Orthodontically induced root resorption: a clinical and radiographic survey

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To Despoina. The woman who brought me to life and became the most important support to every step of mine till now.

CONTENTS

ABSTRACT

Orthodontically induced root resorption: a clinical and radiographic survey

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In 2005 the Swedish Council on Health Technology Assessment (SBU), in a systematic review, Malocclusions and Orthodontic Treatment in a Health Perspective, concluded that there were low or contradicted evidence for an association between orthodontic treatment and the risks for negative side effects.

The aims of this study was to evaluate the perception of Greek and Swedish orthodontic practitioners view on orthodontically induced root resorption (OIRR), to investigate how root resorption is handled in a large orthodontic clinic and to prospectively study and correlate the prevalence and severity of root resorption seen after an initial treatment period and at the end of treatment, in a cohort of patients treated with fixed appliance.

Orthodontic practitioners' perception of how to evaluate, prevent, predict and diagnose root resorption during orthodontic treatment was the aim of the first two studies. Questionnaires were sent to and received from randomly selected Greek (n - 90) and Swedish (n-106) orthodontic practitioners (Study I) and records of all patients (n-902) who terminated active treatment during one year at the Department of Orthodontics, University Clinics of Odontology, Göteborg, Sweden were examined (Study II). The results showed that because there was no specific approach offered in the literature, the prevention and treatment reassessment in cases of root resorption relied on the individual practitioners' perception (Study I). Periapical radiographs were taken in most cases before treatment and at the end of treatment half of the patients were radiographically examined (Study II). When moderate root resorption was diagnosed the use of lower forces, resting periods and decrease of treatment time were common preventive measures (Study I and II). Light root resorption was found in less than 10% while severe root resorption was noted in 2% of the patients after active treatment (Study II).

The prevalence and severity of root resorption seen during a standardized orthodontic fixed appliance treatment was studied on a cohort of 156 adolescent patients. Cone beam computed tomography (CBCT) examinations were performed before and after treatment and, in a randomly chosen group of 97 patients, six months after treatment initiation (Study III). All teeth from first molar to first molar in both jaws were measured. The results showed that after 6 months of treatment, clinically significant resorption was diagnosed only in 4% of the patients (Study III). At the end of treatment, clinically significant resorption was diagnosed in 25.6% of the patients (Study IV) and no correlation with the resorption seen after 6 months were found (Study IV). The selected risk factors did not have any impact on the amount of resorption seen after 6 months of treatment (Study III) or at end of treatment (Study IV). Since no correlation was found between the severities of root resorption at the end of treatment with the one present at six months, one could conclude that a radiographic examination after 3-6 months of orthodontic treatment will not reduce the number of patients who will have one or more teeth with severe or extreme root resorptions (Study IV).

Keywords: Orthodontics, root resorption, prediction, CBCT, Angle Class I, fixed appliance, six months, risk factors

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PREFACE

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals (I-IV)

I. Makedonas D, Hansen K. Diagnosis, screening and treatment of root resorption in orthodontic practices in Greece and Sweden. Angle Orthod. 2008 Mar;78(2):248-53.

II. Makedonas D, Odman A, Hansen K. Management of root resorption in a large orthodontic clinic. Swed Dent J. 2009;33(4):173-80.

III. Makedonas D, Lund H, Gröndahl K, Hansen K. Root resorption diagnosed with cone beam computed tomography after 6 months of orthodontic treatment with fixed appliance and the relation to risk factors. Angle Orthod. 2012 Mar;82(2):196-201.

IV. Makedonas D, Lund H, Hansen K. Root resorption diagnosed with cone beam computed tomography after 6 months and at the end of orthodontic treatment with fixed appliances and the relation to risk factors. Submitted.

INTRODUCTION

General background

In the literature the terms resorption and absorption have received considerable interest in order to describe apical root material loss (Becks 1932). Root resorption is a normal essential physiologic process for the deciduous teeth and acts as a precursor for permanent teeth eruption. Root resorption of the permanent teeth is a complex biological process of which many aspects remain unclear (Brezniak 1993).

The aetiologic factors causing permanent teeth resorption have been investigated in several studies (Phillips 1955; Reitan 1985; Shafer 1983): physiologic tooth movement, adjacent impacted tooth pressure, periapical or periodontal inflammation, tooth implantation or reimplantation, continuous occlusal trauma, tumours or cysts, metabolic or systemic disturbances, local functional or behavioural problems, idiopathic factors and orthodontic treatments. Since 1914 (Ottolengui 1914) orthodontic treatment has been found to cause root resorption. From then on, studies have accused orthodontics as a major factor for external apical root resorption (Weiland 2003; Lundgren et al. 1996; Sabri 2002; Thilander 1992; Levander et al. 1998) even for the invasive type (Heithersay 1999) and since on, the term orthodontically induced inflammatory root resorption (OIRR) is used in the literature (Brezniak et al. 2002).

Root resorption as a factor induced by orthodontics

Prevalence

Incidence statistics for prevalence of orthodontically induced root resorption vary from 1.1% (Mayoral 1981) to 100% (Harry et al. 1968). This variation depends on: the examination methods (Stenvik et al. 1970); the choice of the criteria of root resorption (Janson et al. 1999); the type of appliance and forces used; the extent of the tooth movement; the group of teeth examined; the

duration of the treatment; and the dental age (Levander et al. 1994). However, in most studies, only a small percentage of severe and/or moderate resorption is reported (Harry et al. 1982; Janson et al. 1999; Ronnerman et al. 1981; Alexander 1996; Lupi et al. 1996; Goldson et al. 1975; Tahrir et al. 1997; Fritz et al. 2003) and even for lingual orthodontics (Fritz et al. 2003). Even if orthodontic treatment is considered to be aggressive from dental professionals concerning the attitude towards root resorption effect, root resorption tends to be an expected side effect of the orthodontic procedure (Lee et al. 2003). The prevalence of more severe root resorption in the literature varies less and ranges from 2-15% (Fritz et al. 2003; Harris et al.1992; Lupi et al. 1996; Tahrir et al. 1997)

From the group of teeth examined, the majority of the published articles considers that those teeth most prone to apical root resorption are the maxillary incisors (Weiland 2003; Linge et al. 1991; Rupp 1995, Fritz et al. 2003) and mostly the laterals (Sameshima et al. 2001; Goldson et al. 1975), followed by the mandibular incisors (Reed 1985; Kennedy et al. 1983), and the maxillary premolars (Newman 1975; Tahrir et al. 1997). Incidence on maxillary molars has also been described (Beck et al. 1994; Tahrir et al. 1975).

Classification

Orthodontically induced inflammatory root resorption is classified regarding the root surface location and the number of affected teeth: as internal or external, local or general. Andreasen (1988) defines three types of root resorption: 1) surface resorption (a self-limiting process); 2) inflammatory resorption (when initial root resorption has reached dentinal tubules); and 3) replacement resorption (when bone replaces the resorbed dental material and leads to ankylosis). Inflammatory resorption is classified as i) transient, when stimulation to the damage is minimal and for a short period which is radiographically undetectable (this damage is repaired by a cementum like tissue (Tronstad 1988); and ii) progressive, when stimulation exists for a long period.

Orthodontics: distinct root resorption as surface resorption or transient

inflammatory resorption. It results from mechanical forces, which, when applied to the biologic system, act similarly on bone and cementum which are separated by the periodontal membrane. Since cementum is more resistant to resorption, applied forces usually cause bone resorption which leads to tooth movement, though, resorption of the cementum and dentin may also occur.

The root resorbing cell, the odontoclast, has the same cytologic and functional characteristics of the osteoclast. Resorption of the calcified dental tissues occurs if osteoclasts obtain access to the mineralized tissue by a breach in cell layer covering the tissue, if the mineral and matrix surfaces coincide, or when the precementum is mechanically damaged or scraped off. The mineralized or denuded root areas attract hard tissue resorbing cells to colonize the damaged area of the root. The demineralization of the calcified tissue and the degradation of the organic matrix have been attributed to osteoclast.

The resorbing activity as a response to mechanical or chemical stimuli by the periodontal ligament cells is characterized by synthesizing prostaglandin E with a concomitant increase cAMP. This process is regulated by hormones (parathyroid and calcitonin), neurotransmitters and cytokines or monokines (interleukin-1, 2, TNF) (Brezniak 1993; Rossi et al. 1996) and due to these factors, permanent teeth exhibit more resistance to enzyme and acid attack than deciduous teeth during differential resorption of the latter (Lee et al. 2004; Davles et al. 2001).

Resorbed lacunae appear mainly in the pressure side and rarely in the tension side. It has been claimed that root resorption during orthodontic treatment occurs in the same areas where physiologic root resorption originates. Hyalinization precedes the root resorption process during orthodontic treatment. Loss of root material occurs adjacent or subjacent to this area. Three grades of hyalinization are described: degeneration, elimination of destroyed products and reestablishment.

After application of force it can take 10 to 35 days for the resorbed lacunae to appear. Clinically this resorption degree cannot be detected radiographically, especially when occurring in buccal and lingual surfaces (Reitan 1974).

According to Schwartz (1932), when pressure decreases to the optimal force (20-26 g/cm2), root resorption ceases. Repair of resorbed lacunae is seen 35 to 70 days after force application.

Correlation factors

The several studies which have been undertaken, posed significant correlation of orthodontically induced root resorption and several factors which can be classified as biologic, mechanical and combined (Brezniak 1993).

Individual susceptibility, which discloses a genetic component, is considered a major factor in determining root resorption potential with or without orthodontic treatment in permanent and deciduous teeth (Kharbanda et al. 2004; Harris et al. 1997; Qawasmi et al. 2003). Susceptibility to root resorption has been identified even between different races (Sameshima et al. 2001).

Systemic factors, attributed to endocrine problems such as hypothyroidism, hypo- or hyper-pituitarism, or Paget's disease, have been linked to resorption (Becks 1939). Pathological lesions, periodontal problems (Rupp 1995), and allergies (Moll 1995) also act positively to the presence of root resorption.

Chronological age. A positive relationship has been reported (Linge 1983), though most of the studies consider age as not significant (Weiland et al. 2003; Horiuchi et al. 1998; Costopoulos et al. 1993; McFadden et al. 1989; Hendrix et al. 1994; Thongudomporn et al. 1998; Harris et al. 1997; Beck et al. 1994).

Dental age. Root development can affect the susceptibility to root resorption. Teeth with not completely formed roots present lower susceptibility (Hendrix et al. 1994; Mavragani et al. 2002; Dougherty 1968).

Gender. Treated random samples showed no correlation (Linge et al. 1991; Parker et al. 1998; McFadden et al. 1989; Goldin 1989; Spurrier et al. 1990; Fritz et al. 2003; Beck et al. 1994). According to other study, females are more susceptible to root resorption (Spurrier et al. 1990).

Presence of root resorption before treatment has been proved to be a strong factor for the severity of root resorption after orthodontic treatment (Kjaer

1995). Moreover root resorption diagnosed in the first stage of treatment (6-9 months), even to a minor degree, is also significantly correlated with the severity of root resorption (Levander et al. 1998, Rupp 1995).

Habits. Finger sucking (Linge et al. 1991) tongue thrust, and nail biting have been statistically correlated with orthodontically induced root resorption (Odenrick et al. 1983, Rupp 1995)

Root formation anomalies, regarding long (Lundgren et al. 1996, Ericson et al. 2000) or short (Lundgren et al. 1996), invaginated, pipette shaped or blunt roots (Thongudomporn et al. 1998; Kook 2003; Kharbanda 2004), agenesis (Levander et al. 1998; Kjaer 1995) or ectopia of adjacent teeth mostly for the maxillary canines (Linge et al. 1991; Sasakura et al. 1984; Oesterle 2000; Rupp 1995), which are considered to be indicative of OIRR potential.

Previously endodontically treated teeth, have been proved more resistant to orthodontically induced root resorption (OIRR) (Spurrier et al. 1990).

Trauma. Previously traumatized teeth exhibit a higher frequency and severity concerning OIRR (Linge et al. 1991; Linge et al. 1983; Rupp 1995; Tulloch et al. 2003).

Skeletal and dentoalveolar parameters have been provided with controversial reports (Ericson et al. 2000; Thilander 1992; Otis et al. 2004; Mirabella et al. 1995;Taithongchai et al. 1996). Facial type has also been attributed a role in OIRR. Significant relations have been found with root cortical proximity (Horiuchi et al.1998) and OIRR.

Types of maloccusion have been significantly correlated with OIRR. Overjet and overbite (Linge et al. 1991; Brin et al. 2003), Class III (Kaley et al. 1991), open bite with the following condylar changes (Kjaer 1995; Rupp 1995; Harris et al. 1992) have been regarded as important factors, even though other studies found no relation of types of malocclusion and OIRR (Thongudomporn et al. 1998; Linge et al. 1983; Harris et al. 1997; Mirabella et al. 1995).

As far as mechanical factors are concerned:

Appliances use is related as a function to the degree of OIRR. Fixed appliances use is more detrimental to the root (Weiland et al.2003; Linge et al. 1991). In comparing the several techniques of orthodontic treatment there has not been found any significant difference in causing OIRR between Begg, standard edgewise, SPEED, and Tweed (Beck et al. 1994; Reukers 1998; Blake et al. 1995; Sameshima et al. 2001), full versus sectional (Alexander 1996), except the boefficient therapy (Janson 1999) which incorporates thin super-elastic wires, resulting in lesser degree of OIRR. The use of Class II intermaxillary elastics has been proved to result in OIRR providing jiggling forces (Linge et al.1983; Mirabella et al. 1995) and even Class III elastics used for anchorage preparation increased mandibular first molars OIRR (Dougherty 1968). Rapid maxillary expansion has been reported to cause significant amounts of root resorption of the first maxillary molar (Cureton et al. 1999).

Extraction versus non-extraction orthodontic treatment approaches has provided contradictory results (Hendrix 1994; Blake 1995; Parker et al. 1998; Sameshima et al. 2001).

Orthodontic movement type. It seems that there is no safe tooth movement. Intrusion is probably the most detrimental to the roots involved (Faltin et al. 1998; Costopoulos et al. 1996), but tipping, torque, bodily movement and palatal expansion can also be implicated (Wehrbein et al. 1995; Wehrbein et al. 1996; Segal et al. 2004).

Orthodontic forces. Higher stress is found to cause more OIRR (Rupp 1995; Darendeliler et al. 2004; Kurol 1996), although there are studies which prove that the amount of OIRR remains stable even when the stress is doubled or increases with forces of low magnitude (Moll 1995, Owman-Moll 1996). Contradictory results have been provided regarding the use of continuous versus intermittent forces (Acar 1999).

The combined biological and mechanical factors include:

Treatment duration. Most studies report that OIRR severity is directly

related to treatment duration (Horiuchi et al. 1998; Sameshima et , al. 2001; Segal 2004, Levander et al. 1998). Only a few studies did not support this finding (Bishara et al. 1999; Beck et al. 1994; Hendrix et al. 1994). Finally the approach of treatment in two phases versus one phase has been proven to lower the amount of OIRR (Brin et al. 2003; Labee et al. 1985). The practitioner as a factor (Sameshima et al. 2001), and the presence of maxillary surgery history (Mirabella et al. 1995) have been correlated with OIRR.

OIRR usually ceases once the active treatment is terminated (Ghafari 1997; Remington 1989) and remodelling of the sharp and blunt edges can be observed and reparative process can be seen two to three weeks after treatment termination (Moll 1995). Recent treatment approaches indicates that OIRR refers to low intensity ultrasound application to the root resorption.

Prediction and diagnosis

Many studies considered orthodontics as a factor for external root resorption. There has been evidence that comprehensive orthodontic treatment causes increased incidence and severity of OIRR. There are reports varying from 1% (Mayoral 1981) to 100% (Harry et al. 1968) for external root resorption among orthodontically treated patients.

The factors that are significant for the development of OIRR and are considered to be prediction factors are: finger and nail biting (Linge et al. 1991; Odenrick et al. 1983; Rupp 1995), root formation anomalies (Mirabella et al. 1995; Nigul 2006; Thongudomporn 1998; Levander et al. 1998), traumatized teeth (Linge 1983; Weltman et al. 2010), allergies (Linge 1983), amount of tooth movement and forces applied (Owman-Moll et al. 2000; de Freitas et al. 2007), duration of treatment (Segal et al. 2004; Pandis et al. 2008; Liou et al. 2010; Apajalahti et al. 2007; Zhong et al. 2007; Jiang et al. 2010), and gender (Mohandesan et al. 2007; Pandis 2008)

The most common tool the clinician uses in order to diagnose root resorption is radiography. The majority of the clinical studies use periapical radiography, which leads to root resorption diagnosis (Brezniak 1993). However the

technique has its own limitations which are difficult to overcome (Brezniak et al. 2004; Gegler et al. 2008; Heo et al. 2001; Reukers et al. 1998). Despite its limitations the radiographic technique that has the most favourable benefit to risk ratio is the paralleling technique. It provides less distortion and superimposition errors compared with the orthopantomogram or the lateral headfilm with the least irradiation to the patient (Sameshima G et al. 2001). The latest incorporation of the digital radiographs, can show small alterations in root length in the early stage.

Another radiographic technique for diagnosis is panoramic radiography. It has been reported in some studies that panoramic radiographs are not an accurate method to depict the anterior maxillary and mandible regions (Witcher 2010; Armstrong et al. 2006). The technique is also sensitive to the patient's positioning because of its relatively narrow sharp layer and shape of focal trough. The use of a lateral radiography in combination with panoramic radiographs has been proposed to reduce the shortcomings in the anterior regions (Leach et al. 2001).

Additional clinical consideration includes the reassessment of treatment goals if moderate root resorption is detected during the beginning of orthodontic treatment; the patient's dental history, or the risk of OIRR and the need for the termination of poor oral habits; the application of orthodontic forces to auto transplanted teeth or surgically repositioned impacted teeth six to nine months after surgery (Desai 1999); and the evaluation of the risk of mobility when the remaining root length of a severely resorbed tooth is less than 10 mm (Levander et al. 2000).

Since it is impossible to predict OIRR, periodic radiographic control should be undertaken for complete orthodontic records and for the assessment of root/bone integrity during treatment. Several protocols suggest that radiographic examination should take place in the first three to six months and then every year after appliance placement. The practical usage of the first radiographic evaluation in the first six months to diagnose and predict OIRR has not yet been studied thoroughly.

Cone beam computed tomography

The evolution in computer science in the late 1990s was the starting point for the use of cone beam computed tomography (CBCT) in dental and maxillofacial imaging (Arai et al. 1999). CBCT was developed as way of imaging the cardiopulmonary function in the beginning of 1980 at the Mayo Clinic Biodynamics Research Laboratory (Robb 1982).

CBCT is a term used to describe a technological development which comprises a large variety of machines which differ from each other. The functional mode of CBCT is that a cone-shaped x-ray beam makes a circular movement around the patient. The center of this circular movement is positioned in the middle of the point of the concerning region.

The lowering of the radiation dose which the patient receives is possible through the aperture from which the radiation exits. The x-ray tube is in the form of a square or rectangle, making the circular base of the cone the same shape. The size and shape of the primary aperture determine the size of the cylindrical tissue volume that becomes irradiated (field of view –FOV). On the other side of the x-ray tube, a detecting device is mechanically connected to the tube by means of a horizontal or vertical gantry; the former is relevant to sitting or standing patients, and the latter for patients in a supine position. The explosion when the tube rotates is either continuous or pulsed, synchronized with the data acquisition. Two-dimensional image data is offered, in either the continuous or pulsed mode, from the machine detector and then all the received data are transferred to a computer where volumetric data are produced during the primary reconstruction. The data can then be seen as two- or three-dimensional by multiplanar reformation for the first (two-dimensional view) or by segmentation of the data set and surface reconstruction for the second (three- dimensional view) (Scarfe and Farman 2008). The unit element of the image volume is the voxel. The size of the voxel is the element which influences the spatial resolution. The contrast resolution depends on the number of gray levels that each voxel can attain. This is described as bit- depth and the number of gray levels is described as two raised to the power of a specific number.

CBCT can produce thin tomographic images at any direction which increases the capability of investigation at the bone level and the root surface, which is not visible with conventional orthopantomographic radiographs. CBCT also ensures that the same anatomical structures can be compared over time. This is possible because the technique creates scenes similar to previous ones and is not influenced by changes in root/tooth position which may occur during the orthodontic treatment procedure.

This technique should not be considered as a CT variant (Molteni 2008). To avoid confusion between the terms CBCT, CT and MSCT (multi-slice CT), the clinicians often used the term DVT (digital volume tomography).

Methods to study root resorption

Intraoral periapical radiography has been used as a primary method to study apical root resorption (Brezniak et al. 1993a, 2002b). This method has limits even when efforts are made to obtain radiographs which are periodontically identical or to compensate for image distortions by using mathematic algorithms (Brezniak et al. 2004a, Katona 2006, 2007, Dudic et al. 2008, Chapnik et al. 1989, Gegler et al. 2008). Root shortening had to occur in order to observe resorptions on the buccal or palatal surfaces of the root's apical part. This was shown in an in vitro study by Follin and Lindvall (2005).

Since teeth are moved, rotated and tipped during orthodontic movement one cannot achieve identical irradiation geometry with standard radiological techniques. Therefore, it can be safely assumed that digital subtraction radiography for OIRR cannot be applied successfully.

Root apices in anterior regions in panoramic radiographs become placed outside the narrow focal trough. In Class II and III cases and in cases with excessively proclined and retroclined teeth is not always possible to position both upper and lower front teeth within the focal trough (Leach et al. 2001). It has been found in the study by Sameshima and Asgarifar (2001) that panoramic radiographs overestimated by 20% or more the amount of root resorption compared with periapical radiographs. Lateral cefalometric radiography is of

no use in detecting root resorption because of the supositioning of the teeth (Leach et al. 2001). Therefore, studies based on this technique were excluded in the review which was held by the Swedish on Council on Technology Assessment in Health Care.

Nowadays, for more demanding tasks CT can be used in the form of multi-slice computed tomography (MSCT). However, in orthodontics the radiation exposure to the patient limits its use to complex maxillofacial malformations and to treatment planning before advanced orthognathic surgery.

GENERAL AIMS

The general aims of the present thesis, based on four studies later referred to by their roman numerals (I-IV), are to investigate how practitioners deal with root resorption and how they react when it is found (Papers I,II) and the incidence, susceptibility of the teeth and the correlation with significant factors mentioned in the literature (Papers III,IV).

Specific aims

The specific aims of the studies on which the present thesis are based are to:

- Evaluate the perception of orthodontic practitioners in Greece and Sweden regarding the occurrence and prognosis of root resorption in orthodontic treatment and to investigate the practitioners' approaches regarding diagnosis of root resorption before treatment, screening of prevalence, and treatment planning when root resorption occurs during treatment (Paper I).
- Investigate, describe and analyze how root resorption is handled in a large orthodontic clinic and if these approaches are in accordance with the guidelines described in the literature. The prevalence of root resorption which was found in radiographic material is also estimated (Paper II).
- Estimate the prevalence and degree of OIRR on individuals after six months of active treatment with fixed appliances and to study the correlation of early root resorption with some risk factors (Paper III).
- Investigate the prevalence and degree of orthodontically induced root resorption (OIRR) after active treatment with fixed appliances, the possible correlation of the severity of root resorption with the root resorption presented after six months and at the end of active orthodontic treatment, and to study its relation to possible risk factors (Paper IV).

MATERIALS AND METHODS

Study material (I, II)

In the first study (I), one hundred and fifty questionnaires were sent to orthodontic practitioners randomly selected for each country (Sweden and Greece). After the research, 233 and 375 registered active orthodontists were found in Sweden and Greece respectively and finally, 106 completed questionnaires were received from Sweden (45 %) and 63 from Greece (16,8%). Of the practitioners who answered the questionnaires, 100% of the Greek respondents and only 18% of the Swedish respondents worked in private practice. Of the Swedish orthodontists, 82% worked in public clinics. The questions to be asked included: i) the presence of pre-treatment history records concerning the possible predisposing factors for root resorption, regarding prognosis of root resorption; ii) the radiographic evaluation of root resorption before, during and after treatment concerning the initial examination, the type and the frequency of radiographs taken; iii) the treatment approach of initial prevention of root resorption concerning the type of appliances, the duration, the type (continuous versus interrupted) and the magnitude of forces used; and iv) the treatment approach and protocols, in cases of radiographic diagnosis of root resorption during treatment (see Appendix I for the full questionnaire).

The examination of all journal and radiographic records was held (Study II) for all patients who underwent termination of active treatment with fixed or removable appliances during the year 2004 at the Department of Orthodontics, University Clinics of Odontology, Göteborg, Sweden. From the written or electronic records, 920 patients were found and, among them, adequate information was found in 837 patients. The factors studied included: treatment information such as type of appliances; duration of treatment and extraction of teeth; the presence of journal recordings of predisposing factors (e.g. trauma, oral habits, bruxism, root shape abnormalities and pre-existing root resorption); the presence of radiographic examinations before, during and after treatment

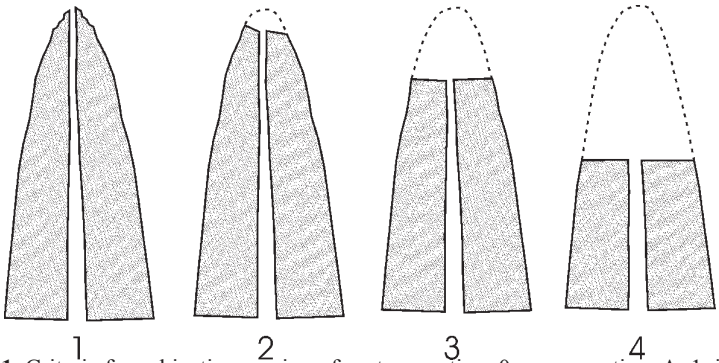


Figure 1. Criteria for subjective scoring of root resorption. 0, no resorption; A, 1, irregular root contour; B, 2, apical root resorption less than 2 mm of original root length; C, 3, apical root resorption from 2 mm to 1/3 of original root length; D, 4, apical root resorption exceeding 1/3 of original root length. Adapted from Malmgren et al 1982.

(i.e. the type, frequency and of which regions radiographs were taken); the prevalence of moderate or severe root resorption reported; and the treatment approach and protocols followed when root resorption occurred before or during treatment. All the patients' journals were analyzed and the information was summarized in a computerized protocol. Comparison of root resorption with the radiographic findings and interpretation into the Malmgren index (1982) was also performed (Figure 1).

Study patients (III, IV)

Between March 2005 and June 2008 patients to the Department of Orthodontics, University Clinics of Odontology, Gothenburg, Sweden, were invited to take part in the study. The patients had to fulfil pre-defined inclusion criteria: aged 9-18 years, Class I malocclusion and a treatment plan which includes the extraction of four premolars. Informed consent from the parents as well as ethical approval from the Ethics Committee and from the Radiation Protection Committee, Sahlgrenska Academy at University of Gothenburg, Sweden was obtained. The treatment protocol was standardized using an MBT pre-adjusted appliance with 0.022-inch slots. For each patient, a protocol was added to the records with notations of known risk factors (Table 1).

Every patient had to complete a questionnaire, before treatment, and pre-existing root resorption and root anomalies were recorded by the examiner.

Table 1. Prevalence of risk factors among 97 patients with and without root resorption

	No root resorption (score 0 & 1)	Root resorption (score 2 & 3)
Nail biting	19	2
Nail biting history	24	4
Finger sucking	0	0
Finger sucking history	17	0
Trauma	22	3
Root form anomaly	21	4

The anomalies were also recorded based on the classification of root shape (Figure 2) derived from Levander and Malmgren (1988).

Radiographic examination

A radiographic examination (CBCT) was performed in all subjects before treatment (88 females and 68 males) before and after treatment, and in 97 patients randomly selected, after six months of active treatment with fixed appliances. All examinations were performed with three-dimensional Accuitomo FPD (J Morita Mfg Corp, Kyoto, Japan) (Figures 3 and 4) the x-ray tube tension was set to 75 kV, the tube current to 4–5.5 mA and volume 60 mm x360 mm with a full 17.5-second scan rotation. The exposure covered all teeth in both jaws. In order to describe root shortening, changes in tooth

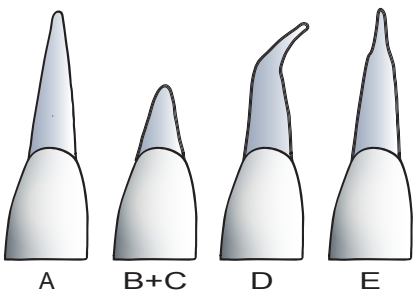


Figure 2. Root shape classification according to Levander and Malmgren (1988). (A) Normal, (B) short, (C) blunt, (D) bent, and (E) pipette shape at root apices.

Figure 3. The CBCT unit.

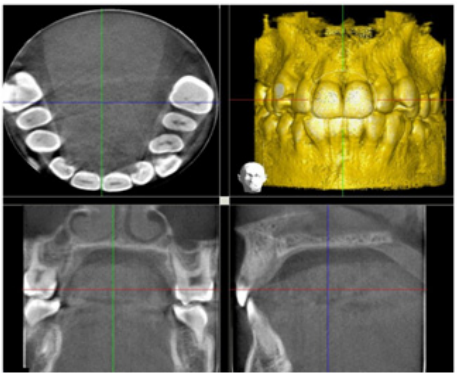


Figure 4 3D CBCT Radiographic images

length between the pre-treatment examination and the six-month examination were subjectively converted into an index originally designed for intraoral radiography by Malmgren et al. 1982 (Figure 1).

Statistical analysis

Statistical analysis was performed for Studies II-IV. Linear regression analysis was used in the second study in order to investigate the association between root resorption (independent value, Malmgren index) and the different anamnestic and treatment parameters. Associations were considered significant if $P<0,05$. Fisher's exact test was used in the third study in order to investigate the incidence of patients with root resorption and existing risk factors. $P>.05$ was considered not statistically significant. The relationship between risk factors and the amount of root resorption was analyzed with Spearman's rank correlation analysis. Fisher's exact test was performed in order to find differences between the numbers of patients with root resorption in the risk factor groups. $P\geq0.05$ was considered not statistically significant. Also, when root resorption at end of treatment was used as a grouping variable in conjunction with number of teeth affected or the duration or treatment the method used was Analysis of Variance.

RESULTS

Diagnosis, screening and treatment of root resorption in practices in Greece and Sweden (Study I)

The study focused on three major steps for the diagnosis, screening and treatment of OIRR. The use of pre-treatment radiographs and especially the periapical radiographs are common in both the Greek and Swedish clinics. From Figures 5 and 6 it can be observed that the percentage of Greek orthodontists using both periapical and panoramic radiographs is 32.3%. On the other hand the percentage among the Swedish orthodontists is 31.5% for using only periapicals and for both periapical and panoramic radiographs this percentage climbs to 47.1%. Figure 7 shows that Swedish orthodontists use periapical radiographs in the upper and lower frontal region more than the screening in the posterior region. In contrast, Greeks use periapical radiographs in mostly the upper and lower canine to canine region. Swedish orthodontists considered – on a scale of 1 to 10 (1 being of no importance and 10 being of great importance) – that panoramic radiographs were of little importance (4/10) for the anterior region and of average importance in the posterior region (7/10). However the Greeks

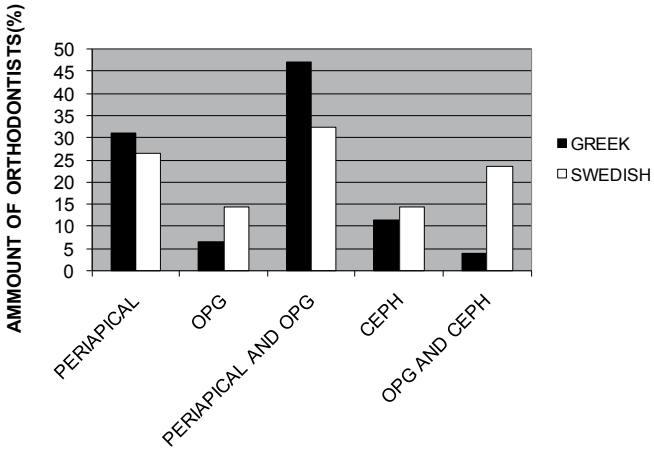


Figure 5. Amount of different types of radiographs used by Greek and Swedish practitioners to diagnose initial root resorption before treatment.

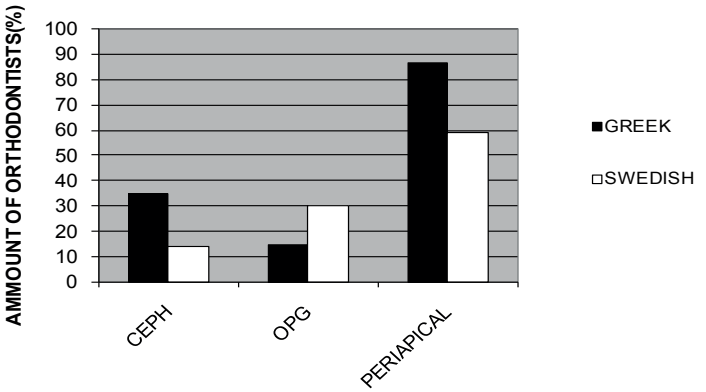


Figure 6. Comparison of the regular use of radiographs by Greek and Swedish practitioners for the initial diagnosis of root resorption.

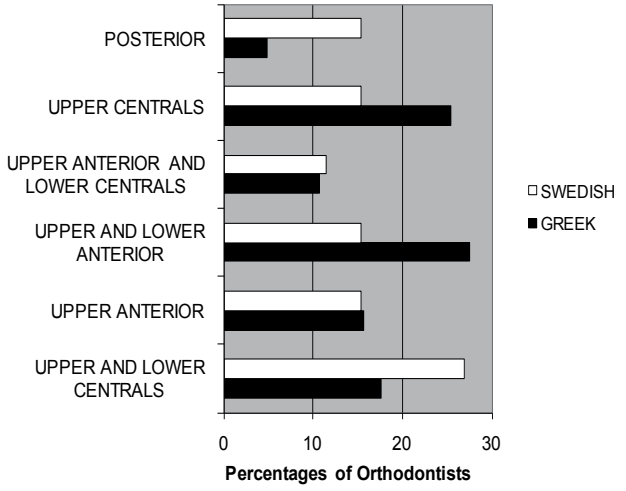


Figure 7. Comparison of the regular use of radiographs by Greek and Swedish practitioners for the initial diagnosis of root resorption.

considered panoramic radiographs to be of average importance (7/10) in both regions.

The risk factors for developing OIRR were also included in this study. Ninety eight per cent of Swedish and 67% of Greek clinicians kept a journal of predisposing factors before treatment. Between the Swedish and Greek clinicians it is accepted that trauma is a considerable risk factor of high importance. Differences were discovered when the two groups were asked to

consider whether root anomalies were a considerable risk factor. Seventy nine per cent of Swedish orthodontists considered root anomalies to be a risk factor. In contrast, 64% of Greek clinicians considered it to be a risk factor. Systemic diseases and oral habits were considered to be of greater importance by Swedish orthodontists (50% and 93% respectively) than by Greek orthodontists (47% and 50% respectively).

Even if pre-existing root resorption had been diagnosed, 83% of Swedish and 44% of Greek clinicians still carried out orthodontic treatment. Among the Swedish orthodontists, 37% would stop treatment if up to one third of the root length was resorbed during treatment and 41% would stop treatment if up to half the root length was resorbed. Of the Greek orthodontists, 48% would stop treatment if up to one third of the root length was resorbed and 29% would stop treatment if up to half the root length was resorbed.

Seventy-five per cent of Swedish orthodontists and 56% of Greek orthodontists performed a radiographic follow-up for diagnosis of root resorption during treatment. Eighty five per cent of Swedish orthodontists and 15% of Greek orthodontists performed a radiographic follow-up after six months of treatment. Moreover, 25% of Swedish orthodontists and 42% of Greek orthodontists performed radiographic follow-ups after one year of treatment.

Eighty-three per cent of Swedish orthodontists and 76% of Greek orthodontists had rarely treated cases with pre-existing root resorption. It has been observed that both groups of clinicians gave instructions concerning the discontinuation of oral habits before treatment (91%).

Greek orthodontists consider, among several factors that are recognized to be important, resting periods, biting foreign objects and bruxism as significant, whereas Swedish orthodontists were more likely to name resting periods and bruxism as significant (Table 2).

When asked to consider the total amount of root resorption in their patients, Greek orthodontists diagnosed no root resorption in 55% after treatment, up to 2mm in 42% of their patients and up to one third resorption in 2.6% of their patients. On the other hand the Swedish clinicians diagnosed no root resorption

Table 2. Evaluation of the importance of predisposing factors for root resorption, from a scale from 0 (no importance) to 10 (great importance).

	Finger sucking	Resting periods	Bruxism	Thin roots	Blunt roots	Biting objects
Greek	LOW (3.6)	HIGH (7.4)	AVERAGE (5.1)	AVERAGE (4.0)	LOW (3.4)	AVERAGE (5.4)
Swedish	LOW (3.5)	AVERAGE (5.9)	AVERAGE (5.6)	LOW (3.4)	LOW (2.0)	LOW (3.8)

in 47% of their patients after treatment, resorption of up to 2mm in 41% of patients and resorption of up to one third in 8% of patients.

When root resorption is diagnosed in a moderate volume (2mm-1/3) the most common approach for the Swedish clinicians was the use of lighter forces, resting periods and alteration of the treatment plan. On the other hand Greeks tended to use lower forces and decrease the total duration of the treatment (Figure 8).

When severe root resorption is diagnosed (> ½) before treatment, the most common approach for both populations of practitioners was not to treat or alter the treatment plan (Figure 9).

When moderate root resorption was diagnosed during treatment, both populations of orthodontists used lower forces and decreased the treatment duration. In addition, the Swedish orthodontists frequently used rest periods (Figure 10).

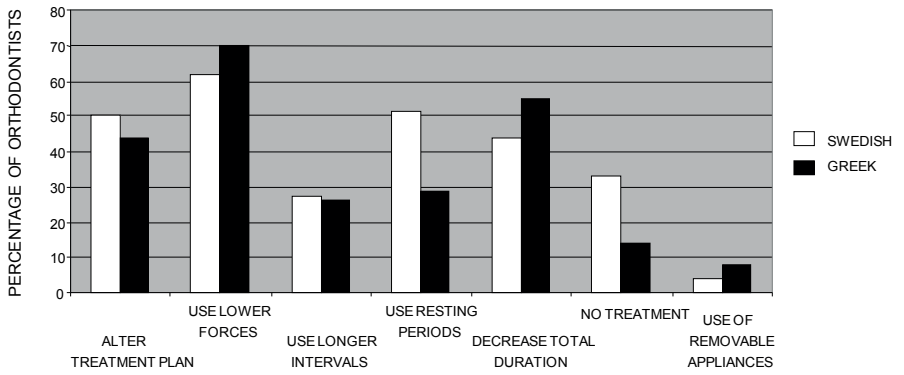


Figure 8. Treatments modalities when moderate root resorption (from 2mm up to one third of the root length) is diagnosed before treatment

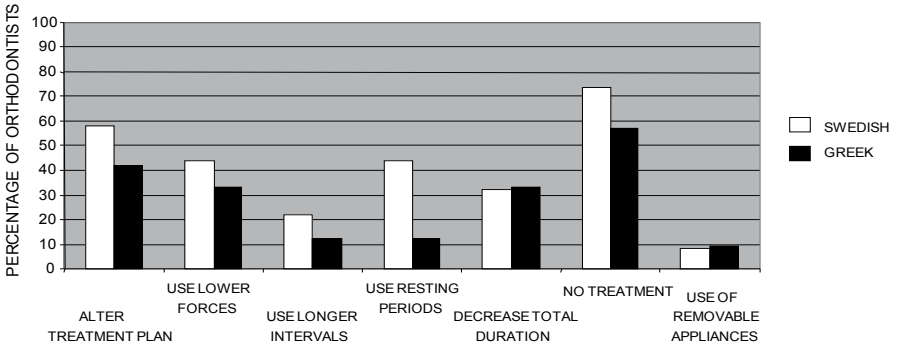


Figure 9. Treatments modalities when severe root resorption (half of the root length or more) is diagnosed before treatment.

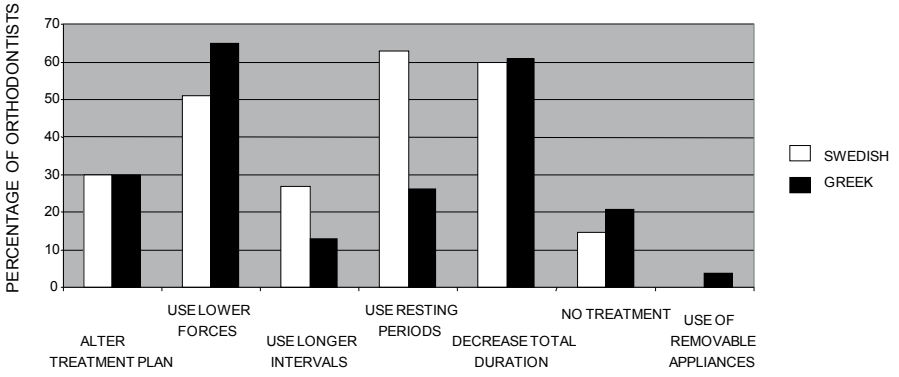


Figure 10. Treatments modalities when moderate root resorption (from 2mm up to one third of the root length) is diagnosed during treatment.

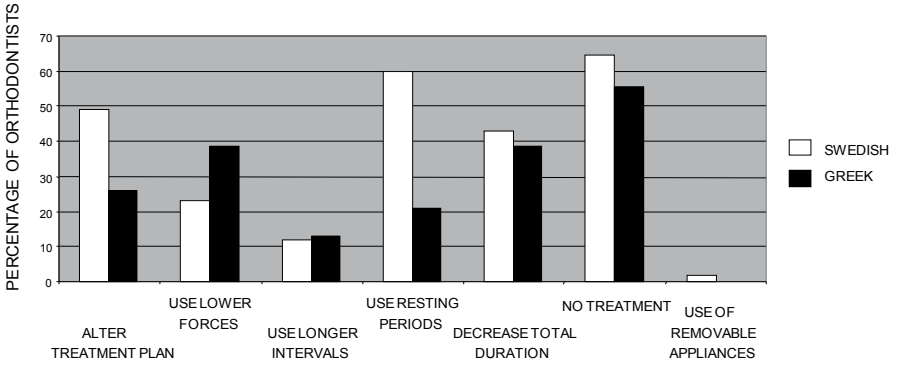


Figure 11. Treatment modalities when severe root resorption (half of the root length or more) is diagnosed during treatment.

When severe root resorption was diagnosed during treatment, both clinicians stopped treatment or decreased the total duration with same degree. The Swedish clinicians used resting periods most frequently. On the other hand Greeks used lower forces more commonly (Figure 11).

Management of root resorption in a large orthodontic clinic (Study II)

The number of patients with adequate records of orthodontic treatment was 837 of which 502 (60%) were females and 335 (40%) were males. The mean treatment duration was eighteen months. Seventy nine per cent of patients were treated with fixed appliances and 12% received removable appliances (i.e. extra oral traction and activators). Nine per cent received combined treatment with growth modification appliances and 54% of patients had two or more premolars extracted during treatment.

In considering the predisposing factors recorded in the patients' records, the most frequent registrations observed were trauma and nail biting (Figure 12). Eight per cent of patients recorded trauma as a predisposing factor, while 20% of patients were recorded as nail biters. Concerning the root shape anomalies or the pre-existing root resorption and finger sucking, these factors were thought to be important predisposing factors. In 19.8% of patients root anomalies were

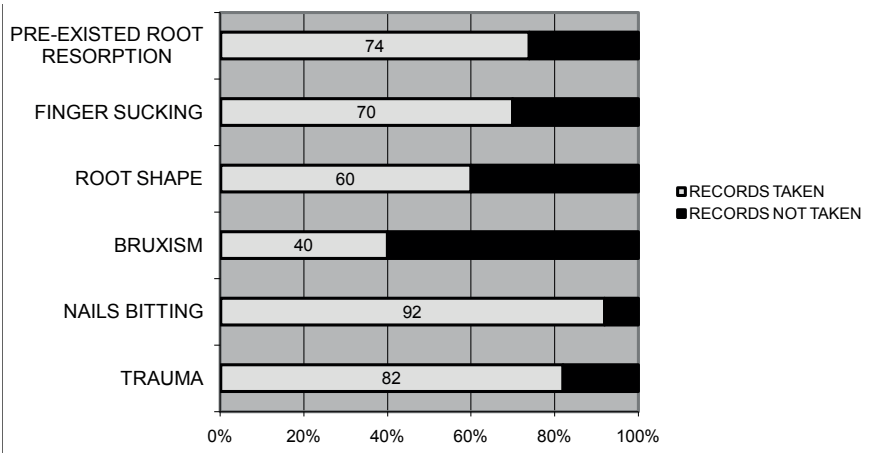


Figure 12. Percentage of history records taken before treatment regarding the various predisposing factors.

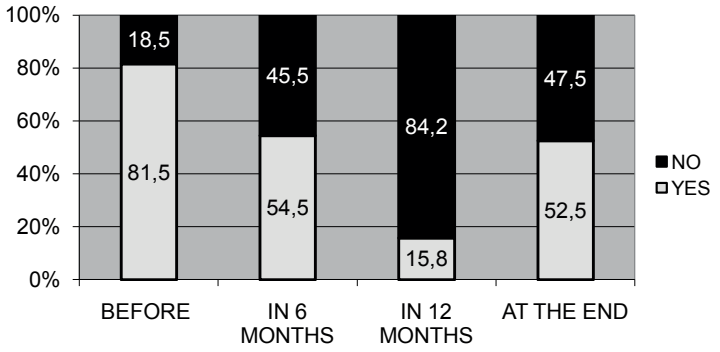


Figure 13. Percentage of periapical xrays taken in different stages of orthodontic treatment.

diagnosed, and in 5% of patients root resorption was found. Furthermore, 2% reported finger sucking habits and 23% reported bruxism at the start of treatment.

Continuously, 81.5% of the patients were examined with periapical radiographs (Figure 13) for the diagnosis of root resorption. After three months' treatment the percentage of patients who were radiographically examined dropped to 54.5% while only 15.8% of the patients were examined twelve months after active treatment. As the end of treatment, 52.5% of the patients were examined with periapical radiographs.

It is necessary to mention that before treatment 2.8% of patients had neither intraoral nor panoramic radiographs while 15.7% had only panoramic radiographs but no periapical. In 82% of the patients examined with intraoral radiographs, the examination covered the upper and lower cuspid to cuspid region while in the remaining 8% the examination was limited to the lateral to lateral region. After six months of active treatment 78% of the periapical radiographs were taken in the same region.

The use of panoramic radiographs before treatment was undertaken in 80.1% of patients, and after treatment in 45% of treated patients (Figure 14).

Cephalometric radiographs were taken in 68.2% of patients before treatment and in 36.3% of patients after treatment (Figure 15).

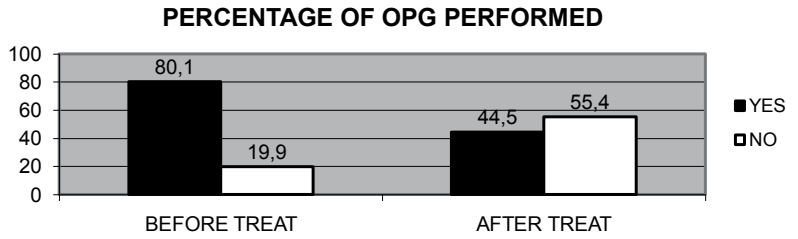


Figure 14. Percentages of panoramic radiographs performed before and after the orthodontic treatment.

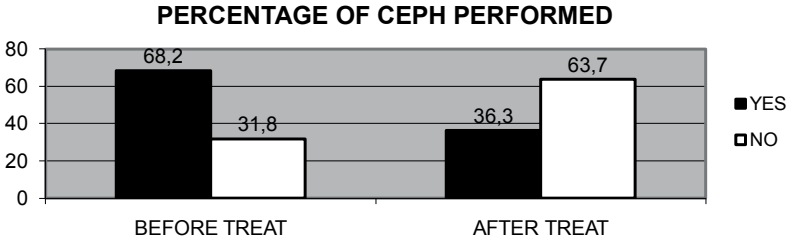


Figure 15. Percentages of cephalometric radiographs performed before and after orthodontic treatment.

Neither panoramic nor cephalometric radiographs were taken in 18.4% of patients before treatment while both types of radiographs were taken in 42.2% of patients before treatment. After treatment the corresponding values were 30.4% and 31% respectively.

In order to calculate the prevalence of root resorption during and after treatment, the patients' records showed light root resorption in 1.9%, 3.2%, 4.9%, and 8.6% at the beginning, six months, twelves months of treatment, and at the end of treatment respectively.

Severe root resorption was only reported in 1% of patients after twelve months of active treatment and in 1.9% at the end of active treatment (Figure 16).

Multivariable regression analysis (Table 3) revealed no significant associations between root resorption reported and gender, treatment duration, extractions treatment, and so on. Association of $P< 0.05$ was, however, found between root

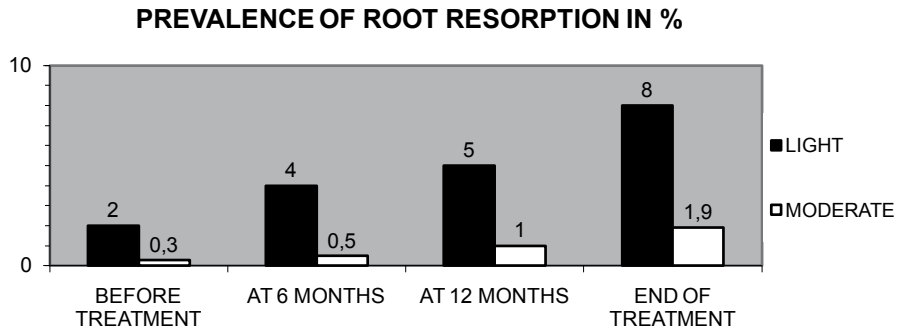


Figure 16. Prevalence of root resorption reported by orthodontic practitioners at the different stages of active treatment.

Table 3. Results of multivariate regression analyses using Root Width indices (I, II, III, and IV) as dependent variables.

Variable	Unit	Effect	P
Age at treat.start	years	0.05	.87
Sex	m(0)/f(1)	0,03	.73
Pre-existed resorption (6 months)	yes/no	0,11	<.05
Treatment duration	months	0,09	.65
Trauma	yes/no	0.04	.69
Root width Index	I, II, III, IV		
Root form anomaly	yes/no	0,09	.20
Finger sucking	yes/no	0.04	.79
Nail biting	yes/no	0.01	.84
Bruxism	yes/no	0.08	.20
Extraction treatment	yes/no	0.06	.22

resorption reported after the first six months of active treatment and at the end of treatment (Table 3).

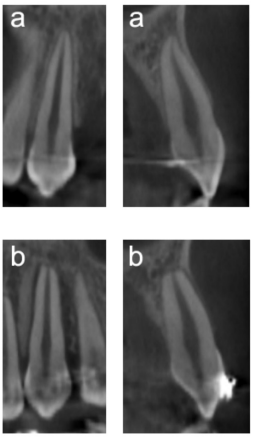
When root resorption was diagnosed in 8% of the cases, the treatment regime was altered. In cases when moderate root resorption (2mm to one third of the root length) was diagnosed, the use of lower forces, resting periods and decrease of treatment time were common preventive measures by clinicians. When severe root resorption occurred, (half or more of the root length) the majority of orthodontists stopped treatment or decreased the total duration of the therapy.

Table 4. Distribution of affected teeth and their severity of root resorption; index scores 2 (II) and 3 (III) according to the index described by Malmgren et al. (1982).

Tooth	16	15	14	13	12	11	21	22	23	24	25	26	43	42	33	35
Case no																
5														II	II	II
8							II									
34					III	III	III	III								
37					III			III	III				III		III	
56						II										
75					II						II					
96					II	II	II	II								
99						II										
104					II	II	II	II								
107								II				II				
111	II			II		II		II								
133					III	III	III	III								
135			III							III						
149							II									

Root resorption after six months of orthodontic treatment – relation to risk factors (Study III)

In Table 4, root resorption is shown together with the number of affected teeth. At the six-month control, ten patients were diagnosed with root resorption with a score of two, a score of three (Figure 17) was found in four patients, and none with a score of four. Irregularities were observed in most of the teeth before orthodontic treatment, thus root resorption was considered present when scores of two and higher were observed. The highest frequency of root resorption was detected in the upper jaw, especially in the incisors. In the lower jaw, in two patients root resorption was found.



Firure 17 Reformatted CBCT images (cropped) of upper left canine in frontal and sagittal views obtained at baseline (a) and after 6 months of treatment (b). Resorption index was judged to be score 3 after the 6 months of treatment

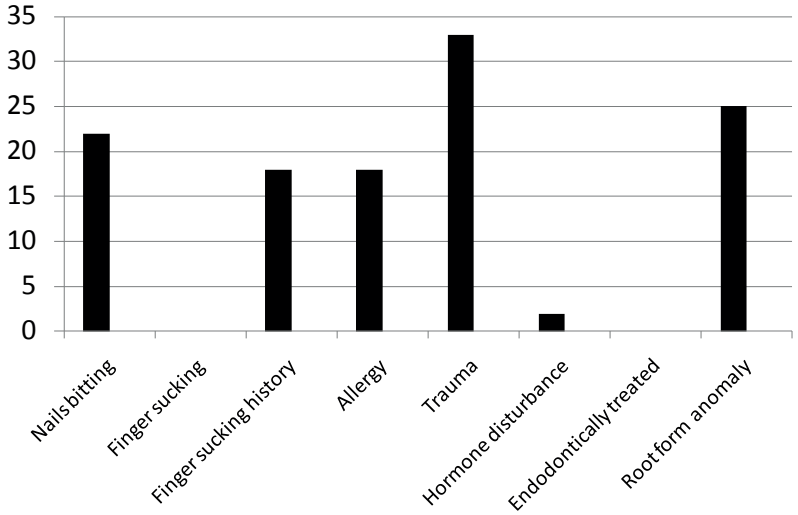


Figure 18. Prevalence (in per cent) of risk factors among patients.

No statistically significant relationship of root resorption with any of the risk factors showed in Table 4 was found among the 97 patients. Nobody had any endodontically treated teeth and none of them was still finger-sucking. Furthermore, no statistically significant correlation of root resorption with the selected risk factors or gender or molars relation has found (Figure 18).

Root resorption at the end of orthodontic treatment – relation to risk factors (Study IV)

The results after the end of the orthodontic treatment showed minor root resorption (a score of two) in 82 patients (52,5%); in 40 patients a score of three was detected (25,6%); and in only one patient a score of four was found. In the anterior zone (lateral incisors), root resorption was most frequently detected in the upper jaw (Figure 19). On the other hand, the lower canines were the most frequently affected teeth. In only one patient root resorption was detected at the end of the treatment (a score of four) in the upper central and lateral incisor. The same teeth, at the six month control was found with root resorption score 3.

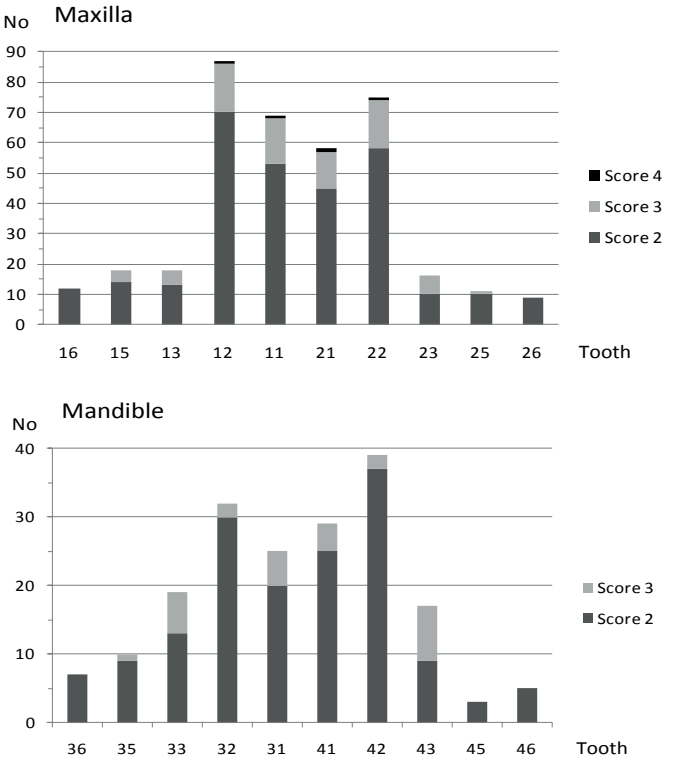


Figure 19. Distribution of root resorbed teeth according to the counts in each teeth group (upper and lower jaw) at the end of treatment.

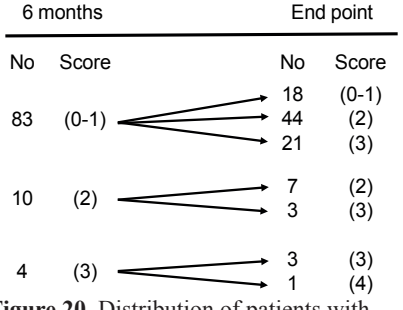


Figure 20. Distribution of patients with different scores of root resorbed teeth according to the presence of different scores of root resorption at six months and at the end of treatment.

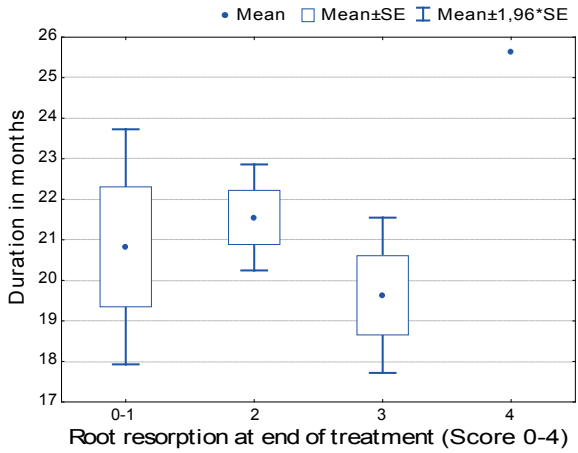


Figure 21. Distribution of patients with different scores of root resorbed teeth according to the treatment duration in months.

No correlation was found between root resorption at six months and at the end of the treatment (Spearman R=0,05, p=NS) (Figure 20).

The statistical analysis showed no significant relation of nail biting with root resorption of upper anterior region (canine-canine). No correlation between the duration of the treatment and root resorption at the end of the treatment was found and no relation of the total number of affected teeth and the duration of the treatment at the end of the treatment can be confirmed (Figure 21).

DISCUSSION

Orthodontic treatment is nowadays, worldwide, very common and the patients who seek treatment have multiplied. The orthodontic process has been accused of causing permanent tooth resorption as a side effect and numerous studies since 1914 (Ottolengui) have induced the term of external tooth resorption. Various studies confirm that incidence statistics for the prevalence of orthodontically induced root resorption varies from 1.1%-100% (Mayoral 1981; Harry and Sims 1968). Orthodontically induced inflammatory root resorption is classified as internal or external, local or general. The several studies which have been undertaken (Weiland 2003; Lundgren et al. 1996; Sabri 2002; Thilander 1992; Levander et al. 1998), posed significant correlation of orthodontically induced root resorption and several factors which can be classified as biologic, mechanical and combined.

Radiographs are commonly used as a diagnostic aid for external root resorption. The radiographs that are most used by the clinician in order to diagnose OIRR are the periapical and panoramic radiographs. Despite its limitations the radiographic technique that has the most favourable benefit to risk ratio is the paralleling technique. It provides less distortion and superimposition errors compared with the orthopantomogram or the lateral headfilm with the least irradiation to the patient. In the present study cone beam computed tomography (CBCT) was used because it can produce thin tomographic images at any direction, which increases the capability of investigation of the bone level and root surface which is not visible with conventional orthopantomographic radiographs. CBCT also ensures that the same anatomical structures can be compared over time. This is possible because the technique creates scenes similar to previous ones and is not influenced by the changes in root/tooth position which may occur during the orthodontic treatment procedure.

The present thesis investigates how practitioners deal with root resorption, how they react when it is found and the incidence, susceptibility of the teeth and the correlation with significant factors mentioned in the literature.

Comparison of diagnosis, screening and treatment between Greek and Swedish practitioners (Study I).

Investigation of diagnosis, screening and treatment of root resorption in two European countries was performed in the first study. The techniques which practitioners use in common for preventing root resorption were revealed. Moreover the differences in the working mode between the two countries were evaluated in order to investigate the influences which might occur in the approach to the root resorption question.

A greater rate of response from Swedish orthodontists was noticed compared with the Greek practitioners. This might bring into question the representative results of this study. This does not influence the results because the point was to investigate the difference in their perceptions and the difference in their guidelines in order to prevent root resorption and how it influences the different working conditions, education and research activities in the two countries. The Swedish orthodontists are highly active in research and produce 2% of the articles published worldwide (Bondemark et al. 2005). According to the Swedish Dental Association, 23.5% of orthodontic practitioners work in private clinics in Sweden (Swedish Dental Association 2003). In contrast, the Greek practitioners provide private services and thus, information are limited for research.

In most countries periapical radiographs are the most common method of diagnosing root resorption. In Greece, more emphasis is given to panoramic radiographs in the anterior region. Among the Swedish practitioners oral habits and root anomalies are in the middle on the scale of the risk factors for the development of root resorption. The influence of the studies of Levander and Malmgren (1998; 1994) has much to do with the practice of Swedish orthodontics that result in the performance of a radiographic follow-up of root resorption six months after initiation of treatment.

On the other hand, Greeks are more confident in their ability to prevent root resorption from developing and reported root resorption of null to 2mm in their treated patients in comparison with 88% of Swedish orthodontists. This

is in accordance with the fact that orthodontists in Greece more rarely perform radiographic follow-ups during and after therapy.

When root resorption occurs in Sweden the treatment change of choice is resting periods rather than the use of lower forces, which are common in Greece. This is the different approach of the treatment plan in the two countries and this is occurred from the fact of lack of literature approach in Greece rather than in Sweden. The prevention and treatment reassessment rely on the individual practitioner.

Management of root resorption (Study II)

The yearly flow of patients at the clinic was around 1,000. Treatment is usually performed with fixed appliances. Patients with removable appliances are mostly treated by general dentists in practices in the Community Dental Health Service in Goteborg, Sweden. This study investigates how the treatment went and from this point of view the type of the study was retrospective. The prospective study will, naturally, change the behaviour of the specialist as they know that their actions are being monitored and registered. The total number of patients recorded in the study was 930. Nine per cent were excluded due to absence or limited data in their records. The majority of the annotations in the journal records that address predisposing factors were related to trauma, root shape anomalies and nail biting (DeShields 1969; Linge et al. 1991; Thongudomporn et al. 1998). The most common radiographic investigation was periapical radiographs in order to diagnose root resorption. Fifty four per cent of patients had a radiographic follow-up performed after six months of active treatment. The recommendations of Levander and Malmgren (1994; 1998) are not followed by all orthodontists. In order to estimate, predict and monitor root resorption, the radiographs were considerably less than that reported in a previous study among Swedish orthodontists conducted using questionnaires (Makedonas et al. 2008). This indicates that although the knowledge exists, daily practice differs due to priorities of daily routine. However, when root resorption was diagnosed before and during orthodontic treatment, all the necessary measures were in accordance with the recommendations of the

literature and in agreement with the previous survey (Levander et al. 1998). After six months of treatment the prevalence of moderate root resorption was 3.2%, and 8.6% at the end of the treatment. The results were in agreement with several studies of root resorption after treatment with fixed appliances (Alexander 1996; Ronnerman et al. 1981). Severe root resorption was prevalent in 9.5% of cases at six months, and 1.9% at the end of treatment. The results were less than the results in previous studies reported (Levander et al. 1998; 2000). In contrast, deviations in the prevalence of root resorption reported in the literature are common due to the differences in the use of the material, methods and criteria. The number of patients examined radiographically decreased significantly between the different examination studies but still 456 and 439 out of 837 were examined radiographically at six months of treatment and at the end of the treatment, respectively. It is obvious that the prevalence of root resorption is based in a large patient sample. The association found in this study, between final radiographic investigation of root resorption and the initial data of predisposing factors of the patients, as gender, extraction treatments, duration of the treatment etc, were not significant (Table 3). These results are in contrast with previous surveys (Linge et al. 1991; De Freitas et al. 2007; Kaley et al. 1991). However this retrospective study is based on journal records and it is not known if all clinician orthodontists asked questions on all predisposing factors and in a structured manner. When the results of the present survey are compared with the first study (which was based on a questionnaire where Swedish orthodontists were asked how they deal with root resorption in their common practice) it seems as if the predisposing factors are recorded, and recommendations on treatment measures are followed, but that radiographic monitoring during treatment is not performed to the extent that the orthodontists stated. More studies are needed to evaluate the evidence of early radiographic detection and prevention of severe root resorption (Swedish Council on Technology Assessment in Health Care 2005).

Ethical consideration

In order to investigate root resorption after six months and at the end of the therapy in patients with fixed appliances, radiographs were taken (Study III,

IV). Therefore informed consent from the parents as well as ethical approval from the Ethics Committee and from the Radiation Protection Committee, Sahlgrenska Academy at the University of Gothenburg, Sweden, was obtained. CBCT was selected because it has a fairly low radiation dosage compared with other advanced radiographic methods (Tsiklakis et al. 2005; Schulze et al. 2004) and the amount of radiation could be considered similar to that of eight panoramic radiographs (Helmrot et al. 2010). Also CBCT has the capability to create scenes similar to the previous scenes despite any changes in tooth/root positions as a result of orthodontic treatment. This advantage ensures the comparison of identical anatomical structures each time.

Root resorption after six months of orthodontic treatment and its relation to risk factors (Study III).

A large and extensive scale of radiographic examination was performed on a number of patients with the same type of malocclusion and with a comparable treatment plan. The ability to detect and quantify root resorption which is associated with the orthodontic treatment is crucial both for patients and clinicians who deal with the sequelae of root resorption and for the researchers who try to decipher its causes and mechanisms. Thus, early detection and monitoring of root loss, and its quantification, are important. The traditional radiographic investigation methods for clinically assessing root resorption are, unfortunately, suspect (Katona 2007). Root resorption assessment estimates cannot reliably compensate for the inherent distortions in radiographic evaluations of EARR, even in the presence of an idealized, perfect linear tooth (Katona 2006). Some studies demonstrate that conventional periapical radiography is not a secure technique in order to detect external root resorption in its early stages (Chapnick 1989). CT scans and CBCT proved to be good for diagnostic evaluation in the identification of simulated external resorption (Silveira 2007; Liedke 2009). Patel et al. (2009), in a further clinical study, compared the accuracy of conventional intraoral radiography and CBCT in the diagnosis and management of external cervical and internal resorption lesions. Durack et al. (2011) clearly demonstrated that CBCT has excellent sensitivity and specificity in the detection of simulated external resorptions lesions, and

that CBCT performs significantly better than digital intraoral radiography in this regard. This is due to the fact that CBCT provides information in the third dimension, coupled with the fact that images can be reconstructed such that overlying noise is eliminated. The effective radiation dose to patients when using CBCT is higher than digital radiography and any benefit to the patient of the CBCT scan should outweigh any potential risks of the procedure in order to be justified. Regardless of the type of ERR, CBCT imaging can only be justified clinically in situations where the possible information it provides will impact directly on treatment. Because of the three-dimensional views of CBCT, Estrela et al. (2009) has proved that root resorption's extension and the surfaces involved were defined more accurately and at earlier stages by using CBCT scans.

The aim was to study the early evidence of root resorption and its relation to certain predictive factors. In order to obtain a correct evaluation of the amount of OIRR and to minimize the error in the radiographic evaluation, the preparation of the study included the use of CBCT examination before, six months after the beginning of, and at the end of the treatment. The so called "Malmgren index" (Malmgren et al. 1982) was originally adopted for use with intraoral periapical radiography. The advantage of the index is that it sets a threshold that is clinically relevant and is fairly easy to apply in daily practice. The CBCT technique revealed that almost every tooth had some irregularity in the apical root contour, even in images obtained before treatment. Hence, there would have been an overestimation of the presence of OIRR if a score of one had been included. Further, irregular root contours are perhaps not clinically significant. A score of two (< 2mm) on the other hand is a small but clear resorption, and from a clinical point of view a useful threshold for defining minor root shortening. In the literature, only a few studies have been published which investigate OIRR in all teeth in both maxillae and mandibles during the beginning of orthodontic therapy. The present study, in agreement with previous surveys (Levander et al. 1998; Smale et al. 2005; Levander et al. 1988) confirms that some orthodontic patients developed OIRR during the initial stage of the therapy with fixed appliances. On the other hand, the number of patients with more evident resorption was small. Four out of 97

patients had been classified with a score of three. In one of these patients OIRR was found on the first maxillary premolars (Table 4), a tooth which is not monitored with radiography during the treatment or included in scientific papers in early root resorption. However resorption was seen only in the upper jaw in the incisor region. One patient was noticed to have an OIRR score of three in the lower canine (Table 4). The findings of this study were less severe in comparison to the results of the Smale et al. (2005) study, who reported that 8.5% of patients with one or more maxillary incisors with a score of three after three to nine months of treatment. In this study the corresponding number was 3.1% (Table 4). Even larger differences were discovered for the less severe OIRR cases, where Smale et al. (2005) found a score of two in one or more incisors in 40 % of patients. In the present study (Table 4) a score of two was registered in 9.3% of maxillary incisors. Levander and Malmgren (1988) also investigated OIRR during initial orthodontic treatment. Their results showed a higher number of resorbed teeth with a score of two than the present study. On the tooth level which is a less correct way of presenting clinical due to the influence of the individual, the number of teeth with more severe resorption (a score of three) in the present study is quite similar to the number of teeth in the studies of Smale et al. (2005) and Levander and Malmgren (1988) and the present study (Table 7). The lower numbers of teeth with minor resorption (a score of two) found in the present study compared to Smale (2005) and Levander and Malmgren (1988) (Table 7) might be explained by the different radiographic technique used. In intraoral radiography especially in orthodontics where teeth are moved and the angulation of the teeth are changing during treatment, projection error is a great problem and this makes periodical identical radiographs more or less impossible. The CBCT technique, however, controls projection geometry for each individual tooth (Lund et al. 2010) and this way projection errors are minimized for tooth length variations of 2 mm. This is possible to explain the low number of score 2 resorption in the present study. More severe root resorption is probably not as sensitive to technique and therefore there no significant differences in the results in these studies (Table 7). No correlation has been found between OIRR and the selected predisposing factors, probably because of the small sample of patients with evident root

Table 7. Root resorption in maxillary incisors on tooth level in three different studies. In the present study 388 maxillary incisors in 97 patients were studied before and after six months of treatment. Resorbed teeth in per cent of maxillary incisors.

	No of teeth	Score 0	Score 1	Score 2	Score 3
Levander & Malmgren	390	29.0%	36.7%	33.1%	1.3%
Smale *et al.*	1081	47.1%	29.9%	19.4%	3.6%
Present study	388	93.3%		4.1%	2.6%

resorption. In a systematic review showed (Weltman et al. 2010) that OIRR is unlike when previous trauma and tooth morphology occurs. This supports the findings of the present study. The results from the present study showed that almost 50% of the patients with an OIRR score of three (>2mm) had abnormal shaped roots, but no statistical significant correlation was found. Levander et al. (1998) has also reported that a higher degree of OIRR in teeth with blunt and pipette-shaped roots, and these findings were also reported in other studies (Mirabella et al. 1995; Nigul et al. 2006; Thongudomporn et al. 1998). In conclusion, 96% of patients during the initial phase of orthodontic treatment did not reveal any clinically significant changes of the root length. Accordingly it may be queried whether it is justified to make radiographic examinations of all patients after three to six months of treatment. Only when the final results of this survey are complete and the numbers and the scale of root resorption can be evaluated in detail when the orthodontic treatment is completed, the benefits of an intermediate radiographic examination can be analyzed.

Root resorption after six months and at the end of orthodontic treatment and its relation to risk factors (Study IV).

The number of 156 patients examined, concerning the 200 patient had been as a target after statistical power analysis is considered successful for a randomized clinical trial, comparing with others, with such a large number of participating patients. Thirty two of the patients who failed to appear after several notices and this can be explained by their fear that these extra radiographical examination was only for diagnostic purposes and not for any obligation beneficial reason. It is noted that eight patients moved to another location in Sweden where the follow-up and CT examination of patients could not take place. The findings

of this study cannot confirm any correlation between root resorption at six months and root resorption at the end of the treatment, probably because the number of patients with more evident resorption was small. One patient with grade 4 in the upper centrals and laterals was found with a score of three in the six months' control. Four of 97 patients had teeth with resorption classified as score three and these patients remained score three for the same teeth at the end of treatment. In contrast with several studies no possible correlation could be confirmed between the presence of minor root resorption at any stage of treatment and the occurrence of severe resorption at the end of treatment (Weltman et al. 2010; Nigul et al. 2006; Brezniak 1993; Artun et al. 2009). Resorption was, however, almost only seen in the upper jaw, especially in the incisor region, in agreement with the findings of other studies that upper front teeth are the most susceptible to root resorption (Jiang et al. 2010; Brezniak et al. 2004) and that in eight patients, resorption with an index score of three was found in the lower canine. Five of these patients were diagnosed with resorption on the first maxillary premolars, a tooth type that is not normally monitored with radiography during orthodontic treatment or included in scientific papers on early root resorption. The findings of this survey are more severe than the majority of the studies reporting clinically significant root resorption at the end of the treatment. Dudic (2009) found by using the same CBCT a moderate root resorption in 19% of patients examined at the end of the treatment and only two maxillary front teeth with severe resorption; Artun (2005) reported 5.3% of root resorption more than 4mm; while Mohandesan (2007) – by defining severe root resorption as more than 1mm – reported that 74% of the upper central teeth and 82% of the upper laterals, were severely resorbed. The difference which concerns the severity of the studies, reporting a lower prevalence using periapical radiographs or panoramic x-rays, might be explained due to the different radiographic techniques used. Projection error is a significant problem in intraoral radiography especially in orthodontics where teeth are moved and the angulations of the teeth change during treatment, making periodical identical radiographs more or less impossible. With the CBCT technique's control of projection geometry for each individual tooth, the tooth length variation of 2mm due to projection error is minimized, which

might explain the low number of score 2 resorption in this survey. More severe root resorption is probably not so sensitive, according to technical limitations, and thus the findings of the other studies are more alike. In agreement with the methodology found in the literature, the five models based on the classification of root shape derived from Levander and Malmgren (1988) have been used, describing root formation anomalies as risk factors. In contradiction with the studies by Mirabella (1995) and Nigul (2006) this study could not confirm any relations of root resorption with the presence of abnormal and short shaped roots. Nor did this study find blunt nor pipette-shaped rooted teeth more susceptible to root resorption as other studies reported (Thongudomporn et al. 1998). One more important finding of this study is that there was not any significant correlation between the duration of the treatment and the severity of root resorption present, in contradiction to other studies (Pandia et al. 2008; Lioy et al. 2010; Apajalahti et al. 2007; Zhong et al. 2007; Jiang et al. 2010). In conclusion, one out of four (25.6%) of the patients at the end of orthodontic treatment presented clinical significant changes of the root length, a finding which was revealed by the sensitivity provided by the CBCT examination. Further, no correlation was found between the severity of root resorption at the end of the treatment with that present at six months; one could speculate, therefore, whether it is indeed justified to undertake radiographic examinations of all patients after three to six months of treatment.

CONCLUSIONS

Study I

- Because there are few sources offered in the literature regarding the prevention and treatment reassessment in cases of root resorption during orthodontic treatment, the approach relies on individual practitioner perception
- Regarding the type of radiograph, there is no specific approach in the literature regarding the types of radiographic examination and the estimation of risk factors for the development of root resorption. Similar procedures followed by Swedish and Greek orthodontists
- Swedish orthodontists perform more radiographic follow-up during treatment than Greeks, who seems to be more confident about avoid root resorption

Study II

- Before treatment periapical radiographs were taken in most cases. The percentage of the radiographs dropped significantly at six months. At the end of treatment half of the patients were examined with periapical radiographs
- In cases when moderate root resorption was diagnosed before or during treatment the use of lower forces, resting periods and decrease of treatment time were common preventive measures.
- In cases when severe root resorption was diagnosed the majority of the operators stopped treatment or decreased the total treatment time.
- Light root resorption was found in less than 10% while severe root resorption was noted in 2% after active treatment.

Study III

- After 6 months of treatment root resorption was diagnosed in 4% of the patients.
- The predisposing risk factors for root resorption did not have any impact on the amount of resorption after 6 months of active treatment

Study IV

- At the end of treatment, minor resorption (score 2), was noted in 52.5 per cent of the patients, severe resorption (score 3) was found in 25,6 per cent and extreme (score 4) was found in only one patient
- There were no correlation between the severity of root resorption after 6 months of treatment and the findings at the end of the orthodontic treatment.
- No relation was noticed between the duration of treatment and root resorption at the end of treatment
- The selected predisposing risk factors for root resorption did not have any impact on the amount of resorption at the end of treatment

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APPENDIX I

QUESTIONAIRE ON ORTHODONTIC PRACTIONERS APPROACH

TO EXTERNAL APICAL ROOT RESORPTION.

1)Which radiographs do you require before start of treatment in order to control root resorption? Mark how regularly you take different radiographs. Mark regular use as (r), occasionally as (o) or seldom/never as (s)

Periapical ☐ Panoramic ☐ Lateral cephalograms ☐

Other types of radiographs ..... ☐

2)In which regions do you take periapical radiographs to control root resorption? Mark in the same way as in question 1. Number refers to the number of pictures you usually take.

Upper centrals ☐ Lower centrals ☐ Upper anterior (13..23) ☐ number: ☐

Lower anterior (33..43) ☐ number: ☐ Posterior regions ☐ number: ☐

3)What is your view of the usefulness of panoramic radiographs to detect root resorptions?

Mark on the scale below.

Bad Fairly bad Fairly good Good

I----------I----------I----------I----------I

4)Are you taking history of preexisted root resorption before treatment? ☐Yes ☐No

When you find that root resorption exist before treatment, which factors can often be assumed to have caused the resorptions

.....

5)Are you taking history of the following relating factors with root resorption?

☐trauma, ☐oral habits ☐ systemic factors ☐root formation anomalies

6)) If you find root resorptions do you hesitate to carry out orthodontic treatment?

Always Often Seldom Never

I----------I----------I----------I

7) What amount of pretreatment root resorption will make you stop doing orthodontics

Up to 1/4 of the root length ☐ 1/4 to 1/3 ☐ >1/3 ☐

6)Do you perform a regular follow up on root resorption diagnosis during treatment?
ΐYes ΐNo

7)If yes, on what regular bases?
a)3 months after initiation treatment? ΐ b)6 months after initiation treatment? ΐ
c)12 months after initiation treatment? ΐ d)18 months after initiation treatment? ΐ
e)after termination of treatment? ΐ
f)depending on the initial diagnosis of preexisting root resorption? ΐ

8)) How many radiographs do you usually take to check for root resorptions during treatment?

1 ☐ 2-3 ☐ ≥4 ☐

In which regions do you usually take these pictures?

Upper front ☐ Lower front ☐ Lateral segments ☐

8)Have you treated any case with root resorption, resulted from orthodontic treatment ΐYes ΐNo

9)In cases of diagnosis of **moderate** (2mm to one third of the root) root resorption **before initiation of treatment**, what is your approach?
i)alter the treatment planning. ΐ ii)use of lighter forces. ΐ
iii)use of longer duration between appointments. ΐ
iv)decrease the duration of the total treatment. ΐ v)allow a resting period ΐ
vi)consider not treatment. ΐ

Other actions to reduce additional resorptions ☐ such as: .....

.....

10)In cases of diagnosis of **severe** (one third to the total length of the root) root resorption **before the initiation of treatment**, what is your approach?

i)alter the treatment planning. ☐ ii)use of lighter forces. ☐
iii)use of longer duration between appointments. ☐
iv)decrease the duration of the total treatment. ☐ v)allow a resting period ☐
vi)consider not treatment. ☐
Other actions to reduce additional resorptions ☐ such as: .....

.....

11)In cases of diagnosis of **moderate** (2mm to one third of the root) root resorption **during treatment**, what is your approach?
i)alter the treatment planning. ☐ ii)use of lighter forces. ☐
iii)use of longer duration between appointments. ☐
iv)decrease the duration of the total treatment. ☐ v)allow a resting period ☐
vi)terminate the treatment.
vii) alter the treatment plan by the use of removable instead of fixed appliances
Other actions to reduce additional resorptions ☐ such as: .....

.....

12)In cases of diagnosis of **severe**(one third to the total length of the root) root resorption **during treatment**, what is your approach?
i)alter the treatment planning. ☐ ii)use of lighter forces. ☐
iii)use of longer duration between appointments. ☐
iv)decrease the duration of the total treatment. ☐ v)allow a resting period ☐
vi)terminate the treatment. ☐
Other actions to reduce additional resorptions ☐ such as: .....

.....

13)In case you diagnose the presence of factors related with root resorption,(oral habits,bruxism), do you give specific instructions for their termination? ☐Yes ☐No

14)) Do you agree/disagree with the following statements (mark on the lines)

Bruxism increases the risk for resorption considerably:

I agree completely not at all

I----------I----------I----------I----------I

Biting on foreign objects increases the tendency to get root rresorptions

I agree completely not at all

I----------I----------I----------I----------I

Thin roots increases the risk for root resorptions:

I agree completely not at all

I----------I----------I----------I----------I

Blunt roots increases the risk for root resorptions:

I agree completely not at all

I----------I----------I----------I----------I

Rest periods make root resorptions heal

I agree completely not at all

I----------I----------I----------I----------I

14) Other comments on root resorptions:

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APPENDIX II

Papers I-IV