THE EFFECT OF FORCE DECAY ON ROOT RESORPTION AND REPAIR

Hassan E Kassem[1], Mohamed I Mowafy[2], Amal R Elhaq[3], Walid A Elkenany[4]

ABSTRACT:

Objective: *To study the effect of force decay on the processes of resorption and repair of root surface.* ***Methods and Materials:*** *Twenty one prospective patients requiring the extraction of mandibular first premolars were recruited according to strict selection criteria. The participants were assigned to three groups according to the period of force application – a five-, seven- and nine-week group. The first premolar on one side was selected at random. An experimental orthodontic appliance was used to deliver 75 cN of buccal tipping intrusive force using NiTi coil spring. The force was not reactivated. At the end of the experiment, the first premolars were extracted. Seven randomly selected non-moved contralateral premolars served as control. The test and control premolars were examined using scanning electron microscope.* ***Results:*** *Significantly less surface resorption was registered in the five-week test group. The seven-week and nine-week test group showed no statistically significant difference in surface resorption. Apical resorption scores were strongly associated with the*

1- Demonstrator, Department of Orthodontics, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
2- Lecturer, Department of Orthodontics, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
3- Professor, Department of Oral Biology, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
4- Professor, Department of Orthodontics, Faculty of Dentistry, Alexandria University, Alexandria, Egypt

experimental periods. Only partial repair of resorption lacunae was evident in the seven- and nine-week group, involving both cellular and acellular cementum. Seven weeks appeared to be sufficient for the process of root resorption to cease, however a nine-week period did not seem long enough for reparative cementum to overlay the resorption lacunae. ***Conclusion:*** *Using a similar force system, an initial force less than 75 cN or an activation cycle longer than 9 weeks would allow for more repair of resorption lacunae.*

INTRODUCTION

Ottolengui, in 1914, perplexed the specialty when he related root resorption directly to orthodontic treatment.(1) In 1927, root resorption was a subject of major concern. Ketcham(2,3) demonstrated radiographic evidence of the change of root shape after orthodontic treatment. This was followed by a wide range of histological, clinical and physiological research on root resorption and orthodontic treatment.(4) The issue still attracts the interest of the investigators because of its alarming clinical and legal implications.(5)

Brezniak and Wasserstein conducted an extensive review(4,6), supplemented later by a second review,(7,8) reporting that multiple factors are involved, including mechanical factors related to orthodontic force type, magnitude, direction and duration. They stated that "while there is no safe tooth movement, intrusion is probably the most detrimental to the roots involved." Apparently, safe tooth movement does not exist.(9) Intrusion has been shown to be the vertical movement most predictive for apical resorption.(10,11,10,12) Light forces are advised because the force is generally concentrated in a small area at the apex.(9) In the course of orthodontic treatment, generally anterior teeth are intruded.(9) However, the advent of skeletal anchorage simplified intrusion of posterior segments and overerupted molars.(13)

Repair of root resorption is a documented biological process.(14) Brudvik and Rygh(15) conjectured if root resorption will cease and be followed by a process of repair provided the active force decayed below a certain level. “Such questions are not readily answered since the determinants that change an ongoing root resorption into a process of repair, are not well understood”[15] The diminution of the applied force before reactivation by the orthodontist might provide an intermission for the repair process to reconstitute a compromised barrier that protects the root surface against further resorption.[15]

Controversy exists to the cessation of the root resorption process.[16] Investigators have observed the repair process to start in the presence of light forces,[14] with treatment interruption,[17] as well as with appliance removal and relapse of tooth position.[9] It may prove possible to identify an optimum cycle of orthodontic force application to maximize the tissue repair potential.[16]

To avoid damage to the tooth supporting structure, the orthodontist would seek to minimize the incidence of resorption and to optimize the potential for repair. Since individual predisposition remains indeterminate, force systems, namely magnitude, duration and type of force, remain the only variables under the control of the clinician. Possibly a force activation cycle exists that would allow for the repair of the precedent resorption before reactivation of the initially applied force. This work uses a human experimental model to simulate one activation cycle where an orthodontic intrusive force is allowed to decay for variable time periods. The test hypothesis is that force decay will have no effect on the registered resorption or repair. Hence, a force-time determinant that might influence the transition of a process of active root resorption into a process of repair could be elicited.

MATERIALS AND METHODS

Subjects: The test material consisted of 21 mandibular first premolars from 21 prospective orthodontic patients (13 females and 4 males), aged 14 – 20 years (mean 15.9 years). The orthodontic treatment plan included the extraction of mandibular first premolars. In all the patients the maxillary first premolars were extracted except for one where the second premolars were extracted. The inclusion criteria were periodontally healthy and non-endodontically treated mandibular premolars with normally shaped and completely developed roots. The patients did not receive any previous orthodontic treatment and had no history of any medical condition that would predispose to root resorption. All selected patients/parents received written information about the purpose and the protocol of the study and signed an informed consent.

According to the period of application of force, the participants were randomly assigned using the table of random numbers to three study groups: a five-week, seven-week and nine-week group (Table I). A premolar on one side was selected at random for intrusion. Seven contralateral premolars served as control material.

Methods: The appliance used to deliver the force was a modification of that described by Acar et al.[18] In this experiment, an eyelet was bonded to the buccal surface of the test premolar at the center of the clinical crown, an edgewise bracket was bonded to the labial surface of the canine, and a band was cemented on the first molar on the test side. A 0.017 x 0.025 – inch stainless steel sectional arch was used. An omega stop was placed at the mesial end of the first molar tube. The sectional arch was stepped down for 6 mm at the first premolar. A V-bend was made in the step-down arm opposite to the button on the premolar to prevent sliding of the force module. A length of NiTi closed coil spring (G&H Wire Company, Franklin, Indiana, USA) was stretched from step-down arm and ligated to the eyelet with stainless steel ligature with no wire intervening between the coil and the eyelet. The length of the coil was adjusted to deliver 75 cN measured by a Correx gauge (Figure 1).

Table I. Demographic characteristics of the study groups

	Five-week group	**Seven-week group**	**Nine-week group**
Patients (n)	7	7	7
Age*(mean ± SD)	17.1±2.3 years	15.3±1.8 years	15.6±2.1 years
Sex (male/female)	4 /3	1/6	3/4

* No significant difference based on one-way ANOVA ($P > 0.05$).

Figure 1: The appliance used to deliver the orthodontic force. A .017 x 0.025- inch stainless steel sectional arch is used in the mandibular arch. The premolar is intruded by NiTi coil delivering a force of 75cN

At the end of each experimental period, the test premolars were extracted and prepared for SEM. All the teeth were immersed in 5% sodium hypochlorite to remove the soft tissue remnants. They were subsequently rinsed three times in normal saline. Then, the roots were separated from the crown, dehydrated in a series of alcohol of ascending concentration. After a slow-drying process, the roots were mounted on the brass stubs with the buccal surfaces oriented horizontally to obtain absolute straight-on images.(19) The roots were vacuum-coated with gold and examined in a JOEL 5300 scanning electron microscope (JOEL Ltd, Tokyo, Japan) at 25 kV. The control material was similarly treated.

Topographic investigation was performed according to the method of Barber and Sims. (20) The buccal side of every specimen was scanned and photographed at low magnification (35X) to produce a composite micrograph of the entire buccal surface.(18) Higher magnification (50X - 1000X) was used to evaluate the morphology of the lesions. The composite micrographs were produced using Adobe Photoshop CS3 (Adobe Systems Incorporated, San Jose, California). The same software was used to determine the total area of the buccal surface of each root and the areas of root resorption. The resorbed areas were calculated as a percentage of the total area.

Qualitative assessment of apical resorption was performed by two independent observers using a modification(21) of the method of Malmgren et al.(22) The severity of root resorption was scored on a scale of 1 to 4:

0- No root resorption
1- Irregular root contour, root length not affected
2- Minor resorption, scalloping or blunting of the apex
3- Moderate resorption, resorption less than one third of the root length
4- Sever resorption, resorption more than one third of the root length

Statistical analysis was performed using SPSS for windows version 16 (SPSS Inc, Chicago, Illinois, USA). To assess the error of measuring root resorption areas, 15 composites were randomly selected and remeasured. Pearson correlation coefficient was used to express the reliability of the method and the absolute random error was calculated. The interobserver reliability coefficient of the visual scoring method and the weighted kappa were calculated to assess the reliability of the method.

Means and standard deviations were calculated for the percentage of resorbed areas in the three groups. Kolmogorov-Smirnov Z test was run to test the normality of the variables. One-way ANOVA was used to compare the relative resorption among the study groups. Levene test of homogeneity of variance was used to determine appropriate post hoc test. Pairwise comparisons were performed by Bonferroni test. Chi square test was used to test the association of the score for apical resorption and the study groups. The strength and direction of association was determined using gamma test. A $P<$ o.o5 was considered significant.

RESULTS

The reliability coefficient of the method of measuring root resorption was 0.93. The absolute random error was 0.55%. The interobserver reliability coefficient of the visual scoring method was 0.8, and the weighted kappa was 0.69.

Root resorption was registered in the three test groups. In the control group, three roots showed shallow resorption craters with no dentin involvement. The mean percentage of resorbed areas in the control, five-week, seven-week and nine-week group were 0.312 ± 0.43%, 3.3 ± 2.25 %, 6.51 ± 2.27% and 6.52 ± 1.37% respectively. The difference between the control group and all the test groups was statistically significant. Compared to the seven-week and nine-week group, the mean percentage of resorbed area of the 5-week group was significantly lower. No significant difference was found between the seven-week and the nine-week group (Table II).

Table I. Comparison of the relative resorption area among the study groups

	Control		5-week group		7-week group		9-week group		P value*
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Relative resorption area (%)	0.31[a,b,c]	0.43	3.3[b,c]	2.25	6.51	2.27	6.52	1.37	0.001†

[a] Significant difference with the 5-week group.

[b] Significant difference with the 7-week group.

[c] Significant difference with the 9-week group.

† Post hoc based on the Bonferroni test, P <0.05.

* P <0.05, based on one-way ANOVA.

Visual scoring did not show any resorption (score 0) in all control premolars, 4 premolars in the 5 weeks group, and one premolar in the seven-week and nine-week group. Score 1was registered in 3, 6 and 4 premolars in the five-week, seven-week and nine-week group respectively. Two premolars of the 9 weeks group showed blunt apices (score 2). A strong positive association was found between the apical score and the duration of force application (χ^2 = 16.29, γ = 0.846, P <0.05) (Figure 2).

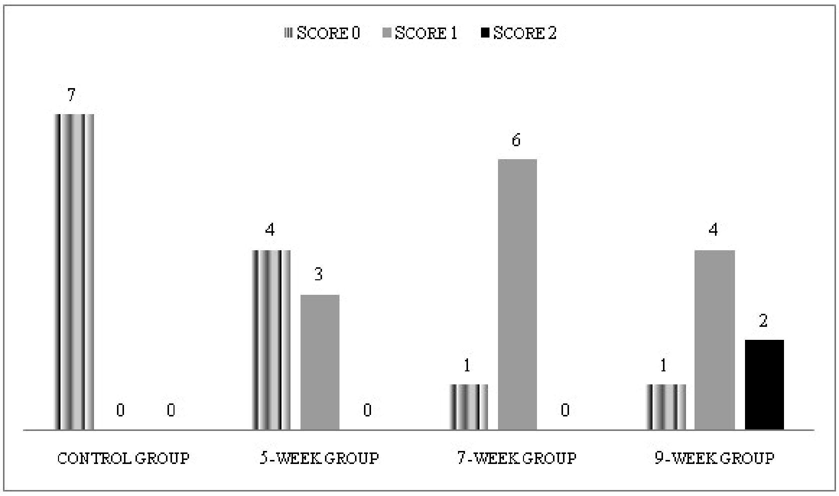
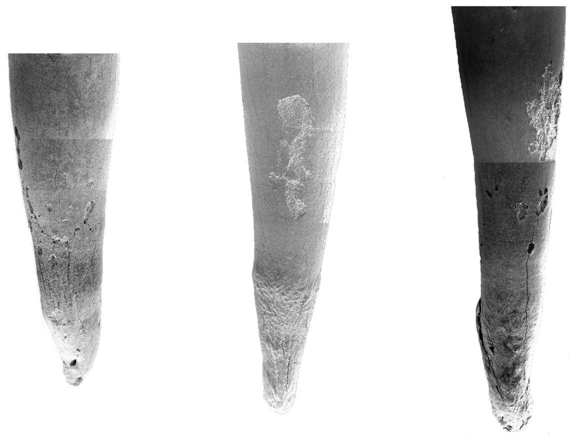


Figure 2: chart of the scores of apical resorption in the study and control groups.

In the test premolars, the resorption craters were scattered along the buccal surface. However, the cervical and middle third regions were predominantly involved in comparison to the apical third. Two patterns of craters were recognized: discrete deep isolated lesions and wide shallow resorption bays. Smaller isolated lesions predominated in the apical thirds, whereas wide resorption bays were more frequently encountered in the middle and cervical thirds of the buccal surface. The pattern of root resorption showed large individual variation. Corresponding experimental teeth of different individuals showed a predilection to one pattern of cratering or no specific pattern at all (Figure 3).

Areas of resorption were characteristically smooth and multilocular. A rim of relatively sheer and undermined cementum delineated the lesion (Figure 4). Despite the large number of craters examined, no lesions were found to occur exclusively in cementum; dentin was involved in the majority of the lesions to a greater or lesser extent. No apparent variation was noted between the lacunae in either tissue. Although the individuals in each test group were treated similarly, the severity of root resorption varied markedly within the same test group.



a b c

Figure 3: Composite pictures of the buccal surfaces of three test premolars showing different patterns of cratering. (a) Multiple isolated craters in the middle and apical thirds. (b) Wide resorption bay extending in the cervical and middle thirds. (c) A wide crater is seen in the cervical third and smaller isolated craters in the middle third. (35X)

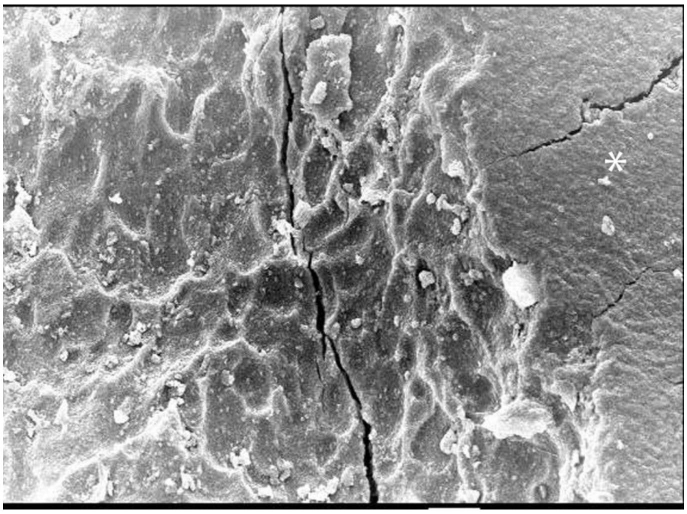


Figure 4: Representative picture of a resorption crater with numerous concavities representing How ship's lacunae adjacent to acellular cementum (asterisk).

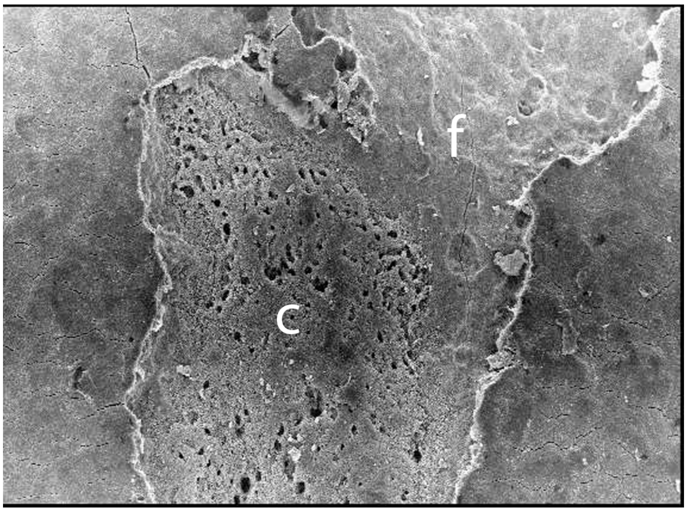


Figure 5: A resorption crater showing repair by both cellular (c) and fibrillar (f) cementum. Cellular cementum shows lacunae like depressions indicative of cementocyte embedding while fibrillar cementum appears smooth and glossy

Cementum repair was registered after seven and nine weeks. However, most lesions showed both repair and resorption processes simultaneously. Two types of healing tissue were observed. One type of tissue had a smooth glossy appearance resembling extrinsic fiber acellular cementum. The other type of tissue was characterized by the presence of micro-calcospherites of mineralized material in the resorption lacunae. Lacuna-like depressions were registered in the mineralizing front, indicative of cementocyte embedding; thus resembling cellular cementum (Figure 5). Both types of tissue were sometimes noticed simultaneously in the same lesion. Reparative tissue was observed in the floor of the resorption bays obliterating the lacunae in the central part of resorbed areas. The reparative cementum was not always in contact with the peripheral normal cementum. Occasionally, the repair tissue appeared bordering the craters and radiating centrally. Only partial repair was registered. Repair cementum partially covered the lesions.

DISCUSSION

The present study is a randomized controlled clinical trial designed to register the processes of resorption and repair of human roots following the decay of experimental intrusive forces applied for different time periods.

The participants in this study were of the adolescent age group since they represent the majority of individuals seeking orthodontic treatment.(23) Because of differences in maxillary and mandibular root morphology and bone densities, the study was restricted to mandibular premolars. Moreover, mandibular first premolars are mostly single rooted which would simplify data collection.(24) Subjects from both sexes were selected. Most studies found no consistent association between gender and root resorption(25,26,27) except for two studies(28,29) that yielded opposite gender predilection. The medical history of the patients was reviewed to rule out diseases and medications implicated with root resorption such as chronic asthma(30,31) and allergies(32), L-thyroxine(33,34), prostaglandins(35), bisphosphonates(36,37), corticosteroids(38,39) doxycline(40) , and increased intake of fluoride.(41) The selected subjects presented normally developed dentition since anomalies such as hypodontia was suspected to put existing teeth at increased risk of resorption.(29,42). Root morphology was evaluated from orthopantomograms to ward off pipette shaped, pointed and dilacerated premolars.[26]In addition, Subjects with endodontically treated premolars were not included.[43] Habits predisposing root resorption such as bruxism[44] and nailbiting[45] were precluded.

The subjects were randomly assigned to three groups according to the duration of force application – a five-week, a seven-week and a nine-week group. Resorption of the cementum occurs as a part of hyaline zone elimination.[46,9] The elimination of hyalinized tissue is usually complete in humans after 20 to 25 days. The resorptive process, however, continues after the removal of the necrotic tissue.[47] Repair of resorption lacunae has been observed as early as 3 to 5 weeks after the initiation of light orthodontic forces.[48] A five-week period was considered suitable to examine both the resorption and repair processes. Obviously, time limits are imposed by the ethical need to continue treatment in human subjects. Accordingly, the experimental period could not be extended longer than nine weeks.

To study root surface changes incident to orthodontic force application, an intrusive force was employed. Intrusion has been described as the worst type of orthodontic tooth movement for the susceptibility of root resorption.[49] Several studies concluded that intrusion is the type of vertical movement most predictive of root resorption.[11,12,28] A finite element model demonstrated that intrusive forces can induce apical resorption mainly because the root shape concentrates the pressure at the conical apex.[50] The experimental model of intruding a single tooth mimics the clinical situation of intruding an overerupted molar – an application made easier with the use of miniscrews.[51]

Root surface changes following the application of intrusive forces has been studied using SEM [18,21,49,52] and micro-computed tomography [53]. An important point to stress is that in these experiments, the present work included an experimental tooth movement. The experimental model is different from a clinical situation where an abnormal dental relation is corrected to a more normal one in the latter. However, since these studies aimed to examine the human dental material ex vivo, an experimental model is the only possible approach. Still, the results of these models should be considered with in this context.

The experimental model used in this study simulates a one force-activation cycle. Several authors used the same model in humans[46,49,53] and in rats.[14,15] Some experimental models studying root resorption used forces that are reactivated weekly to provide continuous forces. [18,21,52] Studies of repair attempted to either retain the moved teeth for variable periods of time using passive appliances[54,55], or to release the applied force.[56] One force-activation cycle closely mimics the clinical situation. In addition, it is suitable for the discussion of the transition of a process of active root resorption into a process of tissue repair. [15]

The magnitude of the applied force in this work was 75 cN. Experimental intrusion was done with forces ranging from force magnitudes as low as 10 g [57] to a high of 250 g.[58] A force of 75 cN was considered sufficient for provoking experimental root resorption.

A sectional appliance was used to deliver the force to the test premolar. Several authors have used similar designs.[52,53] In other studies, full arches were employed where the anterior teeth were engaged.[18,21,49] Thus, selection of subjects was limited to cases with minimal crowding of the incisors – a restriction not imposed by a sectional arch. In addition, less chair-time was needed for the set up of the experimental appliances.

Intrusion of the test premolar was achieved by ligating a Ni-Ti coil spring, attached to the sectional arch, to an eyelet bonded on the buccal surface of the tooth; a one-point force-application system. Similar designs were used by other authors.[18,21,49] In an attempt to produce pure intrusive forces, Faltin et al[52] used a cantilever spring tied to a bracket on the buccal surface of the test premolar that delivered a simultaneous intrusive buccal tipping force and a counteracting lingual crown torque moment. This force system seems to be very difficult to calibrate, hence the resultant force might be unpredictable. Besides, it hypothesizes the uniformity of the response of bone and periodontal ligament on the buccal and lingual sides of the tooth. In addition, engaging the cantilever in the bracket slot might cause mesiodistal tipping. The appliance used by Harris et al[53] was constructed of a buccal and a palatal cantilever spring, each delivering equal amount of force, engaged to brackets on the corresponding surfaces of the test premolars. Again, the used force system would not negate buccal, lingual, mesial or distal tipping. Although, the one-point force application system used in this study delivers a buccal tipping force, the compression zone and the resorption fronts are clearly defined – the buccal surface and the apical area of the test premolar. Mesial and distal tipping would not be expected.

A closed Ni-Ti coil spring was the force module used in this study. Other authors used intraoral elastics changed by the patient every day and calibrated by the author every week. [18,21] Since the experimental model used in this work simulates a one-force activation cycle, the appropriate force module to use should deliver an initial force that would decay over the experimental period. Accordingly, a force module to be replaced by the patient was not suitable for this purpose. According to previous studies,[59,60] NiTi closed coils appeared to exert a light continuous force over a long range of increasing or decreasing activation. Compared to elastomeric chains, force decay of NiTi coil springs was little influenced by exposure to moisture and temperature changes.[61]

The test and contralateral teeth were extracted and prepared according to established standard procedures[20] for examination using SEM. During specimen preparation, the organic tissue was dissolved, allowing alteration of the mineral fronts of the root surface and the 'foot prints' of odontoclasts on the mineralized tissue to be observed.[62] Root surface alterations are three-dimensional. Attempts at quantifying root resorption in three dimensions ex vivo included laser scanning microscopy,[63] SEM image pairs[64] and microcomputed tomography[53] – all methods associated with an image analysis computer program. Each crater has to be pictured separately in laser and electron microscopy. This would be considered inconvenient for roots exhibiting large numbers of craters. Microcomputed tomography eliminated the complexities associated with SEM such as specimen preparation, graphic reconstruction of the crater, acquisition of a pair of images for each crater.[53] Despite a limitation in the volume-estimation software [53], it is the belief of the authors that ex vivo studies quantifying root resorption should be based on microcomputed tomography. In this study, the measurement of surface area was considered satisfactory for comparison of data among the experimental groups. The third dimension was assessed by the extension of the lesion into the cementum only or into the dentine. Several authors have followed the same method.[18,21,62]

For comparing surface and apical resorption quantitatively, the teeth were mounted with their buccal surfaces facing upwards towards the source of electrons in the microscope. This standardized exposure geometry enabled the acquisition of straight-on images to allow image composition of the entire surface, measurement of surface resorption and scoring of apical resorption.

Examination of the control teeth revealed resorption crater in three of seven teeth (43%). This was in agreement with other reports on root resorption.(18,21,49,65) Mean relative resorption area in this study varied from 0.3% to 1% with a mean of 0.31%. These values are comparable to those found by Acar et al (18) that varied between 0.1% and 1.8% and Han et al (21) with a mean of 0.52%. Quantitative comparison with other studies could not be made. Jones and Boyde(66) expressed surprise at the high frequency of occurrence of small areas of resorption, particularly near the root apices of newly erupted teeth. They concluded that they were related to the establishment of occlusal function. Small resorption pits have been considered a normal process, triggered by intermittent damage of the periodontal ligament and root surface at the margin of the alveolar crest.(67) In standing teeth, these lesions may be related to physiological drifting or occlusal trauma. On the other hand, Faltin et al(52) found no resorption in their control material. Regarding root resorption, large individual variation appears to be the rule rather than the exception.

Resorption has been registered in all test teeth. Craters were predominantly found in the cervical and middle thirds of the buccal surface and the lingual apical area. Authors using the same force system, a buccally tipping intrusive force, registered the same distribution.(18,46,49) This distribution represents the pressure zones on the root and alveolar bone surfaces where over compression of the periodontal ligament, subsequent hyalinization and root resorption would likely occur.(19)

Morphologically, the registered craters showed the classical picture of undermined edges of cementum.(20,47) It was hypothesized that initial resorption of cementum would take place when the barriers on the root surface are eliminated after hyalinization. Once a resorption lacuna would be established, the cementum on the edges of the lacuna would be resorbed from the rear.[47] This would indicate the resistance to resorption of healthy cementum surfaces.[40]

Two patterns of cratering were identified: small deep isolated lesions and wide shallow resorption bays. Similar findings were reported in other studies.[55, 62] It was postulated that shallow lesions could be associated with mononucleated macrophage like cells, while deeper lacunae were excavated by multi-nucleated cells.[62] However, the lesions tended to get wider and shallower toward the middle and cervical regions. This can be explained by the fact that due the morphology of human roots the pressure in the middle and cervical thirds would be distributed over a wider root area, resulting in a wider and a shallower resorption front. Alternatively, it may be argued that acellular cementum predominates in the cervical and middle thirds, while cellular cementum is present in the apical third. Apart from the fact that the two types of tissue might respond differently in a resorptive environment, a recent study has shown that cellular cementum is softer than acellular cementum, hence might be less resistant to resorption.[68]

Morphometrically, relative resorption area was significantly increased in the seven-week and nine-week groups compared to the five-week group. No significant difference was found between the seven-week and nine-week groups. It can be concluded that despite the decay of force, the resorptive process seems to continue after five weeks and cease or slow down after seven weeks. The progression of root resorption has been found to increase with the continuation of force [48] and even after force termination.[47]

Apical scoring showed a strong positive association with the study group. Two test premolars in the nine-week group had a score of two – blunt or scalloped apices. In contrast, relative root resorption was found to be similar in the seven-week and nine-week group. This can be interpreted by the difference in physiology cellular cementum in the apical third and acellular cementum in the middle and cervical thirds.[20] As stated previously, cellular cementum was found to be softer than acellular cementum.[68]

The reparative process was registered in the seven-week and nine-week test material. Comparison of this data with other studies of repair is difficult since most of them examine their material after variable periods of force release[56] or retention of the teeth in their new position.[54,55] Despite the fact that repair appeared to progress from seven to nine weeks, only partial repair was registered at the end of the nine-week activation cycle. It may be concluded that with a similar force system, an initial force less than 75 cN or a longer activation cycle would be more amenable for functional repair to occur.

In the present material, the resorptive and repair processes were registered simultaneously within the same lesion. Barber and Sims[20] reported the same pattern of healing after rapid maxillary expansion. Repair of surface resorption patches appeared to follow two patterns. One pattern seemed to proceed from the periphery of the resorbed areas and the other appeared to start somewhere centrally in the resorbed areas. Similar spatial patterns have been registered by Sismanidou and Lindskog[56]. The repair process has been described as beginning form the periphery,[47] the bottom,[54] or all directions.[67] Both cellular and acellular cementum has been reported in the repair of resorptive lacunae,[54] despite the fact that some studies reported only cellular cementum[20,47] or acellular cementum.[67]

Perhaps better comprehension of the complex field of the biology of tooth movement may someday lead to pharmacological agents for the prevention of root resorption.[69] More immediate promise appears to lie in studies that examine the orthodontic methodology in an attempt to shed light on which force regimens will reduce the incidence of root resorption or maximize the repair potential. After all, the force system lies within the hands of the skilled clinician.

REFERENCES

1. The physiological and pathological resorption of tooth roots. R, Ottolengui. 1914, Den Items Int , Vol. 36, pp. 332-62.
2. A preliminary report of an investigation of apical root resorption of vital permanent teeth. AH, Ketcham. 1927, Int J Orthod, Vol. 13, pp. 97-127.
3. A progress report of an investigation of apical root resorption of vital permanent teeth. AH, Ketcham. 1929, Int J Orthod, Vol. 15, pp. 310-28.

4. Root resorption after othodontic treatment: Part 1. Literature review. Brezniak N, Wassertein A. 1, 1993, Am J Orthod Dentofac Orthop, Vol. 103, pp. 62-66.

5. S, Papaconstantinou. Metabolic profile of orthdontic patients exhibity root resorption: An assessment of the biologic predispositon hypothesis. [book auth.] Eliades T, Athanasiou A Graber TM. Risk management in orthodontics: Experts' guide to malpractice. s.l.: Quintessence publishing Co, Inc, 2004, p. 47.

6. Root resorption after orthodontic treatment: Part 2 Literature review. Brezniak N, Wassertein A. 2, 1993, Am J Orthod Dentofac Orthop, Vol. 103, pp. 138-146.

7. Orthodontically induced inflammatory root resorption. Part I: The basic science aspects. Brezniak N, Wasserstein A. 2, 2002, Angle Orthod, Vol. 72, pp. 175-179.

8. Orthodontically induced inflammatory root resorption. Part II: The clinical aspects. Brezniak N, Wasserstein A. 2, 2002, Angle Orthod, Vol. 72, pp. 180-184.

9. Thilander B, Rygh P, Reitan K. Tissue reaction in orthodontics . [book auth.] Vanarsdall RL, Vig K Graber TM. Orthodontics: Current principles and techniques. s.l. : ElsevierMosby, 2005.

10. Apical root resorption in orthodontically treated adults. Baumrind S, Korn EL, Boyd RL. 3, 1996, Am J Orthod Dentofac Orthop, Vol. 110, pp. 311-20.

11. The relationship between apical root resorption and orthodontic tooth movement in growing subjects. Xu T, Baumrind S. 4, 2002, Zhonghua Kou Qiang Yi Xue Za Zhi, Vol. 37, pp. 265-8.

12. Directions of orthodontic tooth movements associated with external apical root resorption of the maxillary incisor. Parker RJ, Harris EF. 6, 1998, Am J Orthod Dentofac Orthop, Vol. 114, pp. 677-83.

13. Orhtodontics in 3 millennia. Chapter 15: Skeletal anchorage. N, Wahl. 5, 2008, Am J Orthod Dentofac Orthop, Vol. 134, pp. 707-10.

14. The repair of orthodontic root resorption: an ultrastructrual study. Brudvik P, Rygh P. 3, 1995, Eur J Ortho, Vol. 17, pp. 189-98.

15. Transition and determinants of orthdontic root resorption-repair sequence. Brudvik P, Rygh P. 3, 1995, Eur J Orthod, Vol. 17, pp. 177-88.

16. Vlaskalic V, Boyd RL. Root resorptions and tissue changes during orthodontic treatment. [book auth.] Bishara SE. Textbook of Orthodontics. First. s.l. : Elsevier, 2001.

17. Evaluation of root resorption in relation to two orthodontic treatment regimes. A clinical experimental study. Levander E, Malmgren O, Eliasson S. 3, 1994, Eur J Orthod, Vol. 16, pp. 223-8.

18. Continuous vs. discontinuous force application and root resorption. Acar A, Canyurek U, Kocaaga M, Erverdi N. 2, 1999, Angle Orthod, Vol. 69, pp. 159-63.

19. Physical properties of root cementum: Part 7. Extent of root resorption under areas of compression and tension. Chan E, Darendeliler MA. 4, 2006, Am J Orthod Dentofac Orthop, Vol. 129, pp. 504-10.

20. Rapid maxillary expansion and eternal root resorption in man: a scanning electron microscope study. Barber AF, Sims MR. 6, 1981, Am J Orthod, Vol. 79, pp. 630-52.

21. Root resorption after orthodontic intrusion and extrusion: an intraindividual study. Han G, Huang S, Von den Hoff JW, Zeng X, Kuijpers-Jagtman Am. 6, 2005, Angle Orthod, Vol. 75, pp. 912-8.

22. Root resorption after orthodontic treatment of traumatized teeth. Malmgren O, Goldson L, Hill C, Orwin A, Petrini L, Lundberg M. 1982, Am J Orthod, Vol. 82, pp. 487-91.

23. WR, Proffit. Malocclusion and dentofacial deformit in contemporary society. [book auth.] Fields HR, Sarver DM Proffit WR. Contemporary orthdontics. s.l. : Mosby Elsevier, 2007, p. 22.

24. The permanent mandibular premolars. [book auth.] Ash MM. Wheeler's dental anatomy, physiology and occlusion. Philadelphis, PA : W. B. Saunders Company, 1993.

25. A heritable component for external apical root resorption in patients treated orthodontically. Harris EF, Kineret SE, Tolley EA. 1997, Am J Orthod Dentofac Orthop, Vol. 111, pp. 301-9.

26. Predicting and preventing root resorption: Part I. Diagnostic factors. Sameshima GT, Sinclair PM. 2001, Am J Orthod Dentofac Orthop, Vol. 119, pp. 505-10.

27. A radiographic study of posterior apical root resorption in orthodontic patients. Hendrix I, Carels C, Kuijpers-Jagtman AM, Van'T Hof M. 1994, Am J Orthod Dentofac Orthop, Vol. 105, pp. 345-9.

28. Apical root resorption in orthodotnically treated adults. Baumrind S, Korn EL, Boyd RL. 1996, Am J Orthod Dentofac Orthop, Vol. 110, pp. 311-20.

29. Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. I, Kjar. 1995, Eur J Orthod, Vol. 16, pp. 25-34.

30. External apical root resorption of posterior teeth in asthmatics after orthdontic treatment. McNab S, Battistutta D, Taverne A, Symons AL. 1999, Am J Orthod Dentofac Orthop, Vol. 116, pp. 545-51.

31. Human histologic tissue response after long-term orthodontic treatment . Wehrbein H, Fuhrmann RA, Diedrich PR. 1995, Am J Orthod Dentofac Orthop, Vol. 107, pp. 360-71.

32. Root resorption after orthodontic treatment in high- and low-risk patients. Owman-Moll P, Kurol J. 2000, Eur J Orthod, Vol. 22, pp. 657-63.

33. Thyroid administration to reduce root resorption. Loberg EL, Engstrom C. 1994, Angle Orthod, Vol. 64, pp. 395-99.

34. The effect of thyroid hormone on orthodontic tooth movement in rats. Shirazi M, Dehpour AR, Jafari F. 1999, J Clin Pediatr Dent, Vol. 23, pp. 259-64.

35. The effects of exogenous prostaglandins on orthdontic tooth movement in rats. Leiker BJ, Nanda Rs, Currier GF, Howes RI, Sinha PK. 1995, Am J Orthod Dentofac Orthop, Vol. 108, pp. 380-88.

36. Inhibitory effedt of the topical administration of a bisphosphonate (riserdrontate) on root resorption incident to orthodontic tooth movement in rats. Igarashi K, Adachi H,Mitani H, Shinoda H. 1996, J Dent Res, Vol. 75, pp. 1644-49.

37. Orthodontically induced root resorption in rat molars after 1-hydroxyethylidene-1, 1-bisphosphonate injection. Alatli I, Hellsing E, Hammarstrom L. 1996, Acta Odontol Scand, Vol. 54, pp. 102-8.

38. The effect of corticosteroid-induced osteoporosis on orthodontic tooth movement. Ashcraft MB, Southard KA, Tolley EA. 1992, Am J Orthod Dentofac Orthop, Vol. 102, pp. 310-19.

39. Orthodontic tooth movement in the prednisolone-treated rat. Ong CK, Walsh LJ, Harbrow D, Taverne AA, Symons Al. 2000, Angle Orthod, Vol. 70, pp. 118-25.

40. Orthodontically induced root and alveolar bone resorption: inhibitory effect of systemic doxycline administration in rats. Mavragani M, Brudvik P, Selvig KA. 2005, Eur J Orthod, Vol. 27, pp. 215-25.

41. Physical properties of root cementum: Part 9. Effect of systemic fluoride intake on root resorption in rats. Foo M, Jones A, Darendelilier MA. 2007, Am J Orthod Dentofac Orthop, Vol. 131, pp. 34-43.

42. Apical root resorption during rothodntic treatment of patients with multiple aplasia: a study of maxillary incisors. Levander E, Malmgrem O, Stenback K. 1998, Eur J Orthod, Vol. 20, pp. 427-34.

43. Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. Mirabella AD, Artun J. 1995, Eur J Orthod, Vol. 17, pp. 93-9.

44. Occlusion. Ramjord SP, Ash MM. 2nd. Philadelphia : WB Saunders, 1971.

45. Nailbiting: frequency and association with root resorption during orthodontic treatment. Odenrick L, Brattstrom V. 1985, Br J Orthod, Vol. 12, pp. 78-81.

46. Initial tissue behavior during apical root resorption. K, Reitan. 1974, Angle Orthod, Vol. 44, pp. 68-82.

47. Orthodontic root resorption studied by electorn microscopy. P, Rygh. 1, 1977, Angle Orthod, Vol. 47, pp. 1-16.

48. Bosshardt DD, Masseredjian V, Nanci A. Root resorption and tissue repair in orthodontically treated human premolars. [book auth.] Mah J Davidovitch Z. Biological mechanisms of tooth eruption, resorption adn replacement by implants. Boston : Harvard society for the advancement of orthodontics, 1998.

49. Root resorpiton in bicuspid intrusion. A scanning electron microscope study. Harry MR, Sims MR. 3, 1982, Angle Orthod, Vol. 52, pp. 235-58.

50. A finite element model of apical force distribution form orthodontic tooth movement. Rudolph DJ, Willes PMG, Sameshima GT. 2, 2001, Angle Orthod, Vol. 71, pp. 127-31.

51. Clinical trial on intrusion of overerupted maxillary molars with microscrew. Ding XF, Zhou YH, Gao XM. 2, 2007, Zhonghua Kou Qiang Yi Xue Za Zhi, Vol. 42, pp. 80-4.

52. Root resorptions in upper first premolars after application of coninuous intrusive forces. Intra-inidividual study. Faltin RM, Arana-Chavez VE, Faltin K, Sander FG, Wichelhaus A. 4, 1998, J Orofac Orthop, Vol. 59, pp. 208-19.

53. Physical properties of root cementum:part 8 Volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: a microcomputed tomographay scan study. Harris DA, Jones AS, Darendeliler MA. 5, 2006, Am J Orthod Dentofac Orthop, Vol. 130, pp. 639-47.

54. Repair of orthdontically induced root resorption in adolescents. Owman-Moll P, Kurol J, Lundgren D. 6, 1995, Angle Orthod, Vol. 65, pp. 403-8.

55. Scanning electron microscopic study of root resorpiton and repair in response to low magnitudes of force. Ghobashy S, Sheneshen S. 2007, Egyptian Orthdontic Journal, Vol. 31, pp. 39-56.

56. Spatial and temporal repair patterns of orthodontically induced surface resorption patches. Sismanidou, Lindskog S. 5, 1995, Eur J Oral Sci, Vol. 103, pp. 292-8.

57. A histologic and cephalometric investigation of premolar intrusion in the Macaca speciosa monkey. E, Dellinger. 5, 1967, Am J Orthod, Vol. 53, pp. 325-355.

58. The effect of experimental tooth intrusion on pulp and dentine. Stevnik A, Mjor I. 4, 1971, Oral Surg Oral Med Oral Path, Vol. 32, pp. 639-48.

59. A randomized clinical trial to compare three methods of orthodontic space closure. Dixon V, Read MJF, O'Brien KD, Worthington HV, Mandall NA. 2002, Am J Orthod Dentofac Orthop, Vol. 29, pp. 31-6.

60. An in vito comparison of the force decay generated by different commericially available elastomeric chains and NiTi closed coil springs. Santos A, Tortamano A, Naccarato S, Dominguez-Rodriguez G, Vigorito J. 2007, Braz Oral Res, Vol. 21, pp. 51-7.

61. The effect of environmental factors on elastomeric chain and nickel titanium coil springs. Nattrass C, Ireland AJ, Sheriff M. 1998, Eur J Orthod, Vol. 20, pp. 169-76.

62. Early root alterations after orthodontic force application studied by light and scanning electron microscopy. Mavragani M, Amundsen OC, Selliseth NJ, Brudvik, Selvig KA. 2, 2004, Eur J Orthod, Vol. 26, pp. 119-28.

63. Constant versus dissipating forces in orthodntoics: the effect on intial tooth movement and root resorption. F, Weiland. 4, 2003, Vol. 25, pp. 335-42.

64. A new method for volumetric measurement of orthodontically induced resorption craters. Chan EK, Darendeliler MA, Petocz P, Jones AS. 2, 2004, Eur J Oral Sci, Vol. 112, pp. 134-9.

65. Scanning electron microscopy of tissue changes on the pressure surface of human premolars following tooth movement. E, Kvam. 5, 1972, Scand J Dent Res, Vol. 80, pp. 357-68.

66. A study of human root cementum surfaces as prepared for and examined in the scanning electron microscop. Jones S, Boyde A. 1972, Z Zellforsch Mikrosk Anat, Vol. 130, pp. 318-37.

67. The hyaline zone and associated root surface changes in experimental orthodontics in rats: a light and scanning electron microscope study. Hellsing E, Hammarstrom L. 1, 1996, Eur J Orthod, Vol. 18, pp. 11-8.

68. Physical properties of root cementum: Part 3. Hardness and elastic modulus after application of light and heavy forces. Srivicharnkul P, Kharbanda OP, Swain MV, Petocz P, Darendeliler MA. 2005, Am J Orthod Dentofac Orthop, Vol. 127, pp. 168-77.

69. JO, Andreason. Summary of root resorption. [book auth.] Davidovich Z. The biological mechanisms of tooth eruption and root resorption. Birmingham : EBSCO media, 1988, pp. 399-401.

70. Scanning electron microscope study of the effect of intrusive force on the root surface. Master Thesis. A, Angbawi. 2007.