On Caries Risk Profiles Using Cariogram and Caries Prevention with Fluoride Toothpaste in Orthodontic Patients

Anas H. Al-Mulla

Departments of Cariology and Orthodontics
Institute of Odontology at Sahlgrenska Academy
University of Gothenburg, Sweden

UNIVERSITY OF GOTHENBURG

MINISTRY OF HIGHER EDUCATION SAUDI ARABIA

Gothenburg 2010
A doctoral thesis at a university in Sweden is produced either as a monograph or as a collection of papers. In the latter case, the introductory part constitutes the formal thesis, which summarises the accompanying papers. They have been published or accepted for publication. No part of this thesis may be reproduced or transmitted, in any form or by any means, without written permission. Permission from journals authors has been acquired to attach all four papers to this thesis. Anas H. Al-Mulla.

The cover page illustration was made by Yvonne Heijl
Abstract

On Caries Risk Profiles Using Cariogram and Caries Prevention with Fluoride Toothpaste in Orthodontic Patients

Anas H. Al-Mulla, Departments of Cariology and Orthodontics, Institute of Odontology, Sahlgrenska Academy, University of Gothenburg, Box 450, SE-405 30 Gothenburg, Sweden

Objective. The aims of this thesis were to: 1) analyse caries-related factors shortly after orthodontic treatment, 2) demonstrate the usefulness of the Cariogram by presenting orthodontic patients with different caries-risk profiles, 3) compare two different toothpastes with different post brushing techniques by using an in situ caries model with orthodontic bands, and 4) test the hypothesis that toothpaste slurry rinsing, combined with some other simple post-brushing advice (in this thesis called the "modified F toothpaste technique, MFTT"), would reduce the number of decayed and filled tooth surfaces (DFS) in a 2-year randomised clinical trial in orthodontic patients. Materials and Methods. In Study I, a total of 100 patients were divided into two groups (50 in each), based on their pre-bonding DFS. A high- (DFS ≥ 5) and a low- (DFS ≤ 2) caries groups were created. In Study II, three cases were selected to present the three caries risk groups, i.e. high, medium and low. In Study III, 20 orthodontic patients were randomised into two groups: 1) a test group using 5,000 ppm F with no post-brushing water rinsing and 2) a control group using 1,450 ppm F with 3 times post-brushing water rinsing. On the upper first premolars, orthodontic stainless steel bands were applied, leaving 2-3 mm of space away from the exposed buccal surface in order to accumulate plaque and create an area for initial caries development. The teeth were extracted after 8 and 9 weeks and were then analysed using Quantitative Light-induced Fluorescence (QLF). Moreover, the oral F retention was studied using the two brushing techniques. The Study IV population consisted of 100 orthodontic patients randomly divided into two groups. Each patient was examined before the beginning of orthodontic treatment (baseline) and shortly after de-bonding (follow-up) within a 2-year study period. The test group patients were instructed to use the MFTT, in which various behavioural factors were standardised in order to improve the caries preventive effect of F toothpaste. The control group patients were given the routine clinic oral hygiene instructions. Results. In Study I, the low-caries group displayed lower DFS (p < 0.001), lactobacilli (p < 0.001) and mutans streptococci (p < 0.001) and higher Cariogram values (p < 0.001). Study II showed that the Cariogram was a useful tool for distinguishing between low, medium and high caries risk patients. In Study III, in comparison to the control group, the test group regimen resulted in a non-significant smaller QLF lesion area and lower average QLF loss of fluorescence (p < 0.05). The highest F concentration under the band was found in the test group (p < 0.001). In Study IV, the clinical (p < 0.001), radiographic (p < 0.001) and clinical + radiographic (p < 0.001) ΔDFS (incidences) were significantly reduced in the test group in comparison to the controls, with prevented fractions of 87%, 78% and 83% respectively. Conclusions. 1) Patients with high DFS before orthodontic treatment ran a higher risk of developing caries. They had significantly higher numbers of mutans streptococci and lactobacilli and had less chance of avoiding new cavities according to the Cariogram. 2) The Cariogram may be a useful pedagogic model for illustrating a patient’s caries risk in the orthodontic clinic. 3) The combination of using a 5,000 ppm F toothpaste and no post-brushing water rinsing had better anti-caries potential and resulted in elevated oral F retention, compared with a 1,450 ppm F toothpaste with 3 times post-brushing water rinsing. 4) Compared with routine oral hygiene instructions including F toothpaste, the use of the MFTT significantly reduces the incidence of new caries lesions in orthodontic patients.


Correspondence to: a.almulla@mac.com
## Contents

Original papers ................................................................. 7  
Introduction ........................................................................... 9  
Aims .................................................................................. 16  
Materials and Methods ..................................................... 17  
Results ............................................................................... 29  
Discussion .......................................................................... 35  
Conclusions ....................................................................... 41  
Acknowledgements ............................................................ 42  
References .......................................................................... 44  
Papers I-IV
This thesis is based on the following four papers, which will be referred to in the text by their Roman numerals:


III. Al Mulla A, Karlsson L, Kharsa S, Kjellberg H, Birkhed D. Combination of high fluoride toothpaste and no post-brushing water rinsing on enamel demineralisation using an in situ caries model with orthodontic bands. Accepted for publication in Acta Odontol Scand.

Introduction

The human oral cavity is a complex ecosystem, inhabited by more than 300 bacterial species, mycoplasmas, protozoa and yeasts (Marcotte and Lavoie, 1998). Any external interference could disturb the balance between components of the microflora in this environment. Fixed orthodontic appliances are an example of this kind of interference. The bonding of brackets usually includes the acid etching of enamel, which results in changes in the morphology and chemical nature of the tooth surface. It has been found that decalcified enamel provides good support for adhesion and the proliferation of mutans streptococci (Boyar et al., 1989). It is also known that living cells easily adhere to and colonise polymeric surfaces (Zühlke et al., 1993; Langer, 1995; West and Hubbell, 1999). As a result, composite resins containing polymers used for attaching brackets to etched enamel provide surfaces that are especially prone to the adhesion and growth of micro-organisms (Weitman and Eames, 1975; Gwinnett and Ceen, 1979; Sukontapatipark et al., 2001). In effect, fixed dental appliances induce the development and retention of bacterial plaque (Zachrisson, 1976; Gorelick et al., 1982; O’Reilly and Featherstone, 1987; Øgaard et al., 1988a; Mitchell, 1992). The development of dental plaque usually leads to an increased level of caries-inducing bacteria in the oral cavity, e.g. mutans streptococci and lactobacilli (Balenseifien and Madonia, 1970, Diamandi-Kiopioti et al., 1987; Boyar et al., 1989). These observations indicate that fixed orthodontic appliances generate some risk of caries development.

Caries risk in orthodontic patients

The risk of developing a caries lesion around a bracket, placed on the buccal tooth surfaces during orthodontic treatment with fixed appliances, is high [Gorelick et al., 1982; Årtun and Brobakken, 1986; Øgaard, 1989]. This risk is attributed to the presence of brackets, arch wires, ligatures and other orthodontic auxiliaries that complicate conventional oral hygiene measures, which in turn leads to increased plaque accumulation at the base of the brackets [Øgaard et al., 1988a; Chang et al., 1997]. In the presence of fermentable carbohydrates, the demineralisation of the enamel around the bracket is a rapid process [Gorelick et al., 1982; Mizrahi, 1983; Øgaard et al., 1988a]. Despite improvements in materials and preventive efforts,
demineralisation may occur around orthodontic appliances after only one month [O’Reilly et al., 1987]. Children between 11 and 14 years, the age group in which orthodontic treatment is usually carried out, are thought to run a high risk of developing caries [Axelsson, 1999]. Fixed orthodontic appliances create extra retention sites, leading to more mutans streptococci soon after the start of treatment [Scheie et al., 1984; Jordan et al., 2002]. A study by Smiech-Sلومkowska et al. [2007] concluded that measures including intensive brushing and careful cleaning with dental floss of the spaces around brackets under arch wires and between teeth was insufficient to reduce mutans streptococcus and lactobacillus levels. For this reason, patients with fixed appliances run a high risk of caries.

**Dental caries in the Kingdom of Saudi Arabia (KSA)**

The caries prevalence in teenagers and adolescents in KSA is high [Al Dosari et al., 2004]. This also applies to preschool children [Wyne et al., 2002]. In 300 military school children (6-7 years old), 288 (96%) were diagnosed with decay, while only 4% were clinically caries free [Al-Malik 2006]. In 1994, it was reported that 90% of 5-year-old children, from nurseries in Al-Kharj, KSA, had heavy plaque on their teeth and one-third never brushed their teeth, while two-thirds had never been to a dentist [Paul et al., 2003]. A recent study by Brown [2009] found a mean of decayed, extracted and filled teeth (deft) of 6.3 in healthy 5-year-old children. The differences found in the oral health behaviour of Saudi Arabian and Irish teenagers are obvious with respect to the intake of sweet foods and drinks [Al-Khateeb et al., 1990].

**Caries prevalence in orthodontic patients**

The prevalence of new enamel lesions among orthodontic patients treated with fixed appliances and using fluoride toothpaste is reported to range from 13 to 75% [Gorelick et al., 1982; Mitchell, 1992; Wenderoth et al., 1999; Fornell et al., 2002]. Although demineralised enamel can remineralise after de-bonding, the lesions are often irreversible [Artun and Brobakken, 1986; O’Reilly and Featherstone, 1987; Øgaard et al., 1988a, b]. Inactive demineralised enamel was found to be present five years after the completion of orthodontic treatment [Øgaard, 1989]. The lesions have been reported to develop on all teeth, but they are most frequently observed on the cervical and middle third of the buccal surface of the lateral maxillary incisors, the
mandibular canines and the first premolars [Gorelick et al., 1982; Årtun and Brobakken, 1986]. The long-term presence of enamel lesions, which appear as white spots, is a concern for both the patient and the orthodontic profession.

Cariogram – a pedagogic model

Caries affects individuals differently, which makes it essential that those at the highest risk are identified early, so that preventive therapies can be targeted at the patients who are most likely to benefit. Bo Krasse introduced the “risk assessment concept” of dental caries more than 20 years ago [Krasse, 1988]. Since then, this has been an interesting and challenging subject for the dental profession [Hausen, 2008]. The concept of caries-risk assessment is simple and straightforward. The ideas are: i) to identify those patients who are most likely to develop caries and ii) to provide these individuals with appropriate preventive measures to stop the disease.

Many studies have been published on caries assessment and prediction [Disney et al., 1992; Schiffner et al., 2005; Zhang et al., 2006], focusing on different oral caries indicators, such as saliva, diet, oral hygiene and past caries history, including DMFT [Leverett et al., 1993; Motohashi et al., 2006; Zhang et al., 2006], and the amount of mutans streptococci and lactobacilli in saliva [Thenisch et al., 2006]. A computer-based program, called the “Cariogram”, has been developed to illustrate caries-risk profiles in teenagers and adolescents [Bratthall, 1996].

The Cariogram is an interactive PC-based program for caries-risk evaluation, illustrating the various caries-related indicators expressing the “actual chance of avoiding new cavities”. Figure 1 shows how the Cariogram appears on the screen. It is possible to choose different values to enter, two on the upper right (country/area and group) and ten caries-related variables/factors on the right side. The orthodontist should decide which kind of country and group he/she is treating and then decide whether the area and group runs a low, standard or high risk of developing caries. After entering at least seven (preferably ten) variables/factors, the Cariogram pie chart starts appearing. Based on the formula inserted in the Cariogram, the values that are entered interact with each other and illustrate five different coloured sectors with different percentages. The sectors are clarified in different colours: dark blue (Diet), red (Bacteria), light blue (Susceptibility), yellow (Circumstances) and green (Actual chance of avoiding new cavities). In other words, the green sector represents the
chance of avoiding cavities; the greater the chance (percentage), the lower the risk of developing caries and vice versa. The Cariogram does not specify the number of cavities that will or will not occur in the future. In recent years, Hänsel-Petersson and co-workers in Sweden have performed a series of studies to evaluate the program with positive conclusions [Hänsel-Petersson et al., 2000, 2002, 2003; Hänsel-Petersson 2003].

Figure 1. A Cariogram showing a patient with a low percentage (11%) of “Actual chance of avoiding new cavities” (green sector)

In situ caries model and Quantitative Light-induced Fluorescence (QLF)

Since the introduction of the intra-oral cariogenicity test by Koulourides et al. [1974], many researchers have used various models to test caries-preventive products and methods. A review by Fejerskov et al. [1994] concluded that in situ models differ distinctively with regard to their “biological potential”, because of regional differences in salivary film velocity, pH and the composition of the microflora. Moreover, local factors in relation to specimen environment, such as the degree of “protection”, may further add to the differences. Because of the pronounced intra-oral variation in certain parameters thought to be important for caries lesion development, the selection of in situ study model design will strongly depend on the aim and purpose of the study. By using in situ models, it may be possible to study both
fundamental aspects of the caries process, such as fluoride in caries prevention [Featherstone and Zero, 1992; Øgaard and Rølla, 1992; Zero, 1995; Zero et al., 2010].

The QLF method provides a fluorescence image of a smooth-surface caries lesion (Figure 2) that quantifies the mineral loss and size of the lesion. Accordingly, the method is suitable for the assessment of early enamel lesions in visually accessible surfaces. It can be used for monitoring mineral changes (regression or progression) over just a few months or even shorter periods. The QLF method has previously been described in detail [Tranaeus et al., 2001] and has been reviewed by Angmar-Månsson and ten Bosch [2001].

![Figure 2. Example of a QLF image of a smooth surface of a premolar tooth obtained from a Study III patient. The dotted line shows the area of decalcification.](image)

Caries prevention in orthodontic patients

Fluoride ions reduce enamel demineralisation, promote remineralisation, and prevent plaque activity and adhesion by blocking enzyme systems. A Cochrane review has recommended that orthodontic patients, who are at risk of caries, should use a 0.05% NaF rinse daily during treatment, in addition to fluoride toothpaste [Benson et al., 2004]. The use of fluoride varnish at sites that are highly susceptible to caries may be advantageous, as it contains a high concentration of fluoride and adheres to enamel for a prolonged period [Hawkins et al., 2003]. Fluoride-containing resins and elastomers cause an initial high burst of fluoride, which in turn causes the formation
of calcium fluoride and helps to remineralise and protect etched enamel. In addition, it has been shown that these materials can imbibe fluoride (thus becoming recharged), such that the fluoride can then be re-released [Wiltshire et al., 1995; Wiltshire 1997, 1999]. However, evidence demonstrating that the use of fluoride-releasing bonding materials, such as glass ionomer cement, helps to reduce the incidence and severity of white spot lesions in vivo is weak [Benson et al., 2004].

**Fluoride toothpaste**

Fluoride toothpaste has been widely used for more than four decades and remains a benchmark for the prevention of dental caries [Marinho et al., 2003; Twetman et al., 2003; Twetman, 2009]. It reduces caries in both primary and permanent teeth [Marinho, 2009]. For this reason, fluoride toothpaste plays an important role as an effective caries-prevention measure worldwide [Twetman, 2009]. Topical fluoride (mouthrinses, gels and varnishes), used in addition to fluoride toothpaste, achieves a modest reduction in caries compared with toothpaste used alone [Marinho et al., 2004]. Numerous studies have shown that even low levels of fluoride, resulting from the regular use of toothpaste, have a profound effect on enamel demineralisation and remineralisation [Bowen, 1995; Lynch et al., 2004]. Considering the widespread use of fluoride toothpaste during orthodontic treatment, there is little evidence to show which method of delivering the fluoride paste is the most effective.

At least four factors influence the anti-caries efficacy of fluoride toothpaste: 1) frequency of brushing, 2) duration of brushing, 3) fluoride concentration in the toothpaste and 4) post-brushing rinsing behaviour. Brushing should be recommended a minimum of twice daily [Davies et al., 2003] and patients should be persuaded to brush for longer periods of time [Creeth et al., 2009]. A recent study by Zero et al. [2010] concluded that both brushing time and dentifrice quantity might be important determinants both of fluoride retention in the oral cavity and of subsequent enamel remineralisation.

There appears to be a correlation between the fluoride concentration of dentifrices and caries prevention [Tavss et al., 2003]. The treatment of demineralised dentine with a toothpaste containing 5,000 ppm fluoride reduces mineral loss and lesion depth on exposed dentine [Bizhang et al., 2009]. In a randomised clinical trial comparing 5,000 and 1,450 ppm fluoride, the high-fluoride toothpaste reversed non-cavitated
fissure caries lesions [Schirrmeister et al., 2007]. Moreover, the group using 5,000 ppm fluoride displayed a significantly higher decrease in the laser fluorescence of enamel than the 1,450 ppm fluoride group. Furthermore, dentifrice containing 5,000 ppm fluoride was significantly better at remineralising root caries lesions than a dentifrice with 1,100 ppm fluoride [Baysan et al., 2001]. In addition, caries-active adolescents using the 5,000 ppm toothpaste had significantly lower progression of caries compared with subjects using the 1,450 ppm toothpaste, after 2 years [Nordström and Birkhed, 2010].

The rinsing method after toothbrushing has been found to correlate with caries experience and caries increment [Chestnutt et al., 1998]. The salivary fluoride concentration measured after dentifrice application decreases significantly with increasing water volume, rinse duration and the frequency of rinsing [Duckworth et al., 1991; Attin and Hellwig, 1996]. A toothpaste technique in which a slurry rinse with the toothpaste is carried out after brushing increases the efficacy of fluoride toothpaste and reduces approximal caries in preschool children by an average of 26% [Sjögren et al., 1995]. A recent study by Sonbul et al. [2010] revealed a 66% preventive fraction effect on approximal caries between the group who used a modified fluoride toothpaste technique compared with the group who continued using their regular oral hygiene habits. Furthermore, eating immediately after brushing reduces the salivary fluoride level about 12-15 times compared with brushing alone [Sjögren and Birkhed, 1994]. There is an increase in fluoride in both proximal saliva and plaque, when using a dentifrice with 5,000 ppm fluoride without post-brushing water rinsing compared with rinsing [Nordström and Birkhed, 2009]. Post-brushing rinsing habits may play an important role in the oral retention of fluoride from dentifrices that may, in turn, affect their clinical efficacy [Duckworth et al., 1991].
Aims

The present thesis focuses on caries risk and prevention in orthodontic patients. The first two papers analyse caries risk, while the last two papers evaluate different ways of reducing caries with fluoride toothpaste in orthodontic patients. The specific aims of the thesis were to:

• analyse caries-related factors shortly after orthodontic treatment and to use the Cariogram computer program to describe the caries risk profiles at follow-up,

• demonstrate the usefulness of the Cariogram by presenting three orthodontic patients with different caries-risk profiles,

• compare the anti-caries potential and the oral fluoride retention of a combination of a high-fluoride dentifrice (containing 5,000 ppm) without post-brushing water rinsing vs. a standard-fluoride dentifrice (containing 1,450 ppm) followed by 3 times post-brushing water rinsing, by using an in situ caries model with orthodontic bands, and

• test the hypothesis that toothpaste slurry rinsing, combined with some other simple post-brushing advice (in this thesis called the “modified fluoride toothpaste technique, MFTT”), would reduce the number of decayed and filled tooth surfaces (DFS) in a 2-year randomised clinical trial in orthodontic patients.
Material and Methods

An outline of the design and topic of the four studies is presented in Table 1.

Table 1. The main topic of the four studies included in this thesis and their corresponding populations and designs.

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Population</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Cross-sectional</td>
<td>100</td>
<td>Caries risk profiles using the Cariogram</td>
</tr>
<tr>
<td>II</td>
<td>Case report</td>
<td>3</td>
<td>Demonstrate the usefulness of the Cariogram in the orthodontic clinic</td>
</tr>
<tr>
<td>III</td>
<td>In-situ experimental model</td>
<td>20</td>
<td>Preventive effect of the combination of a high-fluoride toothpaste (5,000 ppm) and no post-brushing water rinsing</td>
</tr>
<tr>
<td>IV</td>
<td>Prospective, longitudinal</td>
<td>100</td>
<td>Preventive effect of the modified fluoride toothpaste technique (MFTT)</td>
</tr>
</tbody>
</table>

Studies I & II

Subjects

Study I consisted of 100 patients (range 12-29 years) with a mean age of 17.5 years. The patients were divided into two groups (50 in each), based on their pre-bonding DFS. A high- (DFS ≥ 5) and a low- (DFS ≤ 2) caries group were created; individuals with DFS between 2 and 5 were excluded. Study II patients were three cases selected from Study I. They were chosen to present the three caries risk groups, i.e. high, medium and low. Based on their pre-bonding DFS index, patient No. 1 (15 y, female) and patient No. 2 (18 y, female) had > 5 DFS, while patient No. 3 (15 y, male) had < 2 DFS.

All patients were recruited consecutively during a 6-month period in a well-established orthodontic clinic in Riyadh, KSA. They were treated with fixed orthodontic appliances in both jaws for 1-2 years (mean treatment duration 18 months). Synergy brackets were used (Rocky Mountain Orthodontics, Denver, Colorado, USA), bonded with Reliance light bond material (Reliance Orthodontic
Product Corporate, Itasca, III, USA). After bonding, routine clinic instructions were given to all patients to brush their teeth at least twice a day.

**Examination**

The same dentist examined all patients (A.M.). Before bonding, the records, intra-oral photos and the orthopantomographic radiographs were checked carefully for caries lesions. After de-bonding, the patients were examined in the following order: data collection, plaque score, caries examination, saliva samples, bitewings and panoramic radiographs and intra-oral digital photos.

**Data collection**

A standardised form was used to collect all the data needed for the Cariogram (Table 2). Each of the ten parameters was ranked from 0-2 or 0-3, according to the manual. All data were then inserted into the computer program to produce a graphic image (Cariogram), which illustrates the chance of avoiding caries as a percentage value (Figure 1). In order not to change the built-in evaluation, the tenth factor (clinical judgement) was set to Score 1 in all patients. In accordance with the Cariogram manual, all individuals were asked about the presence of general disease, diet frequency and fluoride.

**Plaque scoring**

For plaque scoring, four different scores were used according to the Silness and Löe index [Silness and Löe, 1964]. The amount of plaque in the cervical part of teeth 16, 12, 24, 36, 32 and 44 was registered and four sites on each tooth were recorded (i.e. buccal, lingual and proximal surfaces).

**Clinical and radiographic caries registration**

Prophylaxis and flossing were performed before the registration. Using optimal light, a mirror and an explorer, all kinds of caries lesion, in both enamel and dentine, diagnosed clinically and radiographically (four bitewings), were included in the DFS index. White spot lesions were excluded, as only cavities are included in the ‘caries experience’, according to the Cariogram manual.
Salivary and microbiological factors

Paraffin-stimulated whole saliva was collected for 3 min and the secretion rate was expressed in ml/min and transformed to 4 scores. The same stimulated saliva was used to evaluate buffer capacity and the number of cariogenic micro-organisms in chair-side tests. One saliva drop was poured on the Buffer Strip (Dentobuff Strip®, Orion Diagnostica, Espoo, Finland). Three colours were obtained: blue (Score 0), green (Score 1) and yellow (Score 2). The remaining saliva was then poured onto the Dentocult LB (Dentocult LB®, Orion Diagnostica, Espoo, Finland) agar and incubated at 37°C for 4 days to estimate the lactobacillus counts. The colony density on the agar surface was compared with a model chart with four different values (Table I). A tongue swab of Dentocult SM (Strip Mutans®, Orion Diagnostica, Espoo, Finland) was used to determine the mutans streptococcus counts. The strip was incubated at 37°C for 2 days. The colony density on the test strip was compared with a model chart with four different classes.
Table 2. Cariogram sectors, variables and their corresponding scores.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Variable</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumstances (yellow sector)</td>
<td>Caries experience</td>
<td>0: DFS = 0, caries-free and no fillings 1: DFS = 1–2, better than normal for age group 2: DFS = 2–4, normal for age group 3: DFS &gt; 4, worse than normal for age group</td>
</tr>
<tr>
<td>Related diseases (yellow sector)</td>
<td>Related diseases</td>
<td>0: No systemic disease 1: Diseases/condition, mild degree 2: Severe degree, long lasting</td>
</tr>
<tr>
<td>Diet (dark blue sector)</td>
<td>Diet content, Lactobacillus count (LB)</td>
<td>0: LB &lt; 10^2 CFU/mL 1: 10^2 ≤ LB &lt; 10^3 CFU/mL 2: 10^3 ≤ LB &lt; 10^4 CFU/mL 3: LB ≥ 10^4 CFU/mL</td>
</tr>
<tr>
<td>Diet (dark blue sector)</td>
<td>Diet frequency, number of intakes per day (meals and snacks)</td>
<td>0: Maximum 3 intakes per day 1: Maximum 5 intakes per day 2: Maximum 7 intakes per day 3: More than 7 intakes per day</td>
</tr>
<tr>
<td>Bacteria (red sector)</td>
<td>Plaque amount</td>
<td>0: No plaque 1: Film of plaque adhering to the free gingival margins and adjacent area of the tooth 2: Moderate accumulation of soft deposits in the gingival pocket or on the tooth gingival margins 3: Abundance of soft matter within the gingival pocket and/or on the tooth gingival margins</td>
</tr>
<tr>
<td>Bacteria (red sector)</td>
<td>Mutans streptococci count (MS)</td>
<td>0: MS &lt; 10^3 CFU/mL 1: 10^3 ≤ MS &lt; 10^4 CFU/mL 2: 10^4 ≤ MS &lt; 10^5 CFU/mL 3: MS ≥ 10^5 CFU/mL</td>
</tr>
<tr>
<td>Susceptibility (light blue sector)</td>
<td>Fluoride program</td>
<td>0: Fluoride toothpaste plus fluoride tablets, rinsing, and varnishes (frequently) 1: Fluoride toothpaste plus fluoride tablets, rinsing, and varnishes (infrequently) 2: Only fluoride toothpaste 3: No fluoride</td>
</tr>
<tr>
<td>Susceptibility (light blue sector)</td>
<td>Saliva secretion rate</td>
<td>0: 1.1 mL/min or more 1: From 0.9 to less than 1.1 mL/min 2: From 0.5 to less than 0.9 mL/min 3: Less than 0.5 mL/min</td>
</tr>
<tr>
<td>Susceptibility (light blue sector)</td>
<td>Saliva buffer capacity</td>
<td>0: pH &gt; 5.5 1: pH &lt; 5.5–4.5 2: pH &lt; 4.5</td>
</tr>
<tr>
<td>Clinical judgment</td>
<td>Clinical judgment</td>
<td>0: More positive than what the Cariogram shows based on the scores entered 1: Normal setting, risk according to the other values entered 2: Worse than what the Cariogram shows based on the scores entered 3: Very high caries risk, examiner is convinced that caries will develop, irrespective of what the Cariogram shows based on the scores entered</td>
</tr>
</tbody>
</table>

Study III

Subjects

During a period of 12 months, around 200 patients were screened at the Department of Orthodontics in Gothenburg. The number of mutans streptococci was cultured on selective agar medium using paraffin-stimulated whole saliva. A total of 24 healthy orthodontic patients were recruited during the screening. They had to fulfil the
following three inclusion criteria: 1) medium to high scores of mutans streptococci in saliva, 2) two upper premolars to be extracted and 3) willing to participate. The patients were randomised into two groups: A) a test group using 5,000 ppm fluoride toothpaste (6 males and 6 females, mean ± SD age 16.4 ± 1.8 years) and B) a control group using 1,450 ppm fluoride toothpaste (6 males and 6 females, mean ± SD age 16.2 ± 2.1 years) (Figure 3). They were all in good general health and had sound upper first premolars without any kind of initial caries.

In situ caries model

The model used in this study was first described by Øgaard et al. [1984]. The teeth to be extracted for orthodontic reasons were carefully cleaned with a rubber cup on a hand-piece and a non-fluoride-containing pumice prior to banding (in order to remove the outer fluoride-rich surface). Orthodontic stainless steel bands were then applied on the first upper premolars. An orthodontic separator holder was divided into two pieces
and ligated to the buccal surface of the band before banding, leaving 2-3 mm of space away from the exposed buccal surface of the tooth (see Figure 1 in Paper III). The bands were cemented using a non-fluoride-containing material (zinc phosphate cement). The teeth were extracted in two intervals, i.e. 8 and 9 weeks after banding.

**Toothpaste technique**

During the 8/9-week period, the two groups were instructed to use two different procedures: 1) the test group used a high-fluoride dentifrice containing 5,000 ppm fluoride as NaF (Duraphat, Colgate-Palmolive AB, Danderyd, Sweden) with toothpaste slurry rinsing for 30 s and no post-brushing water rinsing, while 2) the control group used a normal-fluoride dentifrice containing 1,450 ppm (1,000 as NaF and 450 as MFP) (Maximum Cavity Protection, Colgate) with 3 times post-brushing water rinsing, each lasting for about 10 s. All patients were instructed to brush their teeth 3 times a day with a reasonable amount of toothpaste (≈ 1 gram), i.e. after breakfast, after lunch and just before bedtime. They were asked not to brush the banded teeth, thereby avoiding the brush bristles coming close to or reaching the exposed buccal surface of banded premolars. Both groups were carefully instructed and trained in how to brush and rinse at the clinic. They were also given a pamphlet showing the exact procedure to be followed. The patients were instructed not to use any other fluoride products apart from the test toothpaste, not to use any proximal cleaning and not to use chewing gum or snuff products during the test period.

**Intra-oral fluoride retention**

Between week 8 and 9, the patients were asked to come back to the clinic. Unstimulated whole saliva was sampled by asking the patient to spit twice into a beaker. The solution under the band was sampled using standardised, triangular-shaped paper points. After collecting the baseline samples, the subjects brushed their teeth with the same toothpaste and used the same post-brushing water rinsing procedure as during the 8/9-week test period. Sampling of the two sites was then repeated after 1, 3, 5, 10, 20 and 30 min. The patients were also observed during the brushing in terms of water rinsing volume, amount of toothpaste and brushing time.
**Fluoride analysis**

The samples were analysed blind in terms of subjects and methods. A volume of 200 μl of liquid, consisting of distilled water and TISAB III (10:1; Thermo Electron, Waltham, Mass., USA), was added to the samples. The fluoride concentration was measured by an ion-specific electrode (model 96-09, Orion Research, Beverly, MA, USA) by carefully lowering the electrode into the fluid. The sample fluoride concentrations (ppm) were plotted vs. time (min) and the area under the curve (AUC$_{0-30}$ min) was calculated for each individual and each brushing method using a computer program (KaleidaGraph 3.01, Synergy Software, Reading, Pa., USA).

**Quantitative Light-induced Fluorescence (QLF)**

After the 8/9-week period, the banded premolars were extracted and sent to the Divisions of Cariology at the Department of Dental Medicine in Huddinge for QLF measurements. The buccal test surfaces were examined and a computer program (QLF 1.97e Inspektor Research Systems BV, Amsterdam, The Netherlands) was used to display, store, browse and analyse the images. Two values were obtained: 1) lesion area (mm$^2$) and 2) $\Delta F$ (average change in fluorescence, in %).

**Study IV**

**Subjects**

The study population consisted of 150 orthodontic patients at baseline, recruited consecutively during a period of 6 months at a well-established orthodontic clinic in Riyadh, KSA. They were randomly divided into two groups (test group and control group) with 75 individuals in each (Figure 4). They were all going to have fixed appliances in both arches for 2 years (mean of 18 months).

A power analysis with an assumption significance level of 5%, standard deviations of 3.0 DFS, least detectable difference of 2.0 $\Delta$DFS and a power for that detection of 90% was performed and it produced a minimum sample size of 45 observations per group.
**Examination**

The examination consisted of recording the plaque index according to Silness and Löe [Silness and Löe, 1964]. Registration of caries was made according to the WHO [WHO, 1997], after prophylaxis, flossing and a radiographic examination according
to Mejäre et al. [1998], which consisted of four bitewings. A total of 24 surfaces were included in the radiographic DFS index, from the distal surface of the first pre-molars to the mesial surface of the second molars. Filled surfaces underlined with caries were scored as recurring caries.

Upon completion of the examination, the patients in both the test and control groups received a Colgate Max Cavity fluoride toothpaste containing 1,450 ppm (Colgate, Riyadh, KSA).

**Oral hygiene instructions including MFTT**

The test groups received verbal and written instructions relating to the MFTT. They were as follows: 1) use 2 cm (1 gram) of dentifrice on a wet toothbrush, 2) spread the toothpaste evenly in the lower and upper arches, 3) brush all surfaces for 2 min, 4) use a small amount of water the equivalent of a handful together with the dentifrice remaining in the mouth and filter the dentifrice slurry between the teeth by active cheek movements for 30 s before expectorating, 5) avoid further rinsing with water, 6) avoid drinking or eating for 2 h, 7) brush at least twice a day, after breakfast and at night before going to bed, and 8) abstain from all other types of dentifrice during the treatment and until its completion (Figure 3).

The control group was given the routine clinic oral hygiene instructions, which consisted of brushing at least twice a day after breakfast and after dinner before going to bed. At each patient visit to the clinic for the treatment follow-up, the instructions were repeated by the assigned nurse/assistant. To ensure that all patients in both groups had a supply of the study toothpaste, they were supplied with the toothpaste on each visit or as requested.
Figure 3. The Modified Fluoride Toothpaste Technique (MFTT) used in Study IV.
**Statistical analysis**

The Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA, version 18.0, Mac OSX) was used for the statistical analysis of the determined measurements in 3 studies.

In Study I, the descriptive statistics, the mean values with standard deviations were calculated, as well as the minimum and maximum. To determine statistically significant differences between the groups, the independent sample t-test was applied to the two main groups, while the analysis of variance (ANOVA) was applied when three groups or more were analysed.

In Study III, the independent sample t-test was used to compare the two groups regarding the retention of F in the sample (based on AUC\(_{0-30}\)) and QLF data. In each patient, the mean of two extracted teeth was used for QLF analysis. The paired t-test was utilised to check the intra-examiner reliability of 20 randomly selected teeth for the QLF analysis.

In Study IV, ΔDFS and prevented fractions (PF) were calculated according to these two formulas (ΔDFS = follow-up DFS – baseline DFS), (PF = \(\frac{[\text{control group} \Delta DFS - \text{test group} \Delta DFS]}{\text{control group} \Delta DFS} \times 100\)). For the descriptive statistics, the mean values with standard deviations were calculated. To determine statistically significant differences between the groups, the independent sample t-test was applied between the groups. The paired t-test was utilised to check the intra-examiner reliability for the radiographic analysis. The 25 randomly selected radiographs were checked within a one-week interval.

In all the analyses, \(p < 0.05\) was considered statistically significant.
Results

Study I

Caries-related factors

The various caries-related factors that were compared between the two groups are shown in Table 3. The DFS in the high-caries group was more than 4 times higher than in the low-caries group. The following factors differed significantly between the two groups: decayed surfaces, filled surfaces, lactobacilli and mutans streptococci. The plaque index was almost significant (p = 0.051). Regarding the Cariogram values, the “chance of avoiding new cavities” was a mean of 75% in the low-caries group and 42% in the high-caries group (p < 0.001).

Table 3. Mean of various factors in the low-caries group (n=50) and the high-caries group (n=50). The significant differences between the two groups are also shown.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low caries group (n=50)</th>
<th>High caries group (n=50)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>17.2</td>
<td>17.8</td>
<td>ns⁴</td>
</tr>
<tr>
<td>Decayed surfaces (DS)</td>
<td>1.48</td>
<td>4.22</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Filled surfaces (FS)</td>
<td>0.96</td>
<td>5.72</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>DFS</td>
<td>2.44</td>
<td>9.94</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Plaque Index</td>
<td>1.46</td>
<td>1.72</td>
<td>p=0.051</td>
</tr>
<tr>
<td>Lactobacilli¹</td>
<td>3.56</td>
<td>4.64</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Mutans streptococci¹</td>
<td>4.52</td>
<td>5.74</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Saliva secretion²</td>
<td>0.91</td>
<td>0.88</td>
<td>ns³</td>
</tr>
<tr>
<td>Buffer capacity (pH)</td>
<td>5.7</td>
<td>5.6</td>
<td>ns³</td>
</tr>
<tr>
<td>Cariogram (%)³</td>
<td>75</td>
<td>42</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>

¹log CFU/ml, ²Secretion rate (mL/min), ³Actual chance to avoid new cavities, ⁴Not significant

Cariogram profiles

The Cariogram data (i.e. actual chance of avoiding new cavities) were divided into three classes: 1) low (0-40%), 2) medium (41-60%) and 3) high (61-100%). The DFS values in these categories are illustrated in Figure 4. Patients with a low or medium
chance of avoiding new cavities (≤ 60%) had 2-3 times more DFS compared with the group with high chance values (> 60%) (p < 0.001).

Figure 4. Mean values at the top of each column of DFS in all 100 patients of “actual chance of avoiding new cavities” (%) according to the Cariogram, divided into three different groups, i.e. 0-40%, 41-60% and 61-100%.

Study II

The three patients’ Cariogram pie charts are illustrated in Figure 5. For patient No.1, the “actual chance of avoiding new cavities” was 6%, which means that she is a high caries-risk individual. This is mainly due to a medium mutans streptococci score (2), a high lactobacilli score (3) and a very low secretion rate (Score 3). For patient No. 2, the “actual chance of avoiding new cavities” was 58%, which means that she is a medium caries-risk individual. This is mainly due to increased plaque (Score 3) and low scores for mutans streptococci (1) and lactobacilli (1) respectively. For patient No. 3, the “actual chance of avoiding new cavities” was 87%, which means a low caries risk. This is due to good fluoride use (Score 2) and very low scores (0) for all the factors except plaque index and DFS (Score 1).
Study III

Anti-caries effect
The QLF variables are listed in Table 4. In comparison to the test group, the control group had a larger lesion area (no significance difference) and an increased average change in fluorescence ($p < 0.05$).

Table 4. Lesion area and average change in fluorescence based on QLF for the two groups. Significant differences are also shown.

<table>
<thead>
<tr>
<th></th>
<th>Test group (n = 10)</th>
<th>Control group (n = 10)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesion area (mm$^2$)</td>
<td>$1.2 \pm 1.7$</td>
<td>$3.2 \pm 2.7$</td>
<td>NS</td>
</tr>
<tr>
<td>$\triangle F$ (%)</td>
<td>$-10 \pm 3.9$</td>
<td>$-15.8 \pm 6.3$</td>
<td>$P &lt; 0.05$</td>
</tr>
</tbody>
</table>

Oral fluoride retention
The mean fluoride concentration under the band at the various time points and the AUC values are shown in Figure 6. The test group showed the highest fluoride concentration under the band compared with the control group ($p < 0.001$). The difference between the groups was most pronounced within the first 20 min.
Figure 6. Mean values of fluoride concentration under the band (expressed as ppm) at various time points up to 30 min in the two groups using 5,000 and 1,450 ppm F. The AUC values (0–30 min) expressed as the mean ± SD have also been inserted. There were statistically significant differences between the two groups (p < 0.001).

Study IV

Plaque index, clinical and radiographic DFS

The test and control groups' baseline and follow-up plaque index, clinical DFS, radiographic DFS and clinical + radiographic DFS values are shown in Table 5. At baseline, there were no significant differences between the groups. At follow-up, the total number of teeth available was almost the same in both groups (26.9±1.7 test vs. 26.8±1.7 control). At the end of the study, test group patients had a significantly better plaque index in comparison to the control group (p < 0.05). Both groups showed an increase in their DFS index, both clinically and radiographically, with a higher increment in the control group.
Table 5. Plaque index, clinical DFS, radiographic DFS, and total DFS for test and control groups. Mean±SD are given both at baseline and at follow-up. There were no statistically significant differences at baseline and only the plaque index was significant at follow-up between the groups.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test (n=51)</td>
<td>Control (n=49)</td>
</tr>
<tr>
<td>Plaque index</td>
<td>1.4±0.5</td>
<td>1.5±0.6</td>
</tr>
<tr>
<td>Clinical DFS</td>
<td>5.6±5.7</td>
<td>5.7±5.4</td>
</tr>
<tr>
<td>Radiographic DFS</td>
<td>2.7±3.0</td>
<td>2.3±3.2</td>
</tr>
<tr>
<td>Total DFS</td>
<td>8.3±7.5</td>
<td>8.1±8.4</td>
</tr>
</tbody>
</table>

Caries incidence

The clinical, radiographic and clinical + radiographic ΔDFS (incidences) are shown in Figure 7. Compared with the test group, the control group patients had > 7 times clinical DFS (p < 0.001), > 4 times radiographic DFS (p < 0.001) and > 5 times clinical + radiographic DFS (p < 0.001), with a preventive fraction of 87%, 78% and 83% respectively.
Figure 7. Caries incidence (ΔDFS) in the test and control groups after 2 years. The mean values are given at the top of each column. There were statistically significant differences (p < 0.001) between the groups in the clinical, radiographic and total DFS.
Discussion

This thesis focuses on caries risk and prevention in orthodontic patients. According to Studies I & II, caries risk profiles give a clear idea of a specific patient risk of developing caries and the Cariogram is a useful program for visualising a risk of this kind. Studies III & IV identified different ways of preventing caries in orthodontic patients using fluoride toothpastes. According to these two studies, high-concentration fluoride toothpaste combined with no post-brushing water rinsing and the MFTT could be a suitable regimen for patients with a high caries risk.

Cariogram and caries risk profiles (Studies I & II)

Most orthodontists agree that patients seeking orthodontic treatment run a high risk of developing caries [Derks et al., 2007; Dearing et al., 2007]. The question is how this risk should be estimated. In Studies I & II, an advanced caries risk assessment (Cariogram), which has previously been used in both children and adults [Alian et al., 2006; Hänsel Petersson et al., 2002] but never on orthodontic patients, was used.

The Cariogram assesses and predicts the caries risk and can be used routinely in the clinic. It illustrates caries-related factors and suggests the appropriate action. Only seven values are required for its application. The chair-side microbiological tests are easy to perform and can be evaluated by dental assistants. The Cariogram model is freeware, user friendly and easy to understand. It can be used to motivate patients and develop preventive strategies. When evaluating the nine caries-risk indicators, three were found to be of great importance in Study I, i.e, DFS, mutans streptococci and lactobacilli. The number of DFS the patient has before orthodontic treatment is a strong predictive factor of his/her caries risk. Many studies reveal that patient exposure to caries and fillings puts these patients in a higher risk group [Travess et al., 2004; Boersma et al., 2005].

Different authors have discussed multiple factors that lead to a higher caries risk in orthodontic patients [O’Reilly et al., 1987; Pascotto et al., 2004; Øgaard et al., 1988a]. Other authors have tried to concentrate on a single factor to reduce the risk without any good results [Smiech-Slomkowska et al., 2007]. Brathall [1996] pointed out that:

‘‘the complexity of the issue is highlighted, and it is concluded that there is not one single factor explaining the changes observed. Thus, in one and the same population, different explanations may be relevant for different individuals, for different age
Taking bitewing radiographs in teenagers before orthodontic treatment is important for caries-risk assessment. These radiographs allow clinicians to diagnose initial approximal caries lesions, which may not be detected clinically. In Studies I & II, white spot lesions were registered, but they were not used as DFT/DFS values, according to the manual [Cariogram manual]. However, according to multiple authors, white spot lesions or areas of decalcification are caries lesions of varying depth [Årtun et al., 1986; Gorelick et al., 1982; Van der Veen et al., 2007]. Not including them and bitewing radiographs therefore appears to be a weakness of the Cariogram. If it is changed in the future, they should be considered, especially for teenagers undergoing orthodontic treatment.

There is still not much information available about caries-related preventive measures that orthodontists actually use [Derks et al., 2007]. In the author’s opinion, the extra 10 min it takes to collect Cariogram-relevant data are therefore of great importance in order to make a better diagnosis and give the patient customised advice to reduce the risk of caries.

High-fluoride toothpaste (Study III)

Both groups in Study III displayed a loss of fluorescence and an increased lesion area, but the changes over time were relatively small. The reasons could be the short study period, the fact that both groups used fluoride toothpastes and that they brushed 3 times a day. The space between the band and the tooth (2-3 mm) was adequate, leaving a good area for plaque accumulation and initial caries development. The study period of 8/9 weeks might be considered too short, but extending it even more was difficult, as the patients were eager to start the orthodontic treatment as soon as possible. On the other hand, the 8/9-week period has its advantages, as it is easier for the patients to follow the oral hygiene instructions and to maintain frequent contact with the principal investigator throughout the study. Moreover, earlier studies have shown that QLF can disclose the remineralisation of white spot lesions at intervals of only 6 weeks [Tranaeus et al., 2001]. During the 12-month screening period, only 24 patients were recruited. This was mainly due to two reasons: 1) not all orthodontic
patients end up extracting two upper premolars and 2) many of the patients had too low mutans streptococci scores in saliva.

Based on the results of Study III, it is not possible to determine whether the fluoride toothpaste concentration or the post-brushing rinsing behaviour is most important. It is probably a combination of both factors. We decided to focus on the two groups, i.e. 5,000 ppm fluoride with no post-brushing water rinsing and 1,450 ppm fluoride with 3 times water rinsing, based on the recent study data collected at our department by Nordström and Birkhed [2009]. Many countries do not have 5,000 ppm fluoride toothpaste in the market. We believe, however, that using a 1,450 ppm fluoride toothpaste with no post-brushing water rinsing would be a good compromise for caries prevention, which is in agreement with Nordström and Birkhed [2009].

The importance attached to high fluoride exposure in the oral cavity by researchers is well known. In addition, some researchers have developed new systems for achieving a continuous and constant rate of fluoride release in the oral cavity in orthodontic patients [Marini et al., 1999]. Patients with orthodontic appliances should be targeted to use 5,000 ppm fluoride toothpaste.

Modified fluoride toothpaste technique (MFTT) (Study IV)

The MFTT in Study IV aimed to both increase the fluoride concentration and prolong the time during which the fluoride level is elevated in the oral cavity. Spreading dentifrice on the teeth prior to brushing and rinsing with toothpaste slurry immediately after brushing can be expected to produce a more even distribution of the dentifrice and an enhanced fluoride concentration compared with a more conventional technique. Brushing twice daily has been shown to be a very important factor for caries prevention [Attin et al., 2005], while not eating/drinking for two hours secures a longer time period of elevated fluoride concentration. It must be remembered that the MFTT contains a package of advice. It is possible to speculate about the factor that is most important, but it is not possible to identify a specific one that made our test group patients develop significantly less caries.

Duckworth et al. [1994] found that the fluoride concentration in saliva after brushing vanished rapidly as a result of thorough rinsing. Chesters et al. [1992] showed that the water-rinsing pattern among children after brushing influences the
cariostatic effect of fluoride toothpaste. They concluded that children who did not use water beakers for rinsing had a significantly lower (16%) caries incidence, during a 3-year period, than those that used water beakers. Sjögren et al. [1995] studied different types of post-brushing behaviour; they also evaluated the caries-reducing effect of a technique very similar to the one used in Study IV. They concluded that mouth rinsing with the toothpaste foam-water slurry after brushing elevates the concentration of fluoride in saliva for a prolonged period of time as compared to toothbrushing followed by a single or double water rinse; children who used the MFTT developed fewer DFS. These observations are in agreement with Study IV, i.e. the test group patients had a significantly lower mean caries incidence in comparison to the control group. The MFTT technique is easy to teach. Patients can be instructed on how to perform the technique, they can perform it personally at the orthodontic clinic and a pamphlet with clear illustrations and instructions can be handed to them.

The large difference found in the ΔDFS between the test and control group patients in KSA should not be expected in other countries with a low DFS prevalence. For example, Sweden has long traditions of using fluoride toothpaste and other fluoride products in orthodontic patients and the expected caries reduction after using the MFTT is therefore lower.

**Side-effects of high-fluoride toothpaste and no post-brushing water rinsing**

Even if the use of 5,000 ppm fluoride with toothpaste slurry rinsing and no post-brushing water rinsing is interesting from a cariological point of view, patients must be aware of the side-effects. Slurry rinsing with toothpaste can cause some oral discomfort and irritation of the oral mucosa. Our experience is, however, that very few patients experienced any side-effects. Another problem is that a 5,000 ppm fluoride toothpaste delivers more fluoride to the oral cavity than standard toothpastes containing (1,000-1,500 ppm fluoride) and that some part will be retained and swallowed when no post-brushing water rinsing is used. However, only 5-10% is normally swallowed using the slurry rinsing technique [Sjögren et al., 1994]. If 1 g of a 5,000 ppm fluoride toothpaste is used and 5% is swallowed each time, the result is an intake of 0.05 x 5 = 0.25 mg fluoride, which is negligible from a toxicological point of view for an adult. Children under 16 years of age should not use 5,000 ppm
fluoride toothpaste, according to instructions given by the manufacturer. We believe, however, that this age could be lowered to 12 years (when many permanent teeth erupt), if the child has an increased caries risk and is instructed carefully to spit out the toothpaste.

**How to treat orthodontic patients based on an understanding of caries risk and prevention – personal reflections**

For patients with active dental disease and those at high risk of caries, orthodontic treatment should be delayed. For patients with a history of caries, orthodontic treatment should be initiated only when they have been assessed over a period of time as having good periodontal health, a low risk of caries and excellent oral hygiene habits. A period of 3 months of sustained good oral hygiene is probably sufficient to evaluate a patient’s ability to conform to a stringent oral hygiene regimen.

Before treatment, a diet counselling session, including a 5-day detailed diet record, is recommended, particularly for patients with a history of caries. The cariogenic potential of foods should be explained to all patients and patients’ understanding of the concept should be verified by asking them to explain it in their own words. Patients should be advised to avoid sugar-containing foods and to drink water instead of high-sugar drinks.

Patients should be taught effective flossing and toothbrushing techniques with their braces in place and they should then be asked to demonstrate their ability to perform these techniques. They should understand the importance of brushing after meals and of timing themselves while they brush, to ensure an appropriate duration of brushing. An electric or ultrasonic toothbrush can be recommended to increase motivation and to improve oral hygiene, as these tools have been associated with lower plaque scores around brackets [Costa et al., 2007]. The use of high-fluoride toothpaste and MFTT is very important, especially in patients with a high caries risk.

Compared with other dental specialities, orthodontists have a great opportunity to place the emphasis on fluoride toothpaste regimens in their clinics, as their patients usually visit the clinic every 8-12 weeks. Once orthodontic treatment has been initiated, the general dentist and the orthodontist should work as a team, continuously motivating the patient, encouraging effective oral hygiene practices and proper nutrition and diet, and assessing gingival health and caries risk at each appointment. If
evidence of poor oral hygiene and decalcification appears during treatment, and these problems continue despite efforts to improve, the orthodontic wires may be removed. This may increase the total treatment time, but it makes oral hygiene and the use of fluoride procedures simpler and offers the patient a chance to improve. If poor oral hygiene and use of fluoride persists, the orthodontic attachments should be removed and treatment discontinued, to prevent further decalcification until an effective fluoride toothpaste technique, oral hygiene practices, good gingival health, a positive attitude and improved dental intelligence are demonstrated over time.
Conclusions

The main conclusions from this thesis are as follows.

- Patients with high DFS before orthodontic treatment ran a higher risk of developing caries. They had significantly higher numbers of mutans streptococci and lactobacilli and had less chance of avoiding new cavities according to the Cariogram.

- The Cariogram could be a useful pedagogic model that illustrates a specific patient caries-risk profile, which may make it easier for the orthodontist to carry out the proper customised preventive programme determined by the patient’s caries-risk group.

- Using a combination of 5,000 ppm fluoride toothpaste and no post-brushing water rinsing will have better anti-caries potential and produce higher oral fluoride retention, compared with a 1,450 ppm fluoride toothpaste with 3 times post-brushing water rinsing.

- The use of the MFTT significantly reduces the incidence of new caries lesions in orthodontic patients.

Based on this thesis, it is to be hoped that more orthodontists will use the Cariogram in their clinics and recommend high-fluoride toothpaste (if available) and the modified fluoride toothpaste technique to their high caries risk patients.
Acknowledgements

All praise to God almighty for giving me the health, power and strength to complete this project.

I wish to express my sincere gratitude to all who helped me with this thesis. In particular, I wish to thank:

My main supervisor and friend, Professor Dowen Birkhed. The chairman of the Cariology department has had a key role throughout my Ph.D period. He was providing excellent scientific guidance, and always taking time to listen to my “ideas”. Thank you not only for your commitment to research, but also for your concern for the health and well being of your student, and your unfailing support. You’re an amazing tutor and a great friend.

I owe special thanks to Associate Professor Heidrun Kjellberg, my supervisor in the department of Orthodontics, for excellent guidance and never-ending enthusiasm throughout my postgraduate studies. Your intelligence and your extensive knowledge have made a deep impression.

Dr. Saad Al Kharsa, my mentor and big brother, for very generously sharing a lot of his valuable time. It has been a very pleasant period filled with humour and discussions. In a stimulating and very inspiring way he has shared his vast knowledge and research in general. He definitely made this thesis possible, without him there would have been no thesis. I owe him a lot.

Lena Karlsson for her enthusiasm about QLF and her great support in paper III.

Sincere and special thanks to Ann-Britt Lundberg and Ann-Charlott Börjesson, for all the help they provided in the lab.

Jeanette Kliger is acknowledged for linguistic advice and editing.
Many thanks to current and former postgraduate students and to all the staff in the Cariology and Orthodontic departments, at the college of dentistry, university of Gothenburg, Sweden, for support and friendship.

All my previous teachers in Riyadh School for developing my knowledge, and all my previous teachers in King Saud University for making me devoted to Dentistry.

Sahlgrenska International Care AB for their great help during my time in Sweden.

The Ministry of Higher Education in Saudi Arabia, for fully funding my studies in Sweden.

Colgate® for delivering free toothpastes for all four studies.

Special thanks to my dear wife for keeping me happy throughout my studies in Sweden. Her love, support, kindness and understanding made developing this thesis much more easier.

My lovely brothers and dear sister for making sure I am healthy and focused on my education.

Finally, and most importantly, I would like to thank my father, my mother and my grandmother who have risen, supported, taught, and loved me. Thank you for being the best parents in the world.
References


Cariogram manual


Marinho VC, Higgins JP, Sheiham A, Logan S: Combinations of topical fluoride (toothpastes, mouthrinses, gels, varnishes) versus single topical fluoride for


