MASTEROPPGAVE
Fixed Appliance & Root Resorption Possible to Predict?
A Literature Review

Dental students:
Sesilie Beck-Hansen
Iris Hergot Berglund

Supervisors:
Mats Larsson, Specialist in Orthodontics, TkNN
Heidi Kerosuo, Professor, IKO
Abstract

There are many possible causes to external apical root resorption (EARR) as a sequela of orthodontic treatment with fixed appliance. This literature review examines root morphology, age, commonly affected teeth, magnitude of force, continuous versus interrupted forces and duration of treatment, in order to evaluate if root resorption can be predicted. Qualitative analysis of a range of studies in this area has been made. Maxillary incisors seemed to be the teeth most vulnerable to EARR. All of the contributing factors above had a connection to root resorption of varying extents. It is therefore essential for a clinician to be aware of these factors, to be able to estimate the risk of root resorption individually for each patient.

Figure 1: Root resorption in the incisors as result of orthodontic treatment with fixed appliance.
Introduction

The increasing focus on aesthetics plays an important role in today’s community, with dentistry and orthodontics as a genre, as no exceptions. With increasing numbers of patients receiving orthodontic treatment and having higher expectations, the deleterious consequences of treatment should be emphasized. White spot lesions, gingival recessions and other periodontal problems are all possible complications of orthodontic treatment, but the perhaps most commonly suffered is root resorption. (Mitchell 2007) There are many orthodontic treatment options, among them removable appliances, functional appliances and fixed appliances. The focus in this assignment was root resorption as a sequelae of treatment with fixed appliances.

Root resorptions are conditions known to be associated with a physiological or pathological process that causes loss of cementum or dentin from a tooth root. The physiological process of root resorption is normal in the phase when the deciduous teeth are being shed. (D. Healy). The pathological type of root resorption however, is not normal and may for example be due to traumatic injuries or pressure from orthodontic devices, periapical infectious lesions or periodontal diseases (Breznia and Wasserstein 2002). Sometimes the resorption process is idiopathic and the cause is unknown. When a tooth is moved, one way or the other, the orthodontic forces are transmitted from the appliance through the tooth and to the periodontal ligament. The biological process that then occurs is very complex, but the “main” result will be tension on one side of the tooth, and compression of the PDL on the other side. To the compression side, osteoclasts will migrate and the appearance will gradually lead to bone resorption. On the tension side the opposite will happen, and bone deposition will occur due to osteoblasts differentiation. When there is an imbalance between these two processes along with the loss of some of the protective mechanisms of cementum, osteoclasts and cementoclasts will be able to resorb portions of the root (Mitchell 2007, http://www.orthodontists.org.nz/articles/root-resorption.asp) In orthodontics the external type of root resorption is a feared complication of orthodontic therapy. This is a surface resorption that takes place in the apical portions of the root, and the term external apical root resorption (EARR) is often used. Sameshima and Sinclair (2001) strongly suggested that; “there is some component of the root apex that has a lower threshold for irreversible change than other parts of the root.” Many authors have reported that small degrees of root resorption exist in most patients, also patients that have not undergone orthodontic therapy (http://www.orthodontists.org.nz/articles/root-resorption.asp). This type of resorption generally arises no problems for the patients, but whenever severe, the resorption can threaten the longevity of the tooth. The frequency of severe EARR varies, but numbers of 5-20% have been reported (Mirabella and Årtun 1995, Levander 1999, Linge and Linge 1983, Thongudomporn and Freer 1998).

Root resorption as an undesirable consequence and complication of orthodontic treatment has been known for several decades, (Rudolph 1940, DeShields 1969) and although difficult to detect, there has been great improvements in equipment. Several
types of radiological examination modes, traditional x-rays, digital x-rays, CT’s, CBCT’s, OPG’s and also scanning electron microscopes and light microscopes are only a few of the equipments that aids as diagnostic tools in the detection of EARR. DeShields (1969) claimed that intraoral radiographs are a central part of orthodontic treatment. Regular intraoral periapicals have traditionally been the preferred type of radiographic control, “since they have the highest chance of reflecting the severity of the case” (D. Healey). In the purpose of reducing the radiation dose, digital radiographic systems are being used more and more. There are several advantages with digital imaging; the dark-room process is eliminated and the clinician has immediate access to, and can manipulate the images (Levander 1999). Early quantifications of small alterations in the root surface are another advantage of digital vs. conventional systems (Levander 1999). Panoramic imaging, also called pantomography, (OPG) is a technique that produces a single tomographic picture of the facial structures and surrounding structures, and has a broad covering of both jaws. The images are not high resolution images, so sharp details cannot be studied as with periapicals. The radiation dose though is quite low, and the procedure is usually well tolerated by the patient. Today, most orthodontists require an OPG and a cephalogram before treatment start, and many also monitor the treatment situation with panoramic images. Sameshima and Asgarifar (2001) found that the loss of root surface during treatment, were overestimated by approximately 20% when analysed on OPG’s, compared to periapicals. They recommended the use of periapicals, especially in high risk patients. However, Stratomas et al. (2002) stated that OPG is a good enough method for evaluating changes in root length pre- and post treatment.

Small alterations in the root’s surface are extremely difficult to detect even with digital systems, especially alterations on the buccal and lingual aspect of the root (Breznia and Wasserstein 2002). Today, cone beam computed tomography or CBCT is a technique that is being used more and more. With this radiographic modality it is easier for the clinician to detect alterations on the root’s surface on a detail level, which can aid in the decision making process for example when extractions have to be performed.

Several “predisposing” factors to EARR have been proposed like gender, age, roots-morphology, allergy, asthma, nutrition, trauma, genetic disposition, ethnic group, habits, anomalies in number and position of teeth, endodontically treated teeth, most commonly affected teeth, extraction therapy versus non-extractions. There are also some treatment factors that seem to have a great influence on the incidence of EARR, for example type of orthodontic movement, the distance the teeth are being moved, the amount of forces used, use of continuous versus intermittent forces, type of appliance, and finally treatment duration (table 1). The interrelations between these factors are not always clearly understood.
Table 1: Contributory factors to root resorption

<table>
<thead>
<tr>
<th>Included factors in this review</th>
<th>Excluded factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Patient factors</strong></td>
<td></td>
</tr>
<tr>
<td>A: Root morphology</td>
<td>Gender</td>
</tr>
<tr>
<td>B: Age of patient at orthodontic treatment</td>
<td>Systemic factors (allergy, asthma etc.)</td>
</tr>
<tr>
<td>C: Most commonly affected teeth</td>
<td>Trauma</td>
</tr>
<tr>
<td></td>
<td>Nutrition</td>
</tr>
<tr>
<td></td>
<td>Ethnic group</td>
</tr>
<tr>
<td><strong>2. Orthodontic treatment factors</strong></td>
<td></td>
</tr>
<tr>
<td>D: Magnitude of forces</td>
<td>Habits</td>
</tr>
<tr>
<td>E: Duration of treatment</td>
<td>Anomalies of teeth</td>
</tr>
<tr>
<td>F: Continuous vs. interrupted forces</td>
<td>Endodontically treated teeth</td>
</tr>
<tr>
<td></td>
<td>Extraction therapy vs. non-extraction</td>
</tr>
<tr>
<td></td>
<td>Type of appliance</td>
</tr>
<tr>
<td></td>
<td>Genetic disposition</td>
</tr>
<tr>
<td></td>
<td>Idiopathic</td>
</tr>
<tr>
<td></td>
<td>Etc.</td>
</tr>
</tbody>
</table>

**Aim of the study**

The purpose of this assignment is to analyze the described scientific orthodontic literature for the correlation between the occurrence of root resorption and individual refractory factors on the one hand, and finally some orthodontic treatment factors on the other.

**Material and method**

An enhancement in knowledge was first done by literature reading on the subject. The pubmed database was then used to search for information from published literature from 1930 until 2011. The search was limited to human studies. The keywords used were “resorption” and “fixed appliance”. This search gave 136 results. In addition some of the investigations from the thesis of Levander 1999 and Owmann-Moll 1995, were used. Search through the references to included studies were also done.

In total (included the thesis) 59 studies were evaluated as relevant and valid, and included in the assignment. In addition; study literature in form of two books and lecture notes were found to be of relevance to the assignment, hence they were utilized as well.

Four of the publications were dated from the years 1930-1960, 18 publications were from 1961-2000 and 26 publications were from 2001-2011.
Table 2-3: The types of studies/publications included in this review.

Table 2:

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Nr of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospective</td>
<td>43</td>
</tr>
<tr>
<td>Retrospective</td>
<td>16</td>
</tr>
<tr>
<td>Reviews*</td>
<td>5</td>
</tr>
<tr>
<td>Meta-analysis*</td>
<td>1</td>
</tr>
</tbody>
</table>

* Five reviews and one meta-analysis were included in the 16 retrospective studies.

Table 3: List of journals from which the articles of the review were retrieved

<table>
<thead>
<tr>
<th>The included articles were collected from these sources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>European Journal of Orthodontics</td>
<td>12</td>
</tr>
<tr>
<td>American Journal of Orthodontics and Dentofacial orthopedics</td>
<td>8</td>
</tr>
<tr>
<td>Angle Orthodontist</td>
<td>7</td>
</tr>
<tr>
<td>Orthodontics and Craniofacial Research</td>
<td>4</td>
</tr>
<tr>
<td>American Journal of Orthodontics</td>
<td>3</td>
</tr>
<tr>
<td>Journal of American Dental Association</td>
<td>2</td>
</tr>
<tr>
<td>Stomatologija</td>
<td>2</td>
</tr>
<tr>
<td>American association of Orthodontists</td>
<td>1</td>
</tr>
<tr>
<td>Scandinavian Journal of Dental Research</td>
<td>1</td>
</tr>
<tr>
<td>Australian Journal of Orthodontics</td>
<td>1</td>
</tr>
<tr>
<td>Australian Dental Journal</td>
<td>1</td>
</tr>
<tr>
<td>New Zealand Association of Orthodontists</td>
<td>1</td>
</tr>
<tr>
<td>Mondo Orthodontics</td>
<td>1</td>
</tr>
<tr>
<td>Romanian Journal of Morphology and Embryology</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>4</td>
</tr>
</tbody>
</table>

Results

1. Patient factors

A: Root morphology

Since the 1960’s there has been a consensus that orthodontic treatment contribute to external apical root resorption, (EARR) (De Shields, 1969). Thongudomporn and Freer, (1998) reported that 97,3% of the patients revealed some form of EARR post-treatment. In Sameshima and Sinclair’s study from 2004, they stated that the average root-shortening due to orthodontic tooth movement is approximately 10%, and it ranges from 1,2 -1,5 mm. A shortening of the total root length of 10% will in most cases not cause any problems for the tooth’s function. This is possibly because most of the PDL-fibers are in the upper 2/3 of the root (Henry and Weinman 1951).

The severity can however, be grouped into different stages as described by Levander 1999. An index-score from 1-4 is often preferred (figure 2).
1. Irregular root contour
2. Root resorption apically, less than 2mm. (Minor.)
3. Root resorption apically, from 2mm- 1/3 of the root’s length. (Severe.)
4. Root resorption exceeding 1/3 of the root’s original length. (Extreme.)

When the EARR gets severe, (reaches score 3 or 4,) there is reason to concern. The numbers of reported severe EARR varies considerably in the literature. Linge and Linge reported in 1983 that 16, 5% of the patients in their study suffered from severe EARR post-treatment, while Thongudomporn and Freer (1998) found an incidence of severe EARR of approximately 40%. Whenever severe EARR, the longevity of the tooth may be compromised, and this is one of the complications most orthodontists fear the most.

Several pre-treatment factors associated with EARR have been suggested, among them abnormal root shape (Oppenheim 1942, Newman 1975 and Mirabella and Årtun 1995). There are great intra- and interindividual variations regarding tooth morphology, and the aetiology is still unknown. Bang et al. lanced a theory in 1995 that nerve-tissue is implicated in arrested tooth development, and also in anomalous root shapes. Newman, (1975) suggested that short roots may be due to a genetic component. This is in agreement with Brezniak and Wasserstein, (2002) who also claimed a strong familiar association. Nail- biting and traumatic injuries are other possible explanations (Newman 1975).

Classification
The shape of the root can be described and classified in different ways. The classification system proposed by Levander and Malmgren in 1988 has gained widespread acceptance. The shape of roots is then divided into four groups:
Other authors use a slightly different classification system, and also add incomplete roots as an extra group.

Most authors found that an abnormal root form (as stated above) enhanced the risk of EARR (Preoteasa et al. 2009; Oyama et al. 2006; Levander 1999, Thongudomporn and Freer 1998, Sameshima and Sinclair 2001 and Nigul and Jagomagi 2006). However, Zahrowski and Jeske (2006) concluded that; “The incidence of EARR appeared unaffected by tooth morphology.” Sameshima and Sinclair had similar findings. They could not find any significant relation between EARR and root form, in their article from 2004. It should be mentioned that the correlation was almost significant. Mirabella and Årtun (1995) found that an atypical root form was only a significant risk factor for the centrals, although their results indicated that EARR is linked to an abnormal root shape.

Normal roots
The authors all agree that a normal root form do not contribute to EARR.

Short roots
Levander and Malmgren (1988) found no increased risk for EARR in short roots, but emphasized the more severe consequences if EARR were to take place in these roots. Oyama et al. (2006) concluded that there was an enhanced risk for EARR in short roots, due to the decreased crown-root ratio which in turn leads to significantly more stress, concentrated on the root’s middle part. Thongudomporn and Freer (1998) and Nigul and Jagomagi (2006) also found that short roots are more exposed to EARR. A counterpart to these findings is Mirabella and Årtun’s article from 1995, were they did not discriminate between the different abnormal root forms, but found long roots to be more susceptible to EARR. Their possible explanation was that in a longer root, more force is required to move the tooth. The actual displacement of the apex is bigger during tipping/torquing. The clinician would perhaps also be more reluctant to move teeth with short roots the same distance as longer roots.

Blunt roots
Levander and Malmgren reported in 1988 a significant higher degree of EARR in blunt roots. This view is shared by Preoteasa et al. (2009) and Thongudomporn and Freer. (2006) Sameshima and Sinclair (2001) on the contrary, concluded that blunted central incisors showed significantly less EARR, than the other root forms. This is also

Figure 3: Classification of root form according to Levander, 1999.

1. Short
2. Blunt
3. Apically bent
4. Pipette shaped
postulated by Oyama et al. (2006) who reported of no significant stress concentration on these roots.

Apically bent roots
Mirabella and Årtun (1995) were unable to prove a significant correlation between root form and EARR. Their results, however, indicated that roots that were angulated, or roots with deviated apices had an increased risk. Preoteasa et al. (2009) found that angulated roots had the highest prevalence of EARR, and the percentage were actually 92.11%. Oyama et al. (2006) constructed FEM`s, (finite element models) using a three-dimensional computer aided program, and set up five different root models, in accordance with Levander and Malmgren`s classification from 1988. They then “applied” an experimental force load of 2N, at an area simulating the bracket base. Both intrusive and lingual direction of the forces was tested. For the apically bent root, the maximum stress concentration was at the root apex during both lingual and intrusive forces. The conclusion was that a bent apex induces EARR. This finding is also in agreement with several other authors. (Levander 1999 and Sameshima and Sinclair 2001). Levander and Malmgren (1988) stated that it is the bent part of the apex that will be resorbed. Once this part is resorbed, the risk of further EARR is minimal.

Pipette shaped roots
In their study from 1988, Levander and Malmgren reported significantly higher numbers of EARR in roots with pipette shape. This finding is shared by other authors: Pretoteasa et al. 2009, Oyama et al. 2006, Thongudomporn and Freer 1998 and Sameshima and Sinclair 2000.

B: Age as a contributory factor
The influence of age as a factor contributing to EARR, has for a long time caused some degree of disagreement among researchers. Already in the 1930’s and 1940’s Rudolph claimed that a young age at treatment start was beneficial in the matter of EARR. “The younger the patient at the onset of treatment, the more prolonged the treatment be without permanent loss of root tip structure” (Rudolph 1940). In orthodontic patients of more advanced age, larger hyalinised areas, longer duration of hyalinization period and reduced capacity of tissue repair are factors that are thought to increase the risk of EARR (Reitan 1964, Brezniak and Wasserstein 1993 and Mirabella and Årtun 1995). Another influencing factor is the protective mechanisms of precementum and predentine located on the apices of young individuals (Jiang et al. 2010). Predentine is not calcified and is therefore not attacked by resorbing cells (Mavragani et al. 2002). Most studies on EARR concentrate on the maxillary incisors, and many of the articles published in recent years found no association between age and the amount of EARR in these teeth (Brezniak and Wasserstein 2002). Brezniak and Wasserstein (2002) claimed that age may not be a significant factor in the contribution of EARR. Sameshima and Sinclair, in their study from 2001 also found no such link. However, when they included the mandibular incisors, the amount of EARR was significantly higher in the adult group.

Jiang et al. (2010) found that; “age had a statistically significant correlation with resorption of all parts of the dentition,” post treatment. Also Nigul and Jagomagi (2006) reported of similar findings; adult
patients had more EARR, although the difference was not statistically significant. This finding is similar to the conclusion of Preoteasa et al. (2009). They had patients older than the age of twelve with resorptions of all degrees. Of the patients under twelve years 50% had EARR, and only first degree EARR. It has been proposed that immature teeth with incomplete root formation will have the benefit of the remaining growth potential, and the result post treatment could be elongation, even with EARR (Mavragani et al 2002). The same study also showed that immature teeth pre-treatment reached a significant greater length post-treatment, than the teeth that had closed apices at the start of treatment. The orthodontic treatment could not be said to have any negative effects of the final root lengths of teeth with incomplete roots (Mavragani et al 2002).

C: Most commonly affected teeth

There have been discussions among researchers of which teeth that are most susceptible to EARR, and Brezniak and Wasserstein (1993) claimed that “different teeth have different tendencies to root resorption.” However, as mentioned above, maxillary incisors are thought to be the teeth most vulnerable to EARR, and therefore many researchers have concentrated their studies on these teeth. “If no apical resorption is found on the incisors, it is assumed that there is only minor risk of severe resorption in other teeth” (Levander 1999). This is in agreement with several other authors as well (D. Healy, Apajalahti & Peltola 2007, Zahrowski & Jeske 2010, Thongudomporn and Freer 1998 and Sameshima & Sinclair 2000). One plausible explanation of why incisors are more easily resorbed, were proposed by Oppenheim already in 1936. He explained that; “this may be because of the extent of movement of these teeth are usually greater than other teeth and their root structure and relation to bone and periodontal membrane tend to transfer the forces mainly to the apex.” This is in agreement with Apajalahti and Peltolas article from 2007. They claimed that maxillary incisors are the first teeth to respond when fixed appliances are activated. Hence, the duration of force will be longer and thus the potential of EARR increases. Sameshima and Sinclair (2001) pointed out that maxillary incisors are the teeth that most often show deviating root form and other developmental anomalies. Also, the erupting canine is the second most often impacted tooth, and often resorbs part of the lateral’s root. Which teeth that follow the incisors when it comes to EARR “potential,” have caused somewhat more controversy. Some authors claim that all maxillary anterior teeth are especially vulnerable to EARR, and that the maxillary laterals are the most often resorbed teeth followed by the centrals, mandibular centrals and then the maxillary canines (Lopatiene and Dumbravaiete 2008). There seem to be a mutual understanding that mandibular first molars, and especially the distal root often is affected (D. Healy, Zahrowski & Jeske 2010). EARR in premolars are very rare, (Lopatiene and Dumbravaiete 2008) but Apajalahti and Peltola (2007) found that in patients with affected premolars, there was a high percentage (47%) of severe EARR. In these cases there has often been performed significantly more tooth movements due to for example extractions, and this in turn may contribute to the more severe type of EARR. Sameshima and Sinclair (2001) came to the same conclusion, but they also found that patients with only upper premolar extractions did not have more severe EARR than non extraction cases.
They could however, not explain this finding.

2. Treatment factors

D: Forces applied in orthodontic treatment

In addition to predisposing factors, forces applied during orthodontic treatment are generally regarded as an important factor that may affect the degree of root resorption. An optimal orthodontic force is characterized by a maximal cellular response from the tooth supporting tissues at the same time as maintenance of the vitality of these tissues is secured. This includes apposition and resorption of alveolar bone (Melsen et al. 1985). In 1952 Storey and Smith introduced the “optimal force”-theory. It indicated that a pressure from 150-200g produced the maximum tooth movement for maxillary canines in man. Since then, various suggestions of the “optimal force” are presented.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Ref.</th>
<th>C/BT</th>
<th>Teeth</th>
<th>Force (cN)</th>
<th>D</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storey and Smith</td>
<td>1952</td>
<td>2</td>
<td>B</td>
<td>Dmax</td>
<td>175-300</td>
<td>9w</td>
<td>Optimum force range for maximum rate of movement is 150-200 cN for canines</td>
</tr>
<tr>
<td>Lee</td>
<td>1984</td>
<td>34</td>
<td>B/T</td>
<td>Lmax</td>
<td>&gt;150</td>
<td>12w</td>
<td>Higher forces yielded 2.5 times tooth displacement of the lower force</td>
</tr>
<tr>
<td>Andreasen</td>
<td>1987</td>
<td>35</td>
<td>T</td>
<td>Mmax</td>
<td>200</td>
<td></td>
<td>Higher forces per unit root area increase the rate of TM</td>
</tr>
<tr>
<td>Hixon</td>
<td>1989</td>
<td>35</td>
<td>T</td>
<td>Mmax</td>
<td>300</td>
<td>6w</td>
<td>Higher forces produce more rapid movement than lighter ones</td>
</tr>
<tr>
<td>Hixon</td>
<td>1972</td>
<td>37</td>
<td>T</td>
<td>Mmax</td>
<td>300</td>
<td></td>
<td>Higher forces produce more rapid movement than lighter ones</td>
</tr>
<tr>
<td>Boedtler</td>
<td>1972</td>
<td>3</td>
<td>T</td>
<td>Mmax</td>
<td>55</td>
<td>10w</td>
<td>55 cN force yielded less TM than 140, 225, and 300 cN, whereas latter three forces produced the same amount of TM</td>
</tr>
<tr>
<td>Anderensen</td>
<td>1980</td>
<td>38</td>
<td>T</td>
<td>LM</td>
<td>140</td>
<td>10w</td>
<td>In general greater forces produce greater rate of tooth movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RM</td>
<td>225</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LC</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lee</td>
<td>1995</td>
<td>39</td>
<td>B</td>
<td>Lmax</td>
<td>35-650</td>
<td>7w</td>
<td>Maximum rates of TM is 0.70-1.34 mm/mw for tipping movement with force average 337-388 cN, and 0.86-1.37 mm/mw for bodily movement with force average 354-375 cN (Figure 4)</td>
</tr>
<tr>
<td>Owman Moll</td>
<td>1996a</td>
<td>40</td>
<td>T</td>
<td>Pmax</td>
<td>50</td>
<td>4-7w</td>
<td>No difference in TM in 50 cN group and 100 cN group</td>
</tr>
<tr>
<td>Owman Moll</td>
<td>1996b</td>
<td>41</td>
<td>T</td>
<td>Pmax</td>
<td>100</td>
<td></td>
<td>TM increased 50% with 200 cN as compared to 50 cN</td>
</tr>
<tr>
<td>Lundgren</td>
<td>1996</td>
<td>42</td>
<td>T</td>
<td>Pmax</td>
<td>200</td>
<td>1w</td>
<td>Horizontal movement of the tooth crown was 0.8 mm during the first week and 3.7 mm after 1w</td>
</tr>
<tr>
<td>Iwasaki</td>
<td>2010</td>
<td>43</td>
<td>B</td>
<td>Mmax</td>
<td>19</td>
<td>12w</td>
<td>10 cN could produce effective TM</td>
</tr>
</tbody>
</table>

Today’s hypothesis includes that a certain magnitude of force and forces characteristics (continuous vs. intermittent, constant vs. declining, etc.) would be able to produce a maximum rate of tooth movement without adverse tissue effects and with maximum patient comfort. Ren et al. (2003) concluded in their systematic review that: “...from current literature, no evidence-based force level could be recommended for the optimal efficiency in clinical orthodontics” (Figure 4). The “optimal force” may differ from each tooth, movement type (intrusion, bodily movement etc.), for each individual patient, type of appliance etc.
D: The degree of EARR when the magnitude of forces increases (Table 4)

Table 4: EARR when the magnitude of force increases — a summary table

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Duration of study (in weeks)</th>
<th>Nr of teeth</th>
<th>Tooth</th>
<th>Magnitude of force</th>
<th>Type of force</th>
<th>EARR rate</th>
<th>EARR Severity (surface expansion and depth)</th>
<th>Tooth movement</th>
<th>Ind. variations in EARR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>Stenvik and Mjör</td>
<td>4 to 35 days</td>
<td>35</td>
<td>Max./mand .1. Prem. In most cases</td>
<td>From 35g to 25g</td>
<td>Intrusive forces</td>
<td>More with &lt;100g than &gt; 100g.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>Harry and Sims</td>
<td>14-70 days</td>
<td>18</td>
<td>Premolars</td>
<td>40g-220g</td>
<td>Intrusive forces</td>
<td>More with high force</td>
<td>More with high force</td>
<td></td>
<td>Yes, on the control teeth</td>
</tr>
<tr>
<td>1996</td>
<td>Owmann-Moll et al.</td>
<td>4 and 7</td>
<td>32</td>
<td>Max 1.prem</td>
<td>50g and 100g</td>
<td>Tipping movement</td>
<td>More with 50g than 100g</td>
<td>Not sign. difference</td>
<td>Not sign increased</td>
<td>Great</td>
</tr>
<tr>
<td>1996</td>
<td>Owmann-Moll et al.</td>
<td>7</td>
<td>16</td>
<td>Max. 1.prem.</td>
<td>50g and 200g</td>
<td></td>
<td></td>
<td>Not sign. difference</td>
<td>Not sign. difference</td>
<td>Increased</td>
</tr>
<tr>
<td>2004</td>
<td>Darendeliler et al.</td>
<td>4</td>
<td>36</td>
<td>Max./mand .1. Prem.</td>
<td>0g, 25g, 225g</td>
<td>Buccal directed forces</td>
<td>Not sign. difference</td>
<td>Not sign. difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Chan and Darendeliler</td>
<td>4</td>
<td>36</td>
<td>Premolars</td>
<td>0g, 25g and 225g</td>
<td></td>
<td></td>
<td>Not sign. difference</td>
<td>Not sign. difference</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Harris, Jones and Darendeliler</td>
<td>4</td>
<td>54</td>
<td>Max. 1. prem.</td>
<td>0g, 25g and 225g</td>
<td>Intrusive forces</td>
<td>More with 25g than 0g and more with 225g than 25g.</td>
<td>More with 25g than 0g and with 225g than 25g.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Zahrowski and Jeske</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More with high forces (225g)</td>
<td>More with high forces (225g)</td>
</tr>
</tbody>
</table>

Do increased forces applied by the orthodontist increase the risk for EARR?


For example in the study by Chan and Darendeliler from 2005 the investigators extracted 36 human premolars, and made scanning electron microscope images of them (Figure 5). The teeth had been exposed to light or heavy buccal directed forces for 28 days. In the same patients, the contra lateral premolars were used as controls.
After 3-dimensional quantitative volumetric analysis with commercial software they recorded resorption in light-force (25 g) and heavy-force (225 g) groups. The heavy-force group had 3.31-fold greater total resorption volume than the light-force group (Figure 6).

Similar results were found when Harris, Jones and Darendeliler (2006) used intrusive forces. The heavy-force group had more and larger root resorption craters than the light-force group. They found that the volume of the root resorption was directly proportional to the magnitude of the intrusive force applied (0g, 25g and 225g).

Zahrowski and Jeske published a systematic review in 2011 with corresponding conclusion. They investigated literature on the subject from 1950-2008. They used evidence from 13 valid studies, among them 11 RCT’s. The result showed that the severity of root resorption increased particularly with heavy forces and intrusive movements. Thus the authors support the use of light orthodontic forces, especially with incisor intrusion.
There has been some evidence however, that do not support this conclusions. Owmann- Moll et al. published two articles in 1996 that showed no significantly increase in the rate of EARR when the forces increased. This was the result even when they four- fold the controlled, continuous forces from 50g to 200g. In fact, in one of the studies, the EARR were more frequent in the 50g- group when compared with the 100g- group both after four weeks and after seven weeks. The difference after seven weeks was significant. The severity of EARR (surface extension and depth) did not show any significant difference between the different forces applied, in these two studies. Similar results were showed by Stenvik and Mjör in 1970. They used intrusive forces and found that in the force- group with magnitude < 100g resorption was present in fifteen out of eighteen teeth. In the group with magnitude >100g however, resorption was found in only six out of seventeen teeth.

**E: Duration of treatment**

Some investigators suggest duration of orthodontic treatment to be a more important factor than the magnitude of forces to prevent adverse tissue reactions (Stenvik and Mjör 1964 and Harry and Sims 1982). Sameshima and Sinclair (2001) concluded that a prolonged treatment was significantly associated with increased root resorption (n= 868 patients, retrospective study). In Levander and Malmgrens investigation from 1988, they found that root resorption after six to nine months of orthodontic treatment was detected in 34% of the teeth, meanwhile in the end of orthodontic treatment that had lasted for 19 months, root resorption increased to 56%.

In a Finnish study average treatment length for patients without root resorption was 1.5 years and for the patients with severe root resorption 2.3 years (Apajalahti and Peltola 2007) (n= 601 patients, retrospective study).

**F: Continuous versus intermittent orthodontic force**

The orthodontic force may be continuous or intermittent during treatment. Orthodontic treatment with fixed appliances is usually associated with continuous forces. With removable, and especially functional appliances continuous force is intermitted by brief or extended periods of rest.

Ballard et al. (2009) showed that discontinuous forces might give rise to a smaller amount of EARR than continuous forces, in their experimental study. The maxillary first premolar on one side received interrupted orthodontic forces: 14 days of force application (225g), then three days of rest and finally four days of force application (225g). This was repeated five times. The first premolar on the other side received continuous forces of 225g for eight weeks. The analyze was performed with a micro-CT scan system to make direct volumetric measurements. Discontinuous forces gave significant less EARR. As a conclusion the investigators suggests that: “...intermittent forces might be a safer method to prevent significant root resorption. This regimen, however could, compromise the efficiency of tooth movement”.

Levander et al. (1994) showed that an interruption of treatment for two- three months gave less EARR on initially resorbed maxillary incisors than if the treatment was continued. The investigator is therefore recommending this
interruption period for patients that shows EARR early in treatment. Brezniak and Wasserstein (1993) stated in their review that a pause in treatment allows the resorbed cementum to heal and prevents further resorption.

Owmann-Moll et al. (1994) also investigated maxillary first premolars but they applied only 50 grams of orthodontic force. Two groups of eight patients in each received both continuous and interrupted forces. One group had a test period of four weeks and the other group had a test period of seven weeks. The four-week group received on one side an applied force for three weeks and then a rest period for one week with a passive wire. The seven-week group had the same treatment on one side plus another three new weeks with force application. At the same time the authors applied continuous forces to the premolars on the contralateral side in both groups. The investigators found no significant difference in number or severity of EARR. More tooth movement was achieved in the continuous force group.

The authors of this article implied that the use of continuous forces may be more effective and safer than the use of interrupted forces, however with a degree of caution. The great amount of individual variations in this investigation may have overshadowed the resorption effects of the different force systems. It is possible that a longer observation period and/or a larger sample size would have revealed a more significant difference between the groups with continuous and interrupted forces.

Table 5: A summary of results from reviews and meta-analysis studying EARR and different predisposing factors.

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Type of study</th>
<th>Nr of studies included</th>
<th>Tooth</th>
<th>Root morphology</th>
<th>Type of teeth most related to EARR</th>
<th>Age</th>
<th>Force magnitude</th>
<th>Duration of treatment</th>
<th>Continuous versus interrupted force</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Segal et al</td>
<td>Meta-analysis</td>
<td>9</td>
<td>Max. incisors</td>
<td>—</td>
<td>Max. incisors</td>
<td>—</td>
<td>—</td>
<td>EARR increases with duration/ high correlation</td>
<td>—</td>
</tr>
<tr>
<td>1993</td>
<td>Brezniak and Wasserstein</td>
<td>Review</td>
<td>—</td>
<td>Max. 1.premolar</td>
<td>Deviating roots, blunt-pipette shaped roots: more EARR, especially pipette-shaped roots.</td>
<td>Max. laterals then max. centrals</td>
<td>EARR increases with age. Fully developed roots have a higher risk of EARR.</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2008</td>
<td>Lopatienie and Dumbravaite</td>
<td>Review</td>
<td>24</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>More EARR with high forces</td>
<td>EARR increases with duration/ high correlation</td>
<td>A pause in treatment reduced the risk of EARR</td>
</tr>
<tr>
<td>2011</td>
<td>Zahrowski and Jeske</td>
<td>Systematic Review</td>
<td>13</td>
<td>Max. incisors</td>
<td>Unaffected</td>
<td>—</td>
<td>—</td>
<td>More EARR with high forces (225g)</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

During the PubMed search only the keywords “fixed appliances” and “resorption” were used. Thus the 59 relevant articles for this review were searched out manually. A method using more keywords would have reduced the time spent on the search process. On the other hand this could have excluded valuable studies. The main part of the investigations consisted only of one or a few of the contributory factors (to EARR) of interest. The use of more keywords within the same search may therefore have ignored these studies. This could however have been avoided by performing multiple searches with only one or two of them in each. Authors often use different terms to describe the same phenomenon. For example EARR is also known as ERR or even OIRR (orthodontically induced root resorption). Also in this context this search method assured that relevant articles were not left out. The main part of the included articles was published between 2001 and 2011. The information in this review could therefore be regarded as updated, at the same time as the necessary historical perspectives are taken into consideration.

This review has evaluated if there are certain factors that could have an effect on root resorption. Several studies for each of these factors have been found with sometimes contradictory results. However, some important conclusions have been possible to make on the basis of this assignment.

1. A: root morphology

Apart from Zahrowski and Jeske, (2006) it seems to be an agreement that there exists a correlation between abnormal root shape and EARR, although not always a significant correlation.

Why anomalous roots are resorbed more easily is not known, but the forces during orthodontic tooth movement are often concentrated at the apex of the tooth. The apical cellular cement is less mineralized, hence more fragile and exposed to damage. During orthodontic force, an overloading of this fragile apex can lead to necrosis of the PDL, and EARR (Preoteasa et al. 2009). Sameshima and Sinclair, (2001) pointed out that the deviant process that caused the abnormal root shape may also play a contribution to these roots being easier resorbed. X-rays should be taken at an earlier point in treatment when the risk of EARR is judged to be increased. This view is supported by both Levander (1999), Sameshima and Asgarisfar (2001) and Apajalahti and Peltola (2007). They also recommend an x-ray control after active treatment of six months, when total treatment time exceeds this limit. In the early 1980’s Hollender et al. proposed periodic radiography every three months during active treatment. This opinion has been shared by many orthodontists, although the recommended interval varies between three months up to a year (Brezniak and Wasserstein 1993).

B: Age and root development

In most of the articles there was a positive correlation between age and EARR. Although some of the authors concluded that age is not a significant factor in the occurrence of EARR, this seems to be dependent on which teeth were being evaluated, the inclusion/exclusion criteria in the different surveys and not least, at what number the level of significance was being set. A young individual with incomplete root formation has several
biological advantages in respect of developing EARR during orthodontic treatment or not. It therefore seems likely that young age at treatment start would be beneficial in the matter of evolving EARR.

C: Most commonly affected teeth.

Of the articles that were included in this assignment, there seemed to be a mutual understanding that the maxillary incisors are the teeth that most often suffer from EARR during orthodontic treatment. It seems therefore likely to believe that maxillary incisors are the teeth most prone to EARR during orthodontic treatment.

2. D: Magnitude of force

As it appears in table 5 the results are divergent from each other. The methods vary between the different resorption studies. This makes it difficult to compare the different results and to analyze their validity. For example the magnitude of force applied (Table 5: 25g- 225g), the measurement method for detecting EARR and the type of test teeth used varies. Different type of forces used may also give divergent results. Bodily movement induces less risk for root resorption than tooth tipping (Breznia and Wasserstein 1993). Han (2005) noted: “It was established that teeth intrusion causes four times more root resorption than extrusion”.

After evaluation of the individual studies, the reviews and the meta- analyzes on this issue, it seems that the risk of EARR is higher when increasing magnitude of force is applied. The higher value of N used, the more adverse effect may be expected. Owman- Moll et al. (1996) suggested, individual variations. The great variations in the different studies may have interfered with possible adverse effects of increased magnitude of force.

Another important consideration is that these latter studies used light microscope to detect resorption craters. Chan and Darendeliler (2005), Darendeliler et al. (2004) and Harris et al. (2006) used scanning electron microscope (SEM). The entire buccal and lingual surfaces were analyzed, and the SEM pictures were taken in stereo pairs. Reitan (1964) enlighten that SEM provides higher resolution and more details than histological models prepared and analyzed through light microscopy. SEM studies can detect resorption cavities after a relatively short period of force application. It can therefore be questioned if small resorption craters might have been missed to a higher degree in investigations were they used 2D measurements instead of SEM. Chan and Darendeliler compared these methods in a review published 2004. They could not find a significant difference between 2D- and 3D- measurements of EARR over 28 days, but suggested that a longer experimental period could increase the resorption craters, thus find SEM to be favorable.

E: Duration

According to studies included in this paper the length of treatment period was significantly associated with root resorption, and showed higher severity of resorption with increasing duration. The risk was higher after 1,5 year of treatment. This was partly based on retrospective studies (Samenshima and Sinclair 2001, Apajalatati and Peltola 2007). The high sample size (n= 868 and
601 patients respectively) may have been beneficial for the validity of the result.

F: Continuous versus interrupted forces

The variety of investigation methods makes comparison very difficult. The included articles of continuous versus discontinuous forces used rest periods from three days to three months, with or without reapplication of force. The results were quite contradictory.

Ballard et al. (2009) applied forces of 225 grams, whereas Owmann-Moll et al. (1994) used only 50 grams. It is likely that this disparity in levels of force contributes to the differences in result. The sample sizes of both of the studies mentioned above are only 16 teeth (eight patients). Levander (1999) on the other hand had a more representative sample size of 62 teeth (40 patients).

It seems as if an interruption in force application can have a beneficial outcome in terms of EARR, but as long as investigation methods are not standardized enough, it is not possible to make a reliable conclusion on this issue.

The results of this review suggest that EARR still is highly unpredictable. Further investigations on this matter, including larger samples, standardized research-methods and prolonged test-and-observation-periods, would be preferable.

Conclusion

The clinicians should have in mind that abnormal root morphology may increase the risk of root resorption. This is specially valid for pipette-shaped roots.

Maxillary incisors seem to be the teeth most likely to suffer from EARR.

From the root resorption point of view orthodontic treatment should begin as early as possible since there is less risk of root resorption in young and developing teeth.

Light orthodontic forces seem to present a smaller risk of resorption than heavy forces. The use of interrupted forces seems to give less root resoption than continuous forces.

If initial resorption is detected, a pause in treatment of two-three months should be considered. With sustained quality, treatment duration should always be as short as possible.

It is very important that the patient is fully informed that root resorption can be a consequence of his/her orthodontic treatment with fixed appliance.

References

5. Brezniak N, Wasserstein A. Orthodontically induced inflammatory


Web-sides: