COPYRIGHT AND USE OF THIS THESIS

This thesis must be used in accordance with the provisions of the Copyright Act 1968.

Reproduction of material protected by copyright may be an infringement of copyright and copyright owners may be entitled to take legal action against persons who infringe their copyright.

Section 51 (2) of the Copyright Act permits an authorized officer of a university library or archives to provide a copy (by communication or otherwise) of an unpublished thesis kept in the library or archives, to a person who satisfies the authorized officer that he or she requires the reproduction for the purposes of research or study.

The Copyright Act grants the creator of a work a number of moral rights, specifically the right of attribution, the right against false attribution and the right of integrity.

You may infringe the author’s moral rights if you:

- fail to acknowledge the author of this thesis if you quote sections from the work
- attribute this thesis to another author
- subject this thesis to derogatory treatment which may prejudice the author’s reputation

For further information contact the University’s Copyright Service.

sydney.edu.au/copyright
"A RADIOGRAPHIC ANALYSIS OF APICAL ROOT RESORPTION AFTER ORTHODONTIC TREATMENT WITH STRAIGHT WIRE, SPEED AND TIP-EDGE APPLIANCES"

DAVID ARMSTRONG
BDS, FDSRCS

A Thesis submitted in partial fulfilment
Of the requirements for the degree of
Master of Dental Science (Orthodontics)

Discipline of Orthodontics
Faculty of Dentistry
University of Sydney
Australia
DECLARATION

CANDIDATE CERTIFICATE

This is to certify that the candidate carried out the work in this thesis in the Orthodontic Department, University of Sydney, and has not been submitted to any other University or Institution for a higher degree.
ACKNOWLEDGMENTS

I would like to express my appreciation to:

Professor M Ali Darendeliler
Head of Discipline of Orthodontics, Faculty of Dentistry, University of Sydney, for his valuable supervision, assistance and guidance throughout the course of this study. His enthusiastic support and encouragement over the years were essential in completing this thesis.

Dr. Om P Kharbanda,
Senior lecturer, Discipline of Orthodontics, Faculty of Dentistry, University of Sydney, for his advice with the preparation and proofreading of this work.

Dr. Peter Petocz,
Department of Mathematical Sciences, University of Technology, Sydney, for his advice and assistance with the statistical analysis of this work.

Dr. Russell Kift,
Specialist Orthodontist and Postgraduate Honorary Associate Lecturer, Discipline of Orthodontics, Faculty of Dentistry, University of Sydney, for his assistance in collecting the patient sample as without the unlimited access to his patient records the study would not have been possible.

Dr. Mark Ewing
Specialist Orthodontist Hamilton, New Zealand, for his assistance in collecting the patient sample as without the unlimited access to his patient records the study would not have been possible.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declaration</td>
<td>2</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>3</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>4</td>
</tr>
<tr>
<td>Abstract</td>
<td>5</td>
</tr>
<tr>
<td>Literature Review</td>
<td>7</td>
</tr>
<tr>
<td>Introduction</td>
<td>7</td>
</tr>
<tr>
<td>Root resorption History</td>
<td>10</td>
</tr>
<tr>
<td>Incidence</td>
<td>12</td>
</tr>
<tr>
<td>Classification of Root Resorption</td>
<td>13</td>
</tr>
<tr>
<td>Process of Root Resorption</td>
<td>17</td>
</tr>
<tr>
<td>Aetiology of Root resorption</td>
<td>21</td>
</tr>
<tr>
<td>References</td>
<td>41</td>
</tr>
<tr>
<td>Manuscript</td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>59</td>
</tr>
<tr>
<td>Material and Method</td>
<td>62</td>
</tr>
<tr>
<td>Sample Selection</td>
<td>62</td>
</tr>
<tr>
<td>Sample Description</td>
<td>64</td>
</tr>
<tr>
<td>Experimental procedures</td>
<td>64</td>
</tr>
<tr>
<td>Part 1</td>
<td>65</td>
</tr>
<tr>
<td>Part 2</td>
<td>65</td>
</tr>
<tr>
<td>Part 3</td>
<td>67</td>
</tr>
<tr>
<td>Results</td>
<td>68</td>
</tr>
<tr>
<td>Part 1</td>
<td>68</td>
</tr>
<tr>
<td>Part 2</td>
<td>71</td>
</tr>
<tr>
<td>Part 3</td>
<td>72</td>
</tr>
<tr>
<td>Discussion</td>
<td>74</td>
</tr>
<tr>
<td>Conclusion</td>
<td>88</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>89</td>
</tr>
<tr>
<td>References</td>
<td>90</td>
</tr>
<tr>
<td>List of Tables</td>
<td>112</td>
</tr>
<tr>
<td>List of Figures</td>
<td>127</td>
</tr>
<tr>
<td>Future Directions</td>
<td>136</td>
</tr>
<tr>
<td>Appendix</td>
<td>137</td>
</tr>
</tbody>
</table>
ABSTRACT

Apical root resorption is a complex problem with a multifactorial aetiology. Its extent varies between patients and different teeth within the same patient. One of the treatment related factors thought to influence the amount and severity of resorption is the type of appliance used. This retrospective study was divided into 3 parts. The main aim (part 1) was to compare the amount of apical root resorption, measured on panoramic radiographs (OPT), after orthodontic treatment between the Straight wire appliance, Speed appliance (Strite Industries, Ltd., Ontario, Canada) and the Tip-Edge appliance (TP Orthodontics). Part 2 was to quantify if there were any factors measured from the lateral cephalometric radiograph which would correlate with the amount of resorption measured and part 3 – to establish if the final root angulations of selected teeth (upper and lower canines and contiguous premolars), measured on the final OPT could be used to assess the quality of the final treatment result using the Peer Assessment Rating Index (PAR) as a objective measurement of the final treatment result. The patient sample was taken from the Orthodontic Department, University of Sydney, Australia, and two private practices (Newcastle, Australia and Hamilton, New Zealand). Over 1000 patient files were screened to provide a sample of 114 patients, who were accepted based on specific criteria. The pre- and post-treatment orthopantomograms (OPT) were traced, scanned and digitised to calculate the change in tooth length for the maxillary and mandibular first molars and incisors. There were no statistically significant differences in average apical root resorption between the appliances, extraction/ non-extraction treatment or based on gender. However when the appliance groups were divided into extraction and non-extraction there were differences for the 31 and 41. The three appliances also demonstrated a different pattern of resorption (p<0.01) with the 12,11,21,and 26 most affected in the
straight wire appliance, the 16,26,31,41 and 42 in the Speed appliance and the 31 in the Tip-Edge appliance. The results demonstrated that 38.2% of the teeth measured increased in length and 61.8% of the teeth decreased in length, which perhaps questions the accuracy of vertical measurements from OPTs.

Part 2 consisted of 45 pre-treatment and post-treatment lateral cephalometric radiographs with 8 linear and 2 angular measurements made for the upper incisor and 5 linear and 2 angular measurements for the lower incisor. These measurements were made to identify if the position of the incisors or their direction or magnitude of movement were related to the amount of root resorption. There were no predictive measures correlated to the amount of apical root resorption for the upper incisor and several measurements correlating in the lower. The lower incisor measurements suggested that proclination of the lower incisor or a closer proximity of the apex to the lingual cortex are associated with a reduced tooth length as measured on an OPT.

Part 3 demonstrated that all the appliances treated the malocclusions in this sample to a high standard with mean PAR reductions of 91.4% for the Straight wire appliance, 85.5% for the Speed appliance and 85.0% for the Tip-Edge appliance. The final angulations were compared to the final expected angulations as defined by the prescription of the appliances and demonstrated some statistically significant differences between the appliances in terms of how close they finished to their prescription. However there was no correlation with the variance from the ideal angulation and the quality of final treatment result.
LITERATURE REVIEW

INTRODUCTION

Resorption of the roots of the permanent teeth is a pathological process developing internally or externally. It develops when the natural protection of the predentine and odontoblasts in the root canal, or the precementum and cementoblasts on the root surface are damaged or removed (Andreason and Andreason, 1994). Orthodontic force is just one of several aetiological factors that have been implicated in external root resorption. Other aetiological factors are mechanical or occlusal trauma, periapical inflammation, tooth reimplantation, pressure from adjacent and unerupted teeth and related pathological conditions such as odontogenic and non-odontogenic tumours (Snelgrove, 1995). The process of root resorption involves an elaborate interaction of inflammatory cells, resorbing cells and hard tissue structures. Often this pathological condition is difficult to predict, diagnose and treat (Andreason and Andreason, 1994).

Clinically significant apical root resorption is a common finding in orthodontic patients and occurs in 7-10% of non-orthodontically treated patients, with severe resorption affecting in 1-2% (Harris et al. 1997, Linge and Linge 1991, 1993). It has been well documented in the orthodontic literature that root resorption is a common and unpredictable adverse effect of treatment with a large range in reported incidence, perhaps due to the different methods of measurement and the criteria used. Some studies have demonstrated 100% of teeth display some level of resorption after orthodontic treatment (Kennedy et al. 1983, King and Fischlshweiger 1982) with a ten year evaluation of the quality of treatment involving 3,300 patients finding 1-3mm of resorption occurring in all fixed appliance cases (Ahlgren, 1993). Other reports, where
there is greater than 2.5mm of resorption, have the incidence at 16.5% for adolescents
and 40% of adults (Linge and Linge, 1991; Mirabella and Artun, 1995).

There have been numerous studies into the relationship between root resorption and
orthodontic treatment with several review articles published (Brezniak and
Wasserstein, 1993; Vlaskalic et al., 1998, Killiany, 1999; Harris, 2000; Killiany,
2002; Brezniak and Wasserstein, 2002). It has been concluded that resorption is a
multifactorial condition associated with patient characteristics as well as treatment
related factors. The patient related factors are genetic predisposition, age, gender,
tooth vitality, tooth type, facial and dentoalveolar structure, malocclusion type and
severity, the experience of pre-treatment root resorption, nutrition, habits, medicines,
allergies, root form, previous trauma and dense alveolar bone. The treatment related
factors are magnitude of the orthodontic force, continuous versus intermittent forces,
direction of tooth movement, appliance type and treatment duration.

It is thought that the degree of root damage may be a function of the type of appliance
used. This had been investigated with a lower incidence of root resorption usually
found after treatment with removable appliances (Ronnerman and Larsson, 1980;
Linge and Linge, 1983) and a higher incidence with fixed appliances (DeShields,
1969; Morse 1971; Goldson and Henrikson 1975). Studies comparing fixed appliance
systems have shown that no difference was found between self-ligating brackets
(Speed, Strite Industries Ltd., Ontario, Canada) and an edgewise-straight wire
appliance (Blake et al. 1995). However there was significantly more resorption in
upper central incisors in patients treated with standard edgewise appliance compared
to those treated with straight wire appliance (Mavragani et al., 1999). There was a
reduction of resorption in patients treated with Bioefficient therapy compared to
standard edgewise and edgewise-straight wire appliances (Janson et al. 1999). With
no difference found in one comparison of the Begg and Tweed techniques (Beck and Harris, 1994) but significantly more resorption in the Begg appliance group when compared with an edgewise appliance group (McNab et al., 2000).

In orthodontics there is a rapid development of technology leading to the introduction of new materials and techniques. Recently there has been a greater interest in self-ligating bracket systems. However it is not a new concept with the first one, the Russell lock, introduced in 1935 (Stoltzenberg, 1935). It has been proposed that the constant action of the active spring clip in the Speed appliance may cause more apical root resorption and yet this has only been investigated in one study (Blake et al., 1995), which found no increased incidence of root resorption when compared with an edgewise appliance. There have been no studies comparing any self-ligating appliance and Tip-Edge appliance (TP Orthodontics) or the Tip-Edge appliance and straight wire appliance. Therefore a study was designed in an attempt to answer the question of whether there is a difference in incidence of apical root resorption between straight wire appliance, Speed appliance and Tip-Edge appliance. There were two aims in this study:

(1) To determine if the appliance type, direction and amount of anterior tooth movement, extraction of four premolars, sex, or treatment duration influenced the amount of apical root resorption.

(2) To assess if the quality of treatment could be assessed from selected final root angulations.
ROOT RESORPTION HISTORY

Bates first discussed the resorption of permanent teeth in 1856, when he stated that it was caused by trauma to the periodontal membrane. After this report there was numerous case reports of root resorption in the permanent dentition but these reports were only descriptive and added little to the knowledge concerning its frequency or distribution. One such report was by Schwarzkopf, (1887), who demonstrated apical root resorption in extracted teeth. Ottolengui, in 1914, related root resorption directly to orthodontic treatment and by 1927 it had become a concern to orthodontists. Ketcham in 1927 and 1929 was the first to demonstrate the phenomenon radiographically. He demonstrated that in patients whose teeth were examined radiographically after orthodontic treatment 21% of 500 patients displayed distinct evidence of root resorption. He also stated that root resorption only occurred in 1% of people who were not subjected to orthodontic treatment. It is quite likely that Ketcham only reported the instances of very obvious resorption as evidenced by marked foreshortening of the roots and it must be borne in mind that radiographic techniques were not standardized.

In the 1930’s Becks had several studies and observed that excessive forces did not cause any root resorption in some patients, while moderate forces could cause large amounts in others. Becks felt that a certain amount of the resorption was not directly due to the orthodontic treatment but due primarily to metabolic upsets and concluded that only 20% of the orthodontic patients had incurred resorption due to the mechanical trauma incident to tooth movement whereas the rest, 80%, were due to systemic factors. He stated that certain patients have a predisposition to root resorption and in these orthodontic treatment will cause excessive resorption, while those who do not have this predisposition will not be affected.
In 1936 Rudolph reported that the incidence of root resorption in permanent teeth was 74% during or following orthodontic treatment. He also showed, in 1940, that the incidence of root resorption was 100% in an orthodontically treated group as compared to 5% in an untreated control group (age 7-21 years).

At the University of Illinois College of Dentistry, in 1947, a plan was formulated to analyze the prevalence and mechanism of root resorption in permanent teeth. Henry and Weinmann (1951) histologically made a quantitative analysis of the resorption pattern of cementum in permanent teeth. They found that 90.5% of the 261 teeth examined histologically showed areas of resorption. Contrary to the views held at the time they found little or no resorption in the gingival third of the root, which showed that inflammation, per se, did not cause resorption.

Steadman (1942) tried to explain the variation in the reported incidence of root resorption and suggested that the higher incidence in Rudolph’s study was perhaps due to the fact that the cases were mostly treated by undergraduates, who had never before used an orthodontic appliance clinically. To paraphrase a quote from Dr. Milo Hellman when he discussed Ketcham’s paper; “It is not the kind of appliance that has really any connection with the character of resorption, it is what the appliance is made to do” (Jacobson, 1952).

These early studies demonstrated that resorption was a frequent consequence of orthodontic treatment and have been followed by a wide range of histological, clinical, physiologic and radiographic studies.
INCIDENCE

There is a large variation in the reported incidence of apical root resorption with microscopic signs very common even in non-orthodontically treated teeth, which may suggest that certain amounts of apical root resorption are a normal physiological process, perhaps similar to continuous bone remodeling (Vlaskalic et al., 1998). Historically the incidence of root resorption in permanent teeth in untreated individuals was reported as 1% (Ketcham 1927). However an analysis of patients not treated orthodontically determined the frequency of apical root resorption in the permanent dentitions of patients to be between 7% and 10% (Harris et al. 1993) with severe resorption in 1-2%. There was an increased frequency in the single rooted anterior teeth. The resorption tended to be systemic within the individuals, that is to say if they had one tooth demonstrating resorption they were more likely to exhibit resorption on the other teeth. In another study of patients not treated orthodontically 5% of the teeth demonstrated root resorption (Massler and Malone 1954).

Following orthodontic treatment, macroscopic evidence of root resorption has been reported in up to 100% of patients (Rudolph, 1936). The differences in suggested prevalence of resorption may reflect the criteria used or the methodology of the different studies. For instance it has been reported that greater than 2.5mm of root resorption is present in 16.5% of adolescents (Linge and Linge, 1991) and 40% of adults (Mirabella and Artun, 1995) with 1-2mm of resorption present in 100% of patients (Kennedy et al., 1983). In a long term follow up involving 3,300 patients it was found that 1-3mm of resorption had occurred in all fixed appliance cases (Ahlgren, 1993). One study found a 15% incidence of resorption prior to treatment and a 73% incidence after treatment. The subjects had at least 12 months of fixed appliance treatment. There was only 2% of the teeth showing moderate to severe root
loss prior to treatment and 24.5% demonstrating a moderate to severe loss after treatment (Lupi et al., 1996).

If root resorption is detected early in a pause in treatment is recommended as this has been shown to reduce the amount of final resorption when compared to treatment without a pause (Levander et al., 1994).

CLASSIFICATION OF ROOT RESORPTION

Tooth resorption is classified based on the site, nature and pattern of the process. It is generally differentiated into internal and external resorption. Occasionally, combinations of both internal and external resorption can be found on the same tooth.

INTERNAL ROOT RESORPTION

Internal root resorption is rare in permanent teeth. It has been recorded in 2 % of luxation injuries (Ne et al. 1999). However it has also been reported in non-traumatized teeth. It is usually asymptomatic and discovered during routine radiographic evaluation. It is often misdiagnosed as external resorption. There are two types of internal resorption:

(1) Root canal replacement resorption

Etiology: Appears to result from a low-grade irritation of the pulpal tissue, such as a chronic irreversible pulpitis or partial necrosis that is usually localized to a small area of the root canal system. It involves resorption of the dentine and subsequent deposition of hard tissue that resembles bone or cementum, but not dentine. It can occur as a result of trauma or the application of extreme heat to the tooth.
Clinical Evaluation: Asymptomatic, and may respond normally to thermal or electronic pulp testing. However the condition is painful if the process perforates the root or crown of the tooth.

Radiographic evaluation: Appears as an enlargement of root canal space, including discontinuity of the normal canal space. It has the appearance of partial canal obliteration.

Treatment: Root canal therapy is necessary to remove the pulp and granulation tissue with the odontoclasts in order to arrest the process.

(2) Internal inflammatory resorption

Etiology: Involves the progressive loss of the root substance without deposition of hard tissue in the resorption cavity. It frequently results from chronic inflammation of the pulp and its progression is dependent on the interaction between the vital pulp tissue and necrotic tissue. Chronic irritation of the pulpal tissue occurs when bacteria and their components enter root canals via dentinal tubules that are exposed by mechanical damage. Bacteria can also enter the canals at areas of dilaceration or cracks in the cervical area of the root. It most commonly occurs in the cervical region.

Clinical Evaluation: Generally asymptomatic and usually identified on routine radiographs. The process is only active if part of the pulp remains vital, therefore pulp testing may be positive. It is more usual for the coronal pulp to be necrotic and the apical pulp vital, resulting in a non-responsive test. Pain may occur if there is perforation of the root or the crown. If the resorption is coronal the crown may exhibit a pinkish or reddish hue because of the presence of numerous capillaries in the pulpal granulation tissue undermining the coronal enamel. It can be transient or progressive.
The transient type occurs frequently in traumatized teeth or in teeth that have undergone orthodontic or periodontal treatment.

*Radiographic Evaluation:* Appears as a circumscribed, oval, enlargement (radiolucency) continuous with the root canal wall, usually in the coronal or radicular portion of the tooth. Labially or lingually located external root resorption may have the same appearance. Therefore additional radiographs taken from the mesial and distal angles are recommended to locate the area in question.

*Treatment:* Root canal therapy is the treatment of choice unless the resorption is in the vicinity of the apical foramen and suspected of being related to pulp revascularization. If it has extended into the periodontal ligament via a crown or root perforation, then crown lengthening or root extrusion may be implemented to gain access for repair.

**EXTERNAL RESORPTION**

There are three authors who have defined external resorption:

*(I) *Andreason *(1988)* defined three external resorption types:

(a) *Surface resorption* which is a self limiting process involving small outlining areas, followed by spontaneous repair from adjacent intact parts of the periodontal ligament.

(b) *Inflammatory resorption* where initial root resorption has reached dentinal tubules of infected necrotic pulpal tissue or an infected leukocyte zone.

(c) *Replacement resorption* where bone replaces the resorbed tissue and leads to ankylosis
(2) *Tronstad (1988)* divided inflammatory resorption into two types:

(a) *Transient resorption* occurs when the stimulation causes minimal damage and is for a short period. Usually detected radiographically and repaired by cementum-like tissue.

(b) *Progressive resorption* occurs when the stimulation is for a longer period and is tissue-pressure related, thus once forces are removed resorption should cease. Usually seen as apical resorption and shortening of roots.

(3) *Ghafari (1994)*

(a) *Inflammatory resorption*: inflammatory mediators and phagocytic cells colonise mineralised or denuded cemental surface and later dentinal tubules or pulpal tissues. All resorptions result from an inflammatory response to stimuli.

(b) Surface resorption: External root resorption due to inflammation in the outlining area of the root surface (cementum and possibly dentine and pulpal tissue). Usually transient followed by repair from adjacent intact parts of the periodontal ligament (and cementum) by a cementum like tissue. Generally undetected radiographically. If aetiology is not removed it may progress further.

(c) *Progressive resorption with bone substitution*: present with distinct change in the anatomy of the roots. Bone occupies space of the resorbed tooth substance and the resorption is detected radiographically. Ankylosis or replacement resorption may be the outcome.
(d) Progressive resorption without bone substitution: Progressive inflammation without substitution of the resorbed tooth substance by bone. May be cervical or peripheral. Not reported as a common outcome.

Surface resorption or transient inflammatory resorption is usually seen after orthodontic treatment with replacement resorption occurring rarely (Brezniak and Wasserstein, 1993). Transient resorption is thought to be clinically insignificant (Tronstad, 1998; Ghafari, 1994)

PROCесс OF ROOT RESORPTION

Root resorption of the adult permanent dentition is a pathological process, of internal or external origin, which occurs when the natural protection of the predentine and odontoblasts in the root canal, or the precementum and cementoblasts on the root are damaged or removed. Our knowledge of the underlying mechanisms involved in this process relies on our understanding of the osteoclast cell. Osteoclasts are large, multinucleated cells that originate from blood borne leukocytes from the bone marrow; the precursor cell is from the monocyte cell line (Gunraj, 1999). Osteoclasts locate near the bone surface or in bay-like erosions called Howship’s lacunae at the bone surface. Toward the bone surface, they have a ruffled border delineating clear zones. Osteoclasts resorb bone by releasing demineralising agents and degrading enzymes into the Howship’s lacunae under the ruffled border, then ingest the bone degradation products by phagocytosis. Resorption of the teeth may occur as a result of mechanical stimulation or neoplastic processes. The resorptive process of the dentinal tissue is similar to that of bone, but with some notable differences. The dentin-
resorbing cells (dentinoclasts) have fewer nuclei and have no clear zone in contrast to the well-developed clear zones of the actively resorbing osteoclasts. This has been attributed to the difference in composition of the dental tissues when compared to bone (Hammarstrom and Lindskog, 1985). It is suggested that osteoclast activating factor, macrophage chemotactic factor, prostaglandins, Heparin and bacterial products may play a role in the activation and function of these cells.

Lindskog and Hammarstrom (1980) and Hammarstrom and Lindskog (1985) also suggest there are factors that prevent resorption:

- An anti-invasion factor (a protease inhibitor), which may be produced by an intact periodontal ligament.
- The Hyaline layer of Hopewell-Smith, or the intermediate cementum layer, seen histologically, is important in the prevention of inflammatory resorption of replanted teeth, because it acts as a barrier against the penetration of toxins in pulpal origin into the periodontal ligament.

Jones and Boyd (1988) suggest that the cellular layer covering the root surface such as Sharpey’s fibres, cementum, cementoid and the rest cells of Malassez might contribute to the root surface protection. Uncalcified mineral tissues, osteoid, precementum and predentine have been reported to be resistant to resorption and prevent initial loss of root tissue (Reitan 1985). However continuous pressure will eventually lead to resorption of these areas. Reitan, (1974) suggested when the surface cell layer was breached, the epithelial barrier may permit blood vessels to access the tooth surface and the resorptive process can begin. Resorption of the calcified dentinal tissues occurs when osteoclasts have access to the mineralized tissue through a breach
in the formative cell layer covering the tissue (Tronstad, 1988; Jones and Boyde, 1988). It can also occur if the pre cementum is mechanically damaged or scraped off or when the mineral and matrix surfaces meet (Jones and Boyde, 1988). The type of resorption seen in orthodontics is frequently preceded by hyalinization of the periodontal ligament. During the remodeling process of the hyalinized zone the necrotic hyalinized tissue and alveolar bone wall are removed by phagocytic cells such as macrophages, foreign body giant cells and osteoclasts (Kvam 1970, Rygh, 1974). As a side effect of the cellular activity during the removal of the necrotic periodontal ligament tissue, the cementoid layer of the root and the bone are left with raw unprotected surfaces in certain areas that can be attacked by resorptive cells. Root resorption then occurs around this cell free tissue, starting at the border of the hyalinized zone. Light and transmission electron microscopy have shown that root resorption occurs near the hyalinized zone in close proximity to a rich vascular network (Rygh, 1977). This has been verified by Brudvik and Rygh, (1993, 1994), who demonstrated the occurrence of small lacunae in the cementum both at the coronal and apical peripheries of the hyalinized zone. Their results show the following consistent pattern:

(1) The first sign of root resorption (initial phase) was defined as penetration of cells from the periphery of the necrotic tissue where mononucleated fibroblast like cells, stained negatively by tartrate resistant acid phosphatase (TRAP), started removing the pre cementum/cementum surface.

(2) Root resorption beneath the main hyalinized zone occurred in a later phase during which multinucleated TRAP-positive cells were involved in both removing the main mass of the necrotic periodontal ligament
tissue and the outer layer of the root cementum. Further studies indicated that after the multinucleated TRAP-positive cells reached the subjacent contaminated and damaged root surface and removed the necrotic periodontal tissue, they continued to remove the cementum surface (Brudvik and Rygh, 1994).

When the movement is discontinued, repair of the resorbed lacunae occurs, starting at the periphery. After the force has terminated, active root resorption by TRAP-positive cells in the resorption lacunae is still observed in areas where hyalinized tissue existed (Brudvik and Rygh, 1995). After the hyalinized tissue was eliminated, fibroblast like cells invaded the active resorption site and repair of the lacunae occurred. The process of repair occurs 35-70 days after the force application is removed or is below the optimal level (Harry and Sims, 1982) and occurs in the presence of light forces. New mineralized cementum was observed on the resorbed root surface by 21 days (Brudvik, 1995). Repair is by the migration of the cementoblast over the resorbed surface (Jones and Boyde, 1988). The reparative process commences with a thin covering layer of acellular cementum, however most of the reparative cementum is cellular cementum and always covers the initially formed acellular cementum (Owmann-Moll and Kurol, 1998).
AETIOLOGY OF ROOT RESORPTION

Apical root resorption is a complex process with a multifactorial aetiology. Many factors have been investigated. They can be divided into patient-related factors and treatment related factors.

PATIENT RELATED FACTORS

1. Genetic predisposition
2. Age
3. Gender
4. Endodontically treated teeth
5. Previous trauma
6. Tooth type/Tooth form
7. Facial and dentoalveolar structure
8. Malocclusion type and severity
9. The experience of pre-treatment root resorption
10. Nutrition
11. Habits
12. Systemic Factors/Medicines
13. Allergies
14. Dense alveolar bone.
TREATMENT RELATED FACTORS

1. Magnitude of the orthodontic force
2. Continuous versus intermittent forces
3. Direction of tooth movement
4. Appliance type
5. Treatment duration.
6. Relapse

PATIENT RELATED FACTORS

1. Genetic predisposition

Early studies suggested a genetic component to shortened roots (Massler and Perreault, 1954; Newman 1975) and although no definite genetic conclusion was found, autosomal dominant, autosomal recessive and polygenic modes of inheritance are possible. Harris (1997) investigated the possibility of a genetic factor in susceptibility using a sample consisting of 103 pairs of siblings all treated by one technique and by one orthodontist. The results showed a moderately high heritability for apical root resorption, as there is significantly more variation among families than among siblings within families. A prior sibling’s outcome should be a useful gauge of another siblings risk. Sameghima and Sinclair (2001) in a study of 868 patients treated by 6 orthodontists, all with more than 10 years experience found that there was a racial difference in amount of root resorption with Asian patients having less resorption than White or Hispanic patients. Not all the patients were included in the racial assessment, only the patients from one office where there was a reasonable amount of each of the ethnic groups.
2. Age

Massler and Malone (1954) claimed that even with no orthodontic treatment the incidence of apical root resorption increases with age. Burdi and Moyers (1988) also suggest that there is an increase in more severe types of resorption with age. Sameshima and Sinclair (2001) found that adult patients experienced more root resorption than children in the mandibular anterior segment only. Reitan (1954) observed that the alveolar bone surface was more aplastic before orthodontic treatment, indicating that the periodontal structures were in a state of rest. In adults there are a moderate number of cells and the fibrous cells react more slowly with a slower turnover of collagen than in children. In adults the reduced cellularity results in a delayed onset of tissue changes during tooth movement. These changes are reflected by a higher susceptibility to root resorption. Some investigators (Burdi and Moyers, 1988; Rudolph, 1940; Henry and Weinmann, 1951) have observed a decrease in root length, attributed to resorption, whereas others have found an increase in root length and with age attributed to the deposition of new cementum (Van der Linden and Duterloo, 1976; Zander and Hurzeler, 1958). Bishara et al. (1999) in a longitudinal study assessed the change in root length for 26 subjects from the age of 25 to 45 and found that there were no significant changes in root length. Harris and Baker (1990) examined two orthodontically treated groups. One of adolescents (mean age 12 years) matched for sex, malocclusion and treatment regime to a group of adults (mean age 28 years). They found that although the adults lost greater amounts of crestal bone in treatment changes in the root length was the same for both groups.

It is possible that tooth movement may affect the final root length of a developing tooth. The application of gentle forces has been reported to have little effect on the predestined tooth length (Rudolph, 1936). Rosenberg (1972) found that teeth with
incompletely formed roots, which undergo orthodontic tooth movement, do reach their normal or predestined length. Mavragani et al. (2002) found that the final root lengths when related to pre-treatment age were significantly greater for roots that were incompletely developed at the start of treatment. An indication that there is a mechanism that protects the younger teeth against apical root resorption. Whereas Hendrix et al. (1994) showed that teeth that were immature at the commencement of orthodontic treatment showed root lengthening during active treatment but did not reach their “normal” tooth length.

3. Gender
Newman (1975) indicated that females are more susceptible to apical root resorption with an idiopathic root resorption ratio of 3.7:1, females to males, respectively. Kjaer (1995) found that girls were more susceptible to root resorption than boys. In contrast a greater prevalence of root resorption was detected in a group of adult orthodontic patients, age >20 years, (Baumrind et al., 1996). No statistically significant differences in apical root resorption were apparent between males and females when endodontically treated incisors were compared, but control teeth exhibited significantly more resorption in male patients than female patients (Spurrier et al. 1990). Other studies (Linge and Linge, 1983; Sameshima and Sinclair, 2001) found no sex differences in amount of apical root resorption.

4. Endodontically Treated Teeth
There is inconclusive evidence regarding the frequency or extent of apical root resorption in endodontically treated teeth that are subjected to orthodontic forces. The endodontically treated teeth respond to the orthodontic forces in a manner similar to
normal teeth. However a higher frequency and severity of root resorption of endodontically treated teeth has been reported (Wickwire et al., 1974). Remington et al. (1989) found a decreased amount of resorption and speculated that an increased density of dentine in root filled teeth provides resistance to resorption. Spurrier et al. (1990) concluded that endodontically treated incisors resorb with less frequency and severity than vital control teeth, with no significant differences between male and female patients.

5. Previous Trauma

A significant number of patients who have orthodontic treatment have previously traumatized their incisors. Orthodontically moved traumatized teeth with previous root resorption are more sensitive to further loss of root structure. Brin et al. (1991) concluded that the combination of trauma with orthodontic tipping renders the teeth more susceptible to complications, especially to root resorption and loss of vitality. If there is repeated trauma then 75% of the teeth show resorption compared with 355 of teeth injured only once. The average loss for trauma patients after orthodontic treatment was 1.07mm compared with 0.64mm for untraumatised teeth (Linge and Linge, 1983). Traumatized teeth without signs of resorption are not resorbed more than non-traumatized teeth (Malmgren et al., 1982).

6. Tooth Type/ Tooth form

Most studies report that the upper lateral, upper central and the lower incisors are the most frequently affected teeth. Several studies have shown that maxillary teeth are more affected than mandibular teeth (Ketcham, 1929; McFadden et al., 1986) and maxillary incisors more than mandibular incisors (DeShields, 1969). This may be
explained by the fact that these teeth are subject to greater movement with their root structure and relationship to bone tending to transfer the forces mainly to the apex (Oppenheim, 1936). It is believed that if there is no resorption of the upper and lower incisors then significant apical resorption in other teeth is less likely to occur (DeShields, 1969).

It is possible that patients with dental anomalies have increased risk for apical root resorption during orthodontic treatment. The mechanism may be that the cementum and dentine are affected during tooth formation, thus possibly reducing the ability of the cementum and dentine to resist resorption (Seow and Shusterman, 1994).

Tooth form has been considered as a factor in root resorption with pipette shaped roots (Levander and Malmgren, 1985) and impacted maxillary canines (Linge and Linge, 1991) identified as risk factors. Kjaer (1995) in a study of 107 patients found that there was a connection between anomalies in the dentition, particularly ectopia and agenesis and the pattern of resorption. There was a strong correlation between various dental morphological characteristics, such as invaginations, length of the root, root shape and taurodontism and a tendency for root resorption. Sameshima and Sinclair (2001) who concluded that teeth abnormal root shape (pipette, pointed or dilacerated) and the upper lateral incisors exhibited more resorption. Thongudomporn and Freer (1998) in a study of 111 patient records concluded that patients with one dental anomaly had a significantly higher degree of root resorption than patients with no dental anomaly. Invaginated teeth, teeth with thin or pipette shaped roots and teeth with short blunt roots were likely to be more susceptible to root resorption. In contrast to these studies, Lee et al. (1999), in a study of 84 patients who had periapical radiographs pre- and post-treatment and the presence of at least one dental anomaly found that the presence of one anomaly or more than one anomaly did not increase the
risk of root resorption. Hypodontia or partial anodontia puts existing teeth at risk of root resorption (Levander et al., 1998).

7. **Facial and dentoalveolar structure**

Root contact with the labial or palatal cortical plate at root apex level may cause root resorption. It has been suggested that patients dentofacial morphology may predispose certain patients to these types of movement and therefore contact with the cortical plate and increased resorption. The association between root contact with the cortical plate and root resorption was first reported by Ten Hoeve and Mulie (1976) and Mulie and Ten Hoeve (1976). It has been shown by Kaley and Phillips (1991) that approximation of the maxillary incisor to the cortical plate increases the risk of root resorption. Handleman (1986) analyzed 107 adult cephalometric films in order to measure the width of the alveolar bone anterior and posterior to the incisor in each arch. Thin alveolar widths were found both labial and lingual to the mandibular incisors in class I, II and III individuals with a high SN-MP angle and in a group of class III average SN-MP individuals. Thin alveolar bone was also found to be present lingual to the upper incisors in class II high angle group. Orthodontic tooth movement may be limited in these groups. Horiuchi et al., 1998 investigated the correlation between cortical plate proximity and apical root resorption for the upper incisor and found that root approximation to the cortical plate could account for approximately 12% of the variance found and alveolar bone width for 2%. In contrast Mirabella and Artun (1995) and Wainright (1973) found no association between root contact to the cortical plate and apical root resorption and suggested that the resorption may occur as a result of amount of tooth movement rather than proximity to the cortical plate.
Taithongchai et al. (1996) investigated facial and dentoalveolar structure and they found that in the absence of a history of trauma or pre-treatment signs of root resorption, pre-treatment facial and dentoalveolar structure cannot be used to identify persons who will experience a large amount of apical root shortening during a course of orthodontic treatment.

8. Malocclusion type and severity

The dental and skeletal malocclusion should be considered as certain skeletal patterns have thinner alveolar bone and subsequent tooth movement may approximate the roots to the cortical plate increasing the risk of root resorption (Handleman, 1996). Harris and Butler (1992) found an increased incidence of root resorption in patients with open bites, it was hypothesized that long-term orthopedic forces of tongue thrusting enhance the rate of clastic activity.

Extraction treatment is more likely if there is severe the crowding. A number of authors have indicated that extraction treatment increases the risk of root resorption (Kaley and Phillips, 1991; Taner et al., 1999; Sameshima and Sinclair 2001). Class III patients and patients who required surgery were among those with the most severe resorption in an assessment of 200 consecutively debanded patients (Kaley and Phillips, 1991) suggesting the severity of the malocclusion may play a role in increased resorption.

Mirabella and Artun (1995) found no difference in the amount of root resorption post treatment and the type of initial malocclusion.
9. The experience of pre-treatment root resorption

Phillips (1955) indicated that there is a high correlation between the amount and severity of root resorption present before treatment and the resorption detected after treatment. Whereas Plets (1974) concluded that although roots that are already shortened are reported as having a tendency toward shortening during treatment the effects of specific procedures are not clear.

10. Nutrition

Becks (1936) demonstrated root resorption in animals deprived of dietary calcium and vitamin D. Malnutrition has also been suggested as a cause of root resorption (Marshall, 1929). However there is no conclusive evidence that nutritional imbalance is a major factor in root resorption during orthodontic treatment.

11. Habits

Several habits have been reported to increase the risk of apical root resorption. Heavy mastication or excessive functional use of the teeth has been shown to cause root resorption of the incisors in Eskimos (Hylander, 1977). Similarly individuals who exhibit chronic bruxism often experience root shortening (Ramfjord and Ash, 1971). If there is a history of a finger sucking habit persisting past 7 years or lip/tongue dysfunction the patient is at increased risk of root resorption (Linge and Linge, 1991). Tongue thrust associated with an open bite and increased tongue pressure has been associated with increased resorption (Newman, 1975). Nail biting may constitute a non-physiological force and has been shown to be a significant risk factor in the development op apical resorption (Odenrick and Brattstrom, 1983, 1985).
12. Systemic Factors/ Medicines

The systemic condition of the patient should be carefully considered. External resorption has been found in Hypoparathyroidism, Hyperparathyroidism, Calcinosi s, Turner Syndrome, Paget’s disease and Gaucher’s disease (Infantino and Ingram, 1989).

13. Allergies

It has been hypothesized that allergy might be an etiological factor in increased root resorption induced by orthodontic forces (Davidovitch et al. 1995; Davidovitch, 1996) Owman-Moll and Kurol (2000) analyzed a number of factors that might be associated with root resorption. They found after a preliminary screening of possible risk factors, i.e. root morphology, gingivitis, allergy, nailbiting, medication, only those subjects with allergy showed an increased risk of root resorption, but this was not statistically significant. McNab et al. (1999) using panoramic radiographs measured the apical root resorption occurring in 44 asthmatic patients and 99 healthy patients. They found that there was a statistically significant increase in apical root resorption in the posterior teeth of the asthmatics compared to the controls. However both groups showed equal amounts of moderate and severe resorption.

14. Dense Alveolar Bone

Several authors have reported that more resorption occurs with dense alveolar bone than in less dense alveolar bone (Reitan, 1985; Goldie and King 1984; Ten Hoeve and Mulie, 1976; Remmelnick, 1984). In less dense alveolar bone there are more marrow spaces. Tooth movement is facilitated, as there is a greater formation of active resorptive cells as their number increases according to the number of marrow spaces.
Direct contact between the roots and cortical plate has been shown to precipitate root resorption in the second stage of the Begg technique (Hall, 1978; L’Abee and Sanderink, 1985).

TREATMENT RELATED FACTORS

1. Magnitude of the orthodontic force

The importance of force in orthodontics has been discussed for years with the holy grail of an ideal force still eluding the profession. According to Schwartz (1932) if the applied force exceeds the optimum of 20-26 gm/cm² there is periodontal ischaemia, hyalinisation and subsequently the risk of root resorption. Harry and Sims (1982) found that the distribution of resorbed lacunae was directly related to the amount of stress on the root surface and the rate of lacunae development more rapid with increasing force. Many studies have been performed to investigate the magnitude of applied force and amount of tooth movement (Storey and Smith, 1952; Reitan, 1960; Boester and Johnston, 1974; Andreasen and Zwanziger, 1980) as well as between the magnitude of applied force and root resorptions (Reitan, 1974; Harry and Sims, 1982; Vardimon et al. 1991). King and Fischlschweiger (1982) reported that light forces produced more rapid tooth movements with insignificant cemental cratering whereas heavy forces resulted in slower displacements and a substantial amount of root resorption. Owman-Moll et al. (1996ᵃ) in an intra-individual study compared the use of 50g and 200g forces, where the heavy force was four times the light force. Tooth movements were measured on dental casts and the root resorptions measured histologically. There were no differences in severity or frequency of resorptions between the two groups. Owman-Moll et al, (1996ᵇ) also studied the difference between 50g and 100g force, again in an intra-individual study and found no
difference in resorption between the groups. A surprising finding was that some of the resorptions were larger with the 50g of force at 7 weeks than the 100g force. This is in agreement with Stenvic and Mjor (1970) who found that an increased force level caused a decrease in root resorption when premolars where intruded. There was individual variation in tooth movement in study on four-fold increase in force (Owman-Moll et al., 1996a). The major source in the variation may not be a result of the magnitude of the force but due to a variation in metabolic response.

The second issue of force magnitude is the perceived force applied by the orthodontist as most estimate the forces they apply and do not directly measure them. Kurol et al. (1996) studied the magnitude and variation of forces applied for buccal tipping of the premolars and canines. Nineteen orthodontists bent and activated a sectional arch wire on a typodont. The study showed a substantial difference in applied forces ranging from 30-100g.

2. Continuous versus intermittent forces

Teeth and the supporting tissues may react differently to continuous force and to force interrupted by periods of rest. In fact if root resorption is detected early in treatment a pause in treatment has been shown to reduce the amount of final resorption when compared to treatment without a pause (Levander et al., 1994). It is believed that periods of rest favorably affect cell proliferation in the supporting tissues, which in turn promotes further tissue change when the appliance is reactivated (Reitan, 1985). Maltha and Dijkstra (1996) compared the amount of root resorption after continuous (24 hour a day) and discontinuous (16 hours a day) force applications. They showed that discontinuous forces caused less extensive root resorption.
Owman-Moll et al. (1995) investigated the effects of continuous and interrupted continuous forces of equal magnitude, 50g. They concluded that there was no difference in the amount or severity of root resorption between the two groups, but there was more effective horizontal movement with the continuous force. There were individual variations in both the magnitude of tooth movement and severity and amount of root resorption. Therefore King (1995), in his commentary, urges caution in interpretation of these results.

Acar et al. (1999) applied a 100g tipping force, using elastics, to 22 premolars that were going to be extracted as part of orthodontic treatment. One side was randomly chosen to be the continuous side and the contralateral side became the discontinuous side. Elastics were worn 24 hours on the continuous side and 12 hours on the discontinuous side. The experiment lasted 9 weeks. The roots of the teeth were examined by electron microscopy and the areas affected by resorption determined. Visual scoring assessed the degree of root blunting. The application of a discontinuous force resulted in less root resorption than the application of a continuous force.

3. Direction of tooth movement

Different kinds of tooth movement possibly relating to root resorption have been studied radiographically. Comparison of the studies is difficult as there are large differences in the methods and techniques. It is generally accepted that extensive tooth displacements, torque movements, intrusion and jiggling forces are responsible for root resorption.
Extensive Tooth Displacements:

Baumrind et al. (1996) analyzed the relationship in orthodontically treated adults between upper central incisor displacement measured on a lateral cephalogram and apical root resorption measured on anterior periapical films. The total apical displacement showed a statistically significant association with root resorption.

Costopoulos and Nanda (1996) also demonstrated that upper incisor apex movement was correlated to amount of apical resorption.

Parker and Harris (1998) in a study of 110 adolescents with similar malocclusions who had extraction of the first four premolars were treated with Tweed standard edgewise technique, Begg light wire technique and Roth prescription straight wire technique. The apical and incisal vertical movements and increase in incisor proclination were strong predictors of external apical root resorption. Distal bodily retraction, extrusion and lingual crown tipping had no effect on the amount of resorption.

Torque Movements:

Kaley and Phillips (1991) demonstrated that torque application to the upper incisors increases the chance of root resorption.

Casa et al. (2001) examined 28 upper first premolars extracted from 14 patients after no movement, 300g or 600g torque applied, with a scanning electron microscope. They found that there was an increase in the number of lacunae on the lingual side of the apical third and cervical third on the buccal root surface.

Parker and Harris (1998) found that increased lingual root torque increased the amount of resorption.
**Intrusion:**

Dermaut and DeMunck (1986) examined the possibility of a relationship between the amount of root shortening and duration of the intrusive force. There were 66 incisors with an intrusion period of 29 weeks. There was 3.5mm intrusion performed. The findings clearly showed there was root shortening after intrusion with a mean shortening of 18% of the original tooth length. No correlation was found between the amount of resorption and the duration of intrusion.

McFadden et al. (1987) using a utility arch with 25g activation for intrusion found that there was no relationship between the amount of root shortening and intrusion achieved. The average root shortenings were 1.84mm for the maxillary teeth and 0.61 for the mandibular teeth.

Beck and Harris (1994) in a study of Begg and Tweed treated cases found that in the anchor teeth the root that was intruded typically experienced more resorption whereas the extruded root remained unchanged.

Costopoulos and Nanda (1996) in a study of intrusion of the maxillary incisors using a Burstone-type intrusion arch (15g per tooth) found that the amount of resorption was not correlated to the amount of intrusion. There was 0.6mm resorption in the intrusion group and 0.2 mm in the control group. This study suggests that intrusion with low forces can be effective in reducing the overbite while causing only a negligible amount of apical resorption. A weak correlation (r=0.45) was found between root resorption and movement of the apex, which is similar to the conclusion drawn by other studies investigating buccal/lingual root movement (Kaley and Phillips, 1991) or rectangular arch wires that produce torque (Linge and Linge, 1991).
Jiggling Forces:

Jiggling forces causing occlusal trauma have been shown to increase the amount of apical resorption and also bone loss in the furcation area of multi-rooted teeth. Class II elastics are thought to act like jiggling forces and have been shown to increase the amount of root resorption (Linge and Linge, 1983). A pilot study on the same sample as Linge and Linge (1983) demonstrated that the wearing of a unilateral class II elastic leads to increased resorption of the maxillary incisors on that side.

Bodily Movement:

Reitan (1964, 1985) suggested that the stress distribution along the roots during bodily movement is less than the stress concentration at the apex resulting from tipping. Therefore the risk of root resorption should be less than that of tipping. However tipping movements, with removable appliances have been shown to cause less resorption than fixed appliances (Linge and Linge, 1983). It has been suggested that the teeth even in a straight wire system do not move bodily anyway but by a series of small tipping and uprighting movements or perturbations.

4. Appliance type

Many authors claim that the degree of root damage is a function of the appliance used.

(a) Fixed and removable appliances:

Linge and Linge (1983) compared root resorption in the maxillary incisors of 719 consecutively treated orthodontic patients. They found fixed appliances caused more apical root resorption than removable appliances.
(b) *Begg and Edgewise techniques:*

Kinsella (1971) stated that the Begg technique caused less root resorption than the edgewise technique. Mollenhauer (1987) found that the Begg technique caused more root resorption than the edgewise technique. Beck and Harris, (1994), Malmgren et al. (1982) and Parker and Harris, (1998) found no difference in the amount of apical resorption between the two techniques was found.

(c) *Standard Edgewise and Straight wire techniques:*

Mavragani et al. (2000) compared the two appliance types for 80 patients who had first premolar extractions. They found significantly more resorption for the upper central incisors with the standard edgewise compared to the straight wire appliance.

(d) *Speed Appliance and Edgewise appliance*

Blake et al. (1995) investigated the Speed appliance and edgewise-straight wire appliance to compare the incidence of apical root resorption. There was no statistically significant difference between the two appliance systems found.

(e) *Bioefficient Therapy and Edgewise straight wire appliance*

Janson et al. (1999) compared simplified standard edgewise, edgewise straight wire system and Bioefficient therapy. They found that there was less apical root resorption in the Bioefficient therapy group and proposed it was due to the use of the heat activated and superelastic wires used.

(f) *Sectional and Continuous Mechanics*

Alexander (1996) compared sliding mechanics to sectional mechanics in 56 subjects who had the extraction of the first four premolars. He found that there was no difference in the extent of the apical root resorption between the groups and concluded that the assumption that teeth are more prone to resorption with continuous arch mechanics may be erroneous.
(g) Maxillary Expansion

Radiographic studies only deal with apical resorption, as buccal and lingual resorptions are less perceptible on intra-oral radiographs. Expansion has been demonstrated to cause root resorption. Premolars and molars are pressed in a buccal direction against the thin cortical plate predisposing to resorption (Vardimon and Graber, 1991).

5. Treatment duration.

The time the appliances are acting may influence root resorption. Most studies report that the severity of root resorption is directly related to the treatment duration (Goldson and Henriksson, 1975; Levander and Malmgren, 1988; Goldin, 1989; Linge and Linge 1991; Sharpe et al., 1987; McFadden et al., 1989). Levander and Malmgren (1988) found that after 6-9 months of treatment with fixed appliances 34% of teeth showed apical resorption whereas 56% demonstrated resorption 10 months later at the end of treatment. Goldin (1989) found that the average root loss was 13% or 0.9 mm per year. Levander et al. 1998 found that in patients with multiple aplasia lengthy treatments increased the incidence of root resorption. However several studies do not find a statistical significant increase in root resorption based on treatment time (Phillips, 1955; Kvam, 1972; Vonder Ahe, 1973; Hendrix et al. 1994; Mirabella and Artun, 1995).
6. Relapse

Post-treatment relapse of corrected teeth is a major concern in orthodontic treatment. A periodontium incorporating adequate tooth length and bone support has been stated to be an important factor in the maintenance of post-treatment stability (Riedel, 1960). A reduction in crestal bone support and tooth length by resorption has been reported as sequelae to orthodontic treatment (Zachrisson and Alnaes, 1974; Hollender et al. 1980). Sharpe et al. (1987) determined if there were any significant differences in prevalence, distribution, or severity of root resorption between relapse and non-relapse groups. The relapse group had a definite trend towards a greater reduction in tooth length and alveolar support with the most consistently affected tooth the maxillary central incisor. The subjects in the relapse group had undergone longer periods of treatment and exhibited greater loss of crestal bone. The fact they had greater loss of crestal bone may be part of the reason why there was more relapse. Kalkwarf et al. (1986) using a computer generated mathematical model of an upper right central incisor demonstrated that apical resorption is much less critical in its effect on the area of remaining periodontal support than the loss of alveolar support at the coronal margin secondary to periodontitis. Initially 3mm of root resorption is approximately equivalent to 1 mm of crestal bone loss. Following more than 2mm of loss the ratio is closer to 2mm of root resorption equalling 1mm of crestal loss. If there has been crestal bone loss and apical root resorption the equilibrium the tooth is in may be changed resulting in tooth movement and relapse.

Ronnerman and Larsson (1981) in a longitudinal study followed up 23 patients at 3 years and 10 years. They found that root resorption of 1-3mm was present in 39% of the cases. There was no progression of the root resorption between the 3 and 10-year review appointments. However there was an increase in the overjet by up to 1mm at
the 3-year review and a further slight deterioration by the 10-year review. There was crowding of more than 1mm in the lower incisors in half the patients at the 10-year review. This suggests that the teeth relapsed but did not undergo further resorption from the relapse movements. It did not investigate if the teeth that had the most resorption underwent the most relapse.

Remington et al. (1989) recalled 100 patients who had demonstrated root resorption during active treatment an average of 14.1 years after treatment. The evaluation showed there were no apparent changes in the roots after appliance removal except remodelling of rough and sharp edges. Copeland and Green (1996) suggested that root resorption may occur after the active phase of treatment is completed (retention) if there is traumatic occlusion or active force delivering retainers.
Reference:


Boester CH and Johnston LEA. clinical investigation of the concepts of differential and optimal force in canine retraction. Angle Orthod 1974; 44:113-9


Kvam E. A study on the cell free zone following experimental tooth movement in the rat. Trans Eur Orthod Soc 1970;45:419


Oppenheim A. Biologic orthodontic therapy and reality. Angle Orthod 1936; 6: 69-116


Reitan K. Effects of force magnitude and direction of tooth movement on different alveolar bone types. Angle Orthod 1964; 34:244-55


Rygh P. Ultrastructural changes in tension zones of the rat molar periodontium incident to orthodontic tooth movement. Am J Orthod 1974;70: 269


Zachrisson BU and Alnaes L. Periodontal condition in orthodontically treated and untreated individuals. II. Alveolar bone loss: Radiographic findings. Angle Orthod 1974; 44:48-85

INTRODUCTION

It has been well documented in the orthodontic literature that root resorption is a common and unpredictable adverse effect of treatment. Root resorption is a complex process with a multifactorial aetiology \(^1,^2\). Many factors have been investigated. They can be divided into patient-related factors and treatment related factors \(^3\). The patient related factors are genetic predisposition \(^4,^6\), age \(^7,^10\), gender \(^5,^11-^13\), tooth vitality \(^13-^15\), tooth type \(^4,^8,^16,^17\), facial and dentoalveolar structure \(^18-^24\), malocclusion type and severity \(^20,^25\), the experience of pre-treatment root resorption \(^26\), nutrition \(^27,^28\), habits \(^5,^29-^33\), medicines \(^34\), allergies \(^35-^36\), root form \(^11,^37,^38\), previous trauma \(^39,^40\) and dense alveolar bone \(^41\). The treatment related factors are magnitude of the orthodontic force \(^42-^45\), continuous versus intermittent forces \(^46-^49\), direction of tooth movement \(^12,^17,^20,^50-^54\), appliance type \(^40,^51,^54,^55-^62\) and treatment duration \(^17,^31,^63-^65\).

To accurately assess the incidence and prevalence of root resorption occurring in orthodontic treatment radiographs or histological sections are required \(^3\). As radiographs are routinely taken for patients undergoing orthodontic treatment, material has been available to study the problem of root resorption. Most studies are retrospective with the radiographic views most commonly used being the lateral cephalometric \(^18,^19,^23,^25,^51,^67\), panoramic \(^10,^20,^36,^68\), periapical \(^9,^14,^58,^59,^60,^69\) or combinations \(^12,^17,^61,^63,^65,^70\) of these. Others have reported on the use of digital subtraction imaging \(^71-^73\) and laminography \(^21,^22,^74,^75\). Unfortunately due to a lack of standardization and the variability of the techniques comparisons of the radiographic studies are limited. Diagnosis of apical root resorption from non-standardized serial radiographs can be misleading. In general terms a difference in contrast or film density may affect visualisation of the apical area. The lateral cephalometric
radiograph is limited with only the anterior teeth being measurable due to the lack of clarity posteriorly. Periapical radiographs are influenced by the variation of the projection angle, which can cause foreshortening or elongation of the image. A customised stent may be used in the paralleling technique but due to tooth movement there will be a change in angulation, as the mechanical device cannot maintain the imaging geometry. Patient positioning is critical with panoramic radiography with errors resulting in a distorted image with the teeth appearing foreshortened, magnified and/or out of focus. Digital subtraction radiography requires a standardisation of the brightness, contrast and projection geometry of the radiographs.

The reported incidence of external apical root resorption is highly variable with greater than 2.5mm of resorption reported in 16.5% of adolescents (31) and 40% adults (76). Other studies (16,26) have demonstrated that 100% of teeth display some level of resorption after orthodontic treatment. The roots of patients who underwent extraction of first premolars and were not treated with fixed appliance therapy were longer than those treated with serial extraction alone (77). A ten-year evaluation of the quality of treatment involving 3,300 patients found 1-3mm of root resorption occurred in all fixed appliance cases (78).

The extent of apical resorption varies between patients and different teeth of the same person (1,2,79). The maxillary incisor teeth are most often affected by root resorption, followed by maxillary second premolars, maxillary lateral incisors and maxillary first premolars (5).

The question is whether a reduction in root length will lead to a reduced lifespan? It is speculated that severely shortened teeth are less suitable for resisting masticatory functional loads (80). However we know from a computer generated mathematical model of an upper right central incisor (81) that apical resorption is much less critical in
its effect on the area of remaining periodontal support than the loss of alveolar support
at the coronal margin secondary to periodontitis. Initially 3mm of root resorption is
approximately equivalent to 1 mm of crestal bone loss. Following more than 2mm of
loss the ratio is closer to 2mm of root resorption equalling 1mm of crestal loss.

Extensive resorption does not usually affect the functional capacity of the teeth (14, 82)
and once active treatment has ceased there is no further progression of resorption (83).
A report on 100 patients, who were recalled a mean of 14.1 years post treatment and
had exhibited root resorption during appliance therapy showed no apparent changes
after appliance removal except remodelling of rough or sharp edges and
hypermobility in two instances (14). However we must take a step back and consider
the potential detriment to a dentition by having an unfavourable crown to root ratio. It
may render the tooth unsuitable in later life to act as an abutment for prosthetic
replacement, if the ratio was less than 1:1.

It has often been stated that the degree of root damage is a function of the appliance
used (2) with a link between treatment mechanics and the occurrence of apical root
resorption being discussed in the literature for more than seventy years. Early studies
found more root resorption when the “pin and tube” or “ribbon arch” appliances were
used than when treatment consisted mainly of tipping movements (84,85). An animal
study comparing bodily movement with tipping movement using the same force levels
found less resorption if the teeth were moved bodily (86). More recently Bioefficient
Therapy was compared with simplified standard edgewise and edgewise straight wire
system with less resorption in the Bioefficient Therapy group (59). The upper central
incisors were found to undergo more apical root resorption when standard edgewise
was used compared to straight wire edgewise in the treatment of Angles Class II
division 1 malocclusion with the extraction of at least two maxillary first premolars (59).

No statistically significant difference in apical root resorption was found after orthodontic treatment with edgewise-straight wire and Speed brackets (60).

There were two aims of this study. The first aim was to determine if the sex, race, appliance type, extraction of four premolars, direction and amount of anterior tooth movement or treatment duration influenced the amount of apical root resorption. The second aim was to assess if the quality of treatment could be assessed from selected root angulations.

MATERIAL AND METHOD

SAMPLE SELECTION

This retrospective study utilised the orthodontic treatment records of 114 patients selected from three sources: (1) The orthodontic department at University of Sydney, Australia, (2) A private practice in Australia (employing the Tip-Edge appliance exclusively) and (3) A private practice in New Zealand (employing the Speed appliance exclusively). The selected cases fulfilled the following criteria:

i. Completed orthodontic treatment in a single phase with (a) Straight wire \(n=43\), (b) Speed \(n=33\) or (c) Tip-Edge \(n=38\) appliances.

ii. Treated with no extractions or extraction of four premolars

iii. Had undergone no maxillary expansion, orthognathic surgery or previous orthodontic treatment including growth modification (orthopaedic treatment).
iv. All permanent teeth were present with no history of any trauma to the maxillary incisors either before or during treatment.

v. There was no alteration of the incisal edges during orthodontic treatment i.e. reshaping or restoration.

vi. No impacted teeth or endodontically treated teeth.

vii. No systemic problems or craniofacial anomaly present.

viii. Age was greater than 11 years to ensure that root formation of the permanent teeth was completed before the commencement of treatment so that there would be no residual root growth that would obscure the amount of resorption occurring during treatment (87).

ix. A clear pre-treatment and post-treatment (T₁ and T₂) orthopantomogram (OPT) taken on the same machine. Pre-treatment radiographs were taken within one year of commencement of treatment with post-treatment radiographs taken within six months of deband, except for 10 of the Speed cases which had post treatment radiographs taken up to 12 months after deband. The extension period for the post-treatment radiographs in the Speed group was necessary in order to obtain a sample of sufficient size.

x. Clear T1 and T2 lateral cephalometric radiographs taken on the same machine. Due to the use of different machines for the T1 and T2 radiographs and the unavailability of some T2 radiographs there were only 45 pairs of films available.

xi. Pre- and post-treatment orthodontically trimmed study models. Due to the unavailability of either the pre-, post- or both sets of models, there were 95 patients’ models available.
SAMPLE DESCRIPTION

There were 80 females and 34 males in the sample. The age, sex, ethnicity, presence or absence of asthma, treatment duration, and extraction pattern were recorded for each patient. The mean starting age for treatment was 14.54 ± 2.7 years with a mean treatment duration of 25 ± 6.26 months. Each treatment group was divided into extraction and non-extraction subgroups. The malocclusion types, as classified by the treating clinician were 49 Class I, 48 Class II and 17 Class III (Table I).

EXPERIMENTAL PROCEDURES

The study was divided into three parts: part 1 - to determine the extent of external apical root resorption measured from OPTs for three different appliances (Straightwire, Speed and Tip-Edge), part 2 – to quantify if there were any factors measured from the lateral cephalometric radiograph which would correlate with the amount of resorption measured and part 3 – to establish if the final root angulations of selected teeth (upper and lower canines and contiguous premolars), measured on the final OPT could be used to assess the quality of the final treatment result. To provide a quantitative objective measurement of the quality of treatment the Peer Assessment Rating Index (88,89) was used to assess the pre- and post-treatment study models. This would be compared with the final angulations of the teeth and the extent of the external apical root resorption.
PART 1 METHOD

On the pre- and post-treatment OPTs (114 patients), one operator, under standard conditions, traced the outline of the maxillary and mandibular first molars and incisors using a 0.3mm HB pencil and tracing film acetate (3M, Unitek). Using Presto Page Manager software and an Epson 1600 transmissive scanner each film and tracing was scanned at 300 dpi and saved as a Joint Photographic Expert Group (JPEG) image (Figure 1). Each image was opened in AnalySIS Pro 3.1 and magnified by 200 per cent. In order to standardise measurements the image was calibrated by digitising two points on the ruler that was scanned with each radiograph. The length of the teeth was established by digitising two points for each tooth. The length of the molars was defined as the distance from the mesiobuccal cusp tip to the apex of the mesiobuccal root. The incisal length was defined as the distance from the apex to the incisal edge measured along a line passing from the apex, through the mid point of the cemento-enamel junction line (figure 2). The teeth were then digitised in a specific order (16,12,11,21,22,26,36,32,31,41,42,46) (Figure 3) and the length of the teeth was transferred to a spreadsheet (Microsoft, Excel). Each measurement was repeated five times. The difference from T2 to T1 was calculated for each of the 12 teeth and the means transferred to the Statistical package for the Social Sciences (SPSS for Windows, release 10.0.0, SPSSInc, Chicago Illinois), for statistical analysis.

PART 2 METHOD

The lateral cephalometric radiographs of 47 patients (T1 and T2) were traced by one operator under standard conditions using a 0.3mm HB pencil and tracing film acetate (figure 4). There were two elements to analyse from the lateral cephalometric radiographs. The first was 20 measurements directly measured from the tracings (T1
and T2) using a cephalometric protractor. The second was to superimpose the pre- and post-treatment maxillae on the palatal plane registered at anterior nasal spine (ANS) and the region between ANS and point A\(^{(90)}\). This was to investigate the correlation between apical root resorption and positional change in the upper incisor. The paired films had coordinated tracings\(^{(91)}\) with each aspect of the bony detail common to the two films traced in parallel to ensure that the anatomical detail was sufficient to facilitate superimposition of the maxilla. The upper incisor was transferred from the pre-treatment to the post-treatment radiograph so that any root resorption occurring during treatment would not interfere with the measurements of apical movement. The superimposed images of the maxilla and the pre- and post-treatment mandibular symphysis tracings were transferred to A4 paper and scanned at 300 dpi as previously described (figure 5). The image was opened in AnalySIS Pro 3.1, magnified 200 per cent, calibrated using a ruler and digitised. The horizontal movement, vertical movement and true translation of the upper incisal edge and apex were determined. The distance from the incisal edge to the apex, measured parallel to the palatal plane was determined T1 and T2. The greater this measurement the greater the chance that part of the root would lie outside the focal trough. Seven measurements were made on the T1 and T2 mandibular symphysis (figure 6) to analyse if the lower incisor movement or its proximity to the lingual cortical plate could be correlated to amount of resorption detected in part 1. Each measurement was repeated 5 times as before and the mean transferred to SPSS version 10.0 for statistical analysis.
PART 3 METHOD

On the post-treatment OPT tracing, maxillary and mandibular horizontal reference lines were depicted. The maxillary horizontal reference line was constructed by connecting the most superior point of the left and right condyles, with the mandibular horizontal reference line drawn parallel to the maxillary line and inferior to the apices of the mandibular teeth. The outline of the upper and lower canines and contiguous premolars were traced with the long axis of the teeth drawn and extended apically to intersect with the appropriate constructed horizontal reference line (figure 7). If any teeth were dilacerated, the long axis was taken from the cervical two thirds of the root. The OPT and tracing was scanned and saved as a JPEG image as described previously. The image was opened in ANALYSIS Pro 3.1 and the medial angle the long axis to the horizontal was measured for the eight teeth. The measurements were repeated 5 times. The mean angles were stored on a spreadsheet (Microsoft Excel). The expected final angle of the teeth was calculated from the prescription of the appliances as defined from the relevant manufacturers catalogue. The variance from the expected final angulation was calculated by subtracting the measured angle from the expected angle. The variance of the eight teeth was transferred to SPSS 10.0 for statistical analysis.

The pre-treatment and post-treatment study models were scored using the PAR index. A single operator, who has not completed the PAR Index calibration course, determined the scores of the available 95 patient models. The British weighted (pre-treatment, post-treatment, reduction and percentage reduction) PAR scores were transferred to SPSS 10.0 for statistical analysis.
STATISTICAL ANALYSIS

Statistical analysis was done using the Statistical package for the Social Sciences (SPSS for Windows, release 10.0.0, SPSSInc, Chicago Illanois). The measurements on the OPT were repeated 5 times and an average taken.

RESULTS

PART 1 OPT MEASUREMENT OF ROOT RESORPTION.

The sample was collected from three sources with 48.2% of the sample coming from the orthodontic department at the University of Sydney, 25.4% from the private practice in Australia and 26.3% from the private practice in New Zealand. The distribution of the sources is represented in (Table 2).

The patients were not evenly distributed between the groups with 43 patients in the Straight wire appliance group, 33 patients in the Speed appliance group and 38 patients in the Tip-Edge appliance group. There were more female patients (80) than male patients (34) with the number of extraction patients (58) being approximately equal to the non-extraction patients (56). The mean pre-treatment age for the sample was 14.54 years (SD, 2.70). However there were no statistically significant differences between the mean ages based on gender, extraction/ non-extraction or the appliances used (Table 1).

The mean treatment duration for the sample was 25.16 months (SD, 6.25) with the appliances having mean treatment durations of 24.33 months (SD, 4.67) for the Straight wire appliance, 24.30 months (SD, 7.09) for the Speed appliance and 26.84 months (SD, 6.86) for the Tip-Edge appliance. There were no statistically significant
differences between the three groups. With the appliance types combined and the patients divided into non-extraction and extraction groups the mean treatment duration for the non-extraction group was 23.29 months (SD, 5.85) and the extraction group 27.09 months (SD, 6.13). This was statistically significant (p=0.01) using a bivariate correlation with two-tailed test of significance.

A general linear model, univariate analysis model was used with machine, gender and group assessed as factors in treatment duration (where group was the appliance types divided into extraction and non-extraction). The model gave mean treatment durations of Straight wire non-extraction 21.303 months (Standard Error (SE), 3.66), Straight wire extraction 24.230 months (SE, 1.745), Speed non-extraction 23.615 months (SE, 3.324), Speed extraction 22.958 months (SE, 2.740), Tip-Edge non-extraction 27.113 months (SE, 2.693) and Tip-Edge extraction 30.866 months (SE, 1.752) (Table III).

There were statistically significant differences in treatment durations between the Tip-Edge extraction and the Straight wire non-extraction groups (p=0.000); Tip-Edge extraction and Straight wire extraction groups (p=0.003); Tip-Edge extraction and Speed extraction (p=0.048) groups.

There were five panoramic machines used in the study. (Table IV, A) Three of the machines were used for patients treated at the University of Sydney with one machine being used for each of the private practices. The machine used for the OPTs was considered as a variable in the statistical model with the subsequent results demonstrating that it was not a critical factor in the study and did not, at a statistically significant level, affect the changes calculated for any of the twelve teeth measured for resorption or the eight teeth measured for angulation (part 3).

The OPTs were screened and only radiographs that appeared to have the patients correctly positioned with no distortions were selected. This gave the sample size as
114 patients with ideally 12 teeth measured on each of 228 OPTs (2736 teeth, T1 and T2). However due to a lack of clarity 47 teeth (1.7%) could not be measured (Table IV,B). As some of the teeth that could not be measured were unclear on the T1 and T2 OPTs this led to 43 (3.1%) changes in tooth lengths that could not be established. (Table IV, B) There were 819 teeth (61.8%) that demonstrated shortening and 506 teeth (38.2%) that demonstrated an increase in length.

From the model taking into account gender and machine used there were statistically significant differences between the groups for the 31 and the 41. The significant differences for the 31 were between the Straight wire extraction and Tip-Edge non-extraction groups (p=0.012) with the Tip-Edge non-extraction being 2.921mm shorter (SE, 1.134); The Speed non-extraction and Straight wire non-extraction groups (p=0.049) with the Speed non-extraction being 1.804mm shorter (SE, 0.902); Speed non-extraction and Straight wire extraction (p=0.000) with the Speed non-extraction being 3.558mm shorter (SE, 0.850); and Speed non-extraction and Tip-Edge extraction groups (p=0.041) with the Speed non-extraction being 1.820mm shorter (SE, 0.878). The significant differences for the 41 were between the Speed non-extraction and Tip-Edge extraction groups (p=0.039) with the Speed non-extraction being 1.880mm shorter (SE, 0.896); Straight wire extraction and Straight wire non-extraction groups (p=0.029) with the Straight wire non-extraction being 2.174mm shorter (SE 0.978); Straight wire extraction and Speed non-extraction groups (p=0.002) with the Speed non-extraction being 2.750mm shorter (SE, 0.868); and Straight wire extraction and Tip-Edge non-extraction groups (p=0.047) with the Tip-Edge non-extraction being 2.351mm shorter (SE, 1.165).

As 38.2% of the calculations for change in tooth length demonstrated an increase and we know that the teeth could not have increased in length it indicated that there was a
magnification difference between the T1 and T2 OPTs. As this is most likely due to positioning of the patient we can assume that at T1 and T2 the radiographer is equally as likely to place the patient in a position that would reflect an increase or decrease in the length of the teeth measured, with the differences evenly distributed between the positive and negative. That is to say a normal distribution with a mean of zero. However when the means of the changes in tooth lengths are analysed they do not equal zero, but a small reduction in tooth length, indicating that there has been resorption. For the overall sample the mean shortening was 16 (0.62mm), 12 (0.64mm), 11 (0.9mm), 21 (0.59mm), 22 (0.6mm), 26 (0.66mm), 36 (0.13mm), 32 (0.7mm), 31 (1.31mm), 41 (1.1mm), 42 (0.9mm) and 46 (-0.03mm). When this is analysed by appliance type it shows that in the Straight wire appliance, at a significance level p=0.01, the teeth demonstrating resorption are the 12,11,21 and 26. In the Speed appliance, at a significance p=0.01, the teeth demonstrating resorption are 16, 26, 31,41 and 42. In the Tip-Edge appliance, at a significance p=0.01, only one tooth, the 31, demonstrated resorption.

PART 2 CORRELATION OF LATERAL CEPHALOMETRIC MEASUREMENTS WITH RESORPTION MEASURED ON OPTS

There were 45 lateral cephalometric radiographs traced and superimposed in part 2. The distribution of the patients was as follows: (a) 13 males and 32 females; (b) 10 Straight wire non-extraction, 10 straight wire extraction, 11 Speed non-extraction, 7 Speed extraction, 7 Tip-Edge extraction and 0 Tip-Edge non-extraction; (c) The average age of the patients was 14.32 years (SD, 3.18);(d) The mean treatment
duration was 25.62 months (SD, 6.38) and (e) The distribution between the machines was 9,18,1,17, 0 for machines 1-5 respectively.

A bivariate correlation, with a 2 tailed test of significance, demonstrated that the change in inclination of the upper incisor to SN and palatal plane; the change in the overjet; the vertical, horizontal and total apex movement; the horizontal, vertical and total incisal edge movement; the distance from the incisal edge to the apex measured parallel to the palatal plane were not statistically significant when related to change in tooth length of the upper incisors.

Evaluation of the factors relating to the lower incisor and symphysis demonstrated that the change in lower incisor inclination was statistically significant (p=0.000, 31; p=0.001, 41; p=0.005, 42) and a weaker correlation (p=0.010, 32). The distance from the lingual cortex to apex divided by the distance from the lingual cortex to the buccal, measured parallel to the occlusal plane (L-Ap/LBcT2) was statistically significant for the 41 (p=0.009). Other weaker correlations were detected: (i) p-1/3 sym width T2 with the 32 (p=0.043), 41 (p=0.013) and 42 (p=0.018); (ii) p-distance T2 with the 41 (p=0.043) and 42 (p=0.046); (iii) L-AP/LBcT2 with the 42 (p=0.044); (iv) L-ApT2 with the 41 (p=0.036) and (v) Ap-BcT2 for the 31 (p=0.017).

PART 3 ANGULATIONS MEASURED AND PAR SCORE.

The differences from the ideal angle were compared using a general linear model, univariate analysis. There were no statistical significant differences between the angles and the gender of the patient or OPT machine used. There were statistically significant differences between the appliances for the 14 (p=0.027) and 23 (p=0.014)
and in the extraction and non-extraction comparison for the 14 (p = 0.034), 34 (p = 0.008), 43 (p = 0.002) and the 44 (p = 0.009).

Using a general linear model, multivariate analysis taking into account the gender and machine used there were a statistically significant differences between the appliances for the 14,13,23,33 and 43. The Straight wire and Speed appliance showed statistically significant differences for the 13 (p = 0.006) and the 23 (p = 0.000). The Straight wire appliance finished closer to the expected angle. The Straight wire and Tip-Edge appliances showed statistically significant differences for the 14 (p = 0.036), 13 (p = 0.000), 23 (p = 0.000), 33 (p = 0.023) and 43 (p = 0.003). The Straight wire appliance finished closer to the expected angle for the 13 and 23, with the Tip-Edge appliance closer for the 14,33 and 43. The Speed and Tip-Edge appliances showed statistically significant differences for the 14 (p = 0.013), 33 (p = 0.002) and the 43 (p = 0.000) with the Tip-Edge appliance finishing closer to the ideal angle, as defined by the prescription of the brackets.

The initial PAR scores were 32.11 for the Straight wire appliance, 35.01 for the Speed appliance and 31.79 for the Tip-Edge appliance with mean PAR reductions of 91.44% for the Straight wire appliance, 85.583% for the Speed appliance and 85.013% for the Tip-Edge appliance. (Table VI)

The PAR reduction and percentage PAR reduction were compared between groups and with the variance of the final angulations from the ideal as defined by the manufacturers prescriptions. There were no statistically significant differences between the variance of the angles and the PAR reduction, percentage PAR reduction or final PAR score. There were no statistically significant differences between PAR reduction and the appliances or groups. However there was a statistically significant difference between the PAR percentage reduction between the appliances with
Straight wire and Speed appliances ($p=0.045$) and Straight wire and Tip-Edge ($p=0.015$) different. In the analysis of the groups Straight wire non-extraction and the Tip-Edge extraction groups were different ($p=0.022$) with Straight wire averaging more reduction.

**DISCUSSION**

Many factors have been implicated in external apical root resorption and the treatment related factors: Magnitude of orthodontic force (44,92), treatment mechanics (48,49,61,63,76,93), direction of tooth movement (17,18,50,51,53), appliance type (54,59,60), timing of treatment (immature teeth show less resorption (9)) and treatment duration (24,94) are directly under the control of the clinician. The primary aim of this study was to investigate the appliances types and determine if there were differences in amount of apical root resorption between Straight wire, Speed and Tip-Edge appliances. The three appliances were chosen as they represent the range of bracket systems available and the differences in treatment mechanics. The Speed appliance is a low friction (95,96) active self-ligating bracket system, with the spring clip providing a continuous force. The Straight wire appliance is preadjusted edgewise system and uses elastic modules or ligature ties to secure the wire into the bracket slot, which may increase the friction (97). The Tip-Edge appliance is a modified, pre-adjusted edgewise slot that permits crown tipping in one direction and bodily movement in the other (98). In a previous study no differences were detected on panoramic radiographs for amount of root resorption between Speed appliances and edgewise appliances (60).

In this study the patients were selected based upon the previously discussed criteria. A sufficient sample size was required to evaluate the three different appliances and
determine if there was a variation in apical root resorption. The initial discussion with the statistician indicated that for a power of 0.90 there would need to be 20 patients in each group, that is to say a minimum sample of 120 patients (Table VIII). Over 1000 patient files were screened and all patients who met the criteria were included in the study. Initially only patient files from the Orthodontic department, University of Sydney were to be included but it became apparent that the number of patients would be insufficient and two external sources were used. 48.2% of the sample came from the Orthodontic department at the University of Sydney, 25.4% from the private practice in Australia and 26.3% from the private practice in New Zealand. This potentially caused a bias between the three groups in the way the patients were treated in terms of severity of malocclusion, treatment mechanics, treatment duration and quality of final treatment. Potentially there would have been a greater percentage of more severe malocclusions at the University of Sydney as this is a public hospital with a waiting list for treatment and only severe malocclusions are accepted for treatment. Whereas one would expect that the private practices would accept some milder malocclusions for treatment. Secondarily as the University of Sydney it is a teaching hospital and the treatment undertaken by postgraduate students then the treatment durations may have been increased. (Table II) demonstrates that the treatment durations were similar and using the PAR Index as an assessment of severity of malocclusion and of quality of final treatment result the three sources proved to be similar. However the treatment mechanics were not assessed and is a potential confounding factor in this study.

The Speed Extraction group (12 patients) and the Tip-Edge non-extraction group (14 patients) fell short from the number we ideally required. This shortage in these
particular groups may reflect the philosophy of the operators or the capabilities of the appliances.

The groups combined were well balanced in terms of extraction (58 patients) and non-extraction treatment (56 patients). However there were 80 female patients and only 34 male patients, a ratio of 70:30. The ratio of female to male patients from the three treatment sources ranged from 60:40 (Private practice, New Zealand) to 83:17 (Private practice, Australia). Although gender has been implicated as a factor in root resorption suggesting a female to male ratio of 3.7:1 (5,11) other studies have not found an association (16,17,40) or have found an increased incidence of root resorption in males (12,76)

Patients were not accepted into the sample if they had maxillary expansion, orthognathic surgery or previous orthodontic treatment including growth modification. Maxillary expansion was excluded for two reasons. Firstly the teeth would be moved laterally and their relative position in the focal trough would be changed. The vertical magnification would then be reduced and this would result in a reduction in tooth length and an overestimation of resorption. Secondly expansion itself has been shown to cause root resorption (buccal surface and furcation area) and the resorption detected may be a result of the expansion rather than the appliance being studied (62). Orthognathic surgery cases that have had maxillary surgery have been shown to demonstrate an increased risk of root resorption (odds ratio 8) (20) and were excluded. There is a high correlation between the amount and severity of root resorption present before treatment to the resorption discovered when the orthodontic appliances are removed (99). Therefore patients who had previous orthodontic treatment may have had resorption and were excluded.
Other predisposing factors of root resorption, which led to exclusion, were trauma (31,39) and root canal therapy (13,15). Patients were excluded if there was any incisal adjustment as this would change the physical length of the teeth and also the trauma to the tooth may potentially cause greater resorption (the number excluded was not recorded).

All patients who had systemic problems were excluded as some conditions have been suggested as a cause of root resorption. Although a direct cause and effect relationship has not been established endocrine problems such as hypothyroidism, hypopituitarism, hyperpituitarism, hypophosphatemia and Paget disease have been linked to root resorption (27,100-102). However patients with asthma were not excluded, even though it has been correlated to an increased incidence of root resorption (36). The reasoning behind this was that Australia has a high prevalence of asthma making it a factor we wanted to investigate.

Any patients with impacted teeth were excluded, as there is an increased incidence of resorption of the adjacent teeth. It has been shown (103) that ectopically erupting maxillary canines cause some degree of resorption of adjacent incisors (0.7%) in the 10-13 year age group.

The mean ages at the start of treatment were comparable between the three appliance groups and groups when divided into extraction and non-extraction. The age range was 11.25-31.75 with only 5 patients older than 18 years (maximum age 31.75 years). The minimum age was chosen so that apexification would be completed (87) and the teeth would not get longer during treatment due to further root growth. Any lengthening could then be assumed to be due to magnification or measurement errors. Secondarily it has been shown that less root shortening occurs when treatment is started before age 11 years (9,40), although the roots may reach somewhat less than
their expected root length potential \(^{10}\). This potential confounding factor is eliminated by choice of the minimum age. There was also the possibility that the older patients may have experienced more root resorption as adults have been reported to be more susceptible to root resorption \(^{8,76}\). However other studies \(^{10,12,104}\) have indicated that age, per se, is not an important contributing factor in root resorption.

The OPTs were screened and only clear pre- and post-treatment radiographs taken on the same machine were accepted. The OPT was chosen for analysis for three reasons:

(i) Availability: All orthodontic patients have a pre- and post-treatment OPTs as it conveniently provides the clinician with a comprehensive view of the entire maxillo-mandibular region, with a significantly reduced radiation exposure when compared to a series of intra oral films. However some studies indicate that one or more supplemental anterior radiographs are necessary in order to not miss clinically significant findings \(^{105-107}\).

(ii) Measurement from OPTs has recently been demonstrated to be a reliable tool for the measurement of tooth length, crown-root ratio, the angulation between teeth and reference lines and teeth relative to each other in the same segment, provided the patient is correctly positioned \(^{108,109}\).

(iii) Several authors have used the OPT to measure root resorption and it was hoped to be able to directly compare the results from this study with the others \(^{6,10,20,36,54,61,110}\). In a study \(^{111}\) of 1000 OPTs, the most common error leading to an unsatisfactory image was incorrect patient positioning. Of the randomly selected films only 20.3% were error free with the sample taken by trained technicians having a much lower error rate, 46.8% error free. Similarly 387 radiographs submitted to the Dental Practice Board of England and Wales were examined and 26% were of no diagnostic
value. Therefore with such a large number of radiographs expected to be of poor quality it is no surprise that over 1000 patient records were screened in order to find a sample of 114 patients. Of the 228 OPTs measured (T1+T2) in this study, 47 teeth (1.7%) were not measured due to a lack of clarity. This is low in comparison to one study, who found non-measurability in 14-17% of teeth after taking two radiographs on the same 29 subjects. They also demonstrated that the standard deviation of the measurements ranged from 0.65 to 0.85mm or 2.4% to 3.1%, however 3.6-7.5% of the differences exceeded 2mm. The differences in non-measurability may be accounted for by the fact the OPTs were screened and films with obvious positioning errors were eliminated. The screening process involved analysing the OPTs for any apparent asymmetry. To assess the variation due to positioning one subject had 2 OPTs 2 weeks apart, taken on the same machine by a trained radiographer. The mean change in tooth length was 0.74mm (SD, 0.86), with a range of 0.003 to 2.73mm. This demonstrates that there may be large changes (lengthening or shortening) based on patient positioning.

Ideally all OPTs would be taken on the same OPT machine by the same operator using a more accurate head-positioning device than the manufacturer provides with the machine. The use of a head holder may be appropriate for longitudinal studies and may position the teeth more accurately in the focal trough. There were five panoramic machines used in the study. Three of the machines were used for patients treated at the University of Sydney with one machine being used for each of the private practices. In addition to the fact patient positioning may cause inaccuracies the position, form and size of the zone of sharpness varies considerably between panoramic machines with the three dimensional region of acceptable image unsharpness being determined by the scanning geometry, the source to film distance,
the film transport speed, the focal spot size, the width of the x-ray beam and image receptor. Ideally, a panoramic machine should have a focal trough, which conforms to the shape of an ideal dental arch and is sufficiently wide anteriorly to adequately image the incisor teeth. It should have a beam projection angle between the contact points of all teeth that minimises overlap especially in the premolar region, provide adequate sharpness and dimensional accuracy at least in the central plane of the focal trough. The conformity of the focal trough has been related to the form of the average dental arch (118,119). These studies have demonstrated that all machines produce focal troughs that can encompass the tooth positions in the occlusal plane but rotation of the patient tended to move different teeth out of the focal trough for different machines. That is to say that proper patient positioning is a critical factor in panoramic radiography. Significant differences in width of the dentition and the mandible were found between the sexes and the races but these were too small to be relevant to the application of panoramic radiography. In this study the panoramic machines posed several potential problems. They had different focal troughs and consequently any deviation from proper positioning, either laterally or anteroposteriorly, would result in a lack of image sharpness. This difference in focal trough may result in different teeth being outside the central plane of the layer and subsequently different magnification factors would apply. This should not affect the measurement of tooth length change, as the same machine was used T1 and T2. However there may have been magnification differences between machines and as there was an uneven distribution of the patients between the machines this could potentially bias the measurements and thus the root resorption recorded.

Clear pre- and post-treatment lateral cephalometric radiographs were required for part 2 of the study. There has been a great deal of research into the reliability of the lateral
cephalometric radiograph (120-124). Of the 114 patients who had suitable OPTs only 45 had suitable lateral cephalometric radiographs, which was mainly due to the lack of a T2 film.

Pre- and post-treatment orthodontically trimmed models were required for part 3 in order to assess the malocclusions at the start of treatment and the quality of the finish using the PAR index. 95 patients models were available. The assumption made with the models was that they had been trimmed to the correct occlusion.

Patients are often advised that the average duration of treatment is 2 years, which is a fair estimate based upon the published range of 22.01 months (125,126) for single-phase therapy and 31.2 months (127) for therapy involving multiple phases. The majority of studies report that the severity of root resorption is related to treatment duration, (17,63-65,128). However several reports show that there is no correlation between treatment duration and root resorption (10,26,82). There were no statistically significant differences for treatment duration between the groups (Straight wire, Speed and Tip-Edge) however there was a difference between the extraction and non-extraction patients (p=0.01) with a mean increase in treatment duration of 3.8 months in the extraction group. On analysis with the general linear model there were statistically significant differences between: the Tip Edge extraction group and the Straight wire non-extraction group (p=0.000) with a mean increase in the treatment time of 9.56 months in the Tip-Edge extraction group; the Tip Edge extraction group and Straight wire extraction group (p=0.003) with a mean increase in treatment time of 6.64 months in the Tip-Edge extraction group; and the Tip Edge extraction group and Speed extraction (p=0.048) group with a mean increases in treatment time of 7.91 months. This increased treatment duration itself is an interesting finding, at least from a patient
perspective, as it appears that the appliance choice may influence the length of treatment.

PART 1- TO DETERMINE THE EXTENT OF EXTERNAL APICAL ROOT RESORPTION MEASURED FROM OPTS FOR THREE DIFFERENT APPLIANCES (STRAIGHT-WIRE, SPEED AND TIP-EDGE).

One operator traced, scanned and digitised all the OPTs under standardised conditions. Defined criteria were used for the measurements as it has been shown to improve the accuracy of measurement of tooth lengths on panoramic radiographs (129). All the measurements were repeated five times with the standard deviations for 5 measurements of each tooth length being less than 0.1mm. The fact there was only one operator eliminated any problem with inter-operator variability.

From the multivariate analysis there were only differences between the appliances for the 31 and 41. This may represent an actual difference in tooth lengths or a relative shortening with the roots being outside the focal trough.

The fact 32.8% of the measurements increase when we know that the teeth do not get longer indicates that the measurements from OPTs are perhaps not as reliable as previous studies have reported. The magnification factor has been reported to vary very little in the vertical dimension (130). Stramotas (108), demonstrated that the tooth length and crown-root ratio can be accurately measured and is reliable provided the patient is correctly positioned, especially in reference to the sagittal plane. However they used an OPT machine that provided a constant vertical magnification (1.25). None of the machines used in this study used a constant magnification setting. The reported variation in magnification is 13-15% in the lower premolar region and 17-
28% in the upper second premolar/ first molar region \(^{(13)}\). The palatal root of the upper first molar has the most variation in magnification (17-41%) with the mesiobuccal root having a range of 11-23%. In this study, when looking at the mean difference in tooth length T1 to T2, the least resorption demonstrated was in the 36 and 46. This is the area with the widest focal trough and least variation in magnification. The comparison of the mean resorption per tooth demonstrated different teeth were shorter for the three appliances (p<0.01). The Straight wire appliance showed resorption in the 12,11,21 and 26, the Speed appliance in the 16, 26, 31,41 and 42 and the Tip-Edge appliance in the 31 only. This may reflect an actual difference between the three appliances. This needs to be investigated further with a prospective trial using periapical radiographs (long-cone) or digital subtraction radiography to more accurately measure the resorption. A similar study \(^{(60)}\) comparing Speed appliance and an edgewise–straight wire appliance found a statistically significant gender-appliance interaction, which showed that the edgewise-straight wire appliance showed more resorption for the mandibular lateral incisors. The percentage reduction of the mandibular lateral incisors was 11.14 (SD, 7.52) for the edgewise-straight wire and 3.35 (SD, 6.7) for the Speed group.

PART 2 CORRELATION OF LATERAL CEPHALOMETRIC MEASUREMENTS WITH RESORPTION MEASURED ON OPTS

The lateral cephalometric radiographs were utilised in an attempt to find any factors that may correlate with the amount of apical root resorption. This has been studied before, with vertical, anteroposterior and horizontal apex and incisal edge movement, tooth inclination, incisor protrusion, width of alveolar bone, the proximity to cortical
plate and root form being investigated \((12,18,19,24,50,51,53,65,67)\). The studies are not conclusive but suggest that the amount of apical and incisal edge vertical movement, the incisor proclination and root approximation to the cortical plate are predictors for apical root resorption.

This study demonstrated that there was no association between the amount of apical root resorption and any of the variables measured for the upper incisor. This is in agreement with Phillips\(^{(26)}\) who found no association between the angular or sagittal apical movements of the upper incisor and apical root resorption and Taithongchai \(^{(24)}\) who found no correlation with angular change of the upper incisor and root resorption. However it is in contrast to DeShields \(^{(16)}\), who found significant correlations between apical root resorption and sagittal apical movement and Baumrind \(^{(12)}\) who found that only the total apical movement was correlated with apical root resorption. Although Parker and Harris\(^{(51)}\) found a correlation between a combination of intrusive movement and lingual root torque they did not find that the bodily retraction in a posterior direction or lingual tipping had any effect. The fact root resorption has a multifactorial aetiology may explain why there are no predictive parameters measurable on a lateral cephalometric radiograph.

Two factors potentially reduced the accuracy of measuring the actual translation of the upper incisor. The presence of root resorption may have masked some of the incisor displacement measured. Therefore in an attempt to overcome this limitation the incisor was transferred from the T1 tracing to the T2 tracing. Secondly the superimposition technique used, palatal plane registering at ANS, has been shown to underestimate the vertical eruption of the upper incisors, measured at the incisal edge and apex, by up to 50% \(^{(132)}\).
Then again measurement of the symphysis pre- and post-treatment indicated that the change in lower incisor inclination was significantly correlated to root resorption for the 31, 41 and 42. This may reflect either an actual shortening or the fact that when the teeth are proclined the root apices may move outside the focal trough and appear shorter on the panoramic radiograph \(^{(133)}\). The incisal edge to apex distance measured parallel to the occlusal plane was aimed at being an indirect measurement of when the teeth would lie outside the focal trough. It was thought that as this distance increased there would be an increase in measurement of tooth shortening, which may have allowed discrimination between actual shortening and apparent shortening due to the likelihood that as this distance increased the chance of the apex lying outside the focal trough would be increased. It was not found to be statistically significant. However, if the radiographs had been taken in the natural head position and the measurement made horizontally it would have been more accurate as geometrically as the occlusal plane angle to the horizontal increases the apex of the lower incisor is moved backwards, potentially moving it outside the focal trough, yet the measurement along occlusal plane would be the same. Thus introducing inaccuracy into this measurement.

The distance from the lingual cortex to apex divided by the distance from the lingual cortex to the buccal, measured parallel to the occlusal plane (L-Ap/LBcT2) was statistically significant for the 41 (p=0.009) with weaker correlations for the L-Ap distance T2 (41, p=0.036), p-distance T2 (41, p=0.043) and Ap-BcT2 (31, p=0.017). These statistically significant symphyseal measurements are an indirect measurement of the position of the lower incisor apex in the symphysis. They basically correlate lower incisor apex proximity to the lingual cortex and the lower incisor proclination with a decrease in measured incisal length on the OPT. This could represent an
increases risk of resorption or an increased chance of being out of the focal trough and the appearance of shortening. These measurements may have potential in the future as predictors of apical root resorption.

PART 3 ANGULATIONS MEASURED AND PAR SCORE.

The correct axial inclination of the teeth is one of the aims in the ideal finishing occlusion \(^{(134)}\) with a risk that extraction sites may reopen if the teeth either side of the extraction site are not quite parallel \(^{(135)}\). Panoramic radiography enables the orthodontist to assess both the root resorption and final angulations of the teeth \(^{(136)}\). Provided the object is in the focal trough its mesiodistal angulation has been shown to be measurable to within \(\pm 5^\circ\) \(^{(137)}\). Fourteen male and 28 female Caucasian subjects with normal occlusions, age 12-17 years, were radiographed to establish mesiodistal axial inclination norms \(^{(138)}\). However head positioning errors can affect the resultant angulation of the teeth \(^{(139-141)}\). A study on the cant of the occlusal plane demonstrated that the largest amount of distortion of parallelism is in the canine premolar region (1.2-3.5\(^\circ\)) with the distortion of the long axis of the teeth the least in this region \(^{(142)}\). It was therefore decided to measure the long axis of the premolar and canine relative to a horizontal reference line and relate this to the bracket prescription as a measure of accuracy of finishing.

The differences between the appliance angulations and expected angulations were statistically significant for specific teeth. The range of angular differences between the appliances was 3.21\(^\circ\) (Tip-Edge closer to prescription than Straight wire, upper right premolar) to 6.4\(^\circ\) (Straight wire closer to prescription than Tip-Edge, upper right
canine). This did not take into account that the arch-wires may have been adjusted during finishing and/or the brackets may have been incorrectly positioned. This would have introduced errors as once the arch wire was not flat the measured angle would not truly reflect the bracket prescription accuracy. Incorrectly positioned brackets with a flat arch wire would also not be a good indicator of the bracket prescription accuracy.

The PAR score has been demonstrated to provide a good assessment of severity of the malocclusion (89, 143). The initial PAR scores indicated that the three appliances were well matched in terms of severity of malocclusion with initial PAR cores of 32.11, Straight wire, 35.01, Speed, and 31.79, Tip-Edge. The mean PAR percent reductions were 91.44%, Straight wire, 85.583% Speed and 85.013%, Tip-Edge. There is a slightly higher reduction in the straight wire group and this might be explained by the fact that the majority of the cases were treated by postgraduates and used as presentation cases. This represents a high standard of treatment and compares well to other studies, which report a PAR percent reduction of 75.55 to 87.9% (144-146). However the variance in angulation from the expected angle as defined by the prescription of the brackets could not be used to assess the quality of the treatment result. This is not surprising as the PAR Index is based upon crown position.
CONCLUSIONS

(1) Straight wire appliance, Speed appliance and Tip-Edge appliance all successfully treated the malocclusions to a high standard (PAR percentage reduction 86.66 SD 9.57).

(2) Extraction treatment has an increased treatment duration, 3.8 months longer in this sample

(3) Tip-Edge extraction treatment has increased treatment duration.

(4) There appears to be a specific tendency for different teeth to have apical root resorption in the three different appliances, with the Straight wire appliance demonstrating resorption of the 12, 11, 21 and 26, the Speed appliance 16, 26, 31, 41 and 42 and the Tip-Edge appliance of the 31.

(5) None of the measured variables for the upper incisor was correlated with the amount of apical root resorption.

(6) Several symphyseal measurements were correlated with the amount of tooth shortening measured on the OPTs. This suggests that as the apex of the lower incisor moves closer to the lingual cortex there is a greater chance they will appear short on an OPT. This may be due to root resorption or the apex moving outside the focal trough of the panoramic machine.

(7) The quality of the final treatment cannot be predicted by the final root angulation.
ACKNOWLEDGMENTS

I would like to thank Professor M Ali Darendeliler and Dr. Om P Kharbanda, Discipline of Orthodontics, Faculty of Dentistry, University of Sydney for their advice with the preparation and proofreading of this work, Dr. Peter Petocz, Department of Mathematical Sciences, University of Technology, Sydney, for his advice and assistance with the statistical analysis of this work and Dr Russell Kift and Dr Mark Ewing for their assistance in collecting the patient sample as without the unlimited access to their patient records the study would not have been possible.
Reference:


(72) Holmes JP, Gulabivala K, Van der Stelt PF: Detection of stimulated internal tooth resorption using conventional radiography and subtraction imaging. Dentomaxillofac Radiol 2001; 30:249-54


(106) Taylor NG, Jones AG. Are anterior occlusal radiographs indicated to supplement panoramic radiography during an orthodontic assessment? Br Dent J 1995; 179: 377-81


(116) Ordman J, Cleaton-Jones, Mizraji E, Fatti LP. Head holder for panoramic dental radiography. Angle Orthod 1987; 322-31


(118) Lund TM, Manson-Hing LR, Relations between tooth positions and focal troughs of panoramic machines. Oral Surg 1975; 10(2): 278-293


(130) Samfors KA, Welander U. Angle distortion in narrow beam rotation radiography. Acta Radiol (Stockh) 1974; 15: 570-6


(139) Samawi SSB and Burke PH. Angular distortion in the orthopantomogram. Br J Orthod 1984; 11:100-7


(142) Phillip RG, Hurst RVV. The cant of the occlusal plane and distortion in the panoramic radiograph. Angle Orthod 1978; 48:317-23


# LIST OF TABLES

**TABLE I, A.** DISTRIBUTION OF PATIENTS BY GROUPS WITH AGE, TREATMENT DURATION AND DISTRIBUTION OF MALOCCLUSION

**TABLE I, B.** DISTRIBUTION OF PATIENTS WITH GROUPS AND EXTRACTION PATTERN WITH AGE, TREATMENT DURATION AND MALOCCLUSION

**TABLE I, C.** DISTRIBUTION OF PATIENTS BY EXTRACTION PATTERN WITH AGE, AND TREATMENT DURATION

**TABLE I, D.** DISTRIBUTION OF PATIENTS RECORDS BY GROUP AND EXTRACTION PATTERN

**TABLE II** DISTRIBUTION OF PATIENTS BY SOURCE AND EXTRACTION PATTERN WITH TREATMENT DURATION, AGE AND RATIO OF FEMALES:MALES
TABLE III
MEAN TREATMENT DURATIONS FROM
GENERAL LINEAR MODEL UNIVARIATE
ANALYSIS WITH MACHINE AND GENDER AND
GROUP ASSESSED AS FACTORS IN TREATMENT
DURATION

TABLE IV, A
PANORAMIC MACHINES

TABLE IV, B
DISTRIBUTION OF NON-MEASURABLE TEETH

TABLE V
MEAN DIFFERENCES IN TOOTH LENGTHS AND
STATISTICAL SIGNIFICANCE COMBINED AND
BY GROUP

TABLE VI, A
MEAN DIFFERENCE OF ANGLES FROM IDEAL
BY GROUPS

TABLE VI, B
MEAN DIFFERENCE OF ANGLES FROM IDEAL
BY GROUPS AND EXTRACTION PATTERN

TABLE VII
PEER ASSESSMENT RATING INDEX
DISTRIBUTION BY SOURCE AND EXTRACTION
PATTERN

TABLE VIII A,B
POWER CALCULATIONS

113
TABLE 1.A. DISTRIBUTION OF PATIENTS BY GROUPS WITH AGE, TREATMENT DURATION AND DISTRIBUTION OF MALOCCLUSION

<table>
<thead>
<tr>
<th>APPLIANCE</th>
<th>Number (n)</th>
<th>Males</th>
<th>Females</th>
<th>Mean age (years) T&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Age range (years)</th>
<th>Mean Treatment Duration (months) ± Standard Deviation</th>
<th>Malocclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight wire</td>
<td>43</td>
<td>15</td>
<td>28</td>
<td>15.0 ± 3.96</td>
<td>12.25-31.75</td>
<td>24.3 ± 4.67</td>
<td>20 14 9</td>
</tr>
<tr>
<td>Speed</td>
<td>33</td>
<td>13</td>
<td>20</td>
<td>13.4 ± 1.47</td>
<td>11.5-18.08</td>
<td>24.3 ± 7.09</td>
<td>18 13 2</td>
</tr>
<tr>
<td>Tip-Edge</td>
<td>38</td>
<td>6</td>
<td>32</td>
<td>14.24 ± 1.41</td>
<td>11.25-17.33</td>
<td>26.8 ± 6.86</td>
<td>11 21 6</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>34</td>
<td>80</td>
<td>14.54 ± 2.7</td>
<td>11.25-17.33</td>
<td>25.1 ± 6.26</td>
<td>49 48 17</td>
</tr>
<tr>
<td>APPLIANCE</td>
<td>Number (n)</td>
<td>Males</td>
<td>Females</td>
<td>Mean age (years) T1</td>
<td>Age range (years)</td>
<td>Mean Treatment Duration (months) ± Standard Error</td>
<td>Malocclusion</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------</td>
<td>-------</td>
<td>---------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>--------------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Straight wire non-extraction</td>
<td>23</td>
<td>9</td>
<td>14</td>
<td>15.58 ± 4.52</td>
<td>15.25-22.42</td>
<td>21.3 ± 3.66</td>
<td>12 6 5</td>
</tr>
<tr>
<td>Straight wire extraction</td>
<td>20</td>
<td>6</td>
<td>14</td>
<td>15.05 ± 2.64</td>
<td>12.25-31.75</td>
<td>24.2 ± 1.745</td>
<td>8 8 4</td>
</tr>
<tr>
<td>Speed non-extraction</td>
<td>21</td>
<td>8</td>
<td>13</td>
<td>13.11 ± 1.16</td>
<td>11.50-16.33</td>
<td>23.6 ± 3.32</td>
<td>12 7 2</td>
</tr>
<tr>
<td>Speed extraction</td>
<td>12</td>
<td>5</td>
<td>7</td>
<td>14.18 ± 1.76</td>
<td>12.67-18.08</td>
<td>22.9 ± 2.74</td>
<td>6 6 0</td>
</tr>
<tr>
<td>Tip-Edge non-extraction</td>
<td>14</td>
<td>2</td>
<td>12</td>
<td>14.17 ± 1.19</td>
<td>13.25-16.00</td>
<td>27.1 ± 2.69</td>
<td>3 9 2</td>
</tr>
<tr>
<td>Tip-Edge extraction</td>
<td>24</td>
<td>4</td>
<td>20</td>
<td>14.74 ± 1.79</td>
<td>11.25-17.33</td>
<td>30.9 ± 1.75</td>
<td>8 12 4</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>34</td>
<td>80</td>
<td>14.54 ± 2.70</td>
<td>11.25-17.33</td>
<td>25.1 ± 6.26</td>
<td>49 48 17</td>
</tr>
<tr>
<td>APPLIANCE</td>
<td>Number (n)</td>
<td>Males</td>
<td>Females</td>
<td>Mean age (years) T1</td>
<td>Age range (years)</td>
<td>Mean Treatment Duration (months) + Standard Deviation</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>------------</td>
<td>-------</td>
<td>---------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>-------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Non-Extraction</td>
<td>56</td>
<td>15</td>
<td>41</td>
<td>14.92 ± 3.14</td>
<td>12.25-22.42</td>
<td>23.29 ± 5.85</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
<td>34</td>
<td>80</td>
<td></td>
<td></td>
<td>25.1 ± 6.26</td>
<td></td>
</tr>
<tr>
<td>TECHNIQUE</td>
<td>NUMBER OF OPTs</td>
<td>NUMBER OF LATERAL CEPhALOMETRIC FILMS</td>
<td>NUMBER OF STUDY MODELS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------</td>
<td>---------------------------------------</td>
<td>------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight-wire extraction</td>
<td>20</td>
<td>9</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight-wire non</td>
<td>23</td>
<td>10</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed extraction</td>
<td>12</td>
<td>8</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed non extraction</td>
<td>21</td>
<td>12</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip-Edge extraction</td>
<td>24</td>
<td>8</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip-Edge non-extraction</td>
<td>14</td>
<td>0</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>114</strong></td>
<td><strong>47</strong></td>
<td><strong>97</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Number of Patients</td>
<td>Treatment Duration (months)</td>
<td>Mean Age (months)</td>
<td>Female:Male</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------</td>
<td>-----------------------------</td>
<td>-------------------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extraction</td>
<td>27.85 sd 6.7</td>
<td>15.05 sd 2.37</td>
<td>25:8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Extraction</td>
<td>22.68 sd 3.71</td>
<td>15.61 sd 4.63</td>
<td>13:9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>55</td>
<td>25.85 sd 6.17</td>
<td>38:17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Sydney</td>
<td>Extraction</td>
<td>27.27 sd 2.84</td>
<td>14.16 sd 1.19</td>
<td>12:3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Extraction</td>
<td>22.5 sd 5.89</td>
<td>14.32 sd 1.63</td>
<td>12:2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>29</td>
<td>24.97 sd 5.10</td>
<td>24:5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private Practice, Australia</td>
<td>Extraction</td>
<td>23.78 sd 7.07</td>
<td>14.25 sd 1.85</td>
<td>5:4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Extraction</td>
<td>24.38 sd 7.63</td>
<td>13.11 sd 1.16</td>
<td>13:8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>30</td>
<td>24.2 sd 7.34</td>
<td>18:12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**TABLE III  MEAN TREATMENT DURATIONS FROM GENERAL LINEAR MODEL UNIVARIATE ANALYSIS WITH MACHINE AND GENDER AND GROUP ASSESSED AS FACTORS IN TREATMENT DURATION**

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.303&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.733</td>
<td>17.865 - 24.741</td>
</tr>
<tr>
<td>SWE</td>
<td>24.230&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.754</td>
<td>20.751 - 27.709</td>
</tr>
<tr>
<td>Sp</td>
<td>23.615&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.324</td>
<td>17.022 - 30.208</td>
</tr>
<tr>
<td>SpE</td>
<td>22.958&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.740</td>
<td>17.522 - 28.394</td>
</tr>
<tr>
<td>T</td>
<td>27.113&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.693</td>
<td>21.772 - 32.454</td>
</tr>
<tr>
<td>TE</td>
<td>30.866&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.752</td>
<td>27.392 - 34.340</td>
</tr>
</tbody>
</table>

<sup>a</sup>: Based on modified population marginal mean.
### TABLE IV, A. PANORAMIC MACHINES

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>PANORAMIC MACHINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SORODEX TOME</td>
</tr>
<tr>
<td>2</td>
<td>PLANMECCA PROSCAN</td>
</tr>
<tr>
<td>3</td>
<td>SIEMENS ORTHOPHOS</td>
</tr>
<tr>
<td>4</td>
<td>PANEX-E</td>
</tr>
<tr>
<td>5</td>
<td>CRANEX</td>
</tr>
</tbody>
</table>

### TABLE IV, B. DISTRIBUTION OF NON-MEASURABLE TEETH

<table>
<thead>
<tr>
<th></th>
<th>16</th>
<th>12</th>
<th>11</th>
<th>21</th>
<th>22</th>
<th>26</th>
<th>36</th>
<th>32</th>
<th>31</th>
<th>41</th>
<th>42</th>
<th>46</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Treatment Number</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>Pre-Treatment Percent</td>
<td>3.5</td>
<td>1.8</td>
<td>0.9</td>
<td>0</td>
<td>4.3</td>
<td>5.3</td>
<td>0</td>
<td>1.8</td>
<td>1.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>Post-Treatment Number</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>Post-Treatment Percent</td>
<td>7</td>
<td>0.9</td>
<td>1.8</td>
<td>0.9</td>
<td>1.8</td>
<td>7.9</td>
<td>0</td>
<td>0</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>Total Percent</td>
<td>5.3</td>
<td>1.3</td>
<td>1.3</td>
<td>0.4</td>
<td>3.1</td>
<td>6.6</td>
<td>0</td>
<td>0.9</td>
<td>1.3</td>
<td>0.9</td>
<td>0.9</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>TOOTH</td>
<td>COMBINED</td>
<td>STRAIGHT WIRE</td>
<td>SPEED</td>
<td>TIP-EDGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
<td>---------------</td>
<td>-------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean Difference (mm)</td>
<td>p</td>
<td>Mean Difference (mm)</td>
<td>p</td>
<td>Mean Difference (mm)</td>
<td>p</td>
<td>Mean Difference (mm)</td>
<td>p</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>.6000</td>
<td>.002</td>
<td>.4436</td>
<td>.117</td>
<td>.7955</td>
<td>.017</td>
<td>.5668</td>
<td>.122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>.5807</td>
<td>.015</td>
<td>1.4959</td>
<td>.000</td>
<td>.1826</td>
<td>.577</td>
<td>0.0671</td>
<td>.875</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>.8570</td>
<td>.000</td>
<td>1.6962</td>
<td>.000</td>
<td>-0.0997</td>
<td>.792</td>
<td>.7488</td>
<td>.064</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>.5849</td>
<td>.022</td>
<td>1.4761</td>
<td>.001</td>
<td>-.2269</td>
<td>.576</td>
<td>.4423</td>
<td>.328</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>.6180</td>
<td>.023</td>
<td>1.0159</td>
<td>.017</td>
<td>-0.0545</td>
<td>.906</td>
<td>.6880</td>
<td>.166</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>.1201</td>
<td>.329</td>
<td>0.06139</td>
<td>.729</td>
<td>.1612</td>
<td>.389</td>
<td>.1274</td>
<td>.627</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>.6580</td>
<td>.004</td>
<td>.5369</td>
<td>.054</td>
<td>1.5854</td>
<td>.012</td>
<td>0.0553</td>
<td>.787</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>1.3188</td>
<td>.000</td>
<td>.6859</td>
<td>.132</td>
<td>2.2848</td>
<td>.000</td>
<td>1.1194</td>
<td>.007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>1.0898</td>
<td>.000</td>
<td>.7741</td>
<td>.086</td>
<td>1.8614</td>
<td>.001</td>
<td>.8406</td>
<td>.052</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>.8845</td>
<td>.002</td>
<td>.1462</td>
<td>.087</td>
<td>2.0855</td>
<td>.000</td>
<td>-0.0811</td>
<td>.866</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>-0.0556</td>
<td>.649</td>
<td>.1462</td>
<td>.437</td>
<td>-.4460</td>
<td>.040</td>
<td>.1413</td>
<td>.535</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>.6000</td>
<td>.002</td>
<td>.4436</td>
<td>.117</td>
<td>.7955</td>
<td>.017</td>
<td>.5668</td>
<td>.122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appliance</td>
<td>14 Mean</td>
<td>14 SD</td>
<td>13 Mean</td>
<td>13 SD</td>
<td>23 Mean</td>
<td>23 SD</td>
<td>24 Mean</td>
<td>24 SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td>-5.124</td>
<td>1.014</td>
<td>-8.203</td>
<td>1.086</td>
<td>-7.585</td>
<td>0.937</td>
<td>-4.190</td>
<td>1.033</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appliance</td>
<td>44 Mean</td>
<td>44 SD</td>
<td>43 Mean</td>
<td>43 SD</td>
<td>33 Mean</td>
<td>33 SD</td>
<td>34 Mean</td>
<td>34 SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td>11.436</td>
<td>1.314</td>
<td>10.770</td>
<td>1.298</td>
<td>7.360</td>
<td>1.370</td>
<td>7.427</td>
<td>1.163</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>8.909</td>
<td>1.468</td>
<td>4.864</td>
<td>1.450</td>
<td>2.594</td>
<td>1.530</td>
<td>7.210</td>
<td>1.299</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE VI, B. MEAN DIFFERENCE OF ANGLES FROM IDEAL BY GROUPS AND EXTRACTION PATTERN

<table>
<thead>
<tr>
<th>Appliance</th>
<th>14</th>
<th>13</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (°)</td>
<td>Std. Error</td>
<td>Mean (°)</td>
<td>Std. Error</td>
</tr>
<tr>
<td>TE</td>
<td>-1.863</td>
<td>1.387</td>
<td>-11.856</td>
<td>1.486</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appliance</th>
<th>44</th>
<th>43</th>
<th>33</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (°)</td>
<td>Std. Error</td>
<td>Mean (°)</td>
<td>Std. Error</td>
</tr>
<tr>
<td>SW</td>
<td>9.206</td>
<td>1.873</td>
<td>8.653</td>
<td>1.851</td>
</tr>
<tr>
<td>Sp</td>
<td>1.790</td>
<td>1.464</td>
<td>2.909</td>
<td>1.446</td>
</tr>
<tr>
<td></td>
<td>Number of Patients</td>
<td>Initial PAR</td>
<td>Final PAR</td>
<td>PAR reduction</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------</td>
<td>-------------</td>
<td>-----------</td>
<td>---------------</td>
</tr>
<tr>
<td><strong>University of Sydney</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraction</td>
<td>28</td>
<td>34.11</td>
<td>3.57</td>
<td>30.54</td>
</tr>
<tr>
<td>Non-Extraction</td>
<td>18</td>
<td>28.72</td>
<td>2.06</td>
<td>26.77</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>32</td>
<td>2.97</td>
<td>29.02</td>
</tr>
<tr>
<td><strong>Private Practice, Australia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraction</td>
<td>15</td>
<td>34.93</td>
<td>5.53</td>
<td>29.4</td>
</tr>
<tr>
<td>Non-Extraction</td>
<td>14</td>
<td>28.36</td>
<td>4.0</td>
<td>24.36</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>31.75</td>
<td>4.79</td>
<td>26.97</td>
</tr>
<tr>
<td><strong>Private Practice, New Zealand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraction</td>
<td>5</td>
<td>42.8</td>
<td>4.8</td>
<td>38.0</td>
</tr>
<tr>
<td>Non-Extraction</td>
<td>15</td>
<td>33.07</td>
<td>4.93</td>
<td>28.13</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>35.5</td>
<td>4.9</td>
<td>30.6</td>
</tr>
</tbody>
</table>
TABLE VIII A, POWER CALCULATIONS

<table>
<thead>
<tr>
<th>SAMPLE SIZE</th>
<th>TARGET POWER</th>
<th>ACTUAL POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0.7500</td>
<td>0.7523</td>
</tr>
<tr>
<td>16</td>
<td>0.8000</td>
<td>0.8143</td>
</tr>
<tr>
<td>18</td>
<td>0.8500</td>
<td>0.8627</td>
</tr>
<tr>
<td>21</td>
<td>0.9000</td>
<td>0.9147</td>
</tr>
<tr>
<td>25</td>
<td>0.9500</td>
<td>0.9565</td>
</tr>
</tbody>
</table>

One Way ANOVA

Sigma = 2  Alpha = 0.05  Number of levels = 3

Corrected sum of the squares of means = 2.66667

Means = 2, 2, 4
### TABLE VIII: POWER CALCULATIONS

<table>
<thead>
<tr>
<th>SAMPLE SIZE</th>
<th>TARGET POWER</th>
<th>ACTUAL POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>0.7500</td>
<td>0.7698</td>
</tr>
<tr>
<td>21</td>
<td>0.8000</td>
<td>0.8148</td>
</tr>
<tr>
<td>23</td>
<td>0.8500</td>
<td>0.8521</td>
</tr>
<tr>
<td>27</td>
<td>0.9000</td>
<td>0.9077</td>
</tr>
<tr>
<td>32</td>
<td>0.9500</td>
<td>0.9505</td>
</tr>
</tbody>
</table>

One Way ANOVA

Sigma = 2  
Alpha = 0.05  
Number of levels = 3

Corrected sum of the squares of means = 2

Means = 2, 3, 4
LIST OF FIGURES

FIGURE 1
SCANNED IMAGE OF TRACED PANORAMIC RADIOPHOTO WITH RULER

FIGURE 2, A.
DIGITISED INCISORS

FIGURE 2, B.
DIGITISED MOLARS

FIGURE 3
DIGITISED PANORAMIC RADIOPHOTO

FIGURE 4
LATERAL CEPHALOGRAM TRACING

FIGURE 5, A.
SUPERIMPOSITION OF MAXILLAE ON PALATAL PLANE REGISTERED AT ANS

FIGURE 5, B.
3 MEASUREMENTS WERE MADE FOR THE BOTH THE APEX AND THE INCISAL EDGE

FIGURE 6
SYMPHYSIS MEASUREMENTS

FIGURE 7, A.
ANGULAR MEASUREMENTS

FIGURE 7, B.
ANGULAR MEASUREMENTS MAGNIFIED

__________________________________________________________________

127
FIGURE 1

SCANNED IMAGE OF A TRACED PANORAMIC RADIOGRAPH WITH RULER
FIGURE 2 DIGITISED TEETH

FIGURE 2, A. INCISORS

The length was established by digitising the apex and the incisal edge so that they were effectively joined by a line extending from the apex through the mid point of cemento-enamel junction line to the incisal edge.

FIGURE 2, B. Molars

The length was established by digitising the apex of the mesio-buccal root and the mesiobuccal cusp tip.
FIGURE 3

DIGITISED PANORAMIC RADIOGRAPH
Measurements:

- **SNA**
- **SNB**
- **ANB**
- **1/SN**
- **1/Pal**
- **1/1**
- **/1Md**
- **SN-Pal**
- **SN-Md**
- **Pal-Md**
- **SN-OP**
- **Y-axis**
- **LFH**
- **UFH**
- **LFH:UFH**
- **Jarabak**
- **Overjet**
- **Overbite**
- **Wits**
- **Gonial angle**
FIGURE 5
MAXILLARY SUPERIMPOSITION

FIGURE 5, A.
Example of a scanned maxillary superimposition (superimposed on the palatal plane an ANS) prior to digitisation.

FIGURE 5, B.
8 linear and 2 angular measurements were made on the scanned superimposition.

Linear:
- Ap-H  Horizontal apex movement
- Ap-V  Vertical apex movement
- AP-T  Total apex movement
- IE-H  Horizontal incisal edge movement
- IE-V  Vertical incisal edge movement
- IE-T  Total incisal edge movement
- IE-Ap  Incisal edge to apex measured parallel to the palatal plane for the pre- and post treatment upper incisor.

Angular:
The long axis of the upper incisor to palatal plane pre- and post -treatment
There were 7 measurements made on the mandibular symphysis pre- and post treatment.

1. **Symphysis Width**
   Measured parallel to the mandibular plane (Md), half way along the perpendicular distance from Mandibular Plane to B point (X-Z).

2. **p-distance**
   Distance from lingual cortex to extension of long axis of lower incisor measured parallel to the mandibular plane (X-Y)

3. **L-Ap**
   Lingual cortex to apex measured parallel to the occlusal plane.

4. **Ap-Bc**
   Apex to buccal cortex measured parallel to occlusal plane.

5. **le-Ap**
   Incisal edge to Apex distance measured parallel to the occlusal plane.

6. **/1 Md**
   Lower incisor angulation to mandibular plane

7. **/1Occ**
   Lower incisor angulation to occlusal plane
FIGURE 7. A.
ANGULAR MEASUREMENTS

MAXILLARY AND MANDIBULAR HORIZONTAL REFERENCE LINE

LONG AXIS OF THE TEETH

THE MEASURED ANGLE WAS THE MOST MEDIAL ANGLE MADE BETWEEN THE LONG AXIS OF THE TEETH AND THE HORIZONTAL REFERENCE LINE
THE MEASURED ANGLE WAS THE MOST MEDIAL ANGLE MADE BETWEEN THE LONG AXIS OF THE TEETH AND THE HORIZONTAL REFERENCE LINE
FUTURE DIRECTIONS

To quantify the amount of apical root resorption with the type of appliance used a more accurate method of measurement of the resorption is necessary. Potential methods are digital subtraction radiography, computerised tomography and magnetic resonance imaging.

A more accurate panoramic machine that customises the centre of rotation and path of rotation to the patient's archform to ensure a constant vertical magnification, this would have to be couple with a more accurate method of positioning the patient in the machine.
APPENDIX 1

BOXPLOT OF DIFFERENCES IN TEETH IN APPLIANCES

Boxplot demonstrating change in length differences between appliances for the 16

SW = Straight wire
Sp = Speed
T = Tip-Edge

Boxplot demonstrating change in length differences between appliances for the 12

SW = Straight wire
Sp = Speed
T = Tip-Edge
Boxplot demonstrating change in length differences between appliances for the 11

Boxplot demonstrating change in length differences between appliances for the 21
Boxplot demonstrating change in length differences between appliances for the 22

![Boxplot for 22 samples]

\[\text{SW = Straight wire} \]
\[\text{Sp = Speed} \]
\[\text{T = Tip-Edge} \]

Boxplot demonstrating change in length differences between appliances for the 26

![Boxplot for 26 samples]

\[\text{SW = Straight wire} \]
\[\text{Sp = Speed} \]
\[\text{T = Tip-Edge} \]
Boxplot demonstrating change in length differences between appliances for the 36

![Boxplot 1](image)

**Legend:**
- SW = Straight wire
- Sp = Speed
- T = Tip-Edge

Boxplot demonstrating change in length differences between appliances for the 32

![Boxplot 2](image)

**Legend:**
- SW = Straight wire
- Sp = Speed
- T = Tip-Edge
Boxplot demonstrating change in length differences between appliances for the 31

SW = Straight wire
Sp = Speed
T = Tip-Edge

Boxplot demonstrating change in length differences between appliances for the 41

SW = Straight wire
Sp = Speed
T = Tip-Edge
Boxplot demonstrating change in length differences between appliances for the 42

\[ \text{Boxplot demonstrating change in length differences between appliances for the 46} \]

SW = Straight wire
Sp = Speed
T = Tip-Edge

142
APPENDIX 2

Boxplot demonstrating change in length differences between appliances divided into

**extraction and non-extraction for the 16**

![Boxplot for 16 appliances]  

- **SW** = Straight wire  
- **Sp** = Speed  
- **T** = Tip-Edge

**Boxplot demonstrating change in length differences between appliances divided into**

**extraction and non-extraction for the 12**

![Boxplot for 12 appliances]  

- **SW** = Straight wire  
- **Sp** = Speed  
- **T** = Tip-Edge

**APPLI**
Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 11

\[ \text{DIF11} \]

\[ N = 22, 20, 19, 14, 24 \]

\[ \text{SW} = \text{Straight wire} \]
\[ \text{Sp} = \text{Speed} \]
\[ T = \text{Tip-Edge} \]

Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 16

\[ \text{DIF21} \]

\[ N = 21, 20, 21, 14, 24 \]

\[ \text{SW} = \text{Straight wire} \]
\[ \text{Sp} = \text{Speed} \]
\[ T = \text{Tip-Edge} \]
Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 22

\[ \text{Diagram with boxplots} \]

**SW** = Straight wire  
**Sp** = Speed  
**T** = Tip-Edge

Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 26

\[ \text{Diagram with boxplots} \]

**SW** = Straight wire  
**Sp** = Speed  
**T** = Tip-Edge
Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 36

Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 32
Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 31

Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 41
Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 42

![Graph showing length differences between appliances divided into extraction and non-extraction for the 42]

**SW** = Straight wire  
**Sp** = Speed  
**T** = Tip-Edge

Boxplot demonstrating change in length differences between appliances divided into extraction and non-extraction for the 46

![Graph showing length differences between appliances divided into extraction and non-extraction for the 46]

**SW** = Straight wire  
**Sp** = Speed  
**T** = Tip-Edge
APPENDIX 3

Boxplot demonstrating change in length differences between appliances divided into machines for the 16

Boxplot demonstrating change in length differences between appliances divided into machines for the 12

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

MACHINE
Boxplot demonstrating change in length differences between appliances divided into machines for the 11

Boxplot demonstrating change in length differences between appliances divided into machines for the 21
Boxplot demonstrating change in length differences between appliances divided into machines for the 22

Boxplot demonstrating change in length differences between appliances divided into machines for the 26
Boxplot demonstrating change in length differences between appliances divided into machines for the 36

MACHINE

Boxplot demonstrating change in length differences between appliances divided into machines for the 32

MACHINE

1 = Soredex Tome
2 = Planmecca Prosan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex
Boxplot demonstrating change in length differences between appliances divided into machines for the 31

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

Boxplot demonstrating change in length differences between appliances divided into machines for the 41

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex
Boxplot demonstrating change in length differences between appliances divided into
machines for the 42

Boxplot demonstrating change in length differences between appliances divided into
machines for the 46
APPENDIX 4

Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 16

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction

Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 12

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction
Boxplot demonstrating change in length differences between appliances divided into
machines and extraction/non-extraction for the 11

1 = Sorodex Tome
2 = Planmeca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction

Boxplot demonstrating change in length differences between appliances divided into
machines and extraction/non-extraction for the 21

1 = Sorodex Tome
2 = Planmeca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction
Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 22

MACHINE

Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 26

MACHINE

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction
Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 36

![Boxplot for 36 machines and extraction/non-extraction](image)

1= Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

GROUP
- SW = Straight wire Non-Extraction
- SWE = Straight wire Extraction
- Sp = Speed Non-Extraction
- SpE = Speed Extraction
- T = Tip Edge Non Extraction
- TE = Tip Edge Extraction

Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 32

![Boxplot for 32 machines and extraction/non-extraction](image)

1= Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

GROUP
- SW = Straight wire Non-Extraction
- SWE = Straight wire Extraction
- Sp = Speed Non-Extraction
- SpE = Speed Extraction
- T = Tip Edge Non Extraction
- TE = Tip Edge Extraction

158
Boxplot demonstrating change in length differences between appliances divided into

machines and extraction/non-extraction for the 31

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction

Boxplot demonstrating change in length differences between appliances divided into

machines and extraction/non-extraction for the 41

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction
Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 42

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

GROUP
- SW = Straight wire Non-Extraction
- SWE = Straight wire Extraction
- Sp = Speed Non-Extraction
- SpE = Speed Extraction
- T = Tip Edge Non-Extraction
- TE = Tip Edge Extraction

Boxplot demonstrating change in length differences between appliances divided into machines and extraction/non-extraction for the 46

1 = Sorodex Tome
2 = Planmecca Proscan
3 = Siemens Orthophos
4 = Panex-E
5 = Cranex

GROUP
- SW = Straight wire Non-Extraction
- SWE = Straight wire Extraction
- Sp = Speed Non-Extraction
- SpE = Speed Extraction
- T = Tip Edge Non-Extraction
- TE = Tip Edge Extraction

160
APPENDIX 5

BOXPLOT OF DIFFERENCES IN PAR SCORES BETWEEN APPLIANCES

---

SW = Straight wire
Sp = Speed
T = Tip-Edge

---
APPENDIX 6

BOXPLOT OF DIFFERENCES IN PAR SCORES BETWEEN APPLIANCES DIVIDED INTO EXTRACTION AND NON EXTRACTION

GROUP

SW = Straight wire Non-Extraction
SWE = Straight wire Extraction
Sp = Speed Non-Extraction
SpE = Speed Extraction
T = Tip Edge Non-Extraction
TE = Tip Edge Extraction
APPENDIX 7

Histogram to show the distribution of tooth length change for the 16

Histogram to show the distribution of tooth length change for the 12
Histogram to show the distribution of tooth length change for the 11

Histogram to show the distribution of tooth length change for the 21
Histogram to show the distribution of tooth length change for the 22

Histogram to show the distribution of tooth length change for the 26

165
Histogram to show the distribution of tooth length change for the 36

Histogram to show the distribution of tooth length change for the 32
Histogram to show the distribution of tooth length change for the 31

![Histogram for DIF31]

- Std. Dev = 2.74
- Mean = 1.36
- N = 110.00

Histogram to show the distribution of tooth length change for the 41

![Histogram for DIF41]

- Std. Dev = 2.76
- Mean = 1.10
- N = 111.00
Histogram to show the distribution of tooth length change for the 42

DIF42

Histogram to show the distribution of tooth length change for the 46

DIF46
1) Sella Turcica
2) Mandibular Condyle
3) External Auditory Meatus
4) Mastoid Process
5) Styloid Process
6) Lateral Pterygoid Plate
7) Pterygomaxillary Fissure
8) Articular Eminence
9) Anterior Nasal Spine
10) Ethmoid Sinuses
11) Infraorbital Canal
12) Infraorbital Foramen
13) Zygomatic Process of the Maxilla
14) Incisive or Nasopalatine Foramen
15) Mandibular Foramen
16) Mandibular Canal and Mental Foramen
17) Mental Ridge
18) Hyoid Bone
19) Hard Palate
21) Maxillary Sinus
22) Nasal Fossa
23) Genial Tubercles
24) Hamular Process
25) External Oblique Ridge
26) Internal Oblique or Mylohyoid Ridge
27) Zygomatic Arch
28) Orbit
29) Nasal Septum
SOFT TISSUE SHADOWS

1. Nasopharangeal Air Space
2. Palatoglossal Air Space
3. Shadow of Ear
4. Glossopharangeal Air Space
5. Soft Palate
6. Epiglottis
7. Soft Tissue of Nose

AREAS OF RADIOGRAPHIC ARTIFACT

8. Ghost Image of Contralateral Mandible
9. Ghost Image of Apron too high on Shoulder
10. Ghost image of Spine due to Slumped position of patient
11. Ghost image of Contralateral Hard Palate

NOTE: All artifact areas and shadows are bilateral
APPENDIX 8 SCREENING OF THE PANORAMIC RADIOGRAPHS

Langland and Langlais (1997) advise that the operator should divide the panoramic radiograph into six zones. Three are in the midline and three are bilateral on each side. The zones are:

(1) Zone 1: Dentition
(2) Zone 2: Nose-Sinus
(3) Zone 3: Mandibular body
(4) Zone 4: Condyles
(5) Zone 5: Ramus-Spine
(6) Zone 6: Hyoid

To determine any positioning or processing errors the panoramic radiograph should be examined systematically.

Zone 1: Dentition

The teeth should be arranged with a smile-like upward curve posteriorly and be separated from each other. This separation produces an interocclusal space in the radiograph. The anterior teeth should neither be too large so narrow as to create "pseudospaces" between them. The posterior teeth should not be larger or smaller on one side than the other, nor should there be excessive overlap of the premolars on one side versus the other, the apices of the maxillary or mandibular anterior teeth should not be cut off, nor should the crowns of the anterior teeth appear fractured or obscured.

Zone 2: Nose-Sinus

The images of the inferior turbinates and their surrounding air spaces (meati) should be contained within the nasal cavity. The soft tissues of the nose cartilage should not be seen. The hard palate shadow (double image) and sometimes the ghost images of the palate must be seen within the maxillary sinuses, well above the apices of the posterior teeth. The tongue should be in contact with the hard palate, with no intervening air between these structures.

Zone 3: Mandibular Body

The inferior cortex of the mandible should be smooth and continuous. The double image, or ghost image of the body of the hyoid, should be absent in this area. The midline area should not be overly enlarged superiorly-inferiorly.


Zones 4 and 6: Four Corners: Condyles and Hyoid

Zone 4 contains the condyles bilaterally. The condyles should be more or less centred within the zone and not move off the top or lateral edges of the film. The condyles should be of equal size and on the same horizontal plane, i.e. one condyle should not be higher or lower than the other. Zone 6 contains the body of the hyoid bone and sometimes the greater horn. It should be equal in size bilaterally; although it may touch the mandible, it should not spread across the mandible.
Zone 5: Ramus-Spine

The ramus of the mandible should be the same width bilaterally. The spine, although usually not seen, may be present so long as it does not superimpose on the ramus. When present, the distance between the spine and ramus should be the same bilaterally.
APPENDIX 9 POSITIONING ERRORS

PATIENT TOO FAR FORWARD

DENTITION: Anterior teeth (especially the lowers) are narrowed and blurred. Sometimes with pseudospaces between the teeth. Increased overlap of the teeth in the premolar region.

RAMUS-SPINE: A blurred image of the bony structures in this region. The cervical spine is superimposed on the ramus and condyles symmetrically on both sides.

OVERALL: The whole patient appears to have been narrowed in respect to the size of the panoramic film.

Diagram to demonstrate the position of the dental arch in relation to the image layer. It can be seen that the anterior teeth are forward of the anterior limit of the image layer. This places them closer to the film and they are therefore smaller and blurred. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. Reproduced from Panoramic Radiology, Langland et al.)
Diagram to demonstrate the features of a panoramic radiograph where the patient has been positioned too far forwards. (Reproduced from Panoramic Radiology, Langland et al.)

Panoramic radiograph to demonstrate the features where the patient has been positioned too far forwards. (Reproduced from Principles of Dental imaging, Langland and Langlais.)
PATIENT TOO FAR BACK

DENTITION: Anterior teeth (especially the lowers) are widened and blurred. Widening of teeth is sometimes hard to judge.

NOSE-SINUS: Soft tissue image of the nose cartilage is seen. The lower turbinate and meati are spread-out across the maxillary sinus bilaterally.

MANDIBULAR BODY: The inferior cortex of the mandible should be smooth and continuous. The double image of the body of hyoid should be absent in this area.

CONDYLES: Appear close to or off the lateral edges of the film. Soft tissue outline of the cartilage of the pinna and earlobe visible.

RAMUS-SPINE: The ghost images of the contralateral rami are superimposed on the posterior molars and rami symmetrically bilaterally.

OVERALL: The patient’s image appears too large for the film.

Diagram to demonstrate the position of the dental arch in relation to the image layer. It can be seen that the anterior teeth are too far back in relation to the image layer. This places them closer to the source and they are therefore magnified and blurred. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. Reproduced from Panoramic Radiology, Langland et al.
Diagram to demonstrate the features of a panoramic radiograph where the patient has been positioned too far backwards (Reproduced from Panoramic Radiology, Langland et al.)

Panoramic radiograph to demonstrate the features where the patient has been positioned too far backwards. (Reproduced from Principles of Panoramic Radiology, Langland et al.)
CHIN TIPPED TOO LOW

DENTITION: Maxillary anterior teeth are better than in normal projection. Indistinct or no root structure of the mandibular anterior teeth. Pronounced overlapping of the posterior tooth contacts. Excessive curvature of the occlusal plane.

MANDIBLE: Widened vertically in the anterior region. Poor imaging of the trabecular pattern. There is an elongated double image and/or ghost image of the hyoid bone.

CONDYLES: The condyles approach the upper edge of the film or are cut off by the upper edge of the film symmetrically bilaterally. Narrowing of the intercondylar distance.

Diagram to demonstrate the position of the dental arch in relation to the image layer. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. It can be seen that the lower incisor apices will be placed outside the image layer and therefore be indistinct or demonstrate no root structure. Reproduced from Panoramic Radiology, Langland et al.)
Diagram to demonstrate the features of a panoramic radiograph where the patient's chin has been positioned too low (Reproduced from Panoramic Radiology, Langland et al.).

Panoramic radiograph to demonstrate the features where the patient's chin has been positioned too low. (Reproduced from Principles of Dental Imaging, Lanoland and Lanolais.)
DENTITION: Indistinct or no root structure of the Maxillary anterior teeth. Flattening of the occlusal plane.

NOSE-SINUS: The real, double and ghost images of the palate form a widened, prominent, radiopaque line which is projected downwards to approximate or superimpose on the apices of maxillary teeth.

CONDYLES: The condyles approach the lateral edges of the film or are projected off the edges of the film symmetrically bilaterally. Increased intercondylar distance.

Diagram to demonstrate the position of the dental arch in relation to the image layer. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. It can be seen that the upper incisor apices will be placed outside the image layer and therefore be indistinct or demonstrate no root structure. Reproduced from Panoramic Radiology, Langland et al.
Diagram to demonstrate the features of a panoramic radiograph where the patient's chin has been positioned too high (Reproduced from Panoramic Radiology, Langland et al.).

Panoramic radiograph to demonstrate the features where the patient's chin has been positioned too low. (Reproduced from Panoramic Radiology, Langland et al.).
HEAD TURNED

DENTITION: The posterior teeth on one side are widened and overlap interproximally. On the other side the teeth are narrowed.

NOSE-SINUS: On the side with the wide ramus the inferior turbinate and meati are spread out across the maxillary sinus; the opposite sinus may have an improved image.

CONDYLE: On the side with the wide ramus the ear lobe can be seen.

RAMUS-SPINE: Unequal magnification of the rami. On the side with the wide posterior teeth, the ramus is widened. On the other side the ramus is narrowed and intersected by the ghost image of the contralateral ramus. The spine may approach or superimpose on the ramus.

Diagram to demonstrate the position of the dental arch in relation to the image layer. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. Reproduced from Panoramic Radiology, Langland et al.
Diagram to demonstrate the features of a panoramic radiograph where the patient’s head is rotated (Reproduced from Panoramic Radiology, Langland et al.).

Panoramic radiograph to demonstrate the features where the patient’s head is turned.
(Reproduced from Panoramic Radiology, Langland et al.).
HEAD TILTED

DENTITION: Unequal magnification of right and left sides, i.e. the posterior teeth may be slightly widened on one side. Increased gap between the upper and lower teeth posteriorly on one side and a reduced gap on the other.

MANDIBLE: Unequal distance between the right and left inferior border of the mandible and the inferior edge of the film. The lower edge of the mandible on one side is almost horizontal. On the side with the widened interocclusal gap the mandible is enlarged and the lower edge appears to be directed upward above the horizontal plane.

CONDYLE: On the side with the widened interocclusal gap, the condyle is enlarged and above the contralateral condyle, which is smaller and lower in the image. The enlarged condyle may be off the top of the film.

Diagram to demonstrate the position of the dental arch in relation to the image layer. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. With the head tilted the anterior teeth can be positioned correctly relative to the image layer and the bite block. Reproduced from Panoramic Radiology, Langland et al.
Diagram to demonstrate the features of a panoramic radiograph where the patient's head is tilted. (Reproduced from Panoramic Radiology, Langland et al.).

Panoramic radiograph to demonstrate the features where the patient's head is tilted. (Reproduced from Panoramic Radiology, Langland et al.).
SPINAL COLUMN POSITIONING ERROR

DENTITION: Anterior teeth are difficult to see, especially the lowers. The ghost radiopaque image of the spine is superimposed in this area and obliterates it.

MANDIBLE: The ghost image of the spine extends downward beyond the mandibular teeth to obscure the midportion of the mandible. The image is wider at the inferior edge of the film and tapers superiorly.

Diagram to demonstrate the position of the dental arch in relation to the image layer. The teeth are still well positioned relative to the image layer. Reproduced from Panoramic Radiology, Langland et al.)

Diagram to show relationship of the anterior teeth to the bite block groove and the focal trough. Reproduced from Panoramic Radiology, Langland et al.

Diagram to demonstrate spinal column positioning error. It can be seen that the occlusal plane has been positioned properly in the machine but the spinal column is slumped rather than in a straight position. Reproduced from Panoramic Radiology, Langland et al.)
Diagram to demonstrate the features of a panoramic radiograph where the patient is slumped, or a spinal column positioning error (Reproduced from Panoramic Radiology, Langland et al.).

Panoramic radiograph to demonstrate the features where the patient is slumped, or a spinal column positioning error (Reproduced from Panoramic Radiology, Langland et al.).
TONGUE NOT RAISED AGAINST PALATE

DENTITION: There will be a superimposition of a radiolucent shadow of the palatoglossal air space over the roots of the maxillary teeth. This air space is not always symmetrical, especially if the patient swallows and momentarily drops the tongue away from the hard palate.

NOSE-SINUS: The maxillary apical alveolar bone is obscured by the palatoglossal air space.

Diagram to demonstrate the features of a panoramic radiograph where the patient's tongue is not raised against the palate (Reproduced from Principles of Dental imaging, Langland and Langlais.)

Panoramic radiograph to demonstrate the features where the patient's tongue is not raised against the palate (Reproduced from Principles of Dental imaging, Langland and Langlais.)
CHIN NOT IN REST

An exaggerated distance between the mandible and the chin rest and loss of the superior portion of the sinus image will result. The same finding may be noticed when the film is positioned too low on the patient's neck, which could occur when using machines that allow the chin rest to be moved independently.

BITE GUIDE NOT USED

The film will show an overlap of the maxillary and mandibular teeth.

MACHINE TOO HIGH

If the machine is too high the inferior border of the mandible will not appear on the film. This may be seen with a 5-inch film loaded in the upper 5 inches of a 6-inch cassette.

LIPS OPEN

A relative radiolucent area on the coronal portion of the maxillary and mandibular anterior teeth, especially the incisal third will be seen.

PATIENT MOVEMENT

Results in a distorted image, which is localised to the region being scanned by the rotating beam at the moment that the patient moves. An important sign of error is a discontinuous or wavy image of the inferior border of the mandible.

PROSTHESIS LEFT IN PLACE

Superimposition of the outline of the metallic and porcelain portions of the prosthesis over the teeth and bony structures will be found. Acrylic resins that contain opaque agents will also interfere with the image.
<table>
<thead>
<tr>
<th>ERROR</th>
<th>IDENTIFYING FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient too far forward</td>
<td>Narrow blurred anterior teeth with pseudospace. Superimposition of spine on ramus. Bicuspid overlap bilaterally.</td>
</tr>
<tr>
<td>Patient too far back</td>
<td>Wide, blurred anterior teeth. Ghosting of rami, spread out turbinates, ears, and nose in image. Condyles off edge of film.</td>
</tr>
<tr>
<td>Chin tipped too low</td>
<td>Excessive curving of the occlusal plane. Loss of image of the roots of the lower anterior teeth. Narrowing of the intercondylar distance and loss of the head of the condyles at the top of the film.</td>
</tr>
<tr>
<td>Chin raised too high</td>
<td>Flattening or reverse curvature of the occlusal plane. Loss of image of the roots of the maxillary anterior teeth. Lengthening of the intercondylar distance and loss of the head of the condyles at the edges of the film. Hard palate shadow wider and superimposed on the apices of the maxillary anterior teeth.</td>
</tr>
<tr>
<td>Head turned</td>
<td>Unequal right-left magnification especially of teeth and ramus. Severe overlap of contact points and blurring.</td>
</tr>
<tr>
<td>Head tilted</td>
<td>Mandible appears tilted on the film. Unequal distance between mandible and chin rest at a given point on the right and left sides. One condyle is higher and larger than the other.</td>
</tr>
<tr>
<td>Slumped position</td>
<td>Ghost image of cervical spine superimposed on the anterior region</td>
</tr>
<tr>
<td>Tongue not on palate</td>
<td>Relative radiolucency obscuring the apices of the maxillary teeth (palatoglossal air space)</td>
</tr>
<tr>
<td>Chin not on rest</td>
<td>Sinus not visible on film. Top of condyles cut off. Excessive distance between inferior border of the mandible and lower edge of film.</td>
</tr>
<tr>
<td>Bite guide not used</td>
<td>Incisal and occlusal surfaces of upper and lower teeth overlapped.</td>
</tr>
<tr>
<td>Lips open</td>
<td>Relative radiolucency on the coronal portion of the upper and lower teeth.</td>
</tr>
<tr>
<td>Patient movement</td>
<td>Wavy outline of the cortex of the inferior border of the mandible. Blurring of the image above wavy cortical outline.</td>
</tr>
<tr>
<td>Prosthesis</td>
<td>Evidence of prosthesis in image.</td>
</tr>
</tbody>
</table>