AN EVALUATION OF EXTERNAL APICAL ROOT RESORPTION AFTER ORTHODONTIC TREATMENT

Elizabeth Thomas

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science in Dentistry.

Johannesburg 2011

DECLARATION

I, Elizabeth Thomas, declare that this research report is my own work. It is being submitted for the degree of Master of Science in Dentistry at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

Elizabeth Thomas

....

E. Thomas

…20th…… day of ……October………, 2011

This work is dedicated to my father, Prof. C. T. Mathew, one of the first Orthodontists in Kerala, India, and the founder-Director of the Calicut Dental College.

PUBLICATIONS AND PRESENTATIONS

Conference paper

Thomas, E. (2010). An evaluation of external apical root resorption after orthodontic treatment. Presented at the 45th Indian Orthodontic Conference, 17th-19th December, Mangalore, India.

ABSTRACT

Root resorption is a common problem encountered in all branches of dentistry but is more commonly seen in cases that had been treated orthodontically. Orthodontists are constantly improving materials and techniques to reduce undesirable side effects like root resorption. Therefore in this retrospective study the primary objective was to compare the amount of root resorption observed after active orthodontic treatment with three different appliance systems namely, Tip Edge, Modified Edgewise and Damon. The sample consisted of pre and post-treatment cephalograms of sixty eight cases that were treated in three different groups (i.e., techniques). Root resorption of the maxillary central incisor was assessed from pre- and post-treatment lateral cephalograms using two schemes. In the first method overall tooth length (Black, 1902) from the incisal edge to the apex was measured on both pre and post-treatment lateral cephalograms and root resorption was recorded as an actual millimetre loss of tooth length. Percentage shortening per tooth was also recorded.

The results were subjected to various statistical analyses. There was a significant upward linear trend (p=0.022) for root resorption from Group 1 (Tip Edge) to Group 3 (Damon). Statistical modeling illustrated that only baseline length (pre-treatment incisor length) was a significant confounder. Gender, race, age and treatment time did not have a significant influence on the amount of root resorption seen after orthodontic treatment. In the final analysis after having adjusted for baseline length it was found that there were no significant differences (p=0.133; ANCOVA) in the degree of root resorption observed after the active phase of orthodontic treatment between groups. Similarly the percentage of root resorption

calculated did not differ significantly between groups (p=0.067). The result was also confirmed by following a non-parametric approach by doing an analysis of covariance (ANCOVA) in which data was allocated a rank value.

In the second method root resorption was visually evaluated by using the five grade ordinal scale of Levander and Malmgren (1988). It was found that majority of cases in the sample came under Grade1 and Grade 2 category of root resorption. The upward linear trend between actual measurements and visual measurements was found to be statistically significant (p=0.0183).

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisors Dr. R. Chamda and Professor W.G. Evans, for the valuable guidance, assistance and constant encouragement offered to me in the preparation and execution of this research report.

I am also grateful to Professor Piet Becker, Medical Research Council, Pretoria for his expert help in the statistical analyses contained in this report.

I wish to thank Dr. R. Chamda, Dr. M. Wertheimer and Dr C.Lesar for granting me access to their respective offices, staff and records for data collection. This research would not have been possible without their kindness.

I would also like to thank my colleagues Dr N. Green Thompson and Dr A. Morar for their constructive criticisms.

The assistance of my son George Thomas in copying all the data compiled from the three groups is gratefully acknowledged.

Finally, I would like to acknowledge my husband, Thomas Joseph, who has been a constant pillar of strength and support to me, especially during the execution and submission of this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

External root resorption is a multifactorial problem experienced in all disciplines of dentistry but most commonly in cases receiving orthodontic treatment. Root resorption was first reported by Bates as far back as 1856 (Philips, 1955). Although Ottolengui in 1914 was the first clinician to report apical root loss after orthodontic treatment, the finding was received with little trepidation by the orthodontic profession. However, thirteen years later, Albert Ketcham's dramatic evaluations of apical root loss, derived from a radiographic survey of 385 treated cases in his own practice, forced the discipline to sit up and take note of this complication. A spate of investigations on both experimental animals and human patients followed (Rudolph, 1940; Philips, 1955; Rygh, 1977). These studies dealt with the histological and clinical aspects and with factors affecting apical root loss. At present it is known that the aetiologic factors are complex and multifactorial (Brezniak and Wasserstein, 1993b).

Root resorption is undesirable as it can affect the long term viability of the dentition. A considerable reduction in the root length of the affected teeth results in an unfavorable crown-root ratio, making them less suitable as abutments in prosthetic restorations. An apical root loss of three millimetre is equivalent to one millimetre of crestal bone loss, so periodontitis occurring in teeth affected by root resorption will progress more rapidly to a critical alveolar bone level when compared with teeth unaffected by root resorption.

Ketcham (1929) also made a less well- known discovery, namely that different appliance systems influence the degree of root resorption. Many general dentists and dental specialists in other disciplines believe that root resorption is avoidable and blame the orthodontist involved when it occurs during orthodontic treatment. It is therefore important to identify whether different orthodontic appliance systems are associated with an increased risk of root resorption. In recent years the difference in risk occasioned by different appliance systems has been re-evaluated, but other contributing factors have not been as thoroughly investigated.

The purpose of this study is to examine the influence of variables such as different types of mechanotherapy, age, gender and ethnicity together with duration of treatment time on root resorption.

CHAPTER 2: REVIEW OF LITERATURE

External apical root resorption (EARR) can be defined as a shortening or blunting of the root apex (Malmgren and Levander, 2004). Rudolph (1940) noted that it typically attacks the root tip and travels coronally, creating a “shed roof” effect to the root.

Andreason (1988) classified root resorption into three main categories, namely surface resorption, inflammatory resorption and replacement resorption.

Surface resorption is a self-limiting process usually involving small localized areas. These undergo spontaneous repair by cellular reaction from adjacent areas of the periodontal ligament.

Inflammatory resorption occurs when the initial root resorption has reached the dentinal tubules of an infected necrotic pulpal tissue.

Replacement resorption produces ankylosis of a tooth as in this instance the resorbed root substance is replaced by bone, firmly linking tooth and socket.

Tronstad (1988) believes that inflammatory resorption is related to the presence of multinucleated cells that colonize the denuded cemental surface. He characterizes two kinds of inflammatory resorption: Transient inflammatory resorption occurs when the etiological factors occur for a short period of time and have minimal effect. This defect usually goes undetected radiographically and is repaired by a cementum-like tissue. Progressive inflammatory resorption occurs when the etiological effect or stimulus continues over a long period of time. The severely denuded root areas attract hard- tissue resorbing cells.

Gradually there is complete destruction of the local root structure and replacement resorption with ankylosis of the tooth occurs.

Mechanically induced tooth movement, the foundation of orthodontic treatment, typically produces some external apical root resorption. Radiographic studies have confirmed this (Philips, 1955; Ten Hoeve and Mulie, 1976; Linge and Linge, 1991; Mirabella and Artun 1995; Blake, Woodside and Pharoah 1995; Sameshima and Asgarifar 2001). Replacement resorption, however, is rarely seen in association with orthodontic mechanotherapy (Brezniak and Wasserstein, 1993a).

According to Brezniak and Wasserstein (2002a), orthodontic root resorption is a distinct pathologic process and differs from other types of root resorption. Orthodontic force applications produce a clinical picture that includes all the characteristics of inflammation namely rubor (redness), calor (heat), tumor (swelling), dolor (pain) and to some extent *functio laesa* (inhibited function). The inflammation that occurs is the main culprit underlying the root resorption process. Brezniak and Wasserstein (2002a) suggested a new term: Orthodontically Induced Inflammatory Root Resorption (OIIRR). Patient- related and treatment- related factors are responsible for the onset and progression of this root resorption which results from a sterile necrosis of the periodontal ligament. In orthodontically induced inflammatory root resorption the injury results from the pressure applied to the root during tooth movement. Ischaemic necrosis or hyalinization of the periodontal ligament occurs on the pressure side or area.

Three stages can be described in the hyaline zone namely, degeneration, elimination of destroyed products, and re-establishment. Studies in experimental animals conducted by Brudvik and Rygh (1994) confirmed that OIIRR occurs as a part of the hyaline zone elimination process. Macrophage-like and multinucleated cells are activated by biochemical signals coming from the sterile necrotic tissue, the result of orthodontic force application. Macrophages are scavenger cells of haematopoietic origin and their role is to eliminate necrotic tissue. The initial elimination process takes place at the periphery of the hyaline zone, where blood supply to the periodontal ligament still exists or is even increased. During removal of the hyaline zone, the nearby outer surface of the root can be affected. In severe cases the outer root surface layers, including cementoblasts and the pre-cementum layers can be damaged. The activity of the macrophage- like and multinucleated cells continues until the hyaline tissue has been completely removed and /or the force level decreases. Resorption lacunae that are formed on the root surfaces involved help to increase the root surface area and thereby decrease the pressure exerted through force application. The decompression that occurs allows the process to reverse and the cementum to be repaired.

Force application of an intermittent nature results in lesser root resorption than does application of a continuous force. Intermittent forces permit intervals with an absence of mechanical stress and consequently, allow the resorbed cementum to heal. This in turn helps to prevent further resorption (Brezniak and Wasserstein, 2002a; Pizzo, Licata, Giuglia and Guilianna, 2007).

If the orthodontic force is applied for a long time, the multinucleated cells develop odontoclastic-like morphology and functions and begin a complete cementum resorption, denuding mineralized dentin areas. These cells produce a tridimensional, non-reversible and radio-graphically evident root resorption. This process is usually located in the apical third of the root.

Faltin, Faltin, Sander and Arana-Chavez (2001) in their investigations regarding orthodontic tooth movement with application of continuous intrusive forces using super- elastic wires in humans found that the mineralized surface of the cementum in the apical part is resorbed the most. The changes are directly proportional to the magnitude of the continuous force applied.

Brezniak and Wasserstein (2002a) classified OIIRR into three degrees according to the severity of affliction:

- Cemental or surface resorption with remodeling

  In this process only the outer layers of cementum are resorbed. Later on these layers are completely regenerated or remodelled.

- Dentinal resorption with repair (deep resorption)

  In this process the cementum and outer layers of dentine are resorbed. Repairs usually take place with cementum-like material. The final shape of the root after repair may or may not resemble the original form

- Circumferential apical root resorption

  In this process complete resorption of the apical portion of the hard tissue components of the root occurs and the root is shortened.

This study will examine orthodontically induced external root resorption which has occurred at the apices of the maxillary central incisor roots after active orthodontic therapy.

For the majority of orthodontic patients the biggest motivation for seeking orthodontic treatment is a desire to improve dental and facial esthetics. In Class II Division I malocclusions, the retraction of upper teeth results in a dropping back of the upper lip which may improve the relative protrusiveness of the profile (Looi and Mills, 1986). Hence retraction of maxillary anterior teeth is an essential step in such orthodontic treatment. Rudee (1964) measured associated linear changes in incisor position and upper lip protrusion. He found that three millimetre retraction of upper anterior teeth results in one millimetre retraction of the lips. Garner (1974) found the ratio to be even higher in black males (3.6:1). Thus we see that the upper incisors have to undergo considerable movement to bring about associated and desirable soft tissue profile changes. However, when treating any malocclusion an important objective of the orthodontist is to create or maintain esthetic harmony consistent with a functional occlusion. Under these stringent conditions, when examining the vulnerability of different teeth to root resorption during orthodontic movement, it will be found that the tendencies differ. The maxillary incisors are the teeth most affected by root resorption. In general the extent of movement demanded of these teeth is usually greater due to the nature of the malocclusion, function and to the exigencies of esthetics.

The fact that incisors are single rooted with spindly, cone shaped roots may also be a predisposing factor to external apical root resorption. The root structure and its relationship to bone and periodontal membrane tend to transfer the effect of the forces mainly to the apex. The apical third of a root is covered with cellular cementum and its integrity is dependent on the vascularity of the area. This makes it more fragile and readily injured by heavy forces. Hence the peri-apical portion is more prone to root resorption than the rest of the root (Harris, 2000). It is often stated that if there is no evidence of apical root resorption in the maxillary and mandibular incisors, then significant apical resorption is less likely to occur in other teeth (Copeland and Green, 1986; Goldson and Hendrikson, 1975; Sjolien and Zachrisson, 1973).

Root resorption is a complex process with a multifactorial etiology. It has been postulated that the risk of orthodontically –associated root resorption will vary according to the type of appliance or technique used. The pin and tube and ribbon and bracket appliances produced more resorption than other labial appliances which utilized tipping movements (Ketcham, 1927). Beck and Harris (1994) found no difference in the degree of root resorption in cases treated with the Begg and Tweed techniques. Apical root resorption of central incisors was significantly higher in cases treated using the edgewise technique than in the straight wire group (Mavragani, Vergari, Selliseth, Boe and Wisth, 2000).

Is there a technique or force system that can reduce or prevent external apical root resorption? No previous study could satisfactorily answer this question (Brezniak and Wasserstein, 2002b).

Nevertheless, orthodontists continue to seek improved materials and techniques which may minimize undesirable treatment side effects like apical root resorption. Nickel-titanium wire was first used in orthodontics in 1971. Twenty two years later new super-elastic nickel-titanium wires that deliver light and continuous forces with large amounts of activation and for longer periods of time were developed. Concurrent with the evolution of wires, bracket systems were also improved with the objective of reducing the magnitude of force applied to the teeth during orthodontic treatment. Viazis (1995) introduced triangular brackets with an increased interslot distance, considerably decreasing the forces delivered by the new generation nickel–titanium wires. He called the technique the Bioefficient Therapy. Janson, Canto, Martin, Henriques and De Freitas (1999) compared apical root resorption after orthodontic treatment with Bioefficient Therapy with that recorded in cases treated with the Edgewise Straight Wire system and the Simplified Standard Edgewise Technique. They found less root resorption in cases treated with Bioefficient Therapy. It was suggested that the bracket design, use of heat activated and super-elastic wires as well as limiting wires to smaller rectangular stainless steel arches in a 0.22 x 0.028 inch slot during incisor retraction and in finishing stages may have contributed to the observed decrease.

The Differential Straight Arch technique developed by Kesling (1994) utilizes the Tip Edge bracket, designed to provide all the benefits and advantages of differential tooth movement plus predetermined degrees of final crown tip and torque. Damon (2004) developed a technique that sets out to match each phase of treatment with the natural force systems of normal growth and development. The Damon technique is a low force, low friction system where passive self-ligating brackets and high technology wires are carefully selected with the intention of keeping the force applied on teeth in the optimal force zone. Pandis, Nasika, Polychronopoulou and Eliades (2008) found no statistically significant difference for the incidence of root resorption between cases treated with conventional Edgewise and with passive self-ligating brackets. They found, conversely, that a trend indicating more root resorption for the self-ligating system was evident, although the differences did not reach significance (p=0.06). They stressed, however, that further investigations are needed to validate this claim.

The suggestion that different appliance systems can alter the risk of root resorption is not new but has not been widely tested among contemporary treatment modalities (Pandis *et al*, 2008). To date a thorough search of literature has revealed no study which compares the extent of root resorption recorded during treatment with the Tip Edge appliance with that demonstrated in cases treated using a self-ligating bracket system or a pre-adjusted modified edgewise appliance system.

In this context, the purpose of this retrospective study is to:

1) Assess the incidence and severity of apical root resorption recorded in association with orthodontic treatment undertaken with Tip Edge, Damon and Modified Edgewise techniques

2) Evaluate other possible contributing factors such as age, gender, ethnicity and duration of treatment time.

3) The null hypothesis states that there will be no difference in the extent of apical root resorption seen after orthodontic treatment undertaken with Tip Edge, Damon and Modified Edgewise techniques*.

***An edgewise technique practised in the Department of Orthodontics, University Of Witwatersrand, based on the philosophy of Crockatt and Holdaway (1971) with certain modifications incorporated in to the prescription and procedure**

CHAPTER 3: MATERIALS AND METHODS

The application for ethical clearance for this study was submitted to the Human Research Ethics Committee (Medical), University of the Witwatersrand, Johannesburg on 28.02.2008 and was approved unconditionally (Clearance certificate – M090827).

3.1 Sample Selection:

Pre- and post- treatment lateral cephalometric radiographs of sixty eight cases have been used in this study, comprising twenty six cases from a Tip Edge group (group 1); twenty three cases from a Modified Edgewise group (group 2) and nineteen cases from a Damon group (group 3). In each of these clinical settings the cephalograms had been taken by the same operator, on the same machine, at the same object – film distance.

A total of one hundred and thirty six digital radiographs were therefore included.

Cases fulfilling the following criteria were consecutively selected, irrespective of whether treatment had included extractions or not:

a) Subjects had a Class II skeletal malocclusion as indicated by an original ANB angle of four to eight degrees, and had been treated in the permanent dentition
b) Each case had cephalograms taken before and after the end of active treatment.
c) The overbite was 30%-70% as measured on the cephalogram.
d) The overjet on the cephalogram ranged from two-nine millimetres when measured from the incisal edge of the upper incisor to the labial surface of the lower incisor.

e) Root formation of the maxillary central incisors had been completed before treatment was initiated.
f) There was no history of trauma to the permanent maxillary incisors which were also caries-free, and none had received endodontic treatment
g) None of the subjects showed any apparent genetic or developmental defect of the root.
h) The radiographs were of good quality with reasonable distinction of structures.

The age at start of treatment, gender, total active treatment time and ethnicity were recorded for each case.

Each set of records was assessed to define the degree and severity of external apical root resorption (EARR) which may have occurred on the most procumbent maxillary incisor. Root resorption was assessed by comparing measurements recorded on the pre-treatment and post-treatment lateral cephalograms. A listing of individual results in each group is given in Appendix A (page 43).

The maxillary central incisor was used as the reference test tooth because:

a) This tooth has been shown to have the greatest frequency of external apical root resorption (Copeland and Green, 1986; Goldson and Hendrikson, 1975)
b) It may be readily visualized on lateral cephalograms (Parker and Harris, 1998)

3.2 Calibration of x-rays

A standard method of calibration was devised to compensate for the disparate effects of magnification produced by the three different radiology units. A 12mm thick Perspex sheet of

238mm x 177mm dimensions was cut and a lateral cephalogram tracing was taped on to the surface. The locations of the relevant anatomical areas of the tracing pertinent to this study were identified and marked, mainly the maxillary alveolar region and the maxillary anterior teeth. Holes were drilled strategically around these and other points. Carbon steel ball bearings (Grade I-1000, Rockwell Hardness ± 65, Sampaguita Technology) of a known dimension (16mm diameter) were embedded in these holes using a clear radiolucent adhesive.

The Perspex sheet was then fixed to a narrow rectangular base by means of two screws. The base was secured on to the platform of a camera tripod, being held by a screw which protruded from the tripod base.

Figure 3.1 Set up used for calibration of radiographs (two views)

The tripod supporting the Perspex sheet was then centered between the ear rods of the digital x-ray machine. A spirit level was used to ensure that the sheet was erect and vertical to the ground. These steps served to ensure that the orientation of the sheet closely mimicked that position where the sagittal plane of the head of a patient would have been placed to have a cephalometric radiograph taken. The film was then exposed at the lowest possible radiation dose which produced an image of the carbon steel ball bearings with excellent clarity.

In a digital radiographic unit the scanned data is transmitted directly to a computer where the image could be viewed on the screen. Each such image was examined to ensure the stipulated quality. The cephalometric data in each group were then copied on to an external memory device and transported to the Mensuration Laboratory, School of Oral Health Sciences, University of Witwatersrand. Once there, all the images were loaded on to a computer in which the Olympus Soft Imaging Solutions Analysis software package had been installed. The XY-calibration was automatically set to "1pixel/pixel." To ensure that all the images were correctly calibrated, the magnification within the image analysis program was reset to a magnification factor of "1" before any image was acquired into the program. The test film of the ball bearings from the first group was then loaded on the screen. The image of the carbon steel ball bearing that was in the maxillary incisor region was selected for measurement. Two computer-generated and parallel lines were positioned on either side of the image. Now a perpendicular was constructed to link the two tangentially derived points on the circumference of the image. This distance was measured using the computer pointer. The measurement was adjusted so that the computer showed the distance as 16mms. This represents the true diameter of the ball bearing. The computer was set to read distances in accord with that calibration. The correction factor was then determined in this manner for films recorded in the second and third groups.

3.3 Method of measuring

This study relies on two well established methods of quantifying resorption.

3.3.1 Method one

In the first approach, the tooth length from incisal edge to root apex was measured (Black, 1902). As the incisal edge may be readily visualized on the cephalograms as compared with measurements taken from the cemento-enamel junction, this approach is more reliable (Harris and Butler, 1992). When assessment relies upon measuring the length of the root, accurate location of the cemento-enamel junction is imperative. This is very susceptible to intra-examiner and inter-examiner error. The cemento- enamel junction also changes in height around the circumference of a tooth, which further complicates measurements (Costopoulos and Nanda, 1996). Therefore, in this study, the entire length of the incisor from the incisal edge to the most apical limit of the root apex was measured. The measurements were performed electronically to the nearest 0.01mm, using a software package provided by Olympus Soft Imaging Solutions.

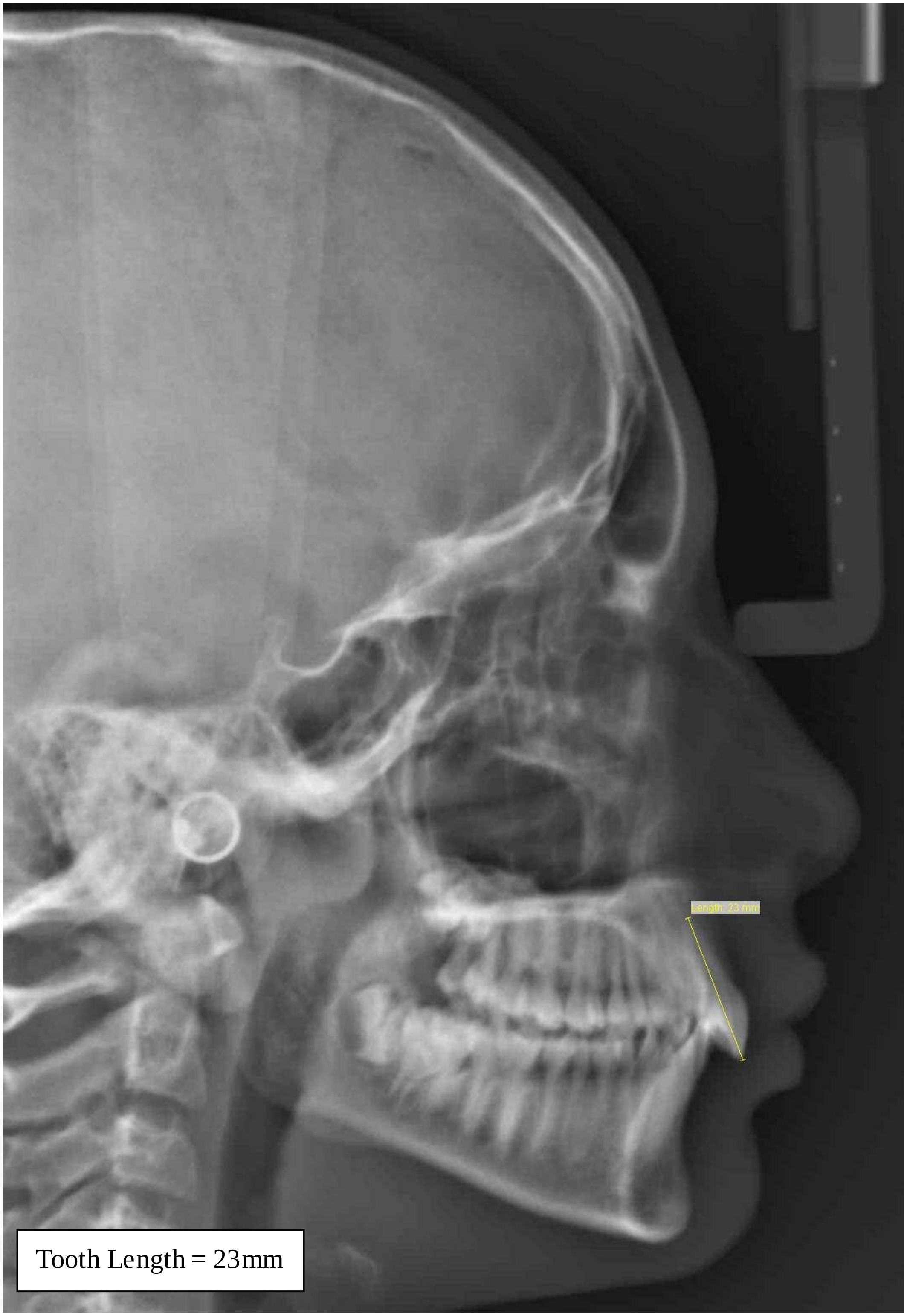

Figure 3.2 Measurement of tooth length

The measurements for each set of radiographs were performed under standard conditions of lighting, and at the same time each day. At each sitting an image was loaded on to the program three times, measured, and the average taken. In the pre-treatment cephalograms the tip of the apex was relatively easy to identify. In the post-treatment cephalograms the apical configurations of the central incisor root showed some variations. Some of the incisor root apices exhibited a rounded or flat outline while others appeared to show root resorption extending from the apex downwards along the lingual root surface creating a definite angular discrepancy towards the labial root surface (Ten Hoeve and Mulie, 1976). In all these cases the point at the most convex outline or the most apical tip of the root was taken as the apex of the incisor root. In this way measurement parameters were standardized.

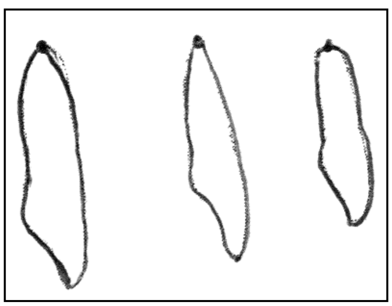

Figure 3.3: Illustration of various root apices seen in post-treatment radiographs. The black dot denotes the absolute apex or apex tip.

The amount of root resorption after active treatment was determined by subtracting the post-treatment length from the pre-treatment length .The image analysis program automatically created descriptive statistics including the average and standard deviation of the three repeated measurements. These descriptive statistical data together with the raw data were then exported on to Microsoft Excel spreadsheets and tabulated for further statistical analysis.

External Apical root resorption (EARR) = T_1 - T_2

Where T_1 = Tooth length before treatment

T_2 = Tooth length after treatment.

Root resorption was recorded as actual millimeter loss of tooth length. Percentage shortening for each tooth was also calculated:

$$\text{Percentage Resorption per tooth} = \frac{\text{EARR}}{T_1} \times 100$$

3.3.2 Method two

In the second method the occurrence and degree of external root resorption at the end of the active phase of orthodontic treatment was assessed using the five grade ordinal scale of Levander and Malmgren (1988)

- Grade 0 = Absence of root resorption
- Grade 1 = Mild resorption, root with its normal length and only an irregular contour
- Grade 2 = Moderate resorption, small area of root loss with the apex exhibiting an almost straight contour
- Grade 3 = Accentuated resorption, loss of almost one third of root length
- Grade 4 = Extreme resorption, loss of more than one third of the root length.

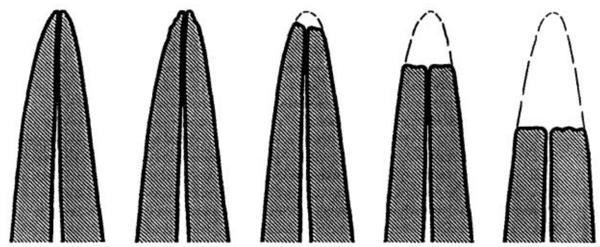

Figure 3.4 Illustration of the five ordinal grades of root resorption

Each set of pre- and post- treatment cephalograms were analysed visually and the ordinal grade of root resorption were noted.

3.4 Statistics

3.4.1 Error of the method: method one

To test the error involved in the measuring technique, ten cephalograms were selected randomly and the measurements repeated ten times under the same conditions over ten consecutive days (10x10=100 measurements). The results were subjected to a statistical evaluation of intra-class correlation. The inter-operator error was assessed by comparing the results recorded by the investigator with those recorded by an experienced orthodontist under the same conditions on a random sample of fifteen cases. Statistical analysis was done to test the inter-class coefficient.

3.4.2 Statistical analysis: method one

The incidence and severity of apical root resorption occurring after active treatment by three different orthodontic techniques were compared statistically. Statistical significance was set at

P< 0.05. The influence of various confounders like technique, pre-treatment incisor length, age, gender, race and duration of treatment were also explored statistically. One or more of these confounders in various permutations were included in an analysis of covariance (ANCOVA).This gave rise to the final analysis where it was necessary to adjust for baseline length (pre-treatment incisor length) only. A nonparametric approach by doing an analysis of covariance for ranks was also done.

3.4.3 Error of the method: method two

Intra -operator error was assessed by randomly selecting fifteen cases and grading them again.

3.4.4 Statistical analysis: method two

Visual assessment of pre- and post-treatment cephalograms to grade the observed root resorption observed showed that the majority of cases in the study sample experienced Grade 1 and Grade 2 resorption. There was also a significant linear trend (p=0.018) over grades 0-3.

3.4.5 Comparative statistics

Statistical analysis was also done to discover whether there was any association between actual millimeter loss of tooth length recorded and the visual assessment of grades, using a one way ANOVA analysis.

CHAPTER 4: RESULTS

The primary concern of this study is to compare the incidence and severity of apical root resorption occurring on the upper incisor during the course of class II correction by three different orthodontic techniques. A listing of individual results recorded for each technique is given in Appendix A (page 43).

4. 1 Descriptive statistics of the sample

The following table illustrates in each group, the mean age of the subjects and the standard deviation of the same variable (age). Groups do not differ significantly with respect to this variable (p=0.349)

Table 4.1: Mean age distribution by groups

Group	Mean	SD
Group 1	15.635	3.510
Group 2	14.402	5.528
Group 3	13.965	3.100

* Note: group 1= Tip Edge, group 2= Modified Edgewise, group 3= Damon

Table 4.2 demonstrates the means and standard deviations of the variable "duration of treatment" in each group. The average treatment times in each group as well as the standard deviations also have been recorded. It can be seen that the longest mean treatment time is in group three and the shortest mean treatment time is recorded in group one. Groups differ significantly with respect to treatment time (p=0.0004). Treatment duration in group 2 and group 3 were significantly longer than group 1.

Table 4.2: Duration of treatment in each group

Group	Duration of treatment in months (Mean)	SD
Group 1	17.538	6.041
Group 2	25.043.	8.471
Group 3	25.789	7.948

Table 4.3 records the results when the Fishers Exact Test has been applied to analyze the interaction between the variables “gender” and “groups” respectively.

Table 4.3: Gender distribution by group, frequency (%)

Gender	Group 1	Group 2	Group 3	Total
Male	11 (42.31%)	6 (26.09%)	13 (68.42%)	30 (44.12%)
Female	15 (57.69 %)	17 (73.91%)	6 (31.58%)	38 (55.88%)
Total	26 (100%)	23 (100%)	19 (100%)	68 (100%)

It can be seen that females constitute the larger proportion of the total number of cases (57.69%, n=15/26) in group 1 (Tip Edge) and, in group 2 (Modified Edgewise) the same trend continues with the females accounting for 73.91 % (n=17/23). In group 3 (Damon) the trend is reversed and females account for only 31.58 % (n=6/19) of the total subjects. In fact the groups differed significantly (p=0.025; Fischer’s Exact Test) with respect to gender distribution.

Table 4.4 displays the distribution of race within groups. Fisher’s Exact Test shows that there is a significant association between race and groups (p< 0.001).

Table 4.4: Race distribution by group

Race	Group 1	Group 2	Group 3	Total
Indian (Code 1)	25 (96.15%)	2 (8.70%)	2 (10.53%)	29 (42.65%)
Black (Code 2)	0 (0.00%)	4 (17.39%)	0 (0.00%)	4 (5.88%)
White (Code 3)	0 (0.00%)	17 (73.91%)	17 (89.47%)	34 (50.00%)
Coloured (Code 4)	1 (3.85%)	0 (0.00%)	0 (0.00%)	1 (1.47%)
Total	26 (100%)	23 (100%)	19 (100%)	68 (100%)

The following codes were used to identify the racial background of the patients in the study:

code 1=Indian code 2=Black code 3=White code 4=Coloured.

Table 4.4 shows that the total number of white patients across groups is thirty-four (50%). Indians account for twenty-nine cases (42.65%) while Black and Coloured races account for four (5.885%) and one (1.47%) respectively. Since the total number of Blacks (4) and Coloured (1) was small it was decided on statistical advice to combine the Indians, Blacks and the Coloured people together for statistical purposes and then to compare this newly formed sample group (code 5) with the Whites (code 3) by groups.

Table 4.5: New racial sample distribution by groups

Code	Group 1	Group 2	Group 3	Total
5	26 (100%)	6 (26.09%)	2 (10.53%)	34 (50.00%)
3	0 (0.00%)	17 (73.91%)	17 (89.47%)	34 (50.00%)
Total	26 (100%)	23 (100%)	19 (100%)	68 (100%)

Groups differ significantly ($p<0.001$; Fisher's Exact Test) with respect to race distribution. Group 1 (Tip Edge group) differs from the other two groups in that the sample drawn from it did not include any white patients.

4.2 Error of the method

4.2.1 Results of intra- and inter-examiner tests for method one

The results of the repeated measurements performed by the investigator over ten days were subjected to a statistical evaluation. Reliability expressed by the intra- class correlation (ICC) for each of the ten days is displayed in table 4.6

Table 4.6 Intra-class correlation

No of Days	Intra-class correlation
Day 1	0.98744
Day 2	0.98829
Day 3	0.99255
Day 4	0.99412
Day 5	0.99575
Day 6	0.99626
Day 7	0.99277
Day 8	0.99511
Day 9	0.99616
Day 10	0.99589

These data confirm that the reliability (intra-rater) for linear measurements is excellent (max possible=1). Inter-operator error was assessed by comparing the results recorded by the investigator with those recorded by an orthodontist under the same conditions on a random sample of fifteen cases. Statistical analysis for inter-operator error revealed an intra- class correlation coefficient of 0.606 which reflects moderate agreement.

4.2.2 Results of intra- examiner tests for method two

The intra-observer agreement was excellent as reflected by kappa statistic of 0.882 with 92.7% agreement.

4.3 Data on assessment of resorption

Table 4.7 reports the arithmetic mean and the standard deviation of the pretreatment length of the central incisors in each group.

Table 4.7: Mean pre-treatment incisor length by groups

Group	Mean pre-treatment incisor length in mm	SD
Group 1	24.145	1.892
Group 2	24.841	2.501
Group 3	25.332	2.321

The sample from group 1 (Tip Edge) recorded the smallest mean pre-treatment length of the central incisor followed by group 2 (Modified Edgewise) and group 3 (Damon).

In Table 4.7 the arithmetic mean and the standard deviation of the post treatment length of the central incisors have been presented

Table 4.8: Mean post-treatment incisor length by groups

Group	Mean post-treatment incisor length in mm	SD
Group 1	22.830	1.864
Group 2	23.234	2.355
Group 3	23.052	2.511

The mean root resorption (ie. reduction in incisor root length) for each group has been illustrated in Table 4. 8. It can be seen that the mean root resorption in group 3 is greater than the other two groups (mean t1-t2=2.282).

Table 4.9: Mean root resorption (t1-t2) seen in each group

Group	t1-t2	SD	Range
Group 1	1.315	1.071	5.22
Group 2	1.607	0.954	3.65
Group 3	2.282	1.828	6.44

4.4 Comparative statistics between groups

When comparing groups with respect to mean root resorption a significant difference was found ($p = 0.051$; group 1 = 1.32 vs. group 2 = 1.61 vs. group 3 = 2.28), in particular the amount of root resorption seen for group 3 is significantly higher than that for group 1. The linear prediction of the groups shows that there is an upward trend ($p=0.052$) in the percentage of root resorption recorded from group 1 (Tip Edge) to group 3 (Damon) as seen from the graph below.

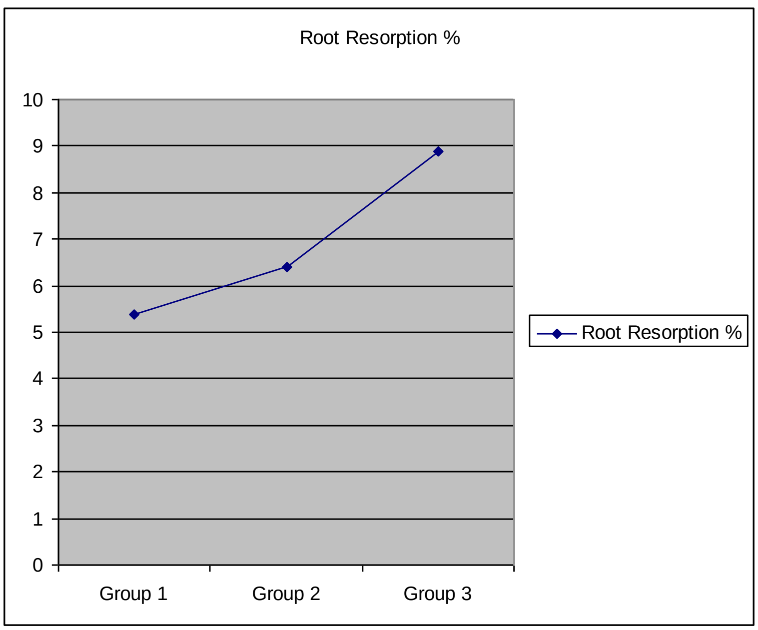

Figure 4.1 Linear prediction of the mean percentage of root resorption

However various confounders may be present, e.g. Baseline (pre-treatment incisor) length, duration of treatment, age of patient, gender and race.

4.5 Results of ANOVA: method one

Statistical modeling showed only baseline length (pre- treatment incisor length) to be a significant confounder. It was confirmed that age, gender, race and treatment time did not affect the quantum of root resorption seen after orthodontic treatment. In the final analysis, having adjusted for baseline length, groups were found not to differ significantly in their experience of root resorption (p=0.133; ANCOVA).

This result was also confirmed by following a nonparametric approach by doing an analysis of covariance (ANCOVA) for rank, i.e. data was substituted with ranks, where p=0.268 for group with p=0.006 for confounder, pre treatment incisor length.

Similarly, the percentage of root resorption observed after treatment did not differ significantly between groups (p=0.067).

4.6 Results for method two

Root resorption for the whole sample was also analyzed using the five grade ordinal scale of Levander and Malmgren(1988). The grades seen in each group after visually assessing and grading the radiographs using the ordinal data has been given in tabular form in appendix B (page 46). It was found that the majority of the subjects (57/68) in this sample experienced Grade 1 and Grade 2 resorption (See Table 4.10).

Table 4.10 Incidence and severity of resorption as assessed in method two

Grade	Number of patients	Mean t1-t2	SD (t1-t2)
0	5	1.286	1.050
1	34	1.402	0.959
2	23	1.847	1.482
3	6	2.988	2.093

4.7 Comparative statistics (method one vs. method two)

This was done to test whether there was any agreement between visual grading and assessment of root resorption using actual measurements. The grades differed significantly with respect to the amount of mean resorption (p=0.041). The ordinal data grades and the objective grades (actual millimeter loss of tooth length) followed the same direction, i.e., as the grade increased the amount of tooth material loss recorded also increased.

The statistics demonstrate a clear consensus between the increasing damage observed visually and the reduced tooth lengths as measured on the cephalograms (p=0.018).

CHAPTER 5: DISCUSSION

The primary purpose of this retrospective study is to assess the occurrence of apical root resorption experienced in association with orthodontic treatment undertaken with Tip Edge, Damon and Modified Edgewise techniques. Secondly, amongst the many factors possibly implicated in apical root resorption to specifically evaluate contributing factors such as:

- Age
- Gender
- Ethnicity
- Duration of treatment time.

The null hypothesis was that there would be no difference in the extent of apical root resorption seen after orthodontic treatment for class II correction undertaken with Tip Edge, Damon or Modified Edgewise techniques.

In this study of root resorption in a sample of cases treated by three different modalities of orthodontic technique, it was found that resorption was a common, although not an overwhelming complication. Quantification of the extent of resorption is more challenging than may first be considered. Although various other records (clinical, histologic, biologic markers) are available to assess the pre- and post-treatment status of the tooth roots, radiographs remain the most popular tool. Radiology also offers a wide variety of formats - periapical films, panoramic films, lateral cephalograms, digital radiographs and computerised tomography. But there are limitations. In the first place resorption occurs not only at the very apex but may also attack the surface of the root at any point in its circumference. Secondly radiological assessment for comparative purposes must also be accurately repeatable.

Sameshima and Asgarifar (2001) compared the efficacy of periapical and panoramic films in the assessment of apical root resorption. They recommended the use of periapical films. However, these views may suffer projection errors and are not readily reproducible. This can be overcome by using the long-cone periapical paralleling technique (Brezniak and Wasserstein, 1993b), which reduces distortion and superimposition errors when compared with panoramic radiographs and lateral cephalograms. Long- cone periapical radiographs are not routinely amongst the standard records for orthodontic patients in private practices in South Africa and hence the method has not been available for this retrospective study. According to Pandis et al (2008) root resorption can be underestimated due to the inherent inability of panoramic radiographs to show loss of tooth structure in a facial direction. Computerised tomography on the other extreme is highly sensitive to site specific evaluation of root resorption (mesial, distal, buccal or lingual). The main drawbacks of this excellent diagnostic technology are its high cost and the need for special equipment (Krishnan, 2005). The sensitivity of digital radiographs, according to Levander, Bajka and Malmgren (1998), was comparable to or better than conventional film- based radiographs. In addition the radiation exposure is much less than that delivered by conventional x-rays.

In this retrospective study digital lateral cephalograms were used as they are an integral part of standard diagnostic records in private practices in South Africa. These films also provide a convenient image of the specific tooth (central incisor) selected for assessment of root resorption. Several authors have also used lateral cephalograms for assessment of resorption due to the high degree of reproducibility the technique offers (Costopoulos and Nanda, 1996; Harris, Kineret and Tolley, 1997; Horiuchi, Hotokezaka and Kobayashi, 1998).

.

Different teeth have different tendencies to root resorption. It is claimed that if there is no evidence of apical root resorption in maxillary and mandibular incisors then significant apical resorption in other teeth is less likely to occur (Copeland and Green, 1986; Sjolien and Zachrisson, 1973). In the maxillary dentition, the incisors are the teeth most affected by root resorption (Brezniak and Wasserstein, 1993a). Upper central incisors showed more root resorption than the upper lateral incisors (Janson *et al*, 1999). In general the extent of movement experienced by these teeth is usually greater due to the demands of esthetics, nature of malocclusion and function. In addition Oppenheim (1942) suggested that the morphology of roots of the incisors served as a catalyst in tooth resorption. The conical shapes of these roots contribute to a rapid diminution in the cross-sectional area towards the apex. Hence axial components of force exert relatively more force per unit area probably leading to a higher degree of resorption at the root apex.

Two methods have been generally used to quantify resorption namely: visually assessed grades of resorption (ordinal scale data) and measurements with calipers or some computer based software program. In this study both methods have been used to quantify resorption. In the visually assessed method, the scoring criteria of Levander and Malmgren (1988) have provided the grades (method two). Previously this ordinal scale of Levander and Malmgren (1988) has been used almost exclusively to assess root resorption evident on inspection of periapicals and orthopantomograms. In the current study it was used to assess root resorption as demonstrated on lateral cephalograms, in accord with the protocol followed by Harris and

Butler (1992). Lateral cephalograms reveal resorption on the apical, facial and lingual surfaces of the incisor root as opposed to periapicals and orthopantomograms which reveal only the apical, mesial and distal surfaces. Maxillary incisor teeth generally experience more resorption on the lingual surface, especially during torquing. In the post-treatment cephalograms some of the incisor root apices exhibited a rounded or flat outline while others appeared to show root resorption extending from the apex downwards along the lingual root surface creating a definite angular discrepancy towards the labial root surface (Ten Hoeve and Mulie, 1976). This effect tends to be masked in the anterio-posterior view shown in panoramic radiographs. Hence it is believed that visual assessment of the images of the incisors on cephalograms will offer a more accurate grading of root resorption levels as opposed to panoramic films. Direct measurement of the teeth on the radiographs offers an attractive alternate approach. Statistical evaluation tested the extent of agreement in this study between visual measurements and actual measurements and demonstrated a significant association ($p=0.018$) between the methods.

The literature review suggests that in the quantitative assessment of root resorption, either the tooth length (incisal edge to root apex) or root length (cemento-enamel junction to root apex) should be measured on pre-treatment and post-treatment radiographs and the differences compared to evaluate any root resorption which has occurred. In this study, the tooth length was measured as the distance from the incisal edge to the apex of the root (Black, 1902). The most apical limit of the root was taken as the absolute apex of the tooth especially in cases that exhibited an angular or jagged apical outline. This took into account any viable living root material and the periodontal support system encompassing it that was present at the apical limit. Since the right and left incisor teeth are usually moved in tandem it was assumed that the differences arising from a right or left side overlap of central incisor teeth for pre- and post-treatment cephalograms would be minimal. The image of the most procumbent central incisor was measured on the pre-treatment and post-treatment radiographs. The images were magnified by a zoom factor of 100% to facilitate the evaluation of the apex. Any pre-treatment x-ray that showed incomplete root formation or an indistinct apex had been discarded from the study at the outset. The measurements were performed to the nearest 0.01mm, using a software package produced by Olympus Soft Imaging Solutions GmbH.

Statistically significant differences between the means were found when the data from the three groups (Tip Edge, Modified Edgewise, Damon) were compared at a p value of 0.051. The differences were especially significant between group 1 (Tip Edge) and group 3 (Damon).

The mean percentage root resorption between groups was also calculated. The lowest extent was in group 1 (Tip Edge) followed by group 2 (Modified Edgewise) and group 3 (Damon), which differed significantly ($p=0.006$) from group 1 (Tip Edge). However various confounders were present, e.g. baseline (pre-treatment) incisor length, duration of treatment, age of patient, gender and race.

In agreement with Mirabella and Artun (1995) and Sameshima and Sinclair, (2001a) a positive association was found between initial tooth length and the amount of root resorption observed. Their studies report that longer roots are more prone to resorption than shorter roots. A simple explanation might be that longer roots require greater displacement than shorter roots to produce an equal amount of torque expression.

Parker and Harris (1998) confirmed a definite sexual dimorphism for the length of the maxillary central incisor. On an average the central incisor was found to be longer by one millimetre in male subjects. Group 3 (Damon) recorded the longest pre-treatment incisor length in this study although the data was not statistically significant. This might be due to the fact that the percentage of males in the group 3 (68.42%) was significantly higher ($p=0.025$; Fischer's Exact Test) than in either group 1 (42.31%) or group 2 (26.09%). However, when the data was adjusted for pre-treatment incisor length there was no significant difference ($p=0.516$) between genders with respect to the amount of root resorption. These findings are in agreement with other workers who found no significant differences in root resorption between male and female patients (McFadden, Engstrom, Engstrom, Anholm (1989); Mirabella and Artun (1995); Sameshima and Sinclair (2001a).

The four subjects with the greatest amount of root resorption (>3.5mm) in group 3 were of Caucasian origin. The relationship between ethnicity and root resorption after orthodontic treatment was evaluated by Sameshima and Sinclair (2001a). They found that Asian patients had significantly less resorption than did White or Hispanic patients. This might explain the upward linear trend of the incidence of root resorption seen from group 1 (Tip Edge) with a dominant Indian population (96.15%) to group 2 (Modified Edgewise) with 73.91% of White patients to group 3 (Damon) with 89.94% of White patients. This may have accounted for the low mean resorption percentage (5.394%) seen in group 1 when compared with group 3 (8.893%). However race was not shown to be a significant confounder to the mean resorption seen after orthodontic treatment in this study although it must be acknowledged that sample sizes may be too small to draw firm conclusions.

The length of treatment time and root resorption has been shown in many studies to have a positive correlation (McFadden *et al*, 1989; Brezniak and Wasserstein, 1993b; Sameshima and Sinclair, 2001b). In particular there is a significant association between longer treatment duration and increased root resorption of maxillary incisors (Sameshima and Sinclair, 2001b). Other studies report that treatment duration does not affect the amount of root resorption seen after orthodontic treatment (Beck and Harris, 1994; Mirabella and Artun, 1995). Although treatment duration is shorter (17.54 months) in group 1 (Tip Edge) when compared with 25.04 months in group 2 (Modified Edgewise) and 25.79 months in group 3 (Damon), statistically significant correlation was not found between treatment time and the extent of root resorption in the current study. The overall correlation between these factors was 0.136 (p=0.270).The correlation coefficient for these two factors in group 1(Tip Edge) was 0.223 (p=0.274), in group 2 (Modified Edgewise) was 0.002 (p=0.993) and in group 3 (Damon) was 0.061 (p=0.803) respectively. Likewise, Dermaut and De Munck (1986) and Levander and Malmgren (1988) found weak and non-significant correlations between treatment time and root resorption.

The risk of resorption seems to be independent of age once root formation is complete. However, adults are speculated to be at a higher risk for root resorption as the rate of alveolar turnover is slower in adults than in children and young adolescents. Tooth movement is also slower in adults (Harris, 2000). Yet, the age of the patient and the incidence of root resorption were reported to be poorly correlated in a study conducted by Beck and Harris (1994). No significant association was found between the patient age and the amount of root resorption observed in the three groups in the present study. This might be due to the fact that root formation was complete for all the patients at the outset of treatment in this sample.

The effect of age is quite different when dealing with children in the mixed dentition. Children treated before their roots are completely formed exhibited less active root resorption, than did their older counterparts. It has been suggested that in fact orthodontic treatment actually slowed and reduced the root growth leaving the roots with relatively shorter final root lengths (Linge and Linge, 1983; Ogaard, 1988).

Therefore, it may be safely concluded that the results of the present study demonstrate that gender, race, treatment time and age do not have a discernible influence on the amount of root resorption seen after orthodontic treatment in the samples investigated. Following a statistical modeling only baseline length (pre-treatment incisor length) was a significant confounder. Once having adjusted for baseline length, and using an analysis of covariance, groups were found to not differ significantly ($p=0.133$), a result confirmed when a nonparametric approach was followed. It was also seen that the groups do not differ significantly ($p=0.067$) with regard to the percentage of root resorption seen after orthodontic treatment.

However, irrespective of the technique employed, every case that had undergone orthodontic treatment in this study exhibited some root resorption. In group 1 actual tooth material loss ranged from 0.01 to 5.23mm. In group 2 it ranged from 0.21mm to 3.86mm and in group 3 from 0.57 mm to 6.58mm. In all three groups some cases exhibited a higher degree of resorption, possibly attributable to individual susceptibility and/or genetic influence. A study conducted by Al-Qawasmi, Hartsfield, Everett, Flury, Liu, Foroud, Macri and Roberts (2003) found that orthodontic patients homozygous for the IL-IB allele-1 polymorphism have a 5.6-fold increase in external apical root resorption over non IL-IB homozygous patients. They concluded that this gene could account for up to 15% of maxillary incisor root resorption. This possibility was not explored in the current study.

What is the long term prognosis of cases where root resorption has been identified? This question is often posed to orthodontists by general dentists and other dental specialists when post-orthodontic patients approach them for restorative rehabilitation. It is accepted that any root resorption ceases after orthodontic treatment has been stopped. Over a period of time the root surface becomes smoother due to the deposition of reparative cellular cementum. The root length does not shorten any further (Krishnan, 2005). Parker (1997) conducted a long term follow up on a case that had exhibited root resorption. He found that even after twenty five years the severely resorbed maxillary incisors were still present and functioning well. Kokich (2008) believes that the need for a permanent lingual splint for teeth with moderate to severe resorption is dictated by the presence of para- functional habits, crown mobility and need for any restorations. In cases that demonstrated moderate to severe root resorption orthodontic re-treatment did not produce any further resorption. Kokich (2008) suggests that the presence of reparative cellular cementum may have played a protective role in inhibiting further root resorption during retreatment.

There was an upward trend (p=0.052) in the expression of root resorption from group 1 (Tip Edge) to group 3 (Damon). A similar trend indicating more external apical root resorption (EARR) for Damon 2 systems when compared with conventional Edgewise systems was reported by Pandis *et al* in 2008. Since the data did not reach significance (p=0.06) it was concluded that no difference should be expected for root resorption between cases treated by conventional Edgewise and Damon appliances.

Light forces are the key to the Damon system. It advocates the use of low forces generated by small dimension “high tech” arch wires to bring about tooth movement. In contrast, the use of light and constant forces has been linked with higher degrees of root resorption. Weiland (2003) explained that the mode of persistent activation of nickel titanium wires originating from their increased work range relative to stainless steel wires might be responsible for the significantly larger resorption seen when these wires are used in treatment of malocclusions. Stainless steel wires generate a rapidly declining force during de-activation whereas super elastic wires deliver a constant force over an extended portion of the deactivation range (Miura, Mogi, Ohura and Hamanaka, 1986). The type and level of force can also influence the development of root resorption in orthodontic patients. Reitan (1985) advocated the use of intermittent forces to prevent the development of root resorption. The pause in treatment with intermittent forces where little or no force is applied allows the resorbed cementum some time to heal. Discontinuous force application seems to be a more favorable mode of force delivery in achieving tooth movement as it causes less vertical root resorption (Kocaaga, Canyurek, Acar and Erverdi, 1997). In this context, it could be postulated that the temporal characteristics of force application to teeth are more important than force magnitude per se in modulating root resorption.

Damon (1998) believes that tooth movement is more efficient when the teeth are allowed to move individually and that passive self-ligating brackets offer more freedom for each tooth to move to their individual natural positions even though they are still interconnected. The arch wire is never actively tied in to the bracket slot. The final position of the teeth in the arch is determined by interplay between the oral musculature and the periodontal forces and not by heavy orthodontic forces. Does this make the teeth more susceptible to resorption by jiggling forces from normal masticatory functions and speech as they are not firmly held in place by heavy stabilizing stainless steel wires? Does this in turn prevent the natural repair process inherent in every biological organ? This speculation is, however, almost contradictory to the effect super elastic wires have on tissues. Proffit and Fields (2000) also advocate caution when using the new light force rectangular wires in the initial phase of treatment. Faltin *et al* (2001) advocated a reduction in continuous force magnitude to preserve the integrity of the tooth and surrounding tissues.

Further investigations are required to expound the differences in root resorption observed with different techniques that use different force systems and materials. The current study revealed no significant difference in the root resorption seen after orthodontic treatment utilizing the Tip Edge, Modified Edgewise and the Damon technique. It could not, however, statistically pinpoint the causative factor for the upward trend in root resorption that was seen from group 1(Tip Edge) to group 3 (Damon). It might be speculated that the longer treatment time, racial character of the patients and gender distribution may have resulted in group 3 (Damon) having the highest degree of root resorption recorded.

Individual susceptibility or a heritable component to root resorption might be the final piece that throws some light into the root resorption puzzle. More research is needed in this regard. Detailed investigations that explore the connection between root resorption and treatment techniques by studying the effect of variables like arch wire sequence, time spent in super elastic wires, method of force application (continuous or intermittent), type of elastics used (intra vs inter), type of bracket and ligation employed in each technique will help us to understand which technique is kinder to the tissues involved.

5.1 Limitations and difficulties encountered in this study

There were several limitations to this study.

1. The retrospective nature of the study.
2. Lack of availability of peri-apical radiographs limited the control of variables exposed using the long cone paralleling technique.
3. This investigation was limited to the assessment of apical resorption on the maxillary incisors only. Although these teeth do in general show a higher degree of root resorption, inferences on the overall severity of root resorption with different appliance systems would require examination of the entire dentition.
4. It was assumed that differences arising from an overlap of right and left sides in measurement of the central incisor teeth would be negligible.
5. Sometimes it was difficult to locate the apex accurately on the radiograph due to superimposition of the images of the alveolar structures or the adjacent teeth. The measurements were repeated three times and the average calculated in an attempt to reduce any inconsistencies.
6. It was assumed that the incisal edge of the incisor in each case was not subject to the effects of attrition or incisal wear and that the change in tooth length between pre and post treatment cephalograms was entirely due to the effects of root resorption.

7. In grading the teeth using the ordinal scale of Levander and Malmgren (1988) it was sometimes difficult to assess the amount of resorption due to the change in inclination of the incisors in the post -treatment radiographs as well as due to the change in an anterior-posterior direction. However, it was seen that the two methods of quantifying resorption used in this study were comparable.

CHAPTER 6: CONCLUSIONS

The current study explored the variations in root resorption seen after orthodontic treatment with Tip Edge, Modified Edgewise and Damon systems.

1. All cases exhibited some amount of resorption after orthodontic treatment illustrating the fact that root resorption is a common phenomenon in this discipline.
2. The majority of patients (84%) in the overall sample exhibited Grade 1 or Grade 2 resorption and only a few patients were affected severely.
3. Tabulation of the results demonstrated considerable individual variation in the amount of root resorption observed in all three groups. Individual variation in the biologic response to orthodontic forces and/ or a genetic component may be the predisposing factor responsible for the results seen.
4. There was a significant upward linear trend ($p=0.022$) from group 1 (Tip Edge) to group 3 (Damon) in the raw data.
5. Statistical analysis revealed that age, gender and race of the patients involved in this study and the duration of treatment did not influence the degree of root resorption observed after treatment.
6. Pre- treatment incisor length was the only significant confounding variable in this sample.
7. Once the baseline pre-treatment incisor length was adjusted this study could not find any significant difference in the degree of root resorption observed after treatment utilizing the three different techniques.

APPENDICES APPENDIX/A

Appendix A1, A2, A3-Listing of individual results in each group

Table A1.1

Group 1 (Tip Edge Group)

Patient ID	Age in years	Gender	Race	Treatment Duration in months	Pre-treatment length(T1)	Post-treatment length(T2)	EARR (T1-T2)	Percentage root resorption
1	21.67	1	1	22	25.79	24.33	1.46	5.68%
2	14.33	1	1	15	22.25	20.79	1.46	6.57%
3	13.67	1	1	13	22.96	22.95	0.01	0.03%
4	17.33	2	1	18	22.58	21.24	1.34	5.93%
5	13.00	2	1	32	21.18	20.70	0.48	2.28%
6	16.17	2	1	12	23.34	22.85	0.49	2.11%
7	16.00	1	1	18	25.80	24.88	0.92	3.55%
8	14.00	2	1	16	23.40	23.03	0.37	1.57%
9	13.42	2	1	13	24.81	23.79	1.02	4.11%
10	15.58	2	4	17	24.68	24.16	0.52	2.11%
11	14.50	2	1	31	24.23	23.27	0.96	3.98%
12	13.75	2	1	21	23.01	22.38	0.63	2.72%
13	16.00	1	1	19	24.07	23.03	1.04	4.34%
14	12.00	1	1	31	20.50	17.32	3.17	15.48%
15	14.42	2	1	16	22.57	22.11	0.46	2.04%
16	13.58	2	1	17	27.24	24.98	2.26	8.31%
17	16.00	2	1	9	26.91	25.73	1.18	4.39%
18	17.00	1	1	11	24.44	24.11	0.34	1.38%
19	12.92	2	1	15	26.43	24.84	1.59	6.02%
20	12.50	1	1	18	24.64	23.42	1.22	4.97%
21	29.00	1	1	18	22.52	20.31	2.21	9.81%
22	12.67	1	1	13	25.99	23.89	2.10	8.09%
23	15.17	2	1	12	24.04	23.13	0.91	3.77%
24	19.67	2	1	11	21.45	20.20	1.25	5.81%
25	15.42	2	1	20	27.45	22.22	5.23	19.06%
26	16.75	1	1	18	25.50	23.93	1.57	6.14%

Table A1.2

Group 2 (Modified Edgewise Group)

Patient ID	Age in years	Gender	Race	Treatment Duration in months	Pre-treatment length(T1)	Post-treatment length(T2)	EARR (T1-T2)	Percentage root resorption
1	30.33	1	2	38	31.18	30.89	0.29	0.92%
2	10.83	2	3	22	25.08	24.45	0.64	2.54%
3	9.00	1	3	17	24.53	23.70	0.82	3.35%
4	11.67	1	3	14	22.01	21.09	0.92	4.19%
5	18.83	2	3	24	22.73	21.23	1.50	6.60%
6	12.50	1	3	24	26.32	23.19	3.12	11.87%
7	14.25	2	2	26	25.09	22.88	2.21	8.81%
8	10.92	1	3	13	25.98	24.10	1.88	7.25%
9	15.58	2	1	18	29.43	25.57	3.86	13.11%
10	14.92	2	3	17	26.47	25.09	1.38	5.22%
11	11.33	2	3	19	24.72	23.00	1.73	6.99%
12	11.58	2	3	19	23.93	22.30	1.63	6.79%
13	11.67	2	3	15	21.93	21.55	0.39	1.76%
14	13.58	2	3	23	24.51	24.30	0.21	0.85%
15	11.00	2	3	32	20.72	19.75	0.97	4.70%
16	13.17	2	3	35	25.97	24.51	1.46	5.60%
17	14.17	2	2	21	25.35	22.08	3.27	12.89%
18	13.92	2	3	25	21.60	19.92	1.68	7.79%
19	15.00	2	3	26	23.10	21.78	1.32	5.71%
20	12.00	2	1	32	23.75	21.87	1.88	7.91%
21	31.00	2	3	37	25.07	23.81	1.25	5.01%
22	12.00	1	3	40	28.43	25.62	2.81	9.88%
23	12.00	2	2	39	23.45	21.71	1.74	7.42%

Table A1.3

Group 3 (Damon Group)

Patient ID	Age in years	Gender	Race	Treatment Duration in months	Pre-treatment length(T1)	Post-treatment length(T2)	EARR (T1-T2)	Percentage root resorption
1	15.67	1	1	16	23.71	22.70	1.01	4.27%
2	11.42	2	3	25	27.09	24.48	2.61	9.62%
3	12.33	1	1	28	27.79	24.78	3.02	10.86%
4	24.67	2	3	17	23.38	18.57	4.81	20.58%
5	12.08	2	3	19	24.38	22.60	1.78	7.29%
6	13.58	1	3	39	25.61	24.37	1.25	4.87%
7	13.92	1	3	39	30.55	28.36	2.20	7.19%
8	13.67	1	3	27	20.92	20.21	0.71	3.40%
9	12.67	1	3	27	24.05	23.17	0.88	3.68%
10	10.67	2	3	24	27.80	27.10	0.70	2.52%
11	13.00	1	3	29	22.96	20.43	2.53	11.02%
12	15.92	1	3	27	24.68	21.12	3.57	14.45%
13	12.75	2	3	18	26.77	24.20	2.57	9.60%
14	11.92	1	3	24	23.42	23.29	0.14	0.58%
15	17.50	2	3	20	24.61	24.04	0.57	2.33%
16	13.00	1	3	16	28.05	21.47	6.58	23.45%
17	13.67	1	3	40	26.76	25.36	1.40	5.24%
18	11.50	1	3	36	25.50	19.58	5.92	23.23%
19	13.50	1	3	19	23.28	22.16	1.10	4.79%

Code for Groups	
1	Tip Edge Group
2	Modified Edgewise Group
3	Damon Group

Code for Gender	
1	Male
2	Female

Code for Races	
1	Indian
2	Black
3	White
4	Colored

The results of the second method of analyzing root resorption using the five grade ordinal scale of Levander and Malmgren (1988) is given below.

Table B 1

Group 1 Tip Edge		Group 2 Modified Edge wise		Group 3 Damon	
No	RR Grade	No	RR Grade	No	RR Grade
1	2	1	0	1	2
2	3	2	1	2	2
3	1	3	1	3	1
4	2	4	3	4	3
5	0	5	2	5	1
6	1	6	2	6	1
7	1	7	1	7	1
8	1	8	0	8	2
9	1	9	2	9	1
10	1	10	1	10	1
11	2	11	2	11	1
12	1	12	1	12	3
13	2	13	1	13	2
14	2	14	1	14	2
15	2	15	0	15	1
16	1	16	1	16	2
17	1	17	2	17	2
18	1	18	1	18	2
19	1	19	2	19	3
20	1	20	1		
21	2	21	2		
22	2	22	0		
23	2	23	1		
24	3				
25	2				
26	2				

REFERENCES

Al-Qawasmi, R.A., Hartsfield, J.K. Jr., Everett, E.T., Flury, L., Liu, L., Foroud, T.M., Macri, J.V., Roberts, W. E. (2003). Genetic predisposition to external apical root resorption. American Journal of Orthodontics and Dentofacial Orthopedics, 123: 242-52.

Andreason, J.O. (1988). Review of root resorption systems and models. Etiology of root resorption and homeostatic mechanisms of the periodontal ligament. Proceedings of the International Conference held at Columbus, Ohio. In: Biological Mechanisms of Tooth Eruption and Root Resorption. Davidovitch Z, ed. Ohio University. p. 9-22.

Beck, B.W., Harris, E.F. (1994). Apical root resorption in orthodontically treated subjects: analysis of edgewise and light wire mechanics. American Journal of Orthodontics and Dentofacial Orthopedics, 105: 350-61.

Black, G.V. (1902). Descriptive anatomy of the human teeth. 4th ed. Philadelphia: SS White Dental Manufacturing Co. p.14.

Blake, M., Woodside, D.G., Pharaoh, M.J. (1995). A radiographic comparison of apical root resorption after orthodontic treatment with the Edgewise and Speed appliances. American Journal of Orthodontics and Dentofacial Orthopedics, 108: 76-4.

Brezniak, N., Wasserstein, A. (1993a.). Root resorption after orthodontic treatment: Part 1. Literature review. American Journal of Orthodontics and Dentofacial Orthopedics, 103: 62-6.

Brezniak, N., Wasserstein, A. (1993 b). Root resorption after orthodontic treatment: Part 2. Literature review. American Journal of Orthodontics and Dentofacial Orthopedics, 103: 138-46.

Brezniak, N., Wasserstein, A. (2002a). Orthodontically Induced Inflammatory Root Resorption. Part I: The basic science aspects. Angle Orthodontist, 72: 175-9.

Brezniak, N., Wasserstein, A. (2002b). Orthodontically Induced Inflammatory Root Resorption. Part II: The clinical aspects. Angle Orthodontist, 72: 180-4.

Brudvik, P., Rygh, P. (1994). Multi-nucleated cells remove the main hyalinized tissue and start resorption of adjacent root surfaces. European Journal of Orthodontics, 16: 265-73.

Copeland, S., Green, L. J. (1986). Root resorption in maxillary central incisors following active orthodontic treatment. American Journal of Orthodontics, 89: 51-5.

Costopoulos, G., Nanda, R. (1996). An evaluation of root resorption incident to orthodontic intrusion. American Journal of Orthodontics and Dentofacial Orthopedics, 109: 543-8.

Crockatt, W.C., Holdaway, R. (1971). Modified Edgewise Technique Manual. Chertkow, S., Fine, M., Errol, S., eds. Department of Orthodontics, University of Witwatersrand, Johannesburg, S.Africa.

Damon, D. H. (1998). The Damon low-friction bracket: a biologically compatible straight -wire system. Journal of Clinical Orthodontics, 32: 670-80.

Damon, D.H. (2004). Damon system, The Workbook. Sybron Dental Specialities,Ormco. Orange,CA.p. 5-7

Dermaut, L.R., De Munck. (1986). Apical root resorption of upper incisors caused by intrusive tooth movement: A radiographic study. American Journal of Orthodontics and Dentofacial Orthopedics, 90: 321-26.

Faltin, R.M., Faltin, K., Sander, F.G., Arana-Chavez, V. E. (2001). Ultrastructure of cementum and periodontal ligament after continuous intrusion in humans: a transmission electron microscopy study. European Journal of Orthodontics, 23: 35-49.

Garner, L.D. (1974). Soft tissue changes concurrent with orthodontic tooth movement. American Journal of Orthodontics, 66: 367-76.

Goldson, L., Hendrikson, C.O. (1975). Root resorption during Begg treatment: A longitudinal roentgenologic study. American Journal of Orthodontics, 68: 55-6.

Harris, E.F., (2000). Root resorption during orthodontic therapy. Seminars in Orthodontics, 6: 183-194.

Harris, E.F., Butler, M. L. (1992). Patterns of incisor root resorption before and after orthodontic correction in cases with anterior open bites. American Journal of Orthodontics and Dentofacial Orthopedics, 101: 112-9.

Harris, E. F., Kineret, S. E., Tolley, E. A. (1997). A heritable component for external apical root resorption in patients treated orthodontically. American Journal of Orthodontics and Dentofacial Orthopedics, 111: 301-9.

Horiuchi, A., Hotokezaka, H., Kobayashi, K. (1998). Correlation between cortical plate proximity and apical root resorption. American Journal of Orthodontics and Dentofacial Orthopedics, 114: 311-8.

Janson, R.P.G., Canto, G.L., Martin, S.D.R., Henriques, J.F.C., De Freitas, R. M. (1999) . A radiographic comparison of apical root resorption after orthodontic treatment with three different fixed appliance techniques. American Journal of Orthodontics and Dentofacial Orthopedics, 118: 262-73.

Kesling, P.C. (1994) .Tip-Edge Guide and the differential straight-arch technique. 2nd ed, TP Orthodontics,Inc. La Porte. Indiana. p. I1- 10.

Ketcham, A.H. (1927). A preliminary report of an investigation of apical root resorption of permanent teeth. International Journal of Orthodontia, Oral Surgery and Radiography, 13: 97-127.

Ketcham, A.H. (1929). A progress report of an investigation of apical root resorption of vital permanent teeth. International Journal of Orthodontia, Oral Surgery and Radiography, 15: 310-328.

Kocaaga, M., Canyurek, U., Acar, A., Erverdi, N. (1997). Comparison of continuous and discontinuous force application from the point of root resorption. Abstract. European Journal of Orthodontics, 19: 579.

Kokich, V.G. (2008). Orthodontic and non- orthodontic root resorption: Their impact on clinical dental practice. Journal of Dental Education, 72: 895-902.

Krishnan, V. (2005). Critical issues concerning root resorption: A contemporary review. World Journal of Orthodontics, 6: 30-40.

Levander, E., Bajka, R., Malmgren, O. (1998). Early radiographic diagnosis of apical root resorption during orthodontic treatment-A study on maxillary incisors. European Journal of Orthodontics, 20: 57-63.

Levander, E., Malmgren, O. (1988). Evaluation of the risk of root resorption during orthodontic treatment: A study of upper incisors. European Journal of Orthodontics, 10: 30-8.

Linge, B.O., Linge, L. (1983). Apical root resorption in upper anterior teeth. European Journal of Orthodontics, 5: 173-83.

Linge, L., Linge, B.O. (1991). Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. American Journal of Orthodontics and Dentofacial Orthopedics, 99: 35-43.

Looi, K.L., Mills, J.R.E. (1986). The effect of two contrasting forms of orthodontic treatment on the facial profile. American Journal of Orthodontics, 89: 507-17.

Malmgren, O., Levander, E. (2004). Minimizing orthodontically- induced root resorption. In Graber, T., Eliades, T., Athanasiou, A.E., eds,. Risk Management in Orthodontics: Experts Guide to Malpractice. Chicago: Quintessence, p.61-75.

Mavragani, M., Vergari, A., Selliseth, J.N., Boe, E.O., Wisth, J.P. (2000). A radiographic comparison of apical root resorption after orthodontic treatment with a standard edgewise and a straight – wire edgewise technique. European Journal of Orthodontics, 22: 665-74.

McFadden, W.M., Engstrom, C., Engstrom, H., Anholm, M. J . (1989). A study of the relationship between incisor intrusion and root shortening. American Journal of Orthodontics and Dentofacial Orthopedics, 96: 390-6.

Mirabella, A.D., Artun, J. (1995). Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. American Journal of Orthodontics and Dentofacial Orthopedics, 108: 48-55.

Miura, F., Mogi, M., Ohura, Y., Hamanaka, H. (1986). The super-elastic property of the Japanese NiTi alloy for use in orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics, 90: 1-10.

Ogaard, B. (1988). Marginal bone support and tooth lengths in 19 year-olds following orthodontic treatment. European Journal of Orthodontics 10: 180-6.

Oppenheim, A. (1942). Human tissue response to orthodontic intervention of short and long duration. American Journal of Orthodontics and Oral Surgery, 28: 13-5.

Ottolengui, R. (1914). The physiological and pathological resorption of tooth roots. Dental Items of Interest, 36: 332-62.

Pandis, N., Nasika, M., Polychronopoulou, A., Eliades, T. (2008). External apical root resorption in patients treated with conventional and self-ligating brackets. American Journal of Orthodontics and Dentofacial Orthopedics, 134: 646-51.

Parker, R.J., Harris, E.F. (1998). Directions of orthodontic tooth movements associated with external apical root resorption of the maxillary central incisor. American Journal of Orthodontics and Dentofacial Orthopedics, 114: 677-83.

Parker, W.S. (1997). Root resorption- long term outcome. American Journal of Orthodontics and Dentofacial Orthopedics, 2: 119-123.

Philips, J.R. (1955). Apical root resorption under orthodontic therapy. Angle Orthodontist, 25: 1-22.

Pizzo, G., Licata, M.E., Guiglia, R., Guilianna, G . (2007). Root resorption and orthodontic treatment. Review of literature. Minerva Stomatologica, 56: 31-44.

Proffit W.R., Fields H.W. (2000). The first stage of comprehensive treatment: alignment and leveling. In: Contemporary Orthodontics. 3rd ed. St Louis: C V Mosby; p.527-29.

Reitan, K. (1985). Biomechanical principles and reactions. In: Graber T. M.; Swain, B. F. (eds.) Orthodontics: Current Principles and Techniques. C V Mosby Co, St Louis, p.101-92.

Rudee, D.A. (1964). Proportional profile changes concurrent with orthodontic therapy. American Journal of Orthodontics, 50: 421-34.

Rudolph, C.E. (1940). An evaluation of root resorption during orthodontic treatment. Journal of Dental Research, 19: 367-71.

Rygh, P. (1977). Orthodontic root resorption studied by electron microscopy. Angle Orthodontist, 47: 1-15.

Sameshima, G.T., Asgarifar, K.O. (2001). Assessment of root resorption and root shape: Periapical vs. Panoramic films. Angle Orthodontist, 71:185-9.

Sameshima, G.T., Sinclair, P.M. (2001a). Predicting and preventing root resorption: Part I. Diagnostic factors. American Journal of Orthodontics and Dentofacial Orthopedics, 119:505-10.

Sameshima, G.T., Sinclair P.M. (2001b). Predicting and preventing root resorption: Part II. Treatment factors. American Journal of Orthodontics and Dentofacial Orthopedics, 119:511-5.

Sjolien, T., Zachrisson, B.U. (1973). Periodontal bone support and tooth length in orthodontically treated and untreated persons. American Journal of Orthodontics, 64: 28-37.

Ten Hoeve, A., Mulie, R.M. (1976). The effect of antero-postero incisor repositioning on the palatal cortex as studied with laminagraphy. Journal of Clinical Orthodontics, 10: 804-22.

Tronstad, L. (1988). Root resorption – a multidisciplinary problem in dentistry. In: Biological Mechanisms of Tooth Eruption and Root Resorption, Davidovitch Z. ed., 293-302.

Viazis, A. D. (1995). Bioefficient therapy. Journal of Clinical Orthodontics, 29: 552-68.

Weiland, F. (2003). Constant versus dissipating forces in orthodontics: the effect on initial tooth movement and root resorption. European Journal of Orthodontics, 25: 335-42.

ETHICS CLEARANCE CERTIFICATE.

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Dr Elizabeth Thomas

CLEARANCE CERTIFICATE	**M090827**
PROJECT	An Evaluation of External Apical Root Resorption after Orthodontic Treatment
INVESTIGATORS	Dr Elizabeth Thomas.
DEPARTMENT	School of Oral health Sciences
DATE CONSIDERED	09.08.28
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 30.08.09 **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Dr R Chamda

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...