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Bone structure effect on root resorption

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Structured Abstract

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Objectives – To explore if alveolar bone shape and density might promote external apical root resorption.

Setting and Sample Population – Panoramic radiographs of 700 patients who had orthodontic treatment at Temple University were reviewed and 22 patients with radiographic evidence of root resorption on the lower incisors were selected for the study. Exclusion criteria included a history of systemic diseases, craniofacial abnormalities, tooth injury, endodontically treated teeth, and impacted teeth.

Methods – Pre-treatment (T1) and post-treatment (T2) cephalometric radiographs were converted into digital format and enhanced to reduce contrast variability and improve edge definition. Tooth length, root length, root area, alveolar area around the root including cortical area, area of medullary bone, and area of the symphysis were measured using an interactive software algorithm. A region of interest within the symphysis was also defined and trabecular space area and fractal dimension calculated as an estimate of bone density.

Results – Root area and tooth length were correlated negatively with changes in root area, tooth area, and root length. Larger teeth demonstrated a greater amount of root resorption. Dentoalveolar complex dimensions remained relatively unchanged during tooth movement. The amount of alveolar bone around the root, thickness of cortical bone, density of the trabecular network, and fractal dimension showed no significant correlation with the extent of the external apical root resorption.

Conclusions – The results of this study suggest that the density and morphology of the dentoalveolar complex are not significant factors in the etiology of external apical root resorption.

Key words: external apical root resorption; fractal analysis; orthodontics

Introduction

Although it has long been recognized that orthodontic tooth movement frequently results in external apical root resorption (EARR), the precise etiology remains unclear (1). Despite its prevalence, the severity of resorption related to orthodontic treatment has been shown to be of minimal clinical significance (2, 3). Considering the conical shape of the root, linear measurements of root resorption may be somewhat misleading. The volume of osseous support lost in the apical region is usually quite small as compared with the remaining root surface volume with an intact periodontal attachment (4). Yet, root resorption is a concern for the orthodontic specialty since it lessens the perceived value of successful orthodontic treatment.

Incidence and prevalence of external apical root resorption

There are conflicting reports in the literature concerning the incidence and prevalence of EARR. These varied findings are related to investigational differences in sample size, definition of EARR, and the criteria and methods used to assess resorption. Histological studies report a greater than 90% occurrence of EARR in orthodontically treated teeth (5, 6). Much lower incidences of root resorption are reported when radiographic methods are used to detect EARR. Using periapical radiographs, Lupi et al. (2) reported the incidence of root resorption before and after treatment was 15 and 73%, respectively. However, when a stricter definition of root resorption was applied (greater than one-third of the root resorbed), the incidence of resorption dropped to 2% in the post-treatment group. In a study of 390 maxillary incisors, resorption greater than one-third the root length occurred in only 1% of the incisors examined (7). What is clear from literature is that significant root resorption following orthodontic treatment is a rare event. When it does occur, maxillary central incisors are the most frequently affected teeth (8).

Biological factors affecting root resorption

Although many factors have been speculated to predispose the patient to EARR during orthodontic treatment, to date, no clear causal links have been substantiated. It is likely that EARR is a problem of multi-factorial origin. The traditional belief that orthodontic root resorption increases with age (9, 10) was recently disproved (11–17). Similarly, the common dogma that teeth with a previous history of trauma are more susceptible to root resorption has also been questioned. Although significantly greater root resorption in previously traumatized teeth as compared with controls has been reported by several investigators (9, 13, 18); teeth with slight or moderate injuries may not have any greater tendency toward root resorption during orthodontic treatment than uninjured teeth (19).

Gender does not predispose a patient to root resorption during orthodontic treatment; reports of higher incidence in females (8, 20, 21), as well as males (15, 22) are abound. Still others have concluded that gender does not affect a patient's susceptibility to root resorption (1, 11, 16, 23). Abnormal root shape and other dental anomalies have been reported as risk factors for EARR (7, 16, 20). When rigorous criteria to define EARR is employed, however, no significant correlation between anomalies and resorption can be found (3). A common belief is that short roots undergo more resorption (8, 11). A recent study conducted by Mirabella and Årtun (24), however, supports the opposite view that the tendency for resorption increases with increasing tooth length. Perhaps the most the most influential biological factor governing susceptibility to EARR is genetics. A study of 103 pairs of siblings treated with the same technique by a single orthodontist showed that there were significantly greater variances among-than within-siblings (1). Recently, EARR has been linked to the IL-1B gene substantiating an important genetic predisposition to this problem (25, 26).

The effect of orthodontic treatment modality on root resorption

Although some investigators have suggested that the mechanics of the Begg technique might induce more harmful effects on roots (27–29), many others agree that there is no real significant difference between Begg, Tweed or straightwire techniques (17, 19, 30). The direction of force may influence EARR; e.g. greatest damage with intrusive movements (5, 23, 31). Intrusive movements are thought to concentrate pressure at the apex due to the conical shape of the root (17). Transitional movement on the other hand, places less stress along the root compared with tipping or uprighting movement, thus yielding less resorption (23). The magnitude of force has traditionally been associated with root resorption. During orthodontic tooth movement a heavier force is believed to induce excessive hyalinization and interfere with the repair process of resorption lacunae (32). Owman-Moll could not observe the latter (33). Doubling and quadrupling the force magnitude did not affect the severity of root resorption in his experiments. Comparisons of continuous force and intermittent force demonstrated that the application of an intermittent force results in less root resorption than the application of a continuous force (34–36). Some studies have concluded the length of treatment may be correlated to the severity of EARR (11, 13, 15, 37), while others found no significant association between EARR and treatment time (7, 17, 38). Confounding variables such as more difficult treatment plans or lack of patient compliance may be associated with longer treatment durations. These factors may also contribute to EARR.

Bone density and root resorption

It has been postulated that tooth movement in dense bone requires greater or longer force application and consequently result in more root resorption (32). In a rodent model, teeth were shown to move faster and develop EARR in animals that had a calcium deficiency induced decreased bone density (39). Similar experiments with beagle dogs also showed slower tooth movement in denser dentoalveolar complexes (40).

Root approximation to cortical bone

It is unclear if proximity of the root apex to cortical bone is correlated to root resorption. Kaley and Phillips reported that the risk of root resorption was 20 times greater when the maxillary incisors were in close proximity to the cortical plate (31). The limitation of this study was panoramic radiographs were used to measure root resorption while the proximity of the central incisors to cortical plates was assessed in cephalometric radiographs. A similar study that used only cephalometric radiographs reported a much weaker correlation between the proximity of the root and cortex with the degree of root resorption (21). Investigations that related the width of the alveolus to root resorption are similarly conflicting. In one study, a significant correlation between a narrow alveolar width and the amount of root shortening was found only for right maxillary incisors (41) while no association was found in another study (24).

In a histological study using animals, mandibular incisors were initially moved labially through the cortical plate, and following a 4 month retention period were brought back into cancellous bone. The amount of root resorption that occurred during movement in either direction was similar. It was also shown that tooth movement in cancellous bone was 50% faster than through the cortical plate. This study addressed only the density of bone and its relationship to the degree of root resorption. In clinical reality, the duration of treatment may be the key factor that differentiates the extent of damage between moving teeth through cortical bone and through cancellous bone (42).

Bone density assessments

Although several methods to precisely determine bone density exist (single and dual photon energy X-ray absorptiometry and quantitative computed tomography), they require special radiographic facilities and are relatively expensive (43, 44). Furthermore, short-term localized changes in bone density, such as those encountered during orthodontic treatment, may not be detected by these techniques (45). For these reasons, dental radiographs have frequently been used to serve as an indirect estimate of bone density.

Of the several methods that have been developed to estimate alveolar bone density from dental radiographs, fractal analysis appears to hold the greatest promise. Fractal dimension of the mandible has been shown to increase after experimental demineralization of bone. A significantly higher fractal value was also observed in post-menopausal as compared with pre-menopausal women, suggesting that fractal analysis detects of age-related changes in bone density (46). Similarly, significantly higher fractal dimensions were found in osteoporotic patients as compared with non-osteoporotic patients after adjusting for smoking, gender, age, height and weight (47). The association of fractal dimension with bone density has also been confirmed in animal studies (48). While the fractal dimension has primarily been used to describe the structure and density of trabecular bone (49–56), it has also been found to be negatively correlated to cortical thickness (47). Thus, fractal analysis represents an economical and easily available method to estimate bone density.

Each patient's dentoalveolar complex is unique in terms of size, orientation, pattern, and density. The relationship of bone density and alveolar morphology with EARR has not been established. The purpose of this present study was to investigate these relationships in cephalometric radiographs using the latest digital image enhancement techniques. This method allowed us to measure the dimensions of mandibular incisors and surrounding osseous structures more accurately and further enabled us to study the texture and the density of trabecular bone. From these data, the effects of the root and dentoalveolar characteristics on root resorption were investigated. We measured the quality and quantity of the bone surrounding the teeth and investigated its effects on the extent of apical root resorption.

Materials and methods

Sample selection

Randomly chosen pre- and post-treatment panoramic radiographs of 700 patients, treated at the Temple University Orthodontic Clinic within the past 7 years, were screened to find patients with radiographic evidence of incisor root resorption. The records were reviewed and patients with a history of, systemic illness, craniofacial abnormalities, tooth injury, endodontically treated teeth, or impacted teeth were excluded from the study. The resultant study group included 22 patients comprised of 12 females and 10 males aged 10.4–30.3 (mean 14.9) years at initiation of treatment. They were treated for 15–39 months (mean 26.1). Of the 22 patients, 14 were treated with extractions and eight were treated non-extraction. Tip edge mechanics were used on four of the patients and edgewise mechanics were used on the rest of the patients.

Analysis of cephalometric radiographs

Pre- and post-treatment lateral cephalometric radiographs were converted into digital format using a matrix CCD line transparency scanner (Epson 1640 xenon cold cathode fluorescent lamp; Epson Inc., Long Beach, CA, USA), employing eight bits per pixel producing images. Standard image processing algorithms were applied to reduce the variability between radiographs and processing conditions. The images were windowed and leveled such that all images were displayed over a dynamic range of 256 gray levels. An unsharp mask operator using a convolution kernel was employed to blur the image plane. This kernel was an estimation of the point spread function. The blurred input was then subtracted from the original input, removing the added blurred component along with the original out of focus information, resulting in a sharpened image.

Using an interactive software algorithm, the mandibular incisor teeth were measured for total tooth length, root length, root area (root area of lower central incisor), alveolar area (amount of the alveolar bone buccal and lingual to the root as seen on the cephalometric radiograph); cortical area (the total area of cortical bone in the symphysis), medullary area (area of medullary bone in the symphysis); and symphysis area (the total area of the alveolus). The average root width was calculated by dividing the root area by root length (Fig. 1A, B). As illustrated in Fig. 2, a region of interest within the symphysis just inferior to the tooth apex was selected. It was thresholded to select the pixels representing only the trabecular bone and the pixels representing the trabecular space. The area of the trabecular space was measured and was divided by the region of interest area. This ratio was recorded as the trabecular–space ratio. The fractal

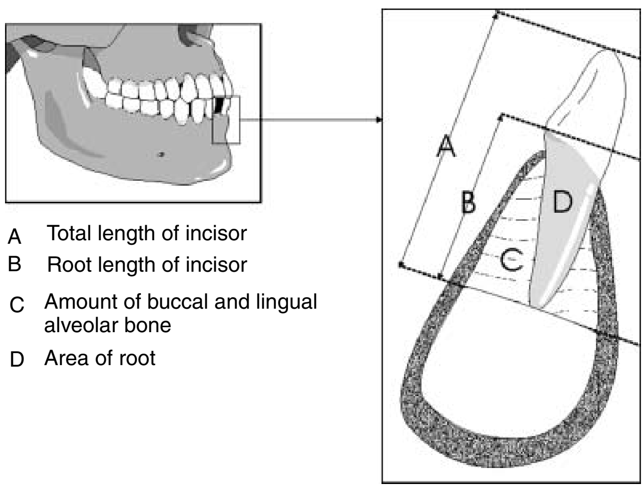

Fig. 1. Individual measurements from a cephalometric radiograph.

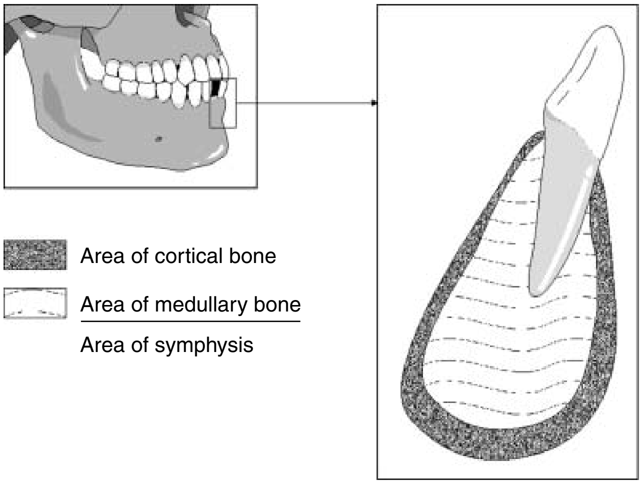

Fig. 2. Area of cortical bone, medullary bone, and symphysis.

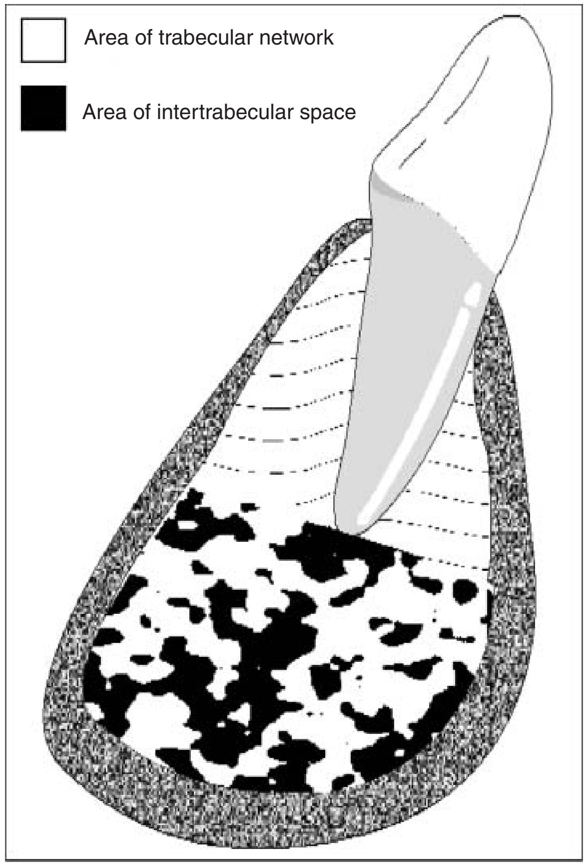

Fig. 3. The region of interest for trabecular space ratio and fractal value.

dimension was calculated as the sum of the elements of a weighted conditional gray level transition probability matrix. The formula used for fractal calculation was:

$$\sum_{i=1}^{N}\sum_{j=1}^{N}(i-j)^2 P_L(i/j)$$

Where $P_L(i/j)$ is the conditional probability of gray level i occurring L pixels away after gray level j occurs, where L is defined as the step size. N is the number of gray levels in the object and N is equal to 8 because the object gray levels are reassigned by histogram equalization into eight bins. Objects with a uniform gray will have a fractal value close to one while an object with a great variation of gray will have a larger fractal value. The fractal measurements were carried out on the same region of interest as for the trabecular–space ratio. One person carried out all of the measurements, each variable was measured in triplicate and the average value recorded (Figs 3–13).

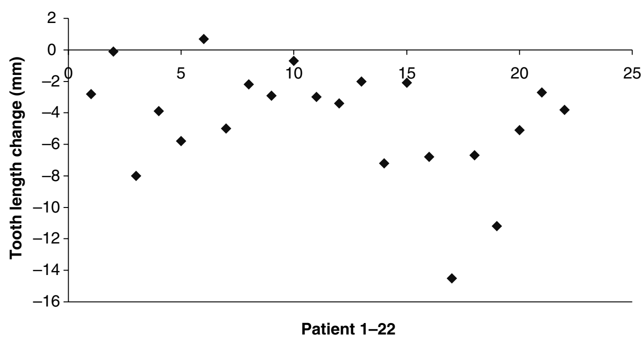

Fig. 4. Distribution of tooth length change.

Data analysis

The change of root area, tooth length, and root length were calculated by subtracting the post-treatment (T2) values from the pre-treatment (T1) values. Correlation coefficients relating the change in the root dimension to; root area (T1), average width of the root (T1), tooth length (T1), alveolar area (T1), average alveolar width/ ratio of alveolar area to root length (T1), root–alveolar ratio, ratio of root area to alveolar area, (T1), medullary

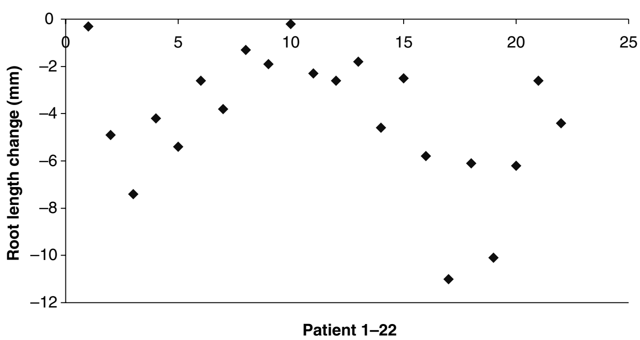

Fig. 5. Distribution of root length change.

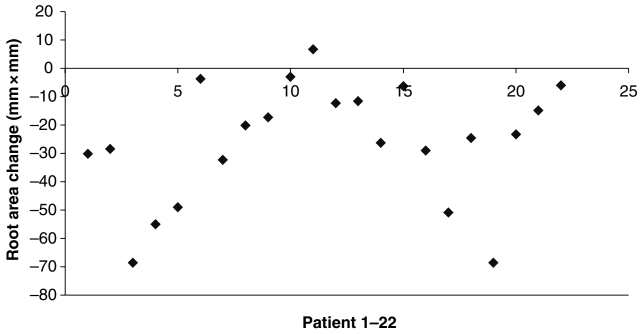

Fig. 6. Distribution of root area change.

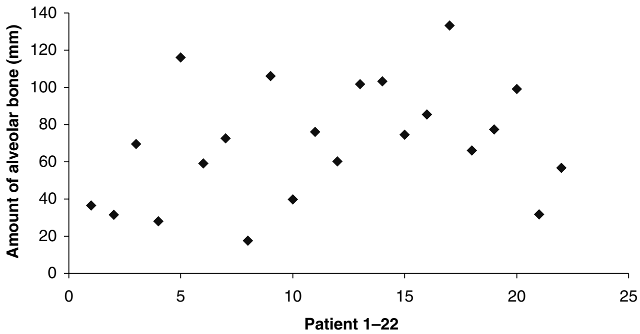

Fig. 7. Distribution of alveolar area.

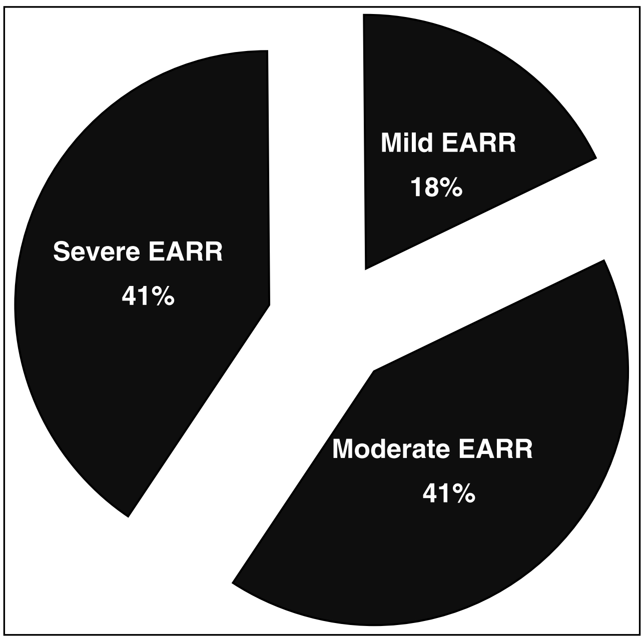

Fig. 8. The percentage distribution of the mild, moderate, and severe EARR groups.

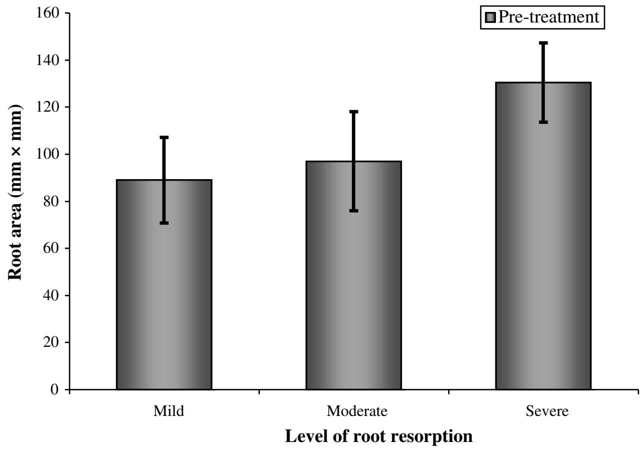

Fig. 9. Mean root area for mild, moderate and severe EARR groups.

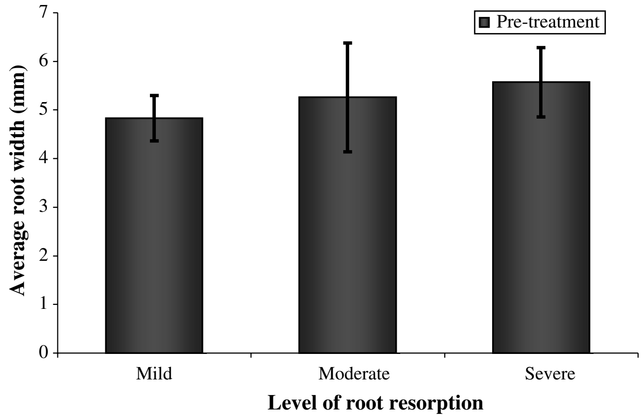

Fig. 10. Mean average root width for mild, moderate, and severe EARR groups.

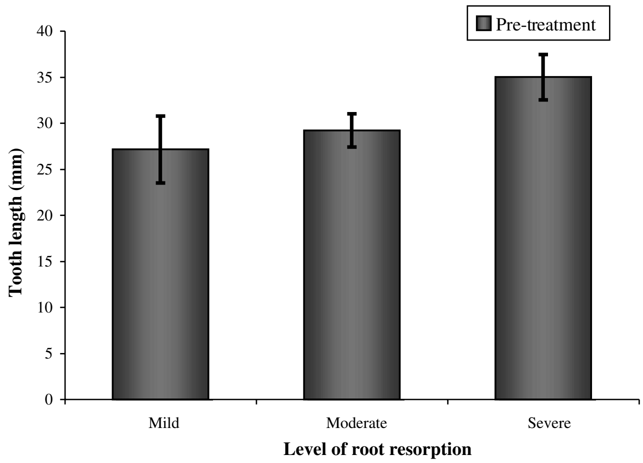

Fig. 11. Mean tooth length of mild, moderate, and severe EARR groups.

area (T1), medullary area (T2), cortex Area (T1), cortex area (T2), cortex–medullary ratio, cortex area divided by medullary area (T1), cortex–medullary ratio (T2). The resulting correlation coefficient ranges from +1.0 (perfect positive correlation) through 0 (no correlation) to −1.0 (perfect negative correlation). Scores of

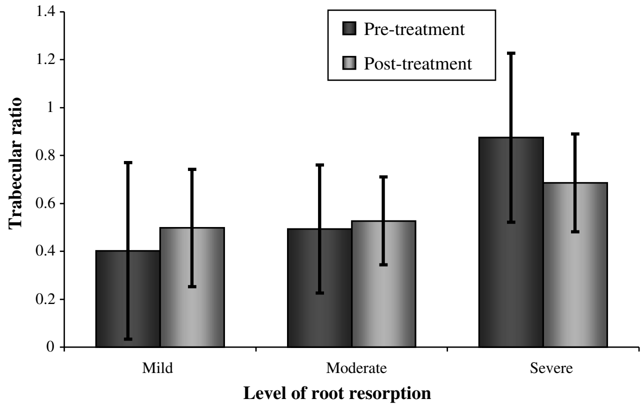

Fig. 12. Mean trabecular space ratio of mild, moderate, and severe EARR groups.

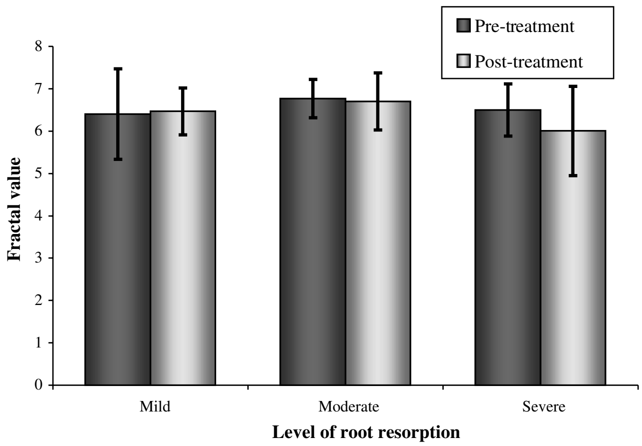

Fig. 13. Mean fractal value of mild, moderate, and severe EARR groups.

0.00–0.30 indicate low, 0.40–0.79 indicate moderate, and 0.80–1.00 indicate high correlation.

Results

Measurements of the tooth length change ranged from 0.7 to −11.2 mm. The mean tooth length change was −4.51 ± 3.57 mm. Measurements of the root length change ranged from −0.2 to −11.0 mm. The mean root length change was −4.18 ± 2.83 mm. The measurements for the root area change ranged from −2.94 to −68.64 mm^2 and the mean root area change was −26.11 ± 20.95 mm^2 (Table 1). Root length and tooth length change were highly correlated ($r = 0.87$) while tooth length change and root area change were moderately correlated ($r = 0.70$). Root length and root area changes were moderately correlated ($r = 0.72$).

Alveolar area and average alveolar width measurements are listed in Table 2. The mean alveolar area was 70.10 ± 31.33 mm^2 and the mean average alveolar width was 3.325 ± 1.221 mm. The proportion of cortical and medullary bone as compared with the symphysis area is shown in Table 3. The mean symphysis area was 481.11 ± 70.05 mm^2 in the pre-treatment radiographs (T1) and 466.86 ± 75.44 mm^2 in the post-treatment radiographs (T2). The mean cortical area was 180.22 ± 33.43 mm^2 at T1 and 180.19 ± 35.14 mm^2 at T2. The mean medullary area was 300.89 ± 53.20 mm^2 at T1 and 286.68 ± 54.75 mm^2 at T2. The mean cortical–medullary ratio at T1 was 0.6140 ± 0.1447 and the mean cortical–medullary ratio at T2 was 0.6442 ± 0.1557 (Table 4). The mean trabecular space ratio was 0.6119 ± 0.3701 at T1 and 0.5786 ± 0.2128 at T2. The mean fractal value was 6.5890 ± 0.6701 at T1 and 6.5042 ± 0.8885 at T2.

The only variables significantly correlated to change in root area were: change in tooth length ($r = -0.79$); change in root length ($r = 0.67$); and root width ($r = -0.60$). While change is tooth length was moderately correlated with alveolar area (−0.57) and trabecular space ratio ($r = 0.57$) no significant correlation of alveolar area or trabecular space area were found with change in root area. None of the remaining variables alveolar area, root–alveolar ratio, medullary area, cortical area, cortical–medullary ratio, trabecular space ratio, and fractal value was correlated with root dimension change.

The sample was divided into three groups based on the amount of root resorption. The patients with a tooth length decrease of 2.0 mm or less were placed in the mild EARR group. Patients with a root resorption between 2.0 and 4.0 mm were placed in the moderate EARR group. Patients with a root resorption of 4.0 mm or above were placed in the more severe EARR group. Eighteen percent of the patients fell into mild EARR group and 41% of the patients were in both moderate EARR group and severe EARR group. As illustrated in Table 5, the mean of root area (T1), average root width (T1), tooth length (T1), and trabecular space ratio (T1 and T2) increased from the mild to moderate EARR group and from the moderate to severe EARR group. The mean of the fractal value (T1 and T2) did not show a consistent pattern of difference between the groups (Tables 6 and 7).

Table 1. **Measurements of lower incisor dimension**

	Root area, T1 (mm^2)	Root Area, T2 (mm^2)	Change of root area (mm^2)	Tooth length, T1 (mm)	Tooth length, T2 (mm)	Change of tooth length, (mm)	Root length, T1 (mm)	Root length, T2 (mm)	Change of root length (mm)
1	119.02	88.91	−30.11	28.8	26.0	−2.8	17.6	17.3	−0.3
2	91.71	63.26	−28.45	26.3	26.2	−0.1	20.2	15.3	−4.9
3	149.45	80.87	−68.58	34.1	26.1	−8.0	23.1	15.7	−7.4
4	119.89	64.94	−54.95	28.6	24.7	−3.9	18.6	14.4	−4.2
5	123.39	74.37	−49.02	34.2	28.4	−5.8	23.8	18.4	−5.4
6	80.60	76.95	−3.65	25.2	25.9	0.7	18.1	15.5	−2.6
7	118.70	86.46	−32.24	34.5	29.5	−5.0	24.5	20.7	−3.8
8	73.01	52.89	−20.12	26.0	23.8	−2.2	16.7	15.4	−1.3
9	112.52	95.23	−17.29	31.0	28.1	−2.9	20.5	18.6	−1.9
10	70.65	67.71	−2.94	24.6	23.9	−0.7	14.4	14.2	−0.2
11	76.21	82.97	6.76	28.9	25.9	−3.0	17.3	15.0	−2.3
12	105.11	92.81	−12.30	32.0	28.6	−3.4	20.4	17.8	−2.6
13	113.08	101.47	−11.61	32.5	30.5	−2.0	20.8	19.0	−1.8
14	118.49	92.18	−26.31	34.3	27.1	−7.2	21.7	17.1	−4.6
15	108.88	102.58	−6.30	29.5	27.4	−2.1	19.8	17.3	−2.5
16	123.59	94.58	−29.01	32.8	26.0	−6.8	21.2	15.4	−5.8
17	131.5	80.69	−50.81	40.8	26.3	−14.5	27.4	16.4	−11.0
18	119.35	94.81	−24.54	33.9	27.2	−6.7	22.0	15.9	−6.1
19	166.93	98.29	−68.64	37.1	25.9	−11.2	24.3	14.2	−10.1
20	122.46	99.19	−23.27	33.5	28.4	−5.1	23.4	17.2	−6.2
21	94.00	79.08	−14.92	27.6	24.9	−2.7	15.9	13.3	−2.6
22	64.37	58.35	−6.02	30.6	26.8	−3.8	20.0	15.6	−4.4
Mean	109.22	83.11	−26.10	31.21	26.70	−4.50	20.53	16.35	−4.18
SD	25.64	14.59	20.94	4.06	1.71	3.57	3.16	1.81	2.83

Table 2. **Correlation coefficients (*r*) of tooth length, root length, and root area change measurements**

	Correlation coefficients
Tooth length change vs. root length change	0.8707
Tooth length change vs. root area change	0.6976
Root length change vs. root area change	0.7181

Discussion

Compared with panoramic images, cephalometric radiographs have the advantage minimal distortion and a projected image closer to its actual size. The capacity to visualize the entire tooth length in a panoramic image depends on the orientation of the tooth within the tomographic image layer. Although minor magnification is present in a cephalometric image; unlike panoramics, it is consistent for all radiographs. Using cephalometric radiographs to measure the proximity of the root to the cortical plate however, has limitations. The actual anatomy of the cortical plate holds numerous curves on its outer surface. A three-dimensional image such as computed tomography provides the most accurate assessment of the amount of bone present around the root. The advantage of our cephlametric image analysis method was that certain structures in the original cephalometric radiographs were not clearly visible prior to the digital reconstruction process. Because of differences in processing conditions, the original images had varying contrast ranges; our algorithm equalized image contrast such that each image was displayed over a maximum dynamic range. Blurred inputs were taken out, improving the visibility of unclear edges. Overall, the reconstruction process allowed for better identification of the root and the

Table 3. **Alveolar area and average width of the bone**

	Alveolar area (mm^2)	Average width of the bone (mm, alveolar bone/root length)
1	36.56	2.077
2	31.61	1.561
3	69.58	3.012
4	28.07	1.509
5	116.02	4.874
6	59.08	3.264
7	72.53	2.960
8	17.58	1.052
9	106.14	5.177
10	39.72	2.758
11	75.99	4.392
12	60.23	2.952
13	101.64	4.886
14	103.21	4.756
15	74.53	3.764
16	85.49	4.032
17	133.22	4.862
18	66.09	3.004
19	77.40	3.185
20	99.08	4.234
21	31.68	1.992
22	56.80	2.840
Mean	70.10	3.325
SD	31.33	1.221

cortical plate, and for more accurate measurements of their length and area. Determining bone density using dental radiographs is an indirect technique and represents an approximation of the true value. In the present study, we used the cortex–medullary ratio, the trabecular space ratio, and the fractal analysis to estimate the bone density. The cortex–medullary ratio has previously been linked to bone density (57). The trabecular space ratio provides a numerical estimate of the proportion of medullary with respect to cortical bone. Higher values indicate a greater area of intertrabecular space vs. bone trabeculae. The fractal dimension has been shown to represent an estimate of bone density bone (49–56, 58).

The mean difference in tooth length change and root length change was only 0.32 mm. This finding confirms that most of the change occurred at the root. Since root resorption is a three-dimensional change, we measured both the change in length as well as change in root area. Overall, differences in root area, tooth length, and root length in pre- and post-treatment measurements were correlated. The tooth length change and the root length change measurements showed a higher correlation with each other than with the root area change measurements. The differences can also be explained by the fact that root area measurements were more error prone. Measurements of root area required tracing the entire root, while length measurements consisted of merely identifying of two end points. The differences in their correlation can also be due to the fact that the root area change measurement contains both the horizontal and the vertical components while the length measurement records only the vertical change. In terms of the amount of periodontal attachment loss, the root surface area is the most crucial dimension (4).

Short roots have been considered to undergo more EARR (8, 11). The present study, however, showed that pre-treatment tooth length and the root length were both correlated to the amount of root resorption. Thus, a greater amount of root resorption was observed on larger roots. These findings are in agreement with the more recent study conducted by Mirabella and Årtun (24). The correlation coefficients of the vertical tooth dimensions (root length and the tooth length) vs. the change in root area, however, were not as high. Similarly, the average width of the root (T1) was correlated with the root area change, but not with the tooth length change or the root length change. These correlations suggest that the root resorption occurred in proportion to the size of the root, but the changes in horizontal dimension were not correlated with the changes in vertical dimension. The finding that larger roots resorb more is an interesting one. It suggests the possibility that a bigger root might be seated in a denser trabecular space. We analyzed this potential, but could not demonstrate that the size of the root and bone density was correlated.

Our measurements of alveolar bone were designed to test the effect of osseous characteristics on root resorption. The proximity of the root to the cortical plate was found to have only a minimal effect on the extent of resorption. The pre-treatment alveolar area was slightly correlated with tooth length and the root length change. The effect, however, decreased significantly when root length was taken out of the equation and the

Table 4. **Area of symphysis, cortex, and medullary bone in square millimeters and ratio of cortical bone area over medullary bone area**

	Symphysis (T1)	Symphysis (T2)	Cortex (T1)	Cortex (T2)	Medullary bone (T1)	Medullary bone (T2)	Cort/medu (T1)	Cort/medu (T2)
1	469.41	478.84	223.00	241.62	246.41	237.22	0.9049	1.0185
2	474.74	453.71	212.74	185.10	262.00	268.61	0.8119	0.6891
3	573.48	556.34	224.87	230.55	348.61	325.79	0.6450	0.7076
4	484.77	483.26	211.98	182.58	272.79	300.68	0.7770	0.6072
5	437.94	442.55	155.17	178.86	282.77	263.69	0.5487	0.6782
6	507.05	523.30	182.51	170.00	324.54	353.30	0.5623	0.4811
7	531.33	453.92	173.57	177.04	357.96	276.88	0.4851	0.6394
8	324.52	270.84	123.56	98.23	200.96	172.61	0.6148	0.5690
9	509.12	489.11	204.49	200.66	304.63	288.45	0.6712	0.6956
10	348.85	341.70	161.27	174.10	187.58	167.60	0.8597	1.0387
11	389.25	372.11	122.48	125.71	266.77	246.40	0.4591	0.5101
12	497.72	507.55	161.10	174.08	336.62	333.47	0.4785	0.5220
13	494.11	409.35	160.37	138.50	333.74	270.85	0.4805	0.5113
14	483.89	540.98	175.90	204.86	307.99	336.12	0.5711	0.6095
15	461.21	439.00	164.53	140.41	296.68	298.59	0.5545	0.4702
16	524.52	448.11	173.57	177.04	350.95	271.07	0.4945	0.6531
17	542.77	532.40	207.90	198.44	334.87	333.96	0.6208	0.5942
18	480.31	537.91	130.88	165.58	349.43	372.33	0.3745	0.4447
19	485.43	483.98	179.63	168.22	305.80	315.76	0.5874	0.5327
20	653.88	612.98	245.99	245.67	407.89	367.31	0.6030	0.6688
21	467.04	450.61	164.90	189.49	302.14	261.12	0.5457	0.7256
22	443.27	442.43	204.47	197.37	238.80	245.06	0.8562	0.8053
Mean	481.11	466.86	180.22	180.19	300.89	286.68	0.6140	0.6442
SD	70.05	75.44	33.43	35.14	53.29	54.75	0.1447	0.1557

comparison was based solely on root area. This finding is in agreement with the most of literature where no correlation was found between root approximation to cortical bone and the extent of EARR (21, 24, 42). The root–alveolar ratio and the size of the dentoalveolar complex were not significantly correlated with root dimension changes. These results contradict the findings of the McFadden study in which they considered the size of the mandibular symphysis to be a significant factor in determining the extent of root resorption (11).

The dimensions of the dentoalveolar complex (symphysis area, cortex area, medullary area, and the cortex–medullary ratio) remained relatively unchanged during the tooth movement (Table 4). Moreover, none of these characteristics showed a significant correlation with the extent of root resorption. Of all the dentoalveolar measurements, the trabecular space ratio had the best correlation with root dimension change, but it was still not high enough to be considered as a significant factor.

Dense bone has previously been considered to cause more EARR under the premise that it would induce more pressure on the root (39). We found that fractal dimension was not correlated with root length or root area change. These results are consistent with Wainwright's study, which concluded that bone density does not affect the amount of root resorption (42).

All of our findings suggest that the density and morphology of the dentoalveolar complex have at best a minimal effect on root resorption. Perhaps attention needs to be shifted to other tissues surrounding the root. During orthodontic treatments, roots can be moved out of bone into soft tissue as was evident in our sample group. Can the soft tissue have a significant

Table 5. **Measurements of trabecular space ratio and fractal value**

Patient	Trabecular space ratio (T1)	Trabecular space ratio (T2)	Fractal value (T1)	Fractal value (T2)
1	0.6188	0.3072	6.6110	6.4080
2	0.2997	0.3831	5.4730	6.7420
3	0.7877	0.5484	6.6456	3.6664
4	1.1306	0.8057	7.6899	7.0611
5	0.5540	0.3727	6.8664	5.8532
6	0.3991	0.8140	7.5578	6.8432
7	1.0873	0.5747	7.2956	5.6513
8	0.2411	0.4747	6.8628	8.0989
9	0.3624	0.4235	6.6520	7.5134
10	0.1010	0.2679	5.5184	6.9820
11	0.5363	0.5659	6.2683	7.2605
12	0.3300	0.5761	6.9177	6.2150
13	0.1926	0.3196	5.8933	5.7005
14	1.2214	0.8580	6.8476	6.6496
15	0.3501	0.2488	7.1735	6.1781
16	0.3284	0.5415	5.9028	6.9444
17	1.0058	0.7701	5.4706	6.3886
18	1.0308	0.7060	7.5644	6.0689
19	0.6588	0.8994	6.9052	6.8355
20	1.3565	0.9263	6.0842	6.0426
21	0.5097	0.7338	6.3138	6.5119
22	0.3593	0.6107	6.4451	7.4762
Mean ± SD	0.6119 ± 0.3701	0.5786 ± 0.2128	6.5890 ± 0.6701	6.5042 ± 0.8885

effect on root resorption? The periodontal ligament is another structure that can potentially have an impact on root resorption. During orthodontic tooth movements, the periodontal ligaments rearrange. Is it possible these rearrangements of periodontal ligament fibers influence root resorption? Questions such as these have not yet been answered. In order to better understand external root resorption in the future, research questions should broadened and untouched possibilities explored.

Conclusions

(1) The size of the incisor and the root were related with the extent of root resorption. Root resorption in the vertical direction was negatively correlated with the length of the incisor and the root. Root resorption in the horizontal plane was negatively correlated with the width of the root.

(2) The amount of alveolar bone present around the root showed no significant effect on the extent of root resorption.

(3) The thickness of cortical bone displayed no significant correlation with the amount of the root resorption.

Table 6. **Correlation coefficients (*r*) between mandibular variables**

	Change in root surface area	Change in tooth length	Change in root length
Root area (T1)	−0.8225	−0.7240	−0.6745
Average root width (T1)	−0.5983	−0.3061	−0.1826
Tooth length (T1)	−0.5877	−0.9072	−0.7903
Alveolar area (T1)	−0.1811	−0.5748	−0.4857
Average alveolar width (T1)	0.0635	−0.3850	−0.2476
Root–alveolar ratio	−0.2816	0.2288	0.1824
Medullary area (T1)	−0.4116	−0.3779	−0.2471
Medullary area (T2)	−0.4188	−0.5733	−0.2893
Cortex area (T1)	−0.1672	−0.1928	−0.4033
Cortex area (T2)	−0.2676	−0.1078	−0.3680
Cortex/medullary (T1)	0.2289	0.1842	−0.0845
Cortex/medullary (T2)	0.1736	0.3823	−0.0015
Trabecular space ratio (T1)	−0.3918	−0.5123	−0.4697
Trabecular space ratio (T2)	−0.3921	−0.5732	−0.3032
Fractal value (T1)	0.0508	0.0893	−0.2952
Fractal value (T2)	0.2646	0.3122	0.0640

Table 7. **The mean variables in the mild, moderate, and severe EARR groups**

	Mild RR	Moderate RR	Severe RR
Root area (T1) (mm^2)	89.01 ± 18.21	97.00 ± 21.02	130.42 ± 16.80
Average root width (T1) (mm)	4.83 ± 0.47	5.26 ± 1.12	5.57 ± 0.71
Tooth length (T1) (mm)	27.15 ± 3.63	29.22 ± 1.82	35.02 ± 2.46
Trabecular space ratio (T1)	0.405 ± 0.368	0.493 ± 0.267	0.875 ± 0.353
Trabecular space ratio (T2)	0.498 ± 0.245	0.527 ± 0.184	0.686 ± 0.204
Fractal value (T1)	6.401 ± 1.071	6.770 ± 0.453	6.502 ± 0.617
Fractal value (T2)	6.467 ± 0.554	6.696 ± 0.674	6.004 ± 1.052

(4) The density of the trabecular network in the mandibular symphysis showed no significant correlation with the amount of the root resorption.
(5) Fractal measurements on the bony trabeculae inside the symphysis showed no significant correlation with the amount of root resorption.

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