DIGITAL SUBTRACTION RADIOGRAPHY OF PANORAMIC RADIOGRAPHS TO EVALUATE MAXILLARY CENTRAL INCISOR ROOT RESORPTION AFTER ORTHODONTIC TREATMENT

Aim: To quantitatively assess the extent of morphologic changes of the apical root area and root length of maxillary central incisors after orthodontic treatment using digital subtraction radiography (DSR) and to investigate possible contributing parameters. Methods: The subtracted images of panoramic radiographs of 21 patients before and after orthodontic treatment were evaluated using I/RAS C and Image J software. The retrieved data were analyzed by means of SPSS statistical software, and the method's error was assessed. Results: There was a small but significant decrease of the root dimensions of the maxillary central incisors at the end of orthodontic treatment. The amount of root resorption was not significantly influenced by sex, age, dentition, malocclusion classification, extraction, overjet, overbite, elastic wear, and number of teeth with resorption as measured by DSR. Conclusion: DSR of pre- and posttreatment panoramic radiographs was able to confirm minor root resorption of the maxillary central incisors after orthodontic treatment. World J Orthod 2010;11:142–152.

Key words: root resorption, panoramic radiographs, subtraction radiography, orthodontic treatment, orthodontic tooth movement

Since the first observation of root resorption by Ottolengui and Ketcham in 1914 and 1927, respectively (cited by Beck and Harris1), many articles have confirmed a relationship between orthodontic treatment and external root resorption of the incisors,2–9 as well as that of other teeth.10–15

Root resorption is an unpredictable and irreversible pathologic adverse effect of orthodontic treatment. Its causes are unclear, but systemic, genetic, and treatment-related factors may be involved.16 Systemic or genetic factors may include sex,17,18 patient age,19,20 type of tooth,21 stage of root development,22,23 presence of ectopic teeth,18,24,25 abnormal apical root formation,2,18,26–30 trauma or endodontic treatment,17,22,27,28,31–33 tongue dysfunction (open bite),23,34,35 and allergies,36 as well as endogenetic features.2

Treatment-related factors of apical root resorption may involve duration of orthodontic treatment19,21,22,26,37,38; specific orthodontic appliances and/or treatment techniques1,22,39,40; type of tooth movements, such as intrusion, extrusion, or change in inclination2,41–43; magnitude of applied forces2,21,22,26,44; and intermaxillary elastics and headgear.40,46

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According to current literature, it seems that after orthodontic treatment, patients usually experience mild to moderate apical root resorption of the maxillary central incisors. The amount of resorption varies between 1.00 mm to almost 3.00 mm. These differences may be attributed to one of the aforementioned therapy-related factors, as well as to the length of the follow-up period.

In previous investigations, root resorption was detected mainly through periapical, panoramic, and cephalometric radiographs, as well as through light and scanning electron microscope images. The degree of apical root resorption was usually evaluated by visual scoring. These visual comparisons have, however, inherent limitations, such as interpretation disagreement between two evaluators, or of the same evaluator at different times, as well as limitations to detect small lesions.

During the past 3 decades, digital subtraction radiography (DSR) was introduced into dental radiology. It proved to be efficient in the detection of small lesions of hard tooth tissue. This technique is based on the digital subtraction of one radiographic image from another; thus, the resultant image shows only the differences between the first and second image.

However, the accuracy of DSR is questionable because radiographic images are seldom standardized in brightness, noise, contrast, or projection geometry. In addition, no mechanical device can preserve image geometry. Since 1980, new methods were introduced to correct inconsistencies in image contrast or geometric discrepancies by means of geometric reconstruction algorithms using specific reference points. Dunn et al. showed that it takes four reference points to align a pair of digital radiographic images taken at different projection angles, for example, as a consequence of orthodontic tooth movement. Recently, subtraction registration templates are used to accurately process digitized images and minimize the amount of noise in the subtracted images, further enhancing the efficiency of the DSR technique.

Further, specialized software, such as EMAGO (Oral Diagnostic Systems, ACTA), I/RAS C (Intergraph), MicroStation (Bentley Systems), and DIGORA for Windows (Soredex) have increased diagnostic accuracy.

In contrast to the significant number of studies dealing with the quantitative evaluation of root resorption in orthodontic patients by means of conventional radiographs, the literature concerning root resorption assessed by DSR is relatively lacking.

It was hypothesized that (1) the DSR of panoramic radiographs cannot detect any external apical root resorption of the maxillary incisors following orthodontic treatment and (2) the parameters involved in orthodontic treatment, such as sex, age, dentition, malocclusion classification, extractions, overjet, overbite, and elastics wear, do not affect the amount of root resorption.

Therefore, the aim of this retrospective study was to quantitatively assess the changes of the root area and length of the maxillary incisors following orthodontic treatment by means of DSR of panoramic radiographs, as well as to assess whether such changes are related to any of the various parameters involved in orthodontic treatment.

**MATERIAL AND METHODS**

To select the appropriate number of patients for this investigation, a power analysis for sample size calculation with \( \alpha = .05, 1-\beta = 0.8, \) and effect size index \( d = 0.7 \) was performed. With regard to the hypothesis of no changes in root morphology of the maxillary incisors following orthodontic treatment, calculations revealed that a sample of at least 19 patients was necessary. However, more patients were initially included to account for eventual exclusions or dropouts.

This retrospective investigation was based on panoramic radiographs of patients taken with the same equipment (Orthopantomograph 10E, Palomex Instrumentarium) before and after orthodontic treatment. These radiographs were part of the standard diagnostic records.
and consecutively selected from the archives of the Postgraduate Clinic of the Department of Orthodontics of the Aristotle University of Thessaloniki, Greece. Informed written consent was obtained from all patients or their guardians.

A total of 26 consecutive patient files were selected initially. The selected patients presented with a Class I or II relationship and were treated with or without premolar extractions and fixed appliances. Some Class II patients were treated additionally with extraoral forces or functional appliances. All treatments were performed by the postgraduate students of the department under the supervision of faculty members.

Inclusion criteria were complete records, including patient history and treatment plans, study casts, and pre- and posttreatment panoramic and lateral cephalometric radiographs. Files of patients with dental agenesis or a history of trauma or endodontic treatment of the maxillary incisors were excluded from the sample (n = 5). Thus, 21 patients (12 females and 9 males) remained for further evaluation.

The mean age of the sample at the start of orthodontic treatment was 13.7 ± 2.7 years (range 9.0 to 21.0 years), suggesting that at this time, the maxillary incisors had fully developed roots, except of one 9-year-old patient with probable residual root growth. The detailed characteristics of the study sample are presented in Table 1.

The complete DSR procedure was performed by one investigator. Initially, all panoramic radiographs were converted into digital images by scanning them with an Epson Perfection 3170 scanner (Epson) at a resolution of 300 dpi. Image processing was performed with a Compaq Presario Notebook 705EA equipped with a 15-inch SVGA monitor using the Windows-based I/RAS C 7.0 software (academic edition).

The I/RAS C software has several tools, of which some can adjust contrast and modify image geometry. The geometry commands allow for image registration and point collection to warp and manipulate the geometric orientation of an image. The coordinates of one image must first be assigned, which is referred to as warping, so the image is altered to best fit the coordinates. The actual mathematical algorithms that convert the source coordinates to those of another coordinate system are called transformation models.

In the present study, projective transformation models were used. This transformation has eight parameters that describe a 2D projection between two planes from one center of perspective.

The I/RAS C software was also used for gamma correction to match the histogram of the follow-up to the baseline image. After the density and contrast of the images were corrected, the same software was used to adjust the images for reversible projection errors at the x- and y-axis, as well as to geometrically transform each follow-up image to match the corresponding baseline image.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Characteristics of the study sample</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>9</td>
<td>42.9</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>12</td>
<td>57.1</td>
<td></td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 12 y</td>
<td>7</td>
<td>33.3</td>
<td></td>
</tr>
<tr>
<td>&gt; 12 y</td>
<td>14</td>
<td>66.7</td>
<td></td>
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<tr>
<td><strong>Dentition stage</strong></td>
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<tr>
<td>Mixed</td>
<td>2</td>
<td>9.5</td>
<td></td>
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<tr>
<td>Permanent</td>
<td>19</td>
<td>90.5</td>
<td></td>
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<tr>
<td><strong>Malocclusion classification</strong></td>
<td></td>
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<tr>
<td>Class I</td>
<td>3</td>
<td>14.3</td>
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<tr>
<td>Class II</td>
<td>18</td>
<td>85.7</td>
<td></td>
</tr>
<tr>
<td><strong>Tooth extractions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>5</td>
<td>23.8</td>
<td></td>
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<tr>
<td>Without</td>
<td>16</td>
<td>76.2</td>
<td></td>
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<tr>
<td><strong>Overjet</strong></td>
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<tr>
<td>≤ 4 mm</td>
<td>9</td>
<td>42.9</td>
<td></td>
</tr>
<tr>
<td>&gt; 4 mm</td>
<td>12</td>
<td>57.1</td>
<td></td>
</tr>
<tr>
<td><strong>Overbite</strong></td>
<td></td>
<td></td>
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<tr>
<td>≤ 3 mm</td>
<td>11</td>
<td>52.4</td>
<td></td>
</tr>
<tr>
<td>&gt; 3 mm</td>
<td>10</td>
<td>47.6</td>
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<tr>
<td><strong>Wear of elastics</strong></td>
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<tr>
<td>Yes</td>
<td>15</td>
<td>71.4</td>
<td></td>
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<tr>
<td>No</td>
<td>6</td>
<td>28.6</td>
<td></td>
</tr>
<tr>
<td><strong>No. of teeth with resorption</strong></td>
<td></td>
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<td></td>
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<tr>
<td>1 tooth</td>
<td>13</td>
<td>61.9</td>
<td></td>
</tr>
<tr>
<td>2 or more teeth</td>
<td>8</td>
<td>38.1</td>
<td></td>
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</tbody>
</table>
Due to the magnification error usually inherent to panoramic radiographs, it was decided to evaluate only the maxillary incisors. Because the focal trough is aligned with the maxillary dentition and the patient is instructed to bite forward into the bite rod positioning device, these teeth seemed to be less distorted than the mandibular incisors. Therefore, the maxillary incisor section was cropped from all initial and follow-up images.

To correlate the pre- and posttreatment radiographs, four recognizable anatomical landmarks were identified on the initial image: (1) the crest of the maxilla at the mesial surface of the maxillary incisors, (2) the crest of the maxilla at the distal surface of the maxillary incisors, (3) the anterior nasal spine, and (4) the floor of the nasal cavity or the junction with the anterior border of the maxillary sinus. These reference points were as far from each other as possible, but still readily identifiable. When the crest of the maxilla was not clear, the proximal and distal edges of the incisors were used.

Following identification of the corresponding points on the follow-up image, the I/RAS C software applied the projective algorithm to identify and correlate the coordinates of each pixel of the initial image with the corresponding one of the follow-up one. After detection of the pattern, the points of the two images were matched and a correlation value was calculated. A correlation between 0.8 and 1.0 was considered good. If it was less than 0.8, the entire procedure was repeated until a higher value could be accomplished. Only then was the follow-up image reconstructed according to the wrap model.

**Fig 1** Subtraction radiography to assess a possible root resorption of the right maxillary central incisor of a 12-year-old girl. (a) Section of the panoramic radiograph before treatment, (b) corresponding section after treatment, and (c) application of the I/RAS C software to collect control points to match the follow-up with the baseline image. (ci) Selection of approximate control points on the follow-up image, (cii) selection of a refined control point close to the approximate control point at the zoomed-in area of the same image, (ciii) selection of approximate input points on the baseline image, and (civ) selection of a refined input point close to the approximate input point at the zoomed-in area of the same image. (d) The subtraction of the baseline and reconstructed image performed by means of Adobe Photoshop software. (e) The resulting subtracted image corresponding to the morphologic changes occurred in the apical root area of the right maxillary central incisor during orthodontic treatment. Note the minimal root resorption that took place.
After mathematic correction of the distortion, the Emboss filter was applied to both radiographs using Adobe Photoshop 6.0 software (Adobe Systems). Then, the two images were superimposed with the Move tool, creating a two-layer image. The opacity of the secondary layer was approximately 40% to 60% decreased to observe both images simultaneously. In the next step, the apical region of the incisors of the baseline image was subtracted from the follow-up one. The resulting image represented the root resorption, which took place during orthodontic treatment (Figs 1 and 2). This difference was measured as absolute and relative root resorption by means of the Image J software 1.240 (http://rsb.info.nih.gov/ij/).

The absolute root resorption (area measurement) was calculated by counting the total number of pixels of the subtracted image. The relative root resorption (length measurement) was determined using the formula $(L_1 - L_2)/L_1 \times 100$, where $L_1$ is the tooth length in pixels before and $L_2$ the tooth length in pixels after treatment. Furthermore, to allow a comparison of these data with the results of previous studies, the mean value of relative root resorption was converted to millimeters using the equation 1 pixel = 0.085 mm, since all images were scanned at a resolution of 300 dpi.

To assess the method error, the DSR and the measurement procedure were repeated for all variables and patients after a 4-week interval by the same investigator. The magnitude of the method's error $s(i)$ was calculated by means of the Dahlberg formula, and the reproducibility...
of the measurements (intraexaminer correlation) by means of the Pearson correlation coefficient (r).

Initially, descriptive statistics were performed. Then, data distribution for each variable was evaluated by means of the Shapiro-Wilk test. According to the results of these tests, the one-sample Student t test was applied. However, because the Shapiro-Wilk test revealed a skewed distribution for the absolute root resorption (area) variable, two observations (1 and 20) were omitted because they deviated remarkably in the total number of pixels (50 and 49 pixels, respectively, as compared to 5 to 36 pixels for the rest of the sample).

Analysis of variance (ANOVA) and the two independent samples Student t test were used to investigate whether the various parameters/factors involved in orthodontic treatment affect the amount of root resorption.

All statistical evaluations were performed by means of the software SPSS 14.0 for Windows (SPSS) and the level of significance for all analyses was set at P < .05.

### RESULTS

The evaluation of the maxillary central incisor root resorption by means of DSR was associated with a significantly small method error and a large positive correlation, as shown in Table 2.

According to the results of the Student t test evaluation (Table 3), there was a small but statistically significant difference concerning the absolute root resorption (area) (16.32 ± 8.09 pixels, P < .001) when the two outliers were excluded from the evaluation, as well as concerning the relative root resorption (length) (7.72 ± 5.19 pixels, P < .001).

The Student t test, as well as the ANOVA, revealed that there were no statistically significant effects of the various parameters to the mean value of root resorption (Table 4).

### DISCUSSION

External apical root resorption has been often associated with orthodontic treatment, while maxillary incisors are considered the most affected among all teeth.1–7,8,14,22,26,31,41,72,73 However, data concerning the amount of root resorption are difficult to compare due to the lack of a standardization of serial radiographs and of quantitative evaluation of root resorption.

The initial sample in the current investigation contained 26 patients, from which 5 were excluded, resulting in 21 for the final analysis. Hence, a computation of the power of a two-sided one-sample t test with n = 21 showed that the probability of rejecting a false null hypothesis was greater that 84%.
This retrospective study presents some limitations. The increase in distortion and magnification of panoramic radiographs as compared to periapical ones may lead to an overestimation of root resorption of 20% or more. Nevertheless, it was found that panoramic radiographs are sufficiently accurate for measuring root changes if the occlusal plane is not tilted more than 10 degrees. Panoramic radiographs were used for this evaluation because they are routinely taken before, during, and after orthodontic treatment. Another drawback to register 3D structures in 2D images is that during orthodontic treatment, tooth inclination may change, which affects the radiographically depicted root length. Further, the present study lacks data of a control (untreated) patient sample. However, for ethical reasons, exposing individuals to radiation without treatment benefit cannot be justified.

In the present study, root resorption of the maxillary central incisors was assessed by means of DSR. Because DSR allows direct comparison of two images of the same object at two time points, the focus of this study was mainly the efficiency and reproducibility of the method. The method error evaluation revealed no significant inaccuracy. In addition, a good intraexaminer correlation was observed between the initial and the repeated measurements. Thus, DSR per se, as well as the methodology used in this study, could be considered appropriate.

Because only a few studies concerning root resorption assessed by means of DSR have been published to date, the comparison of the results of this study with data from other studies can only be limited. Absolute root resorption amounted to 19.5 ± 12.6 pixels, with a minimum of 5.0 and a maximum of 50.0 pixels. After exclusion of the outliers, the

### Table 4  Results of the assessment of the effects of the various factors of the study sample on the corresponding variables under investigation by means of the Student t test and ANOVA

<table>
<thead>
<tr>
<th>Factor/levels</th>
<th>Absolute root resorption (area) [pixels]</th>
<th>Relative root resorption (length) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td><strong>Sex</strong></td>
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<tr>
<td>Male</td>
<td>24.11</td>
<td>15.40</td>
</tr>
<tr>
<td>Female</td>
<td>16.00</td>
<td>9.23</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 12 years</td>
<td>23.57</td>
<td>13.84</td>
</tr>
<tr>
<td>&gt; 12 years</td>
<td>17.43</td>
<td>11.92</td>
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<td>Permanent</td>
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<td>4.36</td>
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<td><strong>Tooth extractions</strong></td>
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<td>With</td>
<td>16.40</td>
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<tr>
<td>Without</td>
<td>20.44</td>
<td>13.73</td>
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<tr>
<td><strong>Overjet</strong></td>
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<tr>
<td>≤ 4 mm</td>
<td>14.78</td>
<td>6.96</td>
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<tr>
<td>&gt; 4 mm</td>
<td>23.00</td>
<td>14.89</td>
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<tr>
<td><strong>Overbite</strong></td>
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<td>≤ 3 mm</td>
<td>17.09</td>
<td>11.94</td>
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<tr>
<td>&gt; 3 mm</td>
<td>22.10</td>
<td>13.40</td>
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<td><strong>Wear of elastics</strong></td>
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<td>14.24</td>
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<td><strong>No. of teeth with resorption</strong></td>
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<td>1 tooth</td>
<td>20.08</td>
<td>14.52</td>
</tr>
<tr>
<td>2 or more</td>
<td>18.50</td>
<td>9.50</td>
</tr>
</tbody>
</table>
mean value decreased to 16.3 ± 8.1 pixels, which was still statistically significant. Even if the apex of the maxillary central incisors seems to be frequently affected by orthodontic treatment, the amount of root resorption is minimal; although it is statistically significant, it is of less clinical importance. In fact, the observed small amount of root resorption would not impact treatment planning decisions. However, DSR may be used optionally in everyday clinical practice because it enables early detection of root resorption.

To obtain a more representative assessment of the apical root resorption, the extent of root length shortening was also measured. To correlate a given loss of the root length, the relative amount of root length shortening was evaluated, which amounted to 7.7% ± 5.2% (range: 0% to 16.8%). This is in agreement with the results of Reukers et al45 who observed a mean loss of 7.8% of the initial total tooth length.

After conversion of pixels to mm,66 the mean value of root shortening observed in this study was 0.7 mm ± 0.4, which is again in agreement with Heo et al55 and Smale et al,75 who found a root resorption of approximately 0.5 mm.

Consequently, concerning both the amount of absolute root resorption (area) as well as of relative root resorption (length), the present findings are comparable to those of other studies also using DSR.46,56,66,75

According to the results of this investigation, no significant relationship was found between sex, patient age, dento- tional stage, classification of malocclusion, tooth extractions, overjet, overbite, use of intermaxillary elastics, and number of teeth presented with root resorption on one side and the absolute or relative root resorption of the maxillary central incisors on the other side. These results are not in accordance with those of some previous studies, which reported that the degree of resorption is correlated with factors such as sex, tooth extractions, and type of malocclusion.26,40,42,49 This inconsistency could be attributed either to the small sample of the current study or to the methods used in the various studies.

The detection of even minimal lesions in the current investigation may suggest that DSR is a valuable diagnostic tool in everyday clinical practice. The early detection of root morphology changes during orthodontic treatment is clinically important to prevent irreversible defects.

Finally, it should be also taken into consideration that root resorption is a 3D phenomenon, while DSR, which uses conventional or digital radiographs, can assess hard tissue alterations in only 2D. Future advances and more sophisticated methods based on mainly the introduction of new imaging technologies, such as computed tomography (CT) or cone beam CT,76–80 may lead to an accurate 3D evaluation of morphologic root changes during orthodontic treatment.

CONCLUSION

According to the results of this investigation, the application of DSR in panoramic radiographs was able to detect minimal changes of root morphology of the maxillary central incisors after orthodontic treatment. DSR was associated with a significantly small method error and a positive intraexaminer correlation, thus indicating that the technique may be sufficiently reliable for clinical use. Although the observed changes were statistically significant, they were too small to be clinically significant.

In addition, no significant relationship was found between the various factors under investigation and root resorption of the maxillary central incisors.

REFERENCES


