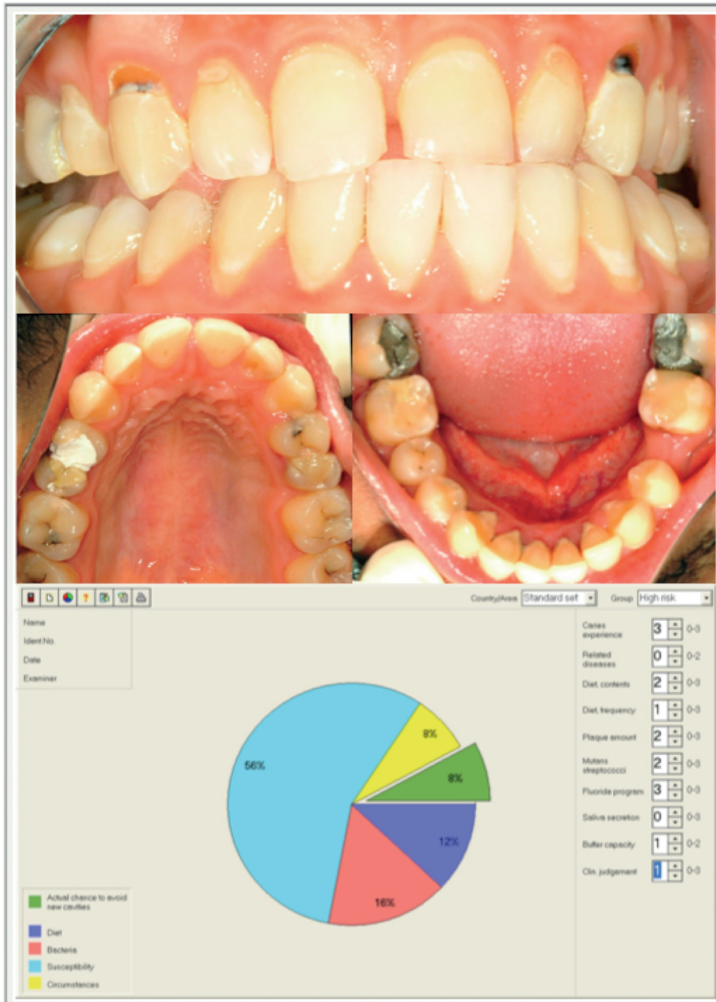
Appendix 1. Clinical photographs and the caries risk profile according to the Cariogram model representing a 26-year-old healthy male. He had a normal salivary secretion rate (2 ml/min). He rarely brushed his teeth with fluoride toothpaste and used to eat a maximum of five times a day as a mean. He displayed a moderate accumulation of soft deposits, which could be seen with the naked eye.
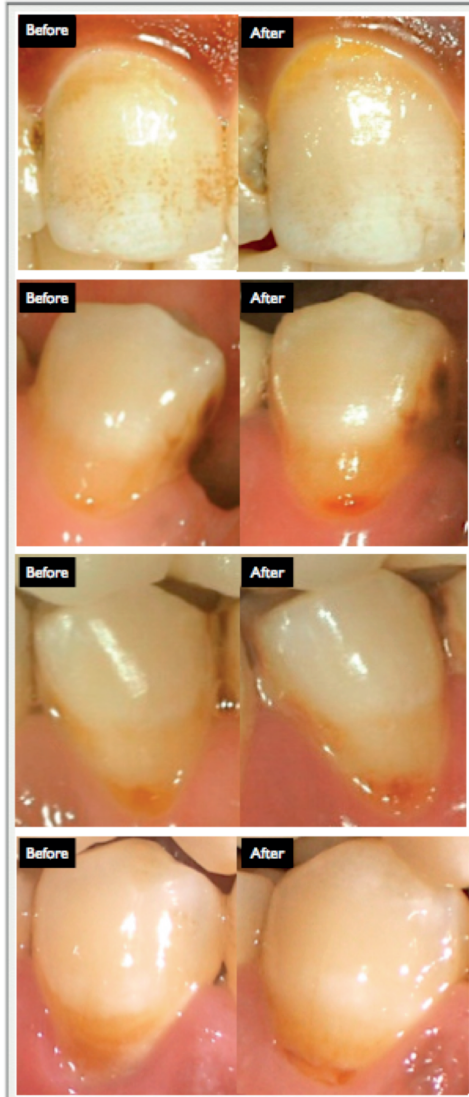
Appendix 2. Clinical photographs and caries risk profile according to a Cariogram model representing a 38-year-old healthy female. She had a normal salivary secretion rate (2ml/min). She regularly brushed her teeth twice a day with fluoride toothpaste and used to eat a maximum of three times a day including main meals. She practised good oral hygiene.
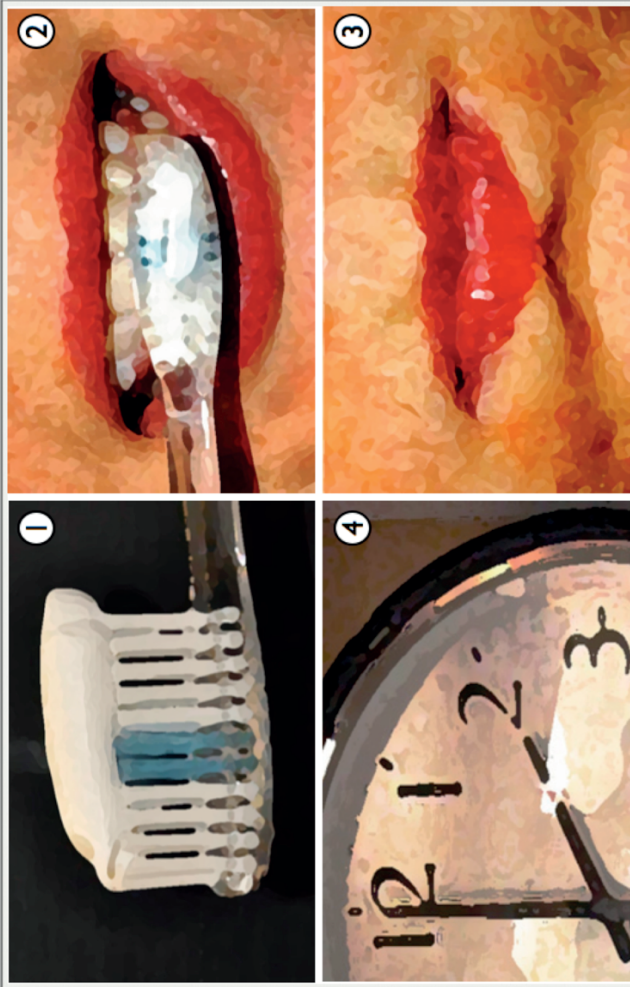
Appendix 3. Photographs reveal the four steps of the "modified fluoride toothpaste technique": (1) 2 cm of the toothpaste, (2) brushing for approximately 2 min, (3) swishing around the remaining toothpaste foam and saliva (slurry) with active movements of the cheeks, lips and tongue, forcing the slurry in between the teeth for about 30 sec before expectorating and (4) no post-brushing water rinsing or eating/drinking for a minimum of 2 hr after brushing.
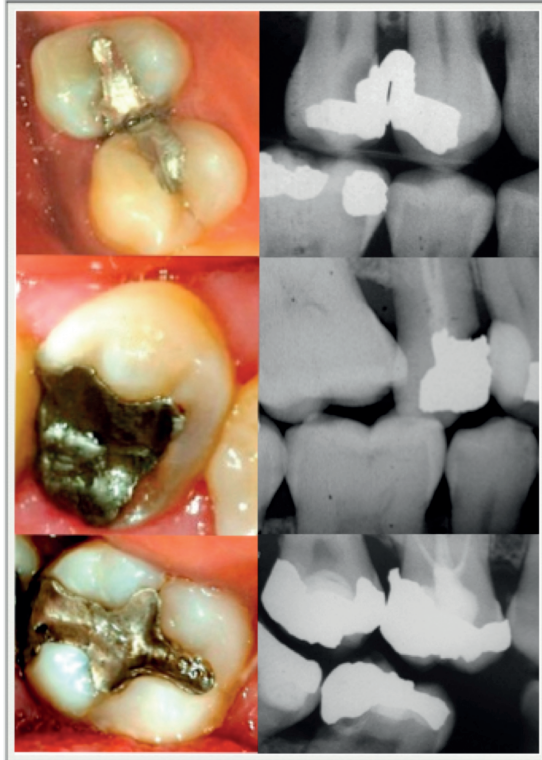
Appendix 4. Clinical photographs of restorations and the corresponding bitewing radiographs in three examples. The bitewing radiographs reveal approximal overhangs and gingival "radiolucency" that could not be detected clinically.

Appendix 5. Clinical photographs of several teeth showing the progression of buccal caries lesions after 2 years (Paper IV).
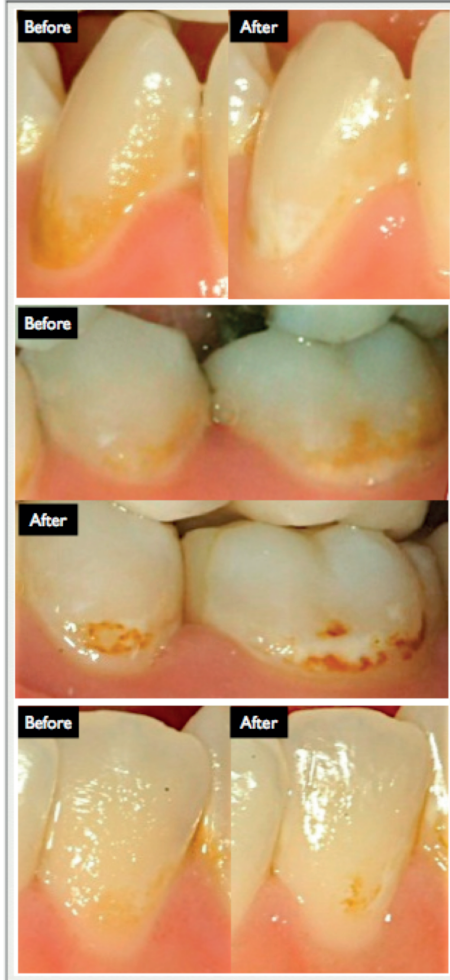
Appendix 6. Clinical photographs representing various incidences of buccal arrested caries after 2 years (Paper IV).