

Caries Assessment in Orthodontic Patients

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For my mother:

Your pride in me was infinite, your trust unequivocal and your love eternal. I wish you could have been here to share this moment with me.

You are always in my heart, "I love you".

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ABSTRACT

Caries Assessment in Orthodontic Patients

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Background and aims: White spot lesions (WSLs) are the most common adverse effect related to orthodontic treatment that may develop into manifest caries lesions if preventive measures are not strictly followed. Caries prevalence has historically been high in the Kingdom of Saudi Arabia (KSA) and the Middle East. Dental caries has previously been evaluated by different techniques. The aims of this thesis were to study: 1) Caries-related factors in orthodontic patients at de-bonding, and compare caries risk profiles between the governmental (G) and private (P) orthodontic patients, 2) The prevalence of buccal caries lesions including WSLs at de-bonding in the G and P orthodontic patients, using the international caries detection and assessment system (ICDAS-II) and the DIAGNOdent Pen, 3) The severity of buccal caries lesions according to ICDAS-II via digital photographs and compare this method with clinical examinations, and 4) Caries-related factors and evaluate caries risks for the G and P orthodontic patients at de-bonding and after four years (longitudinal study).

Methodology: A cross-sectional evaluation was carried out on 89 patients at de-bonding; 45 patients in the G-group and 44 patients in the P-group (*Studies I and II*). Thirteen postgraduate orthodontic students examined 245 close-up digital photographs (*Study III*). A longitudinal evaluation was performed on 40 out of the 89 baseline patients; (G=20) (P=20). Investigations included a questionnaire, oral clinical examinations, plaque scoring, saliva sampling, bitewing radiographs, and using the computerized caries risk program “Cariogram” to illustrate the caries risk profiles (*Studies I and IV*). Assessment of the severity of buccal caries lesions was evaluated by using ICDAS-II, DIAGNOdent Pen (*Study II*), and digital photographs (*Study III*).

Results and conclusions: *Study I*, the findings revealed that “the chance of avoiding new cavities”, according to the Cariogram model, was higher in the P-group compared to the G-group (61% and 28%, respectively) ($P < .001$). Decayed, missing, and filled surfaces (DMFS), plaque index, mutans streptococci and lactobacilli counts were significantly higher in the G-group compared to the P-group ($P < .05$). *Study II*, the G-group showed statistically significantly higher prevalence of buccal caries lesions including WSLs compared to the P-group evaluated by ICDAS-II, DIAGNOdent Pen ($P < .0001$). ICDAS-II showed that 43% of the patients in the P-group and 9% in the G-group were free from any WSLs. In the G-group, 22% of the patients versus none in the P-group had 16 lesions or more. The Spearman’s correlation coefficient between the two methods was 0.71, which revealed that the clinical index (ICDAS-II) showed a good correlation with the DIAGNOdent Pen. *Study III*, intra-examiner reliability and the reliability between each examiner and the clinical examination showed moderate to excellent agreement, with kappa values of 0.52-0.83. The Spearman’s correlation coefficient, between scoring buccal caries lesions via clinical examinations and scoring via photographs, was 0.76, which revealed that scoring buccal caries lesions on digital photographs according to ICDAS-II criteria is a reliable and valid method for assessing the severity of buccal caries lesions. *Study IV*, the chances to avoid new cavities after four years from de-bonding improved from 31% to 52%, and from 58% to 77% in the G-group and the P-group, respectively. This improvement was also observed for all patients (G+P) from 44% to 64% ($P < .001$). Caries risks according to the Cariogram at de-bonding and after four years is greater in the patients treated at the governmental clinics compared to the private clinics.

Keywords: buccal caries, Cariogram, digital photographs, fixed appliance, ICDAS, laser fluorescence, orthodontics, risk assessment, Saudi Arabia, white spot lesions.

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PREFACE

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

- I. Almosa NA, Al-Mulla AH, Birkhed D. Caries risk profile using the Cariogram in governmental and private orthodontic patients at de-bonding. *Angle Orthodontist Journal*. 82: 267–274, 2012.
- II. Almosa NA, Lundgren T, Aldrees AM, Birkhed D, Kjellberg H. Diagnosing the severity of buccal caries lesions in governmental and private orthodontic patients at de-bonding, using the ICDAS-II and the DIAGNOdent Pen. *Angle Orthodontist Journal*, online publication, 21 Oct 2013.
- III. Almosa NA, Lundgren T, Bresin A, Birkhed D, Kjellberg H. Diagnosing the severity of buccal caries lesions in orthodontic patients at de-bonding using digital photographs. *Acta Odontologica Scandinavica*, online publication, 9 Dec 2013.
- IV. Almosa NA, Lundgren T, Al-Mulla AH, Birkhed D, Kjellberg H. Caries risk profile in orthodontic patients: A 4-year longitudinal study using the Cariogram model in governmental vs. private clinics. Submitted.

INTRODUCTION

In humans, the oral cavity is highly complex and composed of hundreds of bacterial species (Marcotte and Lavoie 1998), with the distribution of bacterial species varying qualitatively and quantitatively according to habitat (Smith et al. 1993). In teeth, dental plaque develops favorably on surfaces protected from mechanical friction, such as the sub-gingival area, approximal surfaces between two teeth, and the pits and fissures of the occlusal surfaces (Marsh 1999). Fixed orthodontic appliances are an example of creating retentive areas, therefore increasing the plaque accumulation and the number of cariogenic microorganisms (Chatterjee and Kleinberg 1979; Gwinnett and Ceen 1979; Scheie et al. 1984). Thus, enamel decalcification or the development of White Spot Lesions (WSLs) on the enamel surface is by far the most important iatrogenic effect of fixed orthodontic appliance therapy (Øgaard et al. 2004). Such initial enamel decalcifications can be seen as early as four weeks after the beginning of fixed orthodontic appliances (Øgaard et al. 1988a), and may remain a long time after the orthodontic treatment is completed (O'Reilly and Featherstone 1987).

Despite improvements in materials and preventive efforts, the risk of enamel demineralization, caused by orthodontic treatment, continues to be a considerable side effect (Lovrov et al. 2007). Studies have shown that more than 50% of orthodontic patients may experience an increase in the number of WSLs with fixed orthodontic appliances (Gorelick et al. 1982; Mizrahi 1983; Artun and Brobakken 1986), and are more susceptible to the development of WSLs than untreated patients (Øgaard 1989). Significant decalcification may develop and become irreversible already within six months after orthodontic bonding (Lucchese and Gherlone 2013) (Figure 1). Considering how quickly WSLs can develop and become irreversible, early diagnosis is crucial in evaluating the oral hygiene status of patients during the whole orthodontic treatment period, particularly the first months of treatment, and if necessary, implement preventive actions immediately in order to prevent demineralization.

Several studies have been made to find the proper solution to prevent the development of dental caries during orthodontic treatment with fixed appliances. Some studies have investigated the microbial profile of different bracket materials, and the bonding materials themselves with respect to their ability to reduce the risk of

demineralization (Anhoury et al. 2002; Lin et al. 2008; Schmidlin et al. 2008; Paschos et al. 2009). Some studies were focused on the prevention of caries by using topical fluoride or antibacterial agents in the form of rinses, varnishes or gels (Jenatschke et al. 2001; Øgaard et al. 2001; Benson et al. 2005a; Stecksén-Blicks et al. 2007).

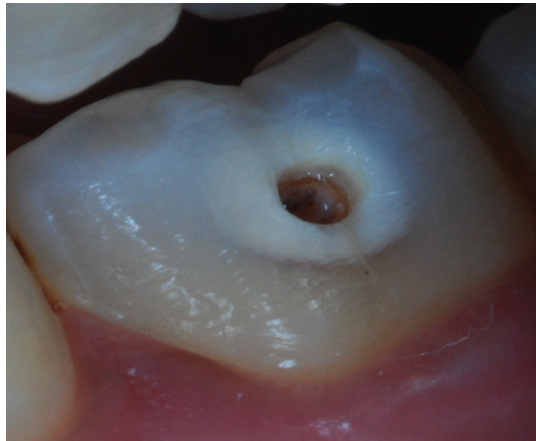


Figure 1. Caries development under bonded tube at de-bonding.

White spot lesions and dental caries

Dental caries is a bacterial disease of the dental hard tissues, characterized by a localized, progressive molecular disintegration of the tooth structure. Dental caries is one of the most common preventable diseases and is reversible in its early stages. The first sign of dental caries when located on smooth surfaces is the WSL, which is defined as “subsurface enamel porosity from carious demineralization that presents itself as a milky white opacity when located on smooth surfaces” (Figure 2). As enamel translucency is directly related to the degree of mineralization, initial enamel demineralization usually manifests itself clinically as a WSL (Summitt et al. 2006a).



Figure 2. White spot lesions after de-bonding.

The demineralization of tooth structures (enamel, dentine, and cementum) is caused through by-products from the bacterial fermentation of dietary carbohydrates (Selwitz et al. 2007). Caries may also appear on root surfaces that are exposed to the oral environment as a result of gingival recession. The frequent ingestion of carbohydrates may lead to the selection of bacteria that are acidogenic (capable of producing acid from carbohydrates) and aciduric (capable of tolerating acid) and concurrent to a low-pH environment. These conditions favor the solubilization of tooth minerals. The pH at which this demineralization begins is known as the critical pH and ranges between pH 5.0 and 5.5 (Loesche 1986).

Malocclusion and caries

Several studies have investigated the association between orthodontic treatment needs and the development of dental caries with contradicting results. Some studies concluded a positive relationship between the severity of malocclusions according to different treatment indices, dental aesthetic index and treatment priority index, and the occurrence of dental caries (Gabris et al. 2006; Singh et al. 2011; Buczkowska-Radlinska et al. 2012; Nalcaci et al. 2012; Baskaradoss et al. 2013). On the other hand, several studies, including a systematic review study, reported no relationship between malocclusions and dental caries (Addy et al. 1988; Helm and Petersen 1989; Stahl and Grabowski 2004; Hafez et al. 2012).

Caries prevalence in the Middle East and the Kingdom of Saudi Arabia

Although caries prevalence has declined among children and adolescents in many countries (World Health Organization 2003), it still remains a problematic issue in the Middle East and the Kingdom of Saudi Arabia (KSA). The caries experience among preschool children was reported to be 72% in the United Arab Emirates and Jordan (Al-Mughery et al. 1991; Janson and Fakhouri 1993). Another study showed that the mean number of decayed, missing, and filled surfaces (DMFS) of a random sample of 1,096 adult Jordanian patients was 34.9. All subjects had coronal caries experience and 93% had untreated lesions (Hamasha and Safadi 2008).

The caries experience among primary and intermediate school-children in the central regions of KSA was more than 90% (Al Dosari et al. 2004), and 63% in the eastern regions of KSA (Wyne et al. 2002). In the western regions of KSA, it was reported that 96% of the children were diagnosed with caries, and only 4% were clinically caries free (Al-Malik and Rehbini 2006). In 2008, it was reported that the overall caries prevalence among preschool children in KSA was approximately 75%. The caries prevalence and severity were significantly higher among children from government preschools compared to those from private preschools (Wyne 2008). Recently, a meta-analysis was performed on a Saudi population to evaluate dental caries. They found that the mean value of the DMFT was 3.3 in the permanent dentition (Khan et al. 2013).

Caries-related factors

The factors involved in the caries process were presented in the 1960s in a model of overlapping circles including the tooth, the diet, and the microflora (Keyes and Jordan 1963). Since then, the model has been modified and supplemented with factors of time, fluoride, saliva, and social and demographic factors (Figure 3).

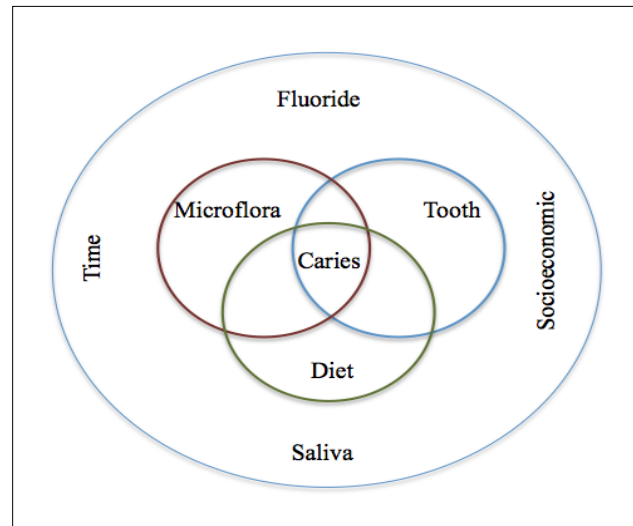


Figure 3. Factors influencing the caries process as first described by Keyes and Jordan.

Teeth

Teeth consist of a calcium phosphate mineral that demineralizes when the pH lowers. As the environmental pH recovers, dissolved calcium and phosphate can re-deposit on mineral crystals in a process called “remineralization”. Remineralization is a slower process than demineralization, and in the absence of this process, the caries lesion will develop (Øgaard et al. 1988c).

Dental plaque and Cariogenic microorganisms

Dental plaque is the term used to describe the biofilms found on the tooth surface. This biofilm consists of microbial communities that are formed in a complex matrix composed of microbial extracellular products and salivary compounds. The microbial composition of dental plaque varies according to the site and the sampling time. Large numbers of bacteria are known to be involved in the composition of dental plaque (Marsh 1999). The change in the ecology of dental plaque is a hypothesis that explains the role of dental plaque in causing dental caries (Marsh 1994). It has been shown that there is a strong positive association between increased levels of mutans streptococci and the initiation of demineralization (Loesche 1986). The prevalence of mutans streptococci and lactobacilli is highly correlated with the incidence of dental caries (Keene and Shklar 1974; Carlsson et al. 1975). Dental plaque could be more cariogenic locally, where mutans streptococci and lactobacilli are concentrated, but in

daily practice, it is still difficult to identify cariogenic plaque. It is much easier to count mutans streptococci and lactobacilli in saliva compared to dental plaque. High numbers of mutans streptococci and lactobacilli are likely a result of a high sugar intake, which results in low pH levels in dental plaque (De Stoppelaar et al. 1970; McDermid et al. 1986). It has been shown that the reduction of sugar intake will reduce the number of mutans streptococci and lactobacilli (Edwardsson and Krasse 1967; De Stoppelaar et al. 1970). One study showed that individuals who followed certain diet programs had a reduction of mutans streptococci and lactobacilli counts by half (Andreen and Köhler 1992).

Dietary intake

Dietary carbohydrates are necessary for bacteria to produce the acids that initiate the demineralization process (Paes Leme et al. 2006). In general, the rule of diet to produce caries lesions is based on three principles: the drop in environmental pH, the frequency of intake, and the cariogenicity of foods (Summitt et al. 2006b). However, an epidemiological study showed that there is a lack of relationship between the amount of sugar consumed and caries occurrence (Woodward and Walker 1994). Moreover, a systematic review investigation has not identified any studies showing that the reduction of sugar intake on its own affects the caries prevalence (Lingström et al. 2003).

Time

Dental caries was commonly considered to be a chronic disease, but time was introduced into the process to indicate that the substrate (dietary sugars) must be present for a sufficient length of time to cause demineralization (Summitt et al. 2006b). Today, it is known that demineralization can be initiated within four weeks after orthodontic treatment (Øgaard et al. 1988a), and its effects can be arrested or repaired by enhancing preventive measures to encourage the remineralization process (Øgaard et al. 1988b).

Use of fluoride

The mechanism by which fluoride inhibits demineralization is by the re-deposit of dissolved calcium and phosphate, thereby preventing these constituents from being latched out of the enamel into the plaque and saliva (Ten Cate and Duijsters 1983).

Fluoride toothpaste may be the main reason for the observed caries decline in developed countries, although other reasons should also be taken into account (Hänsel Petersson and Bratthall 1996). Daily fluoride mouth rinsing in orthodontic patients decreased the WSLs development significantly (Øgaard et al. 1988b). However, high caries prevalence was still observed in a number of populations living in areas with water fluoridation (Al Dosari et al. 2004; Whelton 2004), indicating that fluoride used alone may not be sufficient to overcome other caries-related factors.

Saliva

The important role of saliva is clearly demonstrated by the occurrence of rampant caries that may develop in subjects with a compromised salivary flow rate. Saliva helps to neutralize and clear the acids and carbohydrates from dental plaque. However, the clearance is not uniform throughout the mouth and may be slower at the labial surfaces of maxillary incisors and buccal surfaces of mandibular molars. Saliva has several functions including a specific flushing effect, the maintenance of calcium super-saturation in plaque, the neutralisation of acids, raising the plaque pH and reversing the diffusion rate of calcium and phosphate toward the tooth surface (Lenander-Lumikari and Loimaranta 2000).

Several studies have investigated the effect of fixed orthodontic appliances on the salivary flow rate. Some studies concluded that during the early stages of fixed orthodontic treatment, the whole saliva flow rate increased significantly (Chang et al. 1999; Li et al. 2009; Mummolo et al. 2013), while another study proved that no significant differences were found in the salivary flow rate before, during, and after orthodontic treatment (Sanpei et al. 2010).

Social and Demographic factors

Dental caries is more prevalent in the lower socioeconomic categories and among some ethnic groups (Truin et al. 1998). Some studies have shown that for the prediction of caries development, social and demographic factors could be successful in very young children, but for older individuals, clinical parameters are more predictive (Demers et al. 1992; Grindefjord et al. 1995).

Detection and Diagnosis

Caries risk assessment

Caries risk assessment (CRA) is an essential component in the decision-making process for the prevention and management of dental caries. It is important to include CRA in treatment plans in order to assist the clinician concerning treatment and recall appointments. An ideal CRA system should have high validity and reliability, easy to use in practice and be low in cost (Hänsel Petersson et al. 2010). In case of multifactorial diseases, such as dental caries, the assessment of risk of occurrence is quite difficult. Risk is defined as the possibility of occurrence of a harmful event. Risk assessment is the means of organizing and analyzing all the available scientific information having a bearing on the question under discussion (Rodricks 1992). A proper risk assessment model is the model that takes into consideration multiple variables in order to recognize one or more risk factors for the disease, so that proper intervention can be planned (Beck 1998).

In 2008, the Swedish Council on Technology Assessment in Health Care reported that current CRA models had low accuracy but good reliability in identifying those with a low risk of developing caries (The Swedish Council on Technology Assessment in Health Care 2008). Professional organizations and academic institutions in the past decade have proposed several risk assessment systems/guidelines. Examples of these systems/guidelines reported in literature are: (i) The Cariogram (Bratthall 1996), (ii) The Caries Management by Risk Assessment Philosophy (CAMBRA) advocated by the California Dental Association (Featherstone et al. 2007), (iii) The CRA tool proposed by the American Academy of Pediatric Dentistry (American Academy of Pediatric Dentistry 2008), and (iv) The American Dental Association CRA forms (American Dental Association caries risk assessment forms, accessed January 2013)

Cariogram

The Cariogram (Bratthall 1996) is one example of pedagogic caries risk assessment models that has been used to identify high caries risk individuals. The application of risk assessment models in clinical settings may be useful and has been recommended by major organizations (Featherstone et al. 2003). The Cariogram is a computer-based

program to illustrate the interaction between caries-related factors. This program has been developed for a better understanding of the multifactorial aspects of dental caries and to act as a guide in attempts to estimate caries risks. The main purpose of the Cariogram is to demonstrate the caries risk graphically, expressed as the "chance to avoid new caries" in the near future. In addition, this program is designed to encourage the application of preventive measures to avoid development of new cavities (Cariogram computer program manual, accessed February 2008).

Data of ten caries-related factors ranked from 0-2 or 0-3 are included and scored into the program to produce a pie chart that illustrates the "chance of avoiding new cavities" as a percentage value (Table 1). This pie chart has five colored sectors expressed as percentages (Figure 4); (i) Dark blue sector "Diet", based on a combination of sugar intake and the number of lactobacilli; (ii) Red sector "Bacteria", based on a combination of the plaque score and the number of mutans streptococci; (iii) Light blue sector "Susceptibility", based on a fluoride program, salivary secretion rate and buffer capacity; (iv) Yellow sector "Circumstances", based on past caries experience and general diseases; and (v) Green sector "the chance of avoiding caries", which is the actual outcome of the Cariogram model.

A correlation between the Cariogram results and the caries increment over time for both children and adults was approved (Hänsel Petersson et al. 2002; Hänsel Petersson et al. 2003), and the validity of the Cariogram has been confirmed (Campus et al. 2012). Using the Cariogram in clinical practice as a pedagogical tool has been found to be promising to explain the caries situation to patients and therefore help them to improve their preventive measures (Hänsel Petersson and Bratthall 2000).

Caries Assessment in Orthodontic Patients

Table 1. Caries-related factors and their corresponding scores according to the Cariogram.

Factor (Sector)	Information and data collected	Cariogram scores
Caries experience (Yellow sector)	Past caries experience, including cavities, fillings and missing surfaces due to caries; data from dental examination and bitewing radiographs.	0: Caries-free and no fillings. 1: Better than normal. 2: Normal for age group. 3: Worse than normal.
Related diseases (Yellow sector)	General diseases or conditions associated to dental caries; medical history, medications; data from interviews and questionnaire results.	0: No disease, healthy 1: General disease, indirectly influence the caries process to a mild degree. 2: General disease, indirectly influence the caries process to a high degree.
Diet, frequency (Dark blue sector)	Estimation of number of meals and snacks per day, mean for 'normal days'; data from questionnaire results.	0: Maximum 3 meals per day. 1: 4–5 meals per day. 2: 6–7 meals per day. 3: >7 meals per day.
Fluoride program (Light blue sector)	Estimation of the extent of fluoride available in the oral cavity; data from questionnaire results.	0: Fluoride supplements frequently. 1: Fluoride supplements infrequently. 2: Only fluoride toothpaste. 3: Not using fluoride toothpaste.
Plaque amount (Red sector)	Estimation of hygiene by scoring Plaque Index according to Silness and Loe.	0: No plaque. 1: Seen by probe or disclosing agent only. 2: Moderate seen by naked eye on tooth and gingival margin. 3: Severe film around tooth and in gingival pocket.
Saliva secretion (Light blue sector)	Estimation of flow rate of paraffin-stimulated saliva, as millimeter saliva per minute.	0: Normal, more than 1.1 ml / min. 1: Low, from 0.9 to less than 1.1 ml / min. 2: Low, from 0.5 to less than 0.9 ml / min. 3: Very low, less than 0.5 ml / min.
Diet, contents (Dark blue sector)	Lactobacillus counts (Dentocult) used as a measure of cariogenic diet.	0: $0-10^3$ CFU ^a . 1: 10^3-10^4 CFU. 2: 10^4-10^5 CFU. 3: $>10^5$ CFU.
Mutans streptococci (Red sector)	Estimation of levels of mutans streptococci in saliva, using Strip mutans test, the strip was cultivated for 48 h at 37 °C.	0: $0-10^3$ CFU. 1: 10^3-10^4 CFU. 2: 10^4-10^5 CFU. 3: $>10^5$ CFU.
Saliva buffering capacity (Light blue sector)	Estimation of capacity of saliva, using the Dentobuff test.	0: pH ≥ 6.0 , adequate (blue) 1: pH 4.5–5.5, medium (green) 2: pH ≤ 4.0 , low (yellow)
Clinical judgment	Opinion of dental examiner "clinical feeling".	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.

^aCFU = Colony-forming units.

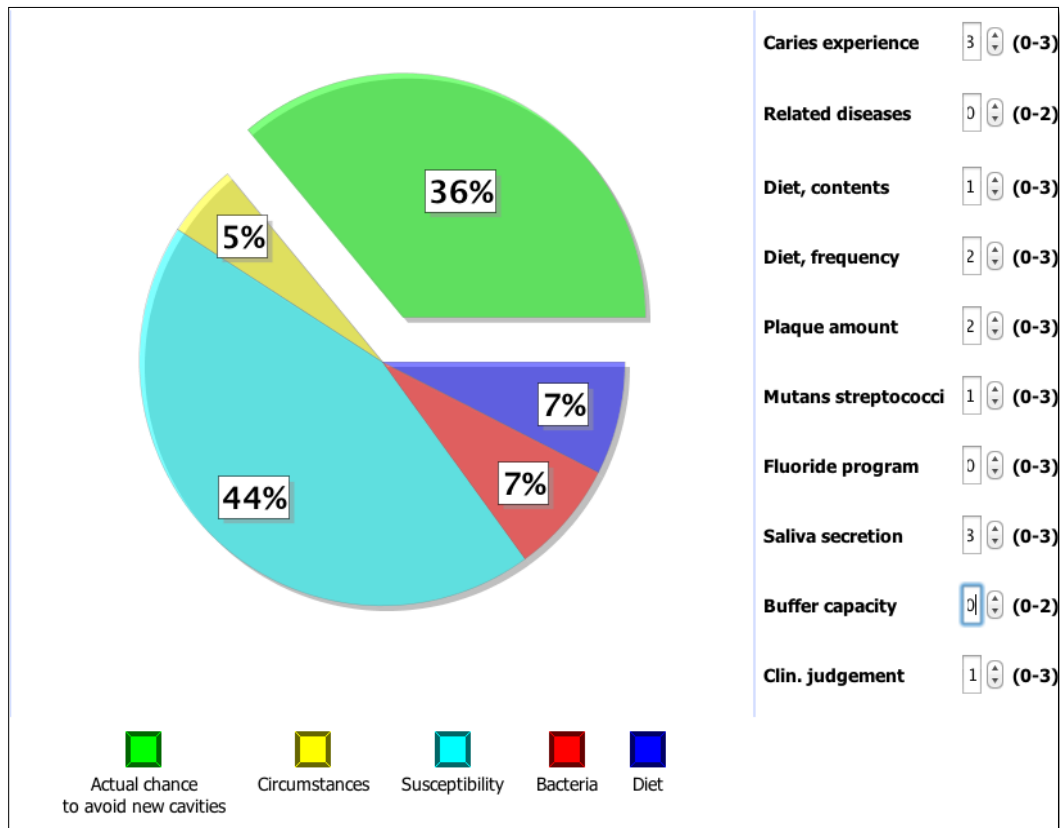


Figure 4. An example of a Cariogram as it appeared on the screen after entering the scores of caries-related factors. The green sector represents “the actual chance to avoid new cavities”.

International Caries Detection and Assessment System

Visual examination to detect caries lesions is the most common method used clinically due to the availability of the technique and the ease of its application (Pitts 1993). The International Caries Detection and Assessment System (ICDAS) is a visual classification system that was developed in 2002 to allow standardized data collection in relation to caries activity in different settings (Pitts 2004). The ICDAS detection codes for coronal caries range from 0 to 6 depending on the severity of the lesion. There are minor variations between the visual signs associated with each code depending on a number of factors including the surface characteristics (pits and fissures versus free smooth surfaces), whether there are adjacent teeth present (mesial and distal surfaces) and whether or not the caries is associated with a restoration or sealant. Later, the criteria were modified and ICDAS-II, that uses a seven-point scoring system to describe the pathology and the extent of caries lesions, was introduced (Table 2) (Ismail et al. 2007). The only difference between the two

systems was that shadowed lesions from underlying dentin (score 3) and the enamel caries lesions (score 4) in ICDAS-I were switched in ICDAS-II; thus, enamel caries lesions became score 3 and shadowed lesions from underlying dentin became score 4 in the ICDAS-II detection system (Ekstrand et al. 2007).

Several studies investigated the reproducibility of the ICDAS-II with the kappa values ranging between 0.62 and 0.93 (Shoaib et al. 2009; Jablonski-Momeni et al. 2010). Validation of the ICDAS-II scoring, and testing the accuracy of its findings in comparison with the histological examination as a golden standard, revealed substantial correlations (Ekstrand et al. 2007).

In epidemiological studies, ICDAS-II provided comparable data to those following the standard WHO criteria (Braga et al. 2009). In addition to the assessment of the caries lesion depth on smooth surfaces, the use of ICDAS-II to detect occlusal caries in the permanent and primary dentition has demonstrated reliable and accurate results (Jablonski-Momeni et al. 2008; Shoaib et al. 2009; Braga et al. 2010). Variability in the diagnosis of occlusal caries following ICDAS-II criteria may appear when calibration is not followed, however, good inter-examiner and intra-examiner reproducibility and validity were achieved when experienced but non-trained examiners were involved (Diniz et al. 2009).

Table 2. International Caries Detection and Assessment System (ICDAS-II) for free smooth surfaces.

Score	Meaning
0	Sound tooth surface: There is no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying). Surfaces with developmental defects such as enamel hypoplasia; fluorosis; tooth wear, and extrinsic or intrinsic stains will be recorded as sound.
1	First visual change in enamel: When seen wet, there is no evidence of any change in color attributable to carious activity, but after prolonged air-drying, a carious opacity is visible.
2	Distinct visual change in enamel when viewed wet: There is a carious opacity or discoloration that is not consistent with the clinical appearance of sound enamel.
3	Localized enamel breakdown due to caries with no visible dentin: There is carious loss of surface integrity without visible dentin.
4	Underlying dark shadow from dentin with or without localized enamel breakdown: This lesion appears as a shadow of discolored dentin visible through the enamel surface beyond the white or brown spot lesion.
5	Distinct cavity with visible dentin. Cavitation in opaque or discolored enamel exposing the dentin beneath. If in doubt, or to confirm the visual assessment, the CPI probe can be used to confirm the presence of a cavity in dentin.
6	Extensive distinct cavity with visible dentin: The cavity is both deep and wide and dentin is clearly visible on the walls and at the base. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.

DIAGNOdent

The evolvement of caries detection and quantification methods has led to the development of devices that are able to measure the extent of caries lesions and monitor its progress (Tranaeus et al. 2005). KaVo DIAGNOdent (KaVo, Biberach, Germany) is a portable laser fluorescence instrument that emits light from a diode laser and can differentiate between sound and carious tooth tissue (Hibst and Gall 1998). It is a diagnostic instrument working on the basis of the differing fluorescence between a healthy and diseased tooth substance. It reliably detects even the smallest lesions without exposing the patient to radiation. The unit gives a digital numeric read-out (0-99) to indicate the amount of fluorescence transmitted back. In the presence of caries, fluorescence increases and the change is registered as a high digital number (Hibst and Paulus 1999).

The authors suggested categorizing the readings into categories based on the extent of the caries lesion for easier interpretation (Lussi et al. 1999; Lussi et al. 2004). Table 3 shows the values of DIAGNOdent and corresponding diagnosis and the recommended

treatment according to the manufacturer. These values are based on the fact that a zero value was first measured on a healthy coronal location. The validity and reproducibility of DIAGNOdent for the detection of caries on different tooth surfaces has been investigated (Lussi et al. 1999; Shi et al. 2001; Pinelli et al. 2002). The conventional DIAGNOdent and DIAGNOdent Pen (Figure 5) showed excellent agreement in the quantification of smooth surface caries (Aljehani et al. 2007).

Table 3. DIAGNOdent pen values and corresponding diagnosis and treatment.

Display values	Diagnosis - Treatment (therapy)
0 - 13	Healthy tooth - professional teeth cleaning (PTC).
14 - 20	Enamel caries - intensive PTC with fluoride treatment etc.
21 - 29	Deep enamel caries - intensive PTC with fluoride treatment and monitoring - minimally invasive restorations - monitor caries risk factors.
≥ 30	Dentin caries - minimally invasive restorations and intensive PTC.

When compared to visual inspection and radiography, DIAGNOdent was more sensitive, but with lower specificity (Bamzahim et al. 2004). Post-orthodontic WSLs are accessible for direct clinical examination. However, due to the dynamic nature of the caries process, the management of WSLs requires a careful evaluation of whether the lesion is active, arrested or remineralized (Neilson and Pitts 1991). Well-defined clinical criteria can validate the visual examination, but more objective assessment of the caries lesion stage could be provided with the new caries detection devices. DIAGNOdent was evaluated for the quantification of WSLs adjacent to fixed orthodontic appliances *in vitro*, but the findings were not compared to calibrate visual examination results (Aljehani et al. 2004).

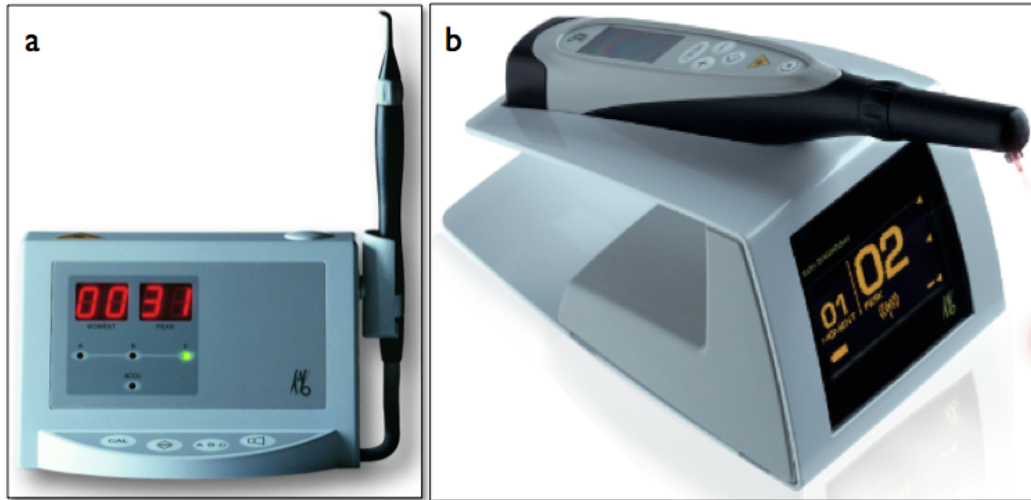


Figure 5. Conventional DIAGNOdent (a), and DIAGNOdent Pen (b). These photos are shown after permission from the company (KaVo Dental GmbH)

Digital Photographs

Photographs are frequently taken before, during, and after orthodontic treatment as a normal procedure for documentations. As orthodontic patients are more susceptible to the development of WSLs than untreated patients due to the presence of brackets, bands and arch-wires, it is important to detect these lesions in the early phases of orthodontic treatment to avoid further breakdown. This leads to the question whether digital photographs can be used as a tool for detecting the progression of WSLs during orthodontic treatment or not.

Measurements of WSLs using different image processing techniques and digitally converted photographs were suggested, and various researchers have confirmed the reproducibility and reliability of these methods (Benson et al. 2000; Willmot et al. 2000; Benson et al. 2003; Livas et al. 2008). Benson *et al.* found that measurements of enamel demineralization, using images from a digital camera, are as accurate and reproducible as images captured from an analogue photographic slide (Benson et al. 2005b). Comparing polarized versus non-polarized photographs showed that the use of a cross-polarizing filter decreases the accompanying flash reflection on digital images, thereby improving the subjective assessment of demineralized lesions surrounding an orthodontic bracket and enhancing the reproducibility of demineralization area measurements (Benson et al. 2008).

Hypotheses and aims

The present thesis focuses on caries risk, the prevalence of caries using different methods in orthodontic patients, and to compare these methods with the clinical examination. *Studies I and IV* analyze caries risk, while *Studies II and III* evaluate the prevalence of caries in orthodontic patients using different methods and comparing these methods with the clinical examination. The hypotheses and specific aims of this thesis were:

1. The hypothesis of *Study I* was that the caries risk for orthodontics patients treated at governmental clinics is higher compared with patients treated at private clinics. The aims were to study the different caries-related factors in orthodontic patients immediately after orthodontic treatment i.e. at de-bonding, and to compare the caries risk profile using the Cariogram model between governmental and private orthodontic patients.
2. The hypotheses of *Study II* were that the prevalence of buccal caries lesions at de-bonding is higher in orthodontics patients treated at governmental clinics compared with patients treated at private clinics, and the null hypothesis is that there is no correlation between the ICDAS-II and DIAGNOdent Pen for detecting buccal caries lesions. The aims were to clinically study the prevalence of buccal caries lesions including WSLs at de-bonding using ICDAS-II and DIAGNOdent Pen in governmental and private orthodontic clinics, and to study the correlation between the two methods for detecting those lesions.
3. The hypothesis of *Study III* was that visual examination for assessing the severity of buccal caries lesions on digital photographs is not a reliable and valid method. The aims were to study the severity of buccal caries lesions according to the ICDAS-II criteria via scoring buccal caries lesions on digital photographs at de-bonding, and to compare this method with clinical examinations.
4. The hypothesis of *Study IV* was that caries risk is higher in patients treated in government clinics compared to those treated in private clinics four years after de-bonding and that the caries risk will decrease over time after de-bonding. The

aims were to analyze various caries-related factors and evaluate “the actual chance to avoid new cavities” according to the Cariogram for governmental and private orthodontic patients at de-bonding and four years after de-bonding, and to compare the caries-related factors and “the actual chance to avoid new cavities” according to the Cariogram for those patients over the four-year period.

MATERIAL AND METHODS

Ethical considerations

The four studies included in this thesis were approved and registered by the College of Dentistry Research Centre Ethics Committee, King Saud University, Riyadh, KSA (Reg. No. NF 2225). All the participants were informed about the nature of the studies, and were given a written informed consent prior to participation. The participants were also assured confidentiality with regard to the collected information, and they were given the choice of not participating or withdrawing from the studies at any time.

Three studies included in this thesis (I, II, and IV) were investigating the difference between orthodontic patients treated in governmental clinics compared with those treated in private clinics in the aspect of the caries situation. It is believed that the results of such investigations may provide the Saudi medical authorities with valuable information that could be used as a base to build a proper dental health care system, particularly during orthodontic treatment. This could also be applicable for other dental systems in different countries where the caries situation is expected to be high.

Study population and design

In general, the same participants were involved in all four studies (I, II, III and IV). All adult orthodontic patients, who came for de-bonding in six representative clinics, were recruited. The six clinics (three governmental and three private) were located in Riyadh, KSA, and the patients were recruited during a five months period from the beginning of January till end of May 2009. The three governmental centers are: King Saud University dental clinics, King Saud Medical Complex, and Prince Sultan Medical Military City. The three private clinics are: Coral Dental Clinic, Ajyal Specialist Clinics, and Dr. Saad Al-Kharsa Orthodontic Clinics. The inclusion criteria were: 1) Willingness to participate in the study, 2) Free from any active caries lesions prior to orthodontic treatment, 3) Treated with buccal fixed orthodontic appliances in both jaws.

In Studies I and II; the sample was comprised of 89 orthodontic patients with a mean age of 21.5 years. They were divided into two groups based on the center of treatment: Governmental (G) group (n = 45), and Private (P) group (n = 44). **In Study III;** the same 89 orthodontic patients were considered as one group since the study was aimed to evaluate a method regardless of which clinic they had been treated at. **In Study IV;** based on power analysis to estimate the sample size as well as to account for dropouts, 40 patients from the 89 patients at the baseline were recalled, from the beginning of December 2012 till end of February 2013. The 40 patients with a mean age of 26.4 years were divided into two groups based on the center of treatment: G-group (n = 20), and P-group (n = 20). In addition, it was decided to include a control group in the follow-up study to be compared with the patients seen four years after de-bonding. This data was not presented in *Study IV* mainly due to space limitation from the journal, as well as lacking the control group in the baseline study. A cross-sectional comparison between the patients seen four years after de-bonding (the test group) and the control group will be presented *briefly* in a separate subheading under the result part of this frame. The control group included 40 participants matched with the test group in age and gender aspects. The control group participants were collected to be the same number as the test group as well as from the same center of treatment: G-group (n = 20), and P-group (n = 20). Table 4 summarizes the study design, the sample sizes and topic of the four studies included in the thesis.

Table 4. The main topic of the four studies included in this thesis and their corresponding designs and populations.

Study	Design	Population	Topic
I	Cross-sectional	89	Caries risk profile using the Cariogram in governmental and private orthodontic patients at de-bonding
II	Cross-sectional	89	Diagnosing the severity of buccal caries lesions in governmental and private orthodontic patients at de-bonding, using the ICDAS-II and the DIAGNOdent Pen
III	Methodological	89	Diagnosing the severity of buccal caries lesions in orthodontic patients at de-bonding using digital photographs
IV	Prospective, longitudinal	40	Caries risk profile in orthodontic patients: A 4-year longitudinal study using the Cariogram model in governmental vs. private clinics

Studies I & IV

Baseline and follow-up data

The number of patients, group, mean age, and gender at the baseline (*Study I*) and the patients included in the follow-up investigation (*Study IV*) are illustrated in Figure 6.

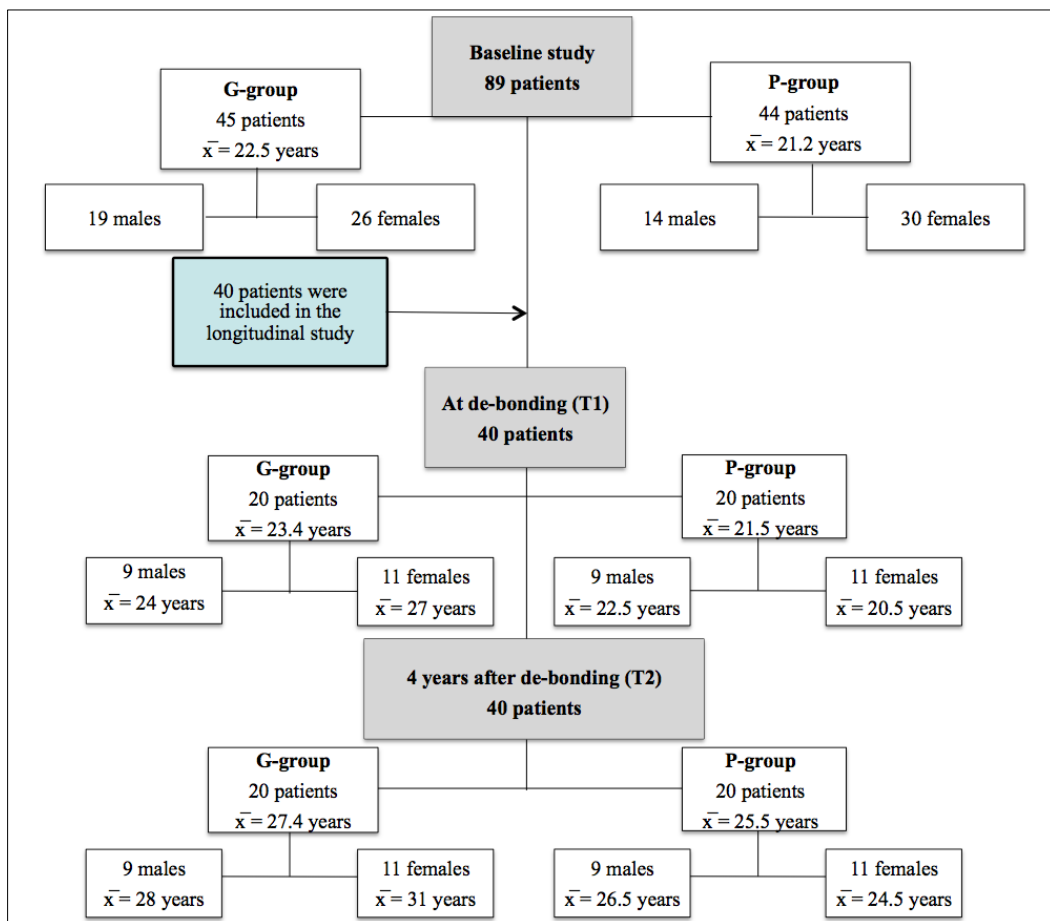


Figure 6. Flowchart illustrating the design for *Studies I and IV*.

Questionnaire

All the patients in the baseline (I) and follow-up (IV) studies were questioned and examined clinically for the presence of caries by the same dentist (Almosa) at de-bonding (T1) and four years after de-bonding (T2). Also, this was applied on the non-presented control group. A standardized structured questionnaire according to the

Cariogram manual (Cariogram computer program manual, accessed February 2008) was used to obtain data regarding medical and dental history, dietary habits and the use of fluoride dentifrices, fluoride mouth rinse solutions, and fluoride tablets. The patients then underwent plaque scoring and saliva sampling followed by bitewing radiographs to evaluate the interproximal surfaces for the presence of caries.

Plaque index

Before professional cleaning and saliva sampling, the plaque index was recorded according to Silness and Løe (Silness and Løe 1964). Four sites (buccal, lingual and proximal surfaces) on six representative teeth (16, 12, 24, 36, 32 and 44) were scored. If any of these teeth were missing, the neighboring tooth was scored.

Salivary and microbiological tests

Paraffin-stimulated saliva was collected for five minutes and the secretion rate was expressed as ml/min. The saliva was analyzed in terms of buffer capacity and the number of mutans streptococci and lactobacilli using chair-side tests (Dentocult SM Strip mutans, Dentocult LB and Dentobuff strip, Orion Diagnostica, Espoo, Finland). The mutans streptococci, lactobacilli and buffer capacity were scored in classes (Table 1), according to the manufacturer's model chart. To determine the buffer capacity of saliva, a drop of saliva was left on the Dentobuff Strip for five minutes, and the pH was then determined by the color presented by the strip in accordance to the manual provided by the manufacturer.

Clinical examination of caries

After plaque scoring and saliva sampling, the teeth were cleaned with a rubber cup, pumice and dental floss. They were dried with compressed air and then examined using a mouth mirror, standard light and dental probe. Caries was scored according to the WHO criteria (World Health Organization 1997). The numbers of decayed (D), missing (M) and filled (F) tooth surfaces (S) were scored for each individual and calculated as DMFS to evaluate the caries experience according to the Cariogram (Table 1). Third molars were not included. Extracted premolars and molars due to caries were scored as 5 missing surfaces, and extracted teeth due to orthodontic treatment and agenesis were not included as missing surfaces. Bitewing radiographs were evaluated for the presence of proximal caries. White spot lesions were excluded

because only manifest lesions are considered in the “caries experience” according to the Cariogram.

Caries risk assessment

Data of ten caries-related factors (Table 1) were scored and entered into the Cariogram program to produce a graphic image that illustrated the “chance of avoiding new cavities” as a percentage value (Figure 4). The tenth factor (clinical judgment) was set to score 1 in all patients in order not to change the built-in evaluation of the Cariogram model.

Study II

Clinical examination of buccal caries

The study included all non-extracted premolars and anterior teeth (incisors and canines). Immediately after de-bonding and remaining resin removal, the teeth were cleaned using a rubber cup, pumice paste, dental floss, and rinsed and dried with compressed air in order to remove plaque and extrinsic stains. Then, the same dentist (Almosa) examined the buccal surfaces of all non-extracted premolars and anterior teeth for the presence of caries lesions by using the two caries detection methods: ICDAS-II and DIAGNOdent pen. The number of teeth examined in each group (G vs. P), illustrated in Figure 7. The prevalence of buccal caries lesions on the G and P groups was determined on the tooth level and on the individual level to evaluate differences between the two groups.

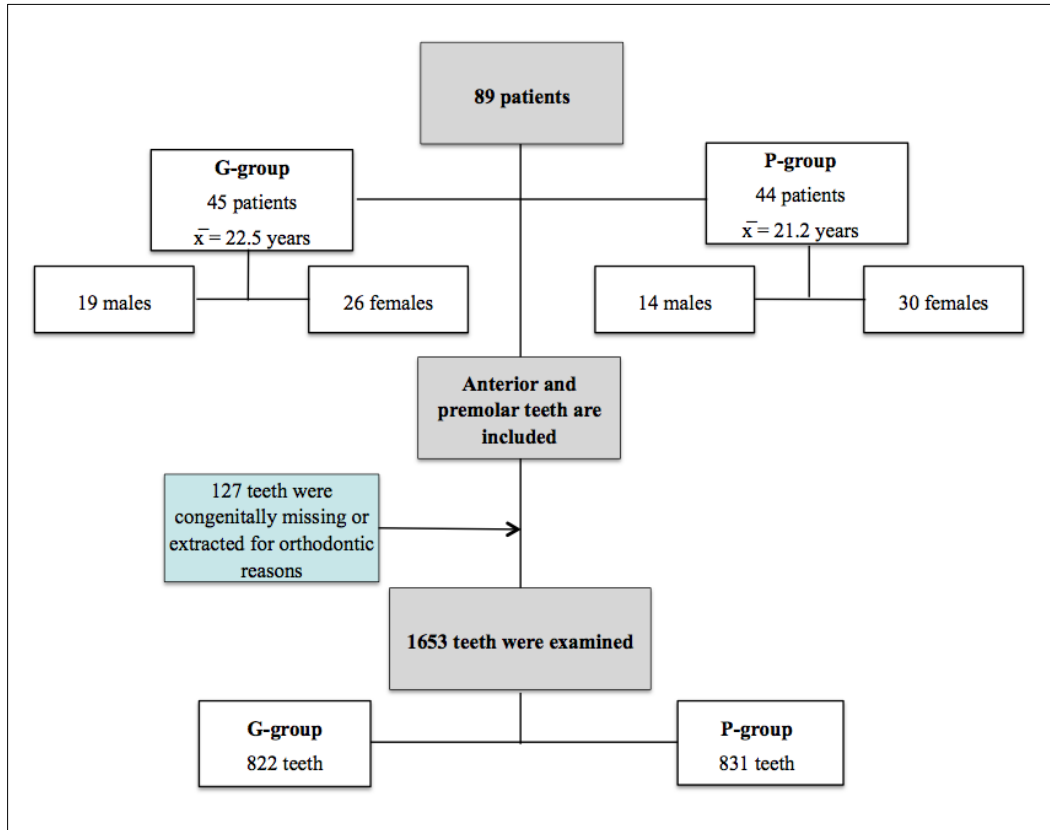


Figure 7. Number of teeth, in governmental (G) and private (P) orthodontic patients, examined at de-bonding for the presence of buccal caries lesions using ICDAS-II and DIAGNOdent Pen.

Examination methods

ICDAS-II clinical criteria (Table 2) and the DIAGNOdent pen (Table 3) were used clinically to examine the buccal caries lesions including WSLs on the G and P orthodontic patients at de-bonding. ICDAS-II has seven scores and the DIAGNOdent pen has four categories. In order to study the prevalence of buccal caries lesions and the correlation between the two methods, the ICDAS-II criteria had been merged from seven scores into four scores based on the histological study performed to validate ICDAS-II (Table 5) (Ekstrand et al. 2007). Thus, the modified ICDAS-II was created as shown in Table 6 and matched with the DIAGNOdent pen values as illustrated in Figure 8. The instructions provided in the manual from the manufacturer of the DIAGNOdent pen were used. Teeth were rinsed and dried before registration, calibration with ceramic standard before each session, flat tip swept across the buccal surfaces, and the peak value was registered.

Table 5. ICDAS II Caries Detection System and Histologic Caries Classification System investigated previously (Ekstrand et al. 2007)

Score	ICDAS-II	Histological classification
0	Sound tooth surface	No demineralization
1	First visual change in enamel	Demineralization limited to the outer 1/2 of the enamel thickness
2	Distinct visual change in enamel	Demineralization between inner 1/2 of the enamel and outer 1/3 of the dentin
3	Localized enamel breakdown due to caries with no visible dentin or underlying shadow	Demineralization in the middle third of the dentin
4	Underlying dark shadow from dentin with or without localized enamel breakdown	As above
5	Distinct cavity with visible dentin	Demineralization in the inner third of the dentin
6	Extensive distinct cavity with visible dentin	As above

Table 6. International Caries Detection and Assessment System (ICDAS-II) after being merged from 7 scores into 4 scores.

Score	Meaning
0 ^a 0 ^b	Sound tooth surface: There is no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying). Surfaces with developmental defects such as enamel hypoplasias; fluorosis; tooth wear, and extrinsic or intrinsic stains will be recorded as sound.
1 ^a 1 ^b	First visual change in enamel: When seen wet, there is no evidence of any change in color attributable to carious activity, but after prolonged air-drying, a carious opacity is visible.
2 ^b	Distinct visual change in enamel when viewed wet: There is a carious opacity or discoloration that is not consistent with the clinical appearance of sound enamel.
3 ^b	Localized enamel breakdown due to caries with no visible dentin: There is carious loss of surface integrity without visible dentin.
2 ^a 4 ^b	Underlying dark shadow from dentin with or without localized enamel breakdown: This lesion appears as a shadow of discolored dentin visible through the enamel surface beyond the white or brown spot lesion.
5 ^b	Distinct cavity with visible dentin. Cavitation in opaque or discolored enamel exposing the dentin beneath. If in doubt, or to confirm the visual assessment, the CPI probe can be used to confirm the presence of a cavity in dentin.
3 ^a 6 ^b	Extensive distinct cavity with visible dentin: The cavity is both deep and wide and dentin is clearly visible on the walls and at the base. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.

^a The modified ICDAS-II after merging the 7 scores into 4 scores.

^b The original ICDAS-II

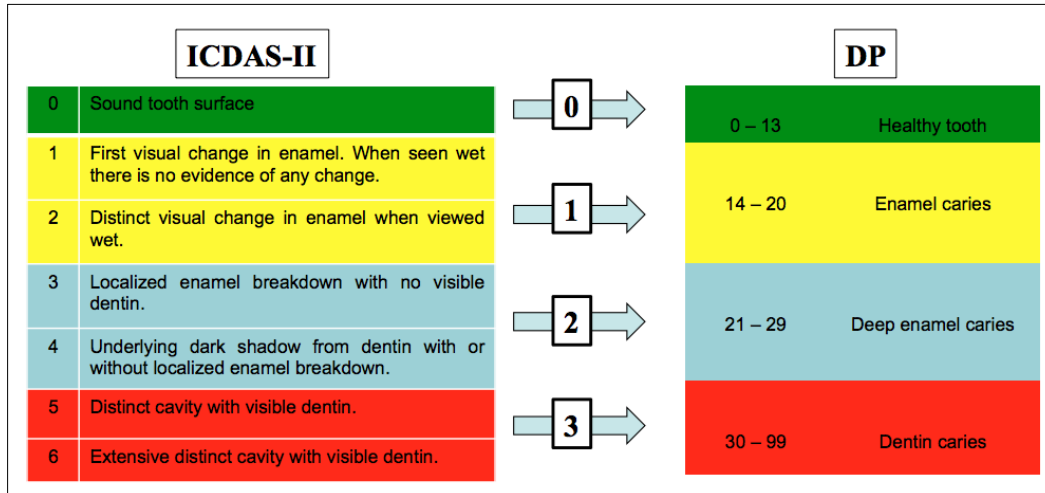


Figure 8. Matching ICDAS-II criteria with the DIAGNOdent pen (DP) values.

Study III

Photographic technique and sample size

Ten close-up digital photographs were taken for the anterior and premolar teeth for each of the 89 patients. The same dentist (Almosa) has taken all photographs using a digital camera (Nikon D60, Nikon corporation, Japan) with a macro objective lens (105 mm F2.8 DG macro, SIGMA, Japan), a ring flash (EM-140DG, SIGMA, Japan), and a polarizing filter. Furthermore, a cross-polarizing technique was applied. The image quality of the camera was set to “fine”, and the ISO sensitivity was set to 200. All images were saved as Joint Photographic Experts Group (JPEG) files. The digital photographs were taken perpendicular to the facial surfaces of the anterior and premolar teeth, and a constant distance was always maintained between the tooth surface and the lens by locking the lens and moving the camera until focus was achieved.

A power analysis was performed to estimate the sample size of photographs. A minimum of 245 photographs was required to achieve an accuracy of 80±5% for detecting different buccal caries lesion scores on digital photographs according to the modified ICDAS-II criteria. Photographs including environmental and developmental alterations such as enamel hypoplasia, fluorosis, and stains on the teeth were excluded. 245 photographs were selected representing different scores of buccal caries lesions according to the clinical examination criteria (ICDAS-II). The only

difference between scores 1 and 2 in the original ICDAS-II criteria is whether the tooth is dry or wet. Since all photographs in this study were taken when the teeth were dry, scores 1 and 2 were therefore merged, and a modified ICDAS-II was used as illustrated in Figure 9. These 245 photographs were given different scores according to the modified ICDAS-II, where scores 0, 1, 2, 3, 4, and 5 were represented in 40.0%, 30.6%, 12.2%, 12.2%, 4.6%, and 0.4% of the photographs, respectively.

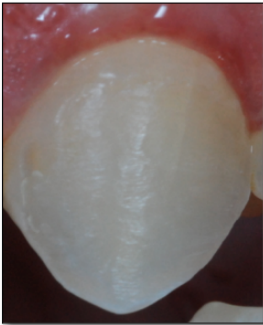

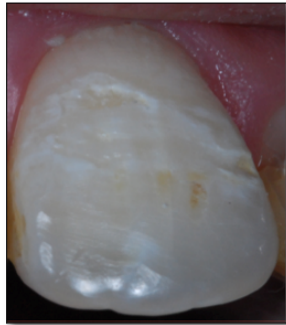


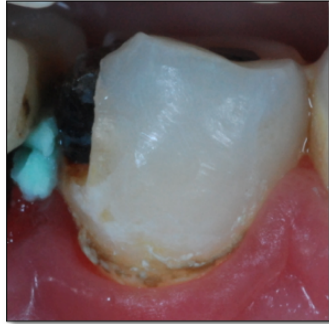
		
<p>0. Sound tooth surface: There should be no evidence of caries or WSL. Staining will be recorded as sound.</p>	<p>1. White discoloration without cavitation or shadowing from dentin.</p>	<p>2. Localized enamel breakdown with no visible dentin. There is carious loss of surface integrity without visible dentin.</p>
		
<p>3. Underlying dark shadow from dentin with or without localized enamel breakdown. This lesion appears as a shadow of discolored dentin visible through the enamel surface beyond the white or brown spot lesion, which may or may not show signs of localized breakdown. This appearance is a darkening and intrinsic shadow, which may be grey, blue or brown in color.</p>	<p>4. Distinct cavity with visible dentin. Cavitation in opaque or discolored enamel exposing the dentin beneath.</p>	<p>5. Extensive distinct cavity with visible dentin. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.</p>

Figure 9. The Modified International Caries Detection and Assessment System (Modified ICDAS-II).

Examination of digital photographs

Thirteen postgraduate students with at least two years of experience as general practitioners participated independently in the evaluation of buccal caries lesions in 245 digital photographs using the modified clinical criteria (ICDAS-II).

The photographs were cropped to equal sizes and shown to all examiners in a random order. Calibrated screens in a dark room were used and all observers performed the scoring early in the morning. For calibration purposes, a lecture was presented before the scoring was performed and a manual with explanations of the modified ICDAS-II scores combined with a decision chart was given to each examiner (Figure 10). Instructions were also given to the examiners to register the worst score if more than two different scores were observed on the same photograph.

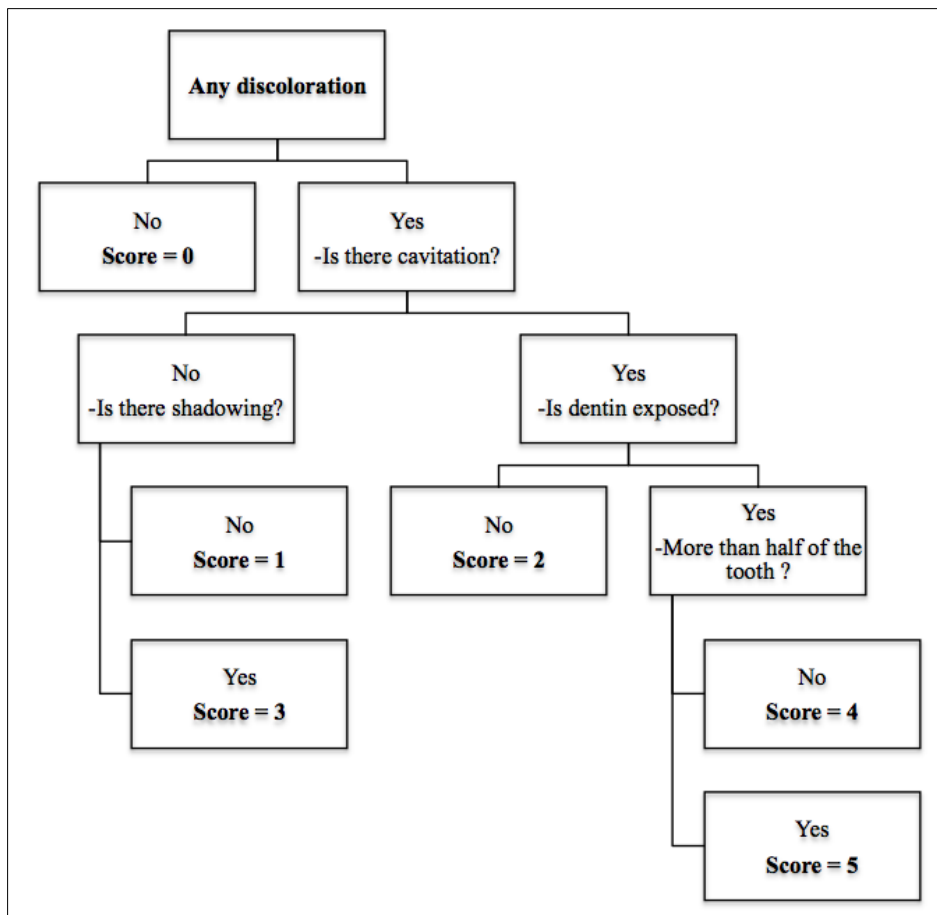


Figure 10. Decision chart for different scores of buccal caries lesions.

Two sessions of registrations were performed to evaluate the intra-examiner reliability with an interval of two weeks between the sessions. The reliability for each examiner's observations of photographs and the clinical examination was calculated. The clinical examination was considered as the gold standard to evaluate the validity of diagnosing the severity of buccal caries lesions using digital photographs. The total number of observations registered on two different occasions to examine 245 photographs for the presence of buccal caries lesions using the modified ICDAS-II criteria is illustrated in Figure 11.

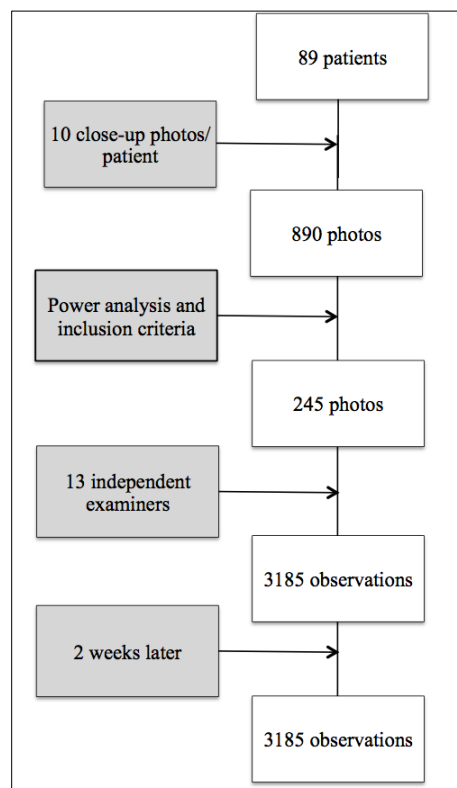


Figure 11. The number of photos and observations performed by thirteen independent examiners.

Statistical analysis

The Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA, version 18.0) was used for the statistical analysis of the determined measurements in all studies included in this thesis.

In *Studies I and IV*, descriptive statistics including the mean, standard deviations and the range of numerical variables were calculated for all individuals in the G and P groups. Moreover, the median values for the Cariogram were calculated. A two-sample t-test was applied to determine the statistically significant differences between the two main groups (G vs. P), while the analysis of variance (ANOVA) was used when three or more groups were compared. Chi-square test (*Study I*) and Fisher's exact test (*Study IV*) were used to compare the scores between the two different groups (G vs. P) (control vs. test). A paired t-test was applied to determine the statistically significant differences for the same individuals over time (*Study IV*).

In *Study II*, descriptive statistics were used to study the mean age, frequency of gender and different scores of the two methods on tooth level, and the frequency of buccal caries lesions on an individual level. The independent sample t-test was applied to the two main groups, G and P, to determine the statistically significant differences of buccal caries lesions on the individual level. Fisher's exact test was used to compare the different categories of the buccal caries lesions count on individual levels. The cross-tabulation was applied to evaluate inter-examiner and intra-examiner reliabilities, as well as to study the correlation between the ICDAS-II index and the DIAGNOdent Pen, by calculating the weighted Kappa and Spearman correlation coefficient.

In *Study III*, the intra-examiner reliability and the reliability between each examiner and the clinical examination were performed with regard to selected variables and the kappa values were calculated. Cross-tabulation was applied to evaluate the correlation between the clinical examination of buccal caries lesions and the examination of digital photographs of the lesions using the ICDAS-II criteria, by calculating Spearman's correlation coefficient.

For all tests, the significance level was $P < .05$.

RESULTS

Study I

Caries experience in G vs. P orthodontic patients

The mean number of DMFS was significantly higher in the G-group compared with the P-group, 13.3 and 8.6, respectively ($P < .05$). The total number of lesions in the G-group was more than two times higher compared to the P-group (150 vs. 68) ($P < .001$). The number of occlusal and buccal caries lesions in the G-group was double compared with the P-group, while approximal and lingual caries lesions in the G-group were three and four times higher, respectively, compared with the P-group (Figure 12).

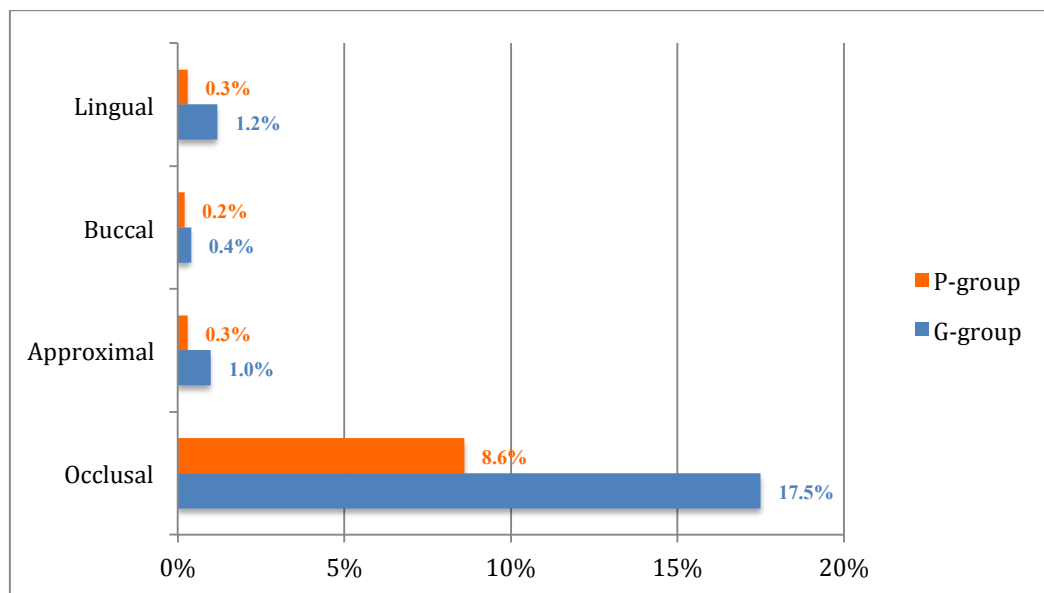


Figure 12. Percentage of manifest caries lesions on different surfaces of all teeth except third molars in governmental (G) and private (P) orthodontic patients at de-bonding.

Caries-related factors in G vs. P orthodontic patients according to Cariogram

There were no statistically significant differences between the two groups in the aspect of the saliva secretion rate, diet frequency and fluoride use. The mean value of the saliva secretion rate was 0.8 ml/min in the G-group and 1 ml/min in the P-group.

Caries Assessment in Orthodontic Patients

The P-group used extra fluoride products more often compared to the G-group. 18% of the P-group vs. 2% of the G-group were using extra fluoride products in addition to toothpaste (i.e. tablets or rinsing solutions). 89% of the G-group and 82% of the P-group used only fluoride toothpaste. Moreover, 9% of the G-group were not using any fluoride products at all. Statistically significant differences were observed between the two groups in the remaining caries-related factors according to the Cariogram as presented in Table 7.

Table 7. Frequency distribution of caries-related factors according to the cariogram score of the total number of individuals in the governmental group (G) and the private group (P). A chi-square test was used to calculate the difference.

Factor	Cariogram score	G-group (n=45)	P-group (n=44)	Significance
Diet frequency				
Maximum 3 meals per day	0	26	20	NS ^a
4-5 meals per day	1	16	21	
6-7 meals per day	2	3	3	
>7 meals per day	3	0	0	
Fluoride program				
Fluoride supplements frequently	0	1	3	NS ^a
Fluoride supplements infrequently	1	0	5	
Only fluoride toothpaste	2	40	36	
Not using fluoride toothpaste	3	4	0	
Plaque index				
No plaque	0	1	12	<i>P</i> < .001
Seen by probe or disclosing agent only	1	16	21	
Moderate	2	18	10	
Severe	3	10	1	
Lactobacillus score (CFU/mL)				
0-10 ³	0	5	12	<i>P</i> < .05
10 ³ -10 ⁴	1	7	13	
10 ⁴ -10 ⁵	2	18	13	
> 10 ⁵	3	15	6	
Mutans streptococcus (CFU/mL)				
0-10 ³	0	6	15	<i>P</i> < .01
10 ³ -10 ⁴	1	8	12	
10 ⁴ -10 ⁵	2	9	11	
> 10 ⁵	3	22	6	
Buffer capacity (pH)				
≥6.0, 'adequate'	0	11	25	<i>P</i> < .01
4.5-5.5, 'medium'	1	17	12	
≤4.0, 'low'	2	17	7	

^aNS not significant.

Caries risk profiles using the Cariogram in the G vs. P orthodontic patients

The actual chance to avoid new cavities (green sector) according to the Cariogram was higher in the P-group compared with the G-group (61% vs. 28%) ($P < .001$). Caries risk, as illustrated by the Cariogram, was divided into three categories according to the values of the actual chance to avoid new cavities: 1) Low ($\leq 25\%$) = high caries risk, 2) Medium (26-74%) = medium caries risk, and 3) High (≥ 75) = low caries risk. Figure 13 shows the number of patients from the G vs. P group in the three different categories. Approximately 53% of the G-group vs. 13% of the P-group were classified in the high caries risk category “low chance to avoid new cavities”, while 7% of the G-group vs. 36% of the P-group were classified as low caries risk “high chance to avoid new cavities”.

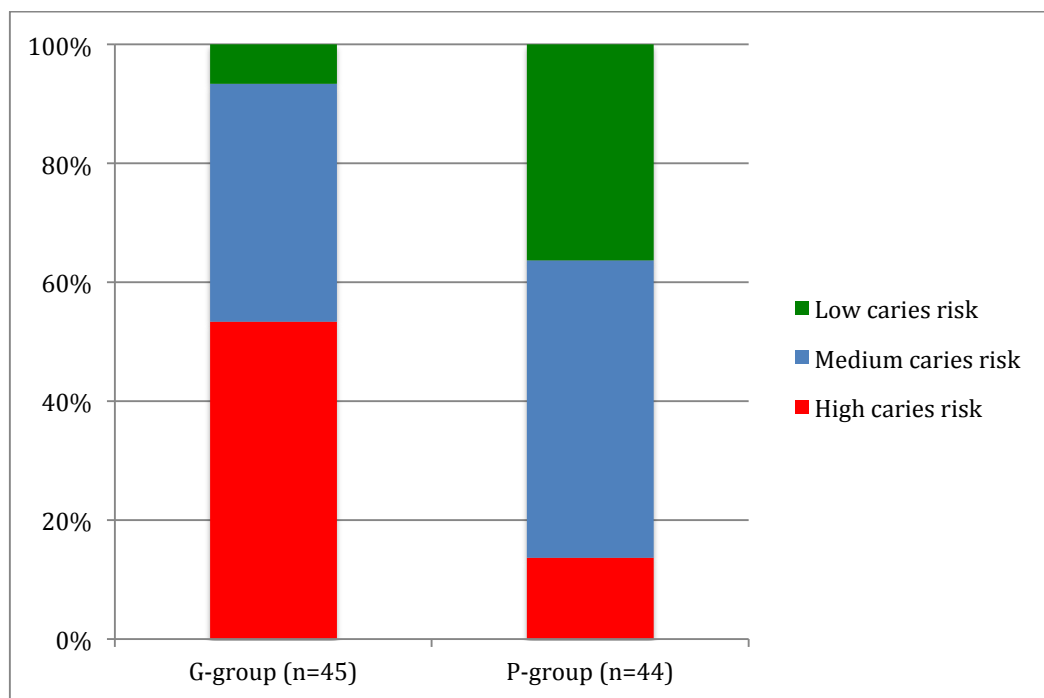


Figure 13. The distribution of patients from the governmental (G) vs. private (P) group with regard to the different caries risk categories according to Cariogram.

Figure 14 shows the relationship between the different caries risk categories and the number of DMFS for both groups merged together. Patients with high caries risk had approximately 2.5 times more DMFS compared with the low caries risk group.

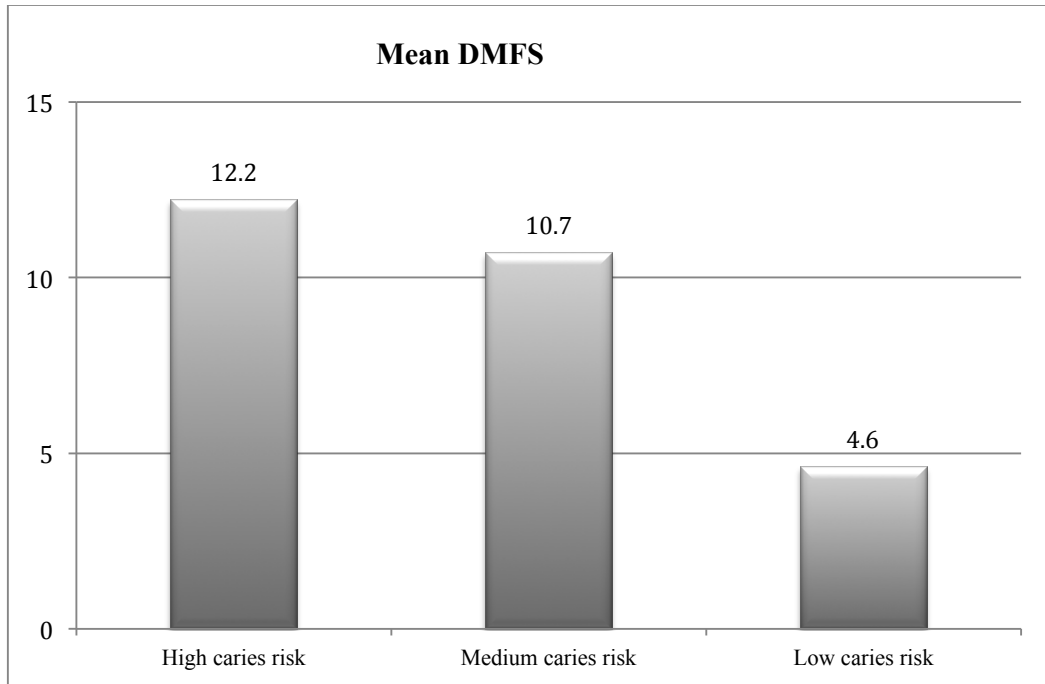


Figure 14. Mean values of DMFS at de-bonding for both governmental and private orthodontic patients pooled together, divided into three different categories of actual chance to avoid new cavities.

Study II

Prevalence of buccal caries lesions at de-bonding on tooth level

Table 8 shows the prevalence of buccal caries lesions in the G and P groups pooled together using the modified ICDAS-II and the DIAGNOdent Pen. The two methods show that approximately 67% and 79% of the buccal surfaces, respectively, were healthy. In addition, ICDAS-II detected scores 1 and 2 (enamel caries and deep enamel caries) almost three times more often than the DIAGNOdent Pen. Moreover, approximately 10% of the total number of teeth in both groups had dentin caries according to the DIAGNOdent Pen.

Table 8. Prevalence (%) of buccal caries lesions in G and P groups using modified ICDAS-II and DIAGNOdent Pen (DP).

Method	Scores			
	0	1	2	3
ICDAS-II	67.3	17.1	14.6	1
DP	78.8	6	5.6	9.6

Figure 15 illustrates the distribution of teeth for both groups (G vs. P) among different scores using the two methods. In overall terms, ICDAS-II reveals that approximately 50% of the teeth in the G-group and 85% of the teeth in the P-group were healthy. Furthermore, teeth in the G-group had a 3-3.5 times higher prevalence of scores 1 and 2, respectively, compared to the P-group. On the other hand, the DIAGNOdent Pen shows that 67% of the teeth in the G-group and more than 90% of the teeth in the P-group were healthy. Moreover, the teeth in the G-group with enamel caries, deep enamel caries and dentin caries were more than two, three and five times higher compared to the P-group, respectively.

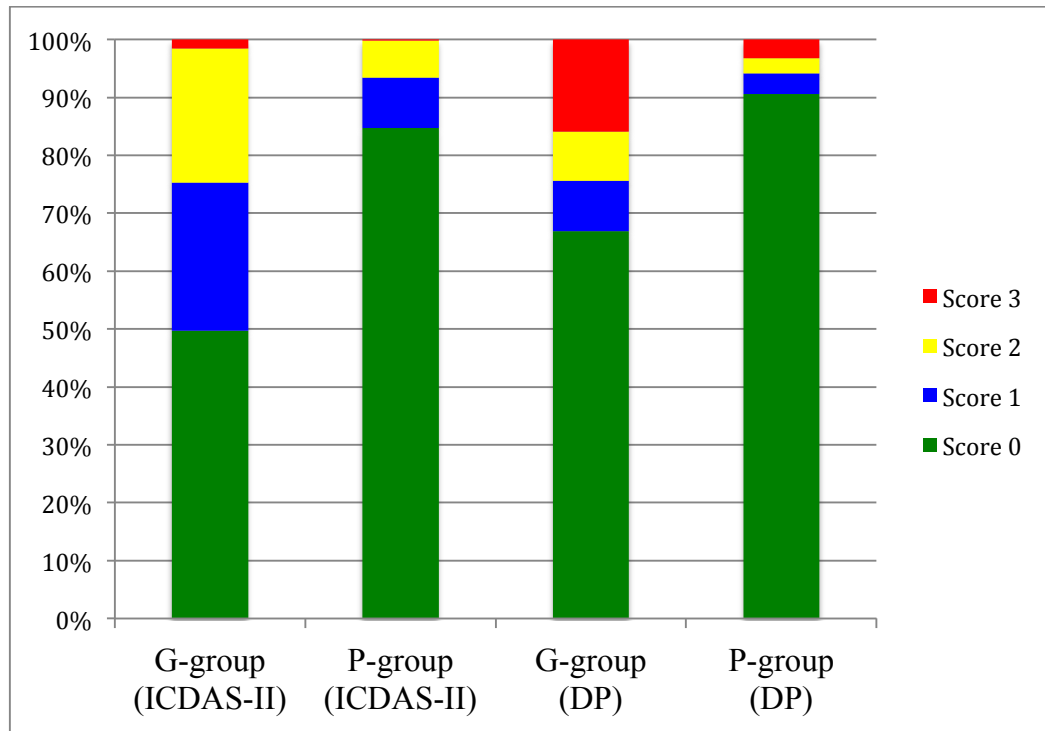


Figure 15. The distribution of teeth from both the governmental (G) and private (P) groups with regard to different scores according to the modified ICDAS-II criteria and DIAGNOdent Pen (DP).

Prevalence of buccal caries at de-bonding on an individual level

No statistically significant difference was found between males and females in the aspect of buccal caries lesions ($P > .05$) by using the two methods (Table 9). Figure 16 shows the G and P groups pooled together that reveals 26% of the patients, 4.5% in the G-group and 21.5% in P-group, were free from any lesion based on the modified ICDAS-II criteria. In addition, 74% of the patients in the G and P groups had at least one lesion, 28% had one to five and 46% had more than six lesions. All patients who had 16 lesions or more were from the G-group, which represents 11% of the whole sample.

Table 9. Prevalence (%) of buccal caries lesions using ICDAS-II and DIAGNOdent Pen (DP) in males and females.

Method	Gender	Scores			
		0	1	2	3
ICDAS-II	Male	67.4	19.4	11.6	1.6
	Female	67.3	15.7	16.6	0.1
DP	Male	79.7	5.3	5.5	9.5
	Female	78.3	6.5	5.6	9.6

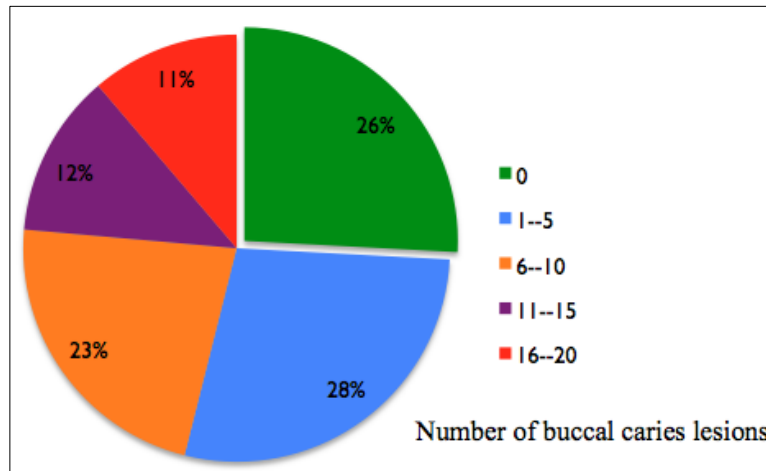


Figure 16. Prevalence of buccal caries lesions including WSLs for both groups, governmental and private, based on the individual level illustrated in five different categories.

Statistically significant differences were noted between the G and P groups in the prevalence of buccal caries lesions ($P < .0001$) (Figure 17). These differences were applied on the total number of lesions as well as after categorizing the lesions into five different counts.

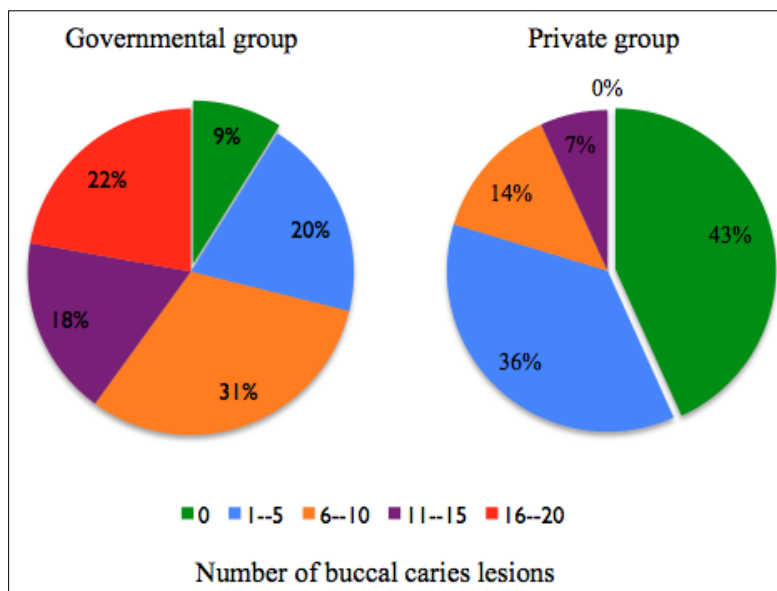


Figure 17. Prevalence of buccal caries lesions including WSLs for the governmental vs. private groups based on the individual level illustrated in five different categories.

The correlation between ICDAS-II and the DIAGNOdent Pen in detecting different scores of buccal caries lesions

Table 10 represents the cross-tabulation between the ICDAS-II and the DIAGNOdent Pen in detecting different scores of buccal caries lesions, from which Spearman’s correlation coefficient was calculated to be 0.71. Given ICDAS-II with scores 0 and 3, the chances to meet the same scores using the DIAGNOdent Pen were 97% and 86%, respectively. However, diagnosing teeth with scores 1 and 2 using ICDAS-II will give a chance of 14% and 22%, respectively, using the DIAGNOdent Pen.

Table 10. The cross-tabulation between ICDAS-II and DIAGNOdent Pen in registering different scores of buccal caries lesions.

		DIAGNOdent Pen				Total
		Score	0	1	2	
ICDAS	0	1079	21	9	4	1113
	1	191	40	29	23	283
	2	32	38	53	120	243
	3	0	1	1	12	14
	Total	1302	100	92	159	1653

Study III

The reliabilities of the examiners

The intra-examiner reliability test for 12 examiners showed substantial to excellent agreement, kappa value ranged between 0.65 and 0.83, while one examiner showed moderate agreement, kappa value of 0.52 (Table 11).

The reliability between 11 examiners and the clinical examinations showed agreement between 65% and 80%, which is classified as being a substantial to almost perfect agreement, while two examiners showed agreement below 65% (Table 11).

Table 11. Weighted Kappa values of the Intra-Examiner Reliability (I.E.R)^{*} for 13 examiners, and the Reliability between each one of the 13 Examiners' observations on photographs and the Clinical examination (R.E.C)^{**}.

	Examiners												
	1	2	3	4	5	6	7	8	9	10	11	12	13
I.E.R [*]	0.82	0.65	0.76	0.77	0.79	0.65	0.79	0.52	0.83	0.79	0.83	0.75	0.68
R.E.C ^{**}	0.80	0.53	0.73	0.70	0.68	0.68	0.77	0.65	0.77	0.69	0.80	0.65	0.52

The correlation between digital photographs and clinical examination of buccal caries lesions

Table 12 represents the cross-tabulation between the clinical examinations and visual scores, using photographs of buccal caries lesions, according to the modified ICDAS-II criteria from which Spearman's correlation coefficient was calculated to be 0.76. The correlation was based on the agreement of the registration on photographs toward the clinical registration, but not vice versa. The agreement for scores 0 and 1 was almost 80%, and this agreement becomes even higher in the evaluation of scores 4 and 5 with 94% and 100%, respectively. However, the agreement between the scoring on digital photographs and the clinical examination decreased for scores of 2 and 3, with 37% and 49.0%, respectively. On digital photographs, there is an approximately 94% chance to detect whether the teeth are healthy or had lesions regardless of the severity of the lesions.

Table 12. The cross-tabulation between clinical registration and observations on photographs using modified ICDAS-II, from which Spearman's correlation coefficient was calculated to be 0.76. The correlation is a column percentage to evaluate the agreement of the registration on photographs toward the clinical registration and not vice versa.

		Clinical registration						Total
		Score	0	1	2	3	4	
Photographs	0	1013	60	32	26	0	0	1131
	1	196	776	128	94	0	0	1194
	2	44	41	145	56	3	0	289
	3	21	97	68	191	4	0	381
	4	0	1	16	22	135	0	174
	5	0	0	1	1	1	13	16
	Total	1274	975	390	390	143	13	3185

Study IV

No statistically significant differences were noticed between the mean of “actual chance to avoid new cavities” according to the Cariogram among the 89 patients investigated at the baseline (T1), and the 40 patients investigated at both T1 and T2, indicating that the 40 patients included in this study comprised a representative sample for follow-up investigation.

Caries risk profile (Cariogram) at T1, T2, and over a 4-year period (T2-T1)

Figure 18 shows the improvement in “the actual chance to avoid new cavities” according to the Cariogram from T1 to T2 for the whole sample, pooling the G-group and P-group together (G+P), as well as for the G and P groups separately. The mean of “the actual chance to avoid new cavities” for the whole sample was significantly higher at T2 compared to T1 ($P < .001$), and this was also significantly higher in the P-group compared to the G-group at T1 and T2 ($P < .01$).

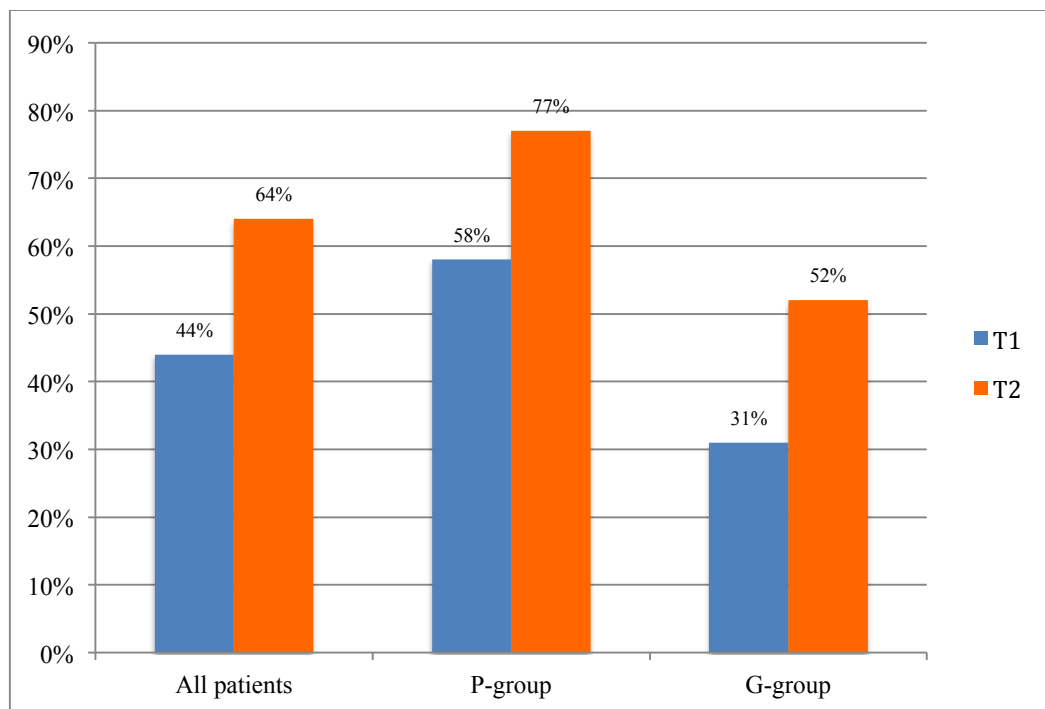


Figure 18. The mean of actual chance to avoid new cavities (%) at de-bonding (T1) and 4 years after de-bonding (T2) for the all patients merged together, and for the governmental (G) and private (P) groups separately.

Differences in caries-related factors between G-and-P groups at T1, T2, and over a 4-year period (T2-T1)

All patients in the G and P groups at T1 and T2 were free of any diseases or conditions that might be associated with dental caries.

The mean values of DMFS for the G-group vs. P-group at T1 and T2 were 15 vs. 8.5 and 16.8 vs. 10.8, respectively. The mean values of saliva secretion rate for the G-group vs. P-group at T1 and T2 were 0.9 vs. 0.9 and 1.6 vs. 2, respectively. Table 13 shows the categorical caries-related factors included in the Cariogram model for the G and P groups at T1, T2, and over the four-year period. The patients in the P-group were significantly better in the aspect of using fluoride products compared to the patients in the G-group, while the plaque count was significantly higher in the G-group compared to the P-group at T1 and T2. However, there was no statistically significant difference between the two groups in the other caries-related factors.

Over the four-year period, the saliva secretion rate was significantly increased, buffer capacity was significantly improved, and the plaque count was significantly decreased for the patients in both groups.

Table 13. Frequency distribution of categorical caries-related factors according to the cariogram score of the total number of individuals in the G-group and P-group at T1, T2; the significant differences are shown over a four-year period (T2-T1).

Factor	Cariogram	T1			T2			T2 - T1	
		G-group	P-group	P	G-group	P-group	P	$P_{G_{T2} - G_{T1}}$	$P_{P_{T2} - P_{T1}}$
Caries experience									
Caries-free	0	0	3		0	2			
Better than normal	1	11	11	NS*	9	11	NS	NS	NS
Normal for age group	2	0	1		0	1			
Worse than normal	3	9	5		11	6			
Diet frequency									
Maximum 3 meals per day	0	14	7		10	14			
4-5 meals per day	1	6	12		10	5			
6-7 meals per day	2	0	1	NS	0	1	NS	NS	NS
>7 meals per day	3	0	0		0	0			
Fluoride program									
F. supplements frequently	0	1	3		0	2			
F. supplements infrequently	1	1	2	< .05	2	4	< .05	NS	NS
Only fluoride toothpaste	2	18	15		17	14			
Not using fluoride toothpaste	3	0	0		1	0			
Plaque index									
No plaque	0	1	5		3	15			
Seen by probe/disclosing agent	1	5	10	< .05	13	5	< .001	< .001	< .001
Moderate	2	9	5		4	0			
Severe	3	5	0		0	0			
Saliva secretion									
Normal, > than 1.1 ml / min	0	3	9		13	12			
Low, 0.9 to < 1.1 ml / min	1	2	1	NS	3	4	NS	< .001	< .001
Low, 0.5 to < 0.9 ml / min	2	10	3		3	4			
Very low, < 0.5 ml / min	3	5	7		1	0			
Lactobacillus score (CFU/mL)									
0-10 ³	0	3	6		5	7			
10 ³ -10 ⁴	1	2	5		6	6			
10 ⁴ -10 ⁵	2	11	6	NS	4	4	NS	NS	NS
> 10 ⁵	3	4	3		5	3			
Mutans streptococcus (CFU/mL)									
0-10 ³	0	4	6		3	7			
10 ³ -10 ⁴	1	2	5		3	8			
10 ⁴ -10 ⁵	2	5	7	NS	10	4	< .05	NS	NS
> 10 ⁵	3	9	2		4	1			
Buffer capacity (pH)									
≥6.0, 'adequate'	0	5	8		13	17			
4.5-5.5, 'medium'	1	8	7	NS	3	2	NS	< .01	< .001
≤4.0, 'low'	2	7	5		4	1			

NS = Not Significant

Differences in the caries risk profile and caries-related factors between the control group and the test group at T2 (non-presented data in Study IV)

The number of participants, group, mean age, and gender are illustrated in Figure 19. No statistically significant differences were observed between the control and the test groups in the aspect of the mean of actual chance to avoid new cavities according to Cariogram. These results are applied when the G-control group was compared with the G-test group as well as when the P-control group was compared with the P-test group as shown in Figure 20.

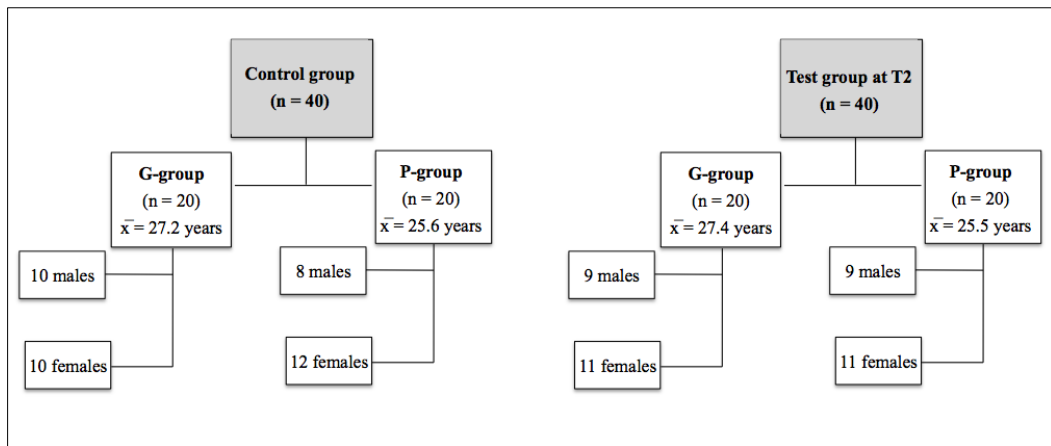


Figure 19. Flowchart shows the number, mean age, and gender of participants in the test and control groups.

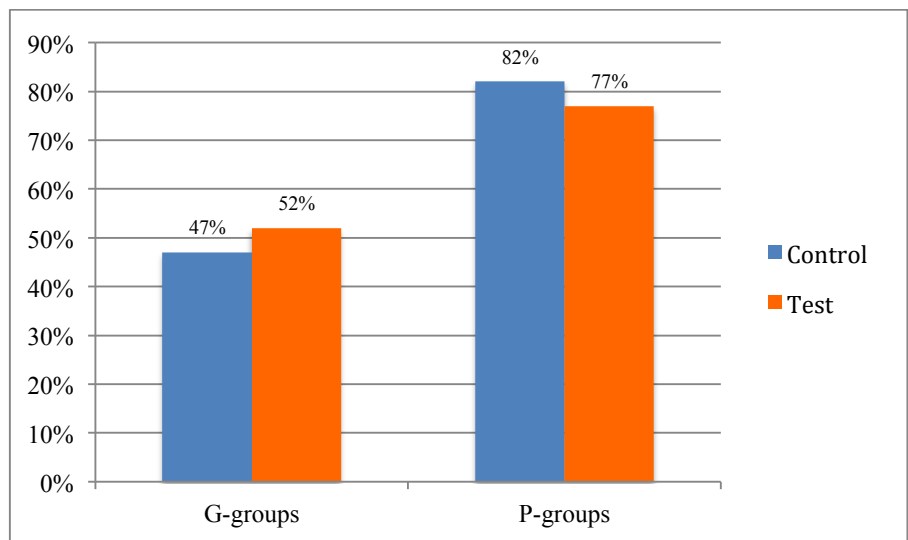


Figure 20. The mean of actual chance to avoid new cavities (%) for the Governmental (G) participants (control vs. test) and the Private (P) participants (control vs. test).

DISCUSSION

The outcome of this thesis reveals that in the KSA, orthodontic patients treated in governmental clinics have higher caries risks, as suggested by the Cariogram model (*Studies I and IV*), as well as a higher prevalence of buccal caries lesions (*Study II*), compared to patients treated in the private clinics. In addition, caries risks decreased four years after the orthodontic treatment for all orthodontic patients in both groups (*Study IV*). Scoring buccal caries lesions on digital photographs according to the clinical criteria was found to be a valid and reliable method (*Study III*).

Caries-related factors and risk in governmental and private orthodontic patients (Studies I and IV)

The alternative hypotheses in both studies were based on the findings of other studies (Wyne 2008; Brennan et al. 2011).

In order to check the intra-examiner reliability for clinical caries registration in the baseline study, the clinical caries examination was performed on two different occasions with two weeks in between for 20% of the patients; the Kappa value was 0.86.

The “caries experience” factor in the Cariogram model is evaluated by using the mean value of DMFS of a certain population. No epidemiological studies were performed to evaluate the mean value of DMFS on the Saudi population for the same age group included in these studies. Thus, the mean DMFS in *Study I* was set to be 4 following a cross-sectional study (Al Mulla et al. 2009), and the mean DMFS in *Study IV* was calculated from the baseline study to be 11. The adjustment in the mean values of DMFS from the baseline to the follow-up investigation may be one reason explaining the change in value of the green sector. However, the impact of the “caries experience” factor in the Cariogram model is unknown.

Salivary and microbiological tests in the baseline and follow-up investigation were performed using the same chair-side tests and analyzed using the same laboratory facilities. Also, the same laboratory technician was involved in reading the saliva and microbiological tests on both occasions (*Studies I and IV*).

The stimulated saliva samples were collected just before the de-bonding time at the baseline study. The results showed a low saliva secretion rate compared to the normal values that were found to be between 1 and 2 ml/minute (Wang et al. 1998). However, the follow-up investigation (*Study IV*) showed a statistically significant increase in stimulated salivary rate four years after de-bonding. This is possibly due to methodological problems, where the patients were unfamiliar with chewing paraffin tablets for the first time. The second explanation might be due to the difficulty of chewing paraffin tablets in the presence of fixed appliances. This finding is in contrast with other investigations claiming that orthodontic appliances increase the saliva secretion rate (Chang et al. 1999; Li et al. 2009; Mummolo et al. 2013). However, these studies were evaluating the saliva secretion rate before and during the early period of orthodontic treatment, while the present studies (*Studies I and IV*) investigated just prior to de-bonding and four years after the orthodontic treatment. Nevertheless, another study proved there were no significant differences in the salivary flow rate before, during, and after orthodontic treatment (Sanpei et al. 2010).

The significantly lower plaque index found four years after de-bonding (*Study IV*) is due to the presence of brackets and arch wires at de-bonding; this could be one of the reasons of decreasing the caries risk four years after de-bonding. This finding, in agreement with other studies, confirmed that fixed orthodontic appliances are associated with increased plaque accumulation (Chatterjee and Kleinberg 1979; Chang et al. 1999; Mummolo et al. 2013).

The number of cariogenic microorganisms, mutans streptococci and lactobacilli, did not significantly change after four years from de-bonding (*Study IV*). This finding contradicts other investigations that proved that cariogenic microorganisms increased after the placement of orthodontic appliances (Chang et al. 1999; Mummolo et al. 2013). However, these studies were investigating the number of cariogenic microorganisms before and during the early period of orthodontic treatment, while the present studies (*Studies I and IV*) investigated the cariogenic microorganisms just prior to de-bonding and four years after orthodontic treatment. Moreover, another study (Peros et al. 2011) showed that the period from the 6th to the 12th week of orthodontic therapy is the peak time for intensive intraoral growth of cariogenic microorganisms. The amount of cariogenic microorganisms then decreased afterward, which supports the findings in these studies (*Studies I and IV*) as the saliva was

collected for mutans streptococci and lactobacilli at de-bonding, 1.5 - 2 years from the start of orthodontic treatment, and four years after de-bonding.

The baseline study (*Study I*) showed that almost all caries-related factors according to the Cariogram were significantly different between the governmental and private groups that will definitely lead to different caries risks (green sector). Although, the follow-up investigation (*Study IV*) shows that few caries-related factors (two factors at de-bonding and three factors four years after de-bonding) were significantly different between the governmental and private groups, the caries risk was still significantly higher in the governmental group. These findings raised a very crucial question “which factor/factors has/have more impact on the Cariogram model?”. The plaque index and fluoride use were the only common factors that significantly differed between the governmental and private groups at de-bonding and four years after de-bonding.

The difference in caries risks between the two groups could be related to the payment method, where the patients in the private orthodontic clinics have to pay the full treatment fee, which in turn may encourage their motivation compared to those receiving orthodontic treatment for free in the governmental centers in the KSA. It has been shown that patients who have been treated in public clinics have poorer oral health than those treated in private dental clinics (Brennan et al. 2011). However, the variations in oral health have been largely attributable to socio-demographic factors and regularity of dental attendance rather than the method of payment itself (McGrath and Bedi 2003).

The differences in fluoride use and the plaque index between the governmental and private patients, as shown in Table 13, may explain the difference in caries risk between the two groups. These findings show the importance of instructing the orthodontic patients to improve the preventive measures, including routine oral hygiene with fluoride toothpaste, especially for the patients treated in the governmental centers. The modified fluoride toothpaste technique is recommended to reduce the incidence of new carious lesions in orthodontic patients (Al Mulla et al. 2010). The governmental patients show a higher prevalence of caries lesions on different tooth surfaces compared with the private patients, whereby this finding is in agreement with another study performed in preschool children (Wyne 2008).

Dental caries is a multifactorial disease caused by an interaction of several factors. It is difficult to accurately identify only one factor to be the main risk indicator for caries. Several studies have investigated different risk indicators for caries and there is no consensus toward a single factor. Some studies showed that the patients' exposure to dental caries at a younger age would place them at a higher caries risk (Delgado-Angulo and Bernabe 2006; Masood et al. 2012), while another, long follow-up study went against this finding (Ekbäck et al. 2012). Other studies investigated caries indicators including socioeconomic, dietary, gingival bleeding, smoking and oral hygiene habits with contradicting results (Boersma et al. 2005; Ayo-Yusuf et al. 2007; Ferreira Zandona et al. 2012). The level of lactobacilli microorganisms is found to be an important indicator for the caries risk assessment during orthodontic treatment (Sanpei et al. 2010). These contradicting results emphasize the need for future investigations and analyses to find out the accurate caries risk indicators and therefore, the proper prevention.

The findings in the comparison between the test and control groups indicated that the caries risk using the Cariogram did not differ significantly between patients who had fixed orthodontic treatment four years ago and those who had no fixed orthodontic treatment at all. This finding indicates that fixed orthodontic treatment increases the caries risk during treatment, but once it is removed, the caries risk decreased. However, this finding is not applicable on WSLs, which is the most frequent side effect of orthodontic treatment, since WSLs are not included in the Cariogram model. This seems to be a limitation of the Cariogram used on orthodontic patients, and this disadvantage should be considered if an updated version of the Cariogram model is planned.

Buccal caries lesions including WSLs in governmental and private orthodontic patients (Study II)

The alternative hypothesis in this study was based on the findings of other studies (Wyne 2008; Brennan et al. 2011).

The advantages of the DIAGNOdent Pen are; the method is more objective; the readings on the digital screen can be shown to the patient as a pedagogic method; it is

more informative to the patient; and it is more accurate. The disadvantages are that the device is expensive and the examination is more time-consuming. On the other hand, the advantages of ICDAS-II are; it costs nothing; is easy to use and less time consuming but is more subjective and less informative to the patient.

The inter-examiner and intra-examiner reliabilities of the ICDAS-II and the DIAGNOdent Pen for examining buccal caries lesions were evaluated and kappa values ranged between 0.87 and 0.93, which reveal substantial agreement (Landis and Koch 1977). These findings were in agreement with other studies (Lussi et al. 1999; Ismail et al. 2007).

A systematic review showed the limitations of using the laser fluorescence device as a principal diagnostic tool for detecting caries due to false-positive readings (Bader and Shugars 2004). In order to avoid false-positive readings by the DIAGNOdent Pen, the teeth included in this investigation were rinsed and dried with compressed air after being polished with a rubber cup and pumice paste as recommended (Lussi and Reich 2005; Lussi et al. 2006).

The percentage of the patients with at least one WSL after orthodontic treatment was 74%. This percentage is similar to another study reported using quantitative light-induced fluorescence (QLF) (Mattousch et al. 2007). Moreover, the prevalence of buccal caries lesions was not significantly differing between males and females. This finding is in agreement with other studies (Øgaard 1989; Lucchese and Gherlone 2013). However, other studies found that males had more tendencies to develop WSLs than females (Gorelick et al. 1982; Enaia et al. 2011), which could be explained by ethnic and cultural differences between the studied groups of patients.

This investigation revealed that the clinical criteria (ICDAS-II) correlated well with the DIAGNOdent Pen (*Spearman*=0.71). This correlation was measured based on the chance for the DIAGNOdent Pen to be in agreement with ICDAS-II for diagnosing different scores of WSL, but not vice versa. For example, 86% of teeth diagnosed with the ICDAS-II score 3 (dentin caries) had the same score using the DIAGNOdent Pen, while approximately 10% of teeth diagnosed with the DIAGNOdent Pen score 3 resulted in less than 1% of teeth having the same score using ICDAS-II. This could be due to the DIAGNOdent Pen tending to give a more positive diagnosis with lower specificity (Bamzahim et al. 2004).

Using digital photographs to evaluate buccal caries lesions in orthodontic patients (Study III)

The question from the beginning was: “Could digital photographs be used as a tool for detecting the progression of WSLs during orthodontic treatment?”. Based on the results showed in this study, which indicated that scoring the severity of buccal caries lesions on digital photographs is a reliable and valid method, the answer is YES.

The photographs in this investigation were taken after de-bonding, which may simplify the direct visual examination on photographs, however, a previous study proved that the presence of brackets would not influence the examination of WSLs on photographs (Livas et al. 2008). In addition, the photographs in this study were taken perpendicular to the facial surfaces since this technique was found to be reliable for evaluating WSLs (Benson et al. 2000; Livas et al. 2008). To validate the standardization, 13 calibrated screens were used to ensure the examiners utilized exactly the same measurements for direct visual examination of photographs. The first session of photograph scoring was utilized for comparison with the clinical examinations; the second session was performed to evaluate the intra-examiner reliability. The second scoring session showed slight improvement with respect to correlation with the clinical examination, with an increase in Spearman’s correlation coefficient from 0.76 to 0.79. This result is to be expected due to the training effect.

The results showed good intra-examiner reliability from the thirteen examiners for detecting different scores of buccal caries lesions, according to the modified ICDAS-II, with an agreement ranged between 52% and 83%. These findings are in agreement with another study that included three examiners (Enaia et al. 2011). In addition, inter-examiner reliabilities between each examiner and the clinical examination were moderate to excellent, with agreement ranged between 52% and 80%. These findings are in agreement with another study (Chapman et al. 2010).

The highest agreement between the direct visual examination of buccal caries lesions on digital photographs and the clinical examination was found during the evaluation of teeth with scores 0, 1, 4 and 5 (Figure 9). The lowest agreement was found when teeth had score 2. This can be explained by the easiness of distinguishing between sound teeth and teeth with exposed dentin (scores 0, 4 and 5), while score 2 lesions show enamel breakdown, which is easier to detect clinically by using the dental

explorer. Moreover, there was confusion when registering scores 1 and 3 on digital photographs. 10% of score 1 lesions examined clinically were registered as score 3 on the photographs, and 24% of score 3 lesions examined clinically were registered as score 1 on the photographs. One explanation could be that both scores (1 and 3) have no cavitation according to the definitions of the clinical criteria (Figure 9). A second explanation is that most of score 3 lesions accompany score 1 as well. Nonetheless, the examiners were instructed to register the worst score during the registration on the photographs. Overall, diagnosing the severity of buccal caries lesions on digital photographs is a valuable diagnostic tool for evaluating the progression of WSLs during orthodontic treatment, but further histological studies are needed to confirm this finding.

Clinical consideration and recommendations

In general, the results of this thesis show that dental caries during orthodontic treatment is a serious dental health problem in the Kingdom of Saudi Arabia. This requires the immediate attention of the government, represented by the Ministry of Health and the dental profession officials, in the Kingdom of Saudi Arabia. Epidemiological studies to construct baseline data for oral health as well as a good understanding of dental caries determinants are necessary for setting appropriate oral health goals. These goals cannot be achieved or even progressed without having baseline data that describes the current situation. A roadmap with a clear starting point, pathway, and destination is a desperately needed tool to improve the oral health of the Saudi Arabian citizens undergoing orthodontic treatment.

CONCLUSIONS

The conclusions from this thesis were that:

- *Studies I and IV:* Caries risks in orthodontic patients at de-bonding and four years after de-bonding were greater in patients treated at governmental clinics compared to those treated at private clinics according to the Cariogram. Caries risks decreased four years after the orthodontic treatment for all orthodontic patients regardless of which clinics they were treated at. Thus, the alternative hypothesis was accepted.
- *Studies I and IV:* Fluoride use and plaque index are the most significant indicators for caries risk when the government and private groups were compared. Increased salivary secretion rate, decreased plaque amount, and the improvement of buffer capacity were the most significant factors in decreasing caries risks four years after de-bonding.
- *Study II:* Orthodontic patients treated at governmental clinics show a higher prevalence of buccal caries lesions at de-bonding, compared to those treated at private clinics, thus, the alternative hypothesis was accepted. The clinical criteria (ICDAS-II) shows a good correlation with the laser fluorescence device (DIAGNOdent Pen), thus, the null hypothesis was rejected.
- *Study III:* Scoring buccal caries lesions on digital photographs according to ICDAS-II criteria is a reliable and valid method for assessing the severity of buccal caries lesions during orthodontic treatment. Thus, the null hypothesis was rejected.

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