Original Article

A Comparison of Three Methods to Accurately Measure Root Length

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Abstract: Measuring the severity of root shortening after orthodontic treatment is a common problem in the dental fields as well as in litigation, legislation, and the ethics arena. The most common method to evaluate root length shortening is by using periapical radiographs. Surprisingly, root elongation after orthodontic treatment in adult patients was reported in the past. The aims of this study were to measure the effects of angular changes between the tooth and the film on the length of the image of a tooth model, to compare three methods to accurately measure root length in different films, and to find the most accurate reference points on the tooth for calculating root lengths. Five amalgam dots were placed on an acrylic model of a maxillary central incisor: ie, most apical, most incisal, mesial CEJ, distal CEJ, and most apical CEJ on the buccal side. The tooth model was placed in a special jig and radiographed at four different film-to-tooth angulations. Root and crown lengths were measured on both the model itself and on a computer monitor displaying the image that resulted from scanning the film into the computer. The results revealed that angular changes between the tooth and the film affect the measured tooth length. The midpoint between the mesial CEJ point and the distal CEJ point (median CEJ) was the best reference point for measuring root length. This was true when the calculations were done with the rule-of-three formula. (*Angle Orthod* 2004;74:786–791.)

Key Words: Root resorption; Accurate measurement; Compensatory formulas

INTRODUCTION

Orthodontically induced inflammatory root resorption (OIIRR) is an inevitable consequence of tooth movement.[1,2] In most instances, this phenomenon is clinically asymptomatic. Although OIIRR is rarely serious, it is a devastating event when it is recognized radiographically, especially when the results of treatment are esthetically and functionally excellent.

In the majority of teeth that were moved by orthodontics, the amount of root loss cannot be detected even with the best imaging techniques. However, when root shortening exceeds a certain amount, the only way to diagnose it is by using roentgenic procedures, such as periapical,[3–6] panoramic,[7] and cephalometric radiographs,[8–10] or computerized tomography and magnetic resonance imaging.[11]

During the last decade, there has been an increased interest in OIIRR primarily because of two reasons, ie, the mapping of the human genome leading to the idea that this might assist in better understanding the pathologic process[12,13] and the number of legal claims against orthodontists mainly because of root shortening. In the December 2002 issue of ‘‘Seminars in Orthodontics,’’ the most commonly discussed legal examples were related to OIIRR.[14]

The literature discussing OIIRR reports the use of at least two methods to evaluate the amount of root shortening.[3–6,15–17] Most methods attempt to accurately quantify the OIIRR[3–6] whereas others are more descriptive in nature.[18,19]

The severity of OIIRR is classified commonly by the amount of root material loss.[18,19] There are various methods to measure accurately the amount of OIIRR. The straightforward method is to subtract the measured radiographic posttreatment tooth length from the pretreatment one.[3] However, because several problems are encountered in taking and analyzing periapical radiographs, two common for-

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FIGURE 1. The model used in the study.

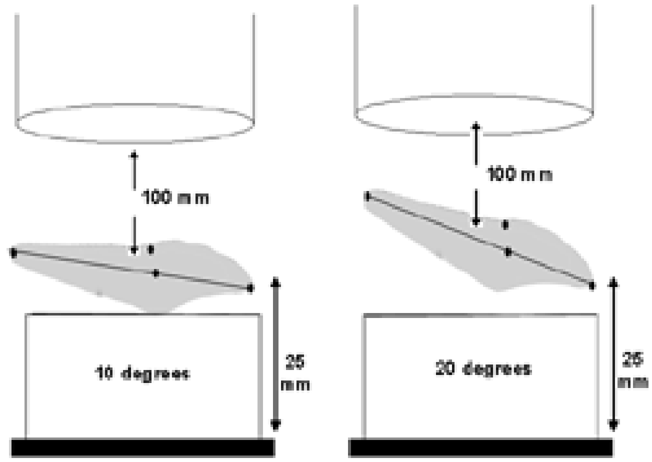

FIGURE 2. The scheme of the jig and the holding device demonstrating 10° (left) and 20° (right) between the tooth and the film—the black line at the bottom of the scheme.

mulas have been developed to compensate for these problems, the rule of three[4] and the crown and root adjustment.[5]

The unexpected reports of root elongation after orthodontic treatment in nongrowing patients[3,20,21] provided a significant incentive to conduct this study. Several factors could interfere with accurate measurements of OIIRR. Therefore, the objectives of this study were to measure the effects of angular changes between the tooth and the film on the radiographic image of a tooth model, to compare three methods to accurately measure root length in different films, and to find the most accurate reference points on the tooth for calculating root lengths.

MATERIALS AND METHODS

Five small amalgam dots were placed on an acrylic model of a maxillary central incisor at the apical edge, incisal edge, mesial CEJ, distal CEJ, and most apical CEJ on the buccal side. The tooth was placed in a special jig built to imitate the actual clinical conditions of the paralleling periapical radiographic technique. The film was placed 25 mm away from the incisal edge of the tooth, and the cone was positioned 100 mm away from the center of the tooth. A special holding device and the jig kept the film parallel to the roentgenic cone, such that the central X-ray beam was always perpendicular to the film. The tooth was radiographed at angles of 10°, 20°, 30°, and 40° to the film (Figures 1 and 2). The distance from the edges of the crown to the cone was kept constant. The films were all developed under the same conditions (Dentax 810 Basic) and later scanned using an Umax Astra 2400S scanner. The image of the tooth was enlarged 7× and analyzed using Adobe Photoshop 5 software (Adobe, San Jose, Calif).

To determine and calculate the changes in root length in two different films, two CEJ points were defined: buccal CEJ, the most apical CEJ point on the buccal side of the crown and median CEJ, the midpoint between the mesial CEJ and distal CEJ points.

Once a week for four consecutive weeks, each of two senior residents (Dr Goren and Dr Zoizner) measured the length of the model tooth using a dial caliper with ground tips (Dentarum, Pforzheim, Germany) and measured the following distances directly on the computer monitor using Photoshop software tools (Figure 3): the total tooth length, from the incisal edge dot image to the apical edge dot image; the root length, as measured from the buccal CEJ dot image to the apex and the median CEJ to the apical edge dot image; the crown length, as measured from the buccal CEJ dot image to the incisal edge dot image and the median CEJ dot image to the incisal edge dot image.

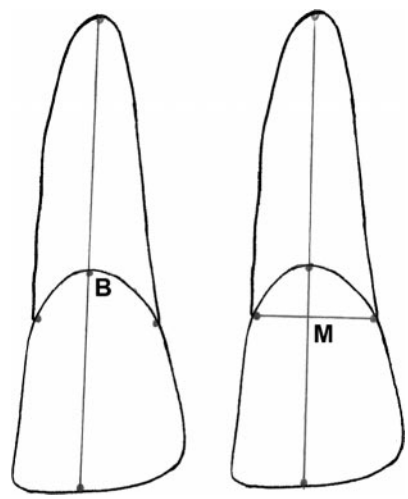

FIGURE 3. B Buccal CEJ and the M Median CEJ as defined in the text and the methods used for the measurements.

The model tooth length was compared with the total tooth lengths measured at the four different angles.

The root lengths and the crown lengths served as data to examine three formulas[3–5] (see below) that compensate for angular and enlargement changes between different radiographs.

TABLE 1. Total Tooth Lengths as Measured at Four Different Angles on the Monitor[a]

The Angle Between the Tooth and the Film (°)	Total Tooth Length (mm)
10	27.39 ± 0.06
20	26.01 ± 0.10
30	24.13 ± 0.10
40	21.99 ± 0.08

[a] $P < .001$ when compared with the tooth model.

TABLE 2. The Subtraction Results of Total Tooth Lengths Due to Angular Changes[a,b] (Formula 1)

The Angular Change (°)	The Subtraction Value (mm)
From 10 to 20	−1.38 ± 0.16
From 20 to 30	−1.89 ± 0.19
From 30 to 40	−2.14 ± 0.14
From 10 to 30	−3.26 ± 0.14
From 10 to 40	−5.40 ± 0.18
From 20 to 40	−4.02 ± 0.15

[a] Negative signs mean that the root became shorter. Opposite angular changes ie, from 20 to 10 etc, reverse the sign from minus to plus, meaning that the root became longer.
[b] $P < .001$, see text.

1. Mirabella and Årtun[3] calculated the root length changes simply by subtracting the measured radiographic posttreatment tooth length from the pretreatment one (formula 1).
2. Linge and Linge[4] used the rule-of-three formula to calculate root length changes due to orthodontic treatment (formula 2). It is assumed that during orthodontic treatment the crown length does not change (unless it was fractured). Therefore, the ratio between the initial crown length (C1) and the final crown length (C2) determines the enlargement factor. If no changes occurred in the root length during treatment, the ratio between the initial root length (R1) and the final root length (R2) should be equal to the C1/C2 ratio. If during treatment the root was shortened, the amount of OIIRR is R1−R2 (C1/C2).
3. McFadden et al[5] used adjustments for the crown length (Cx) and the root length (Radj) in both radiographs (formula 3):
   $Cx = (C1 + C2)/2$;
   $(Radj) = R1\ (Cx/C1)$.
   The amount of OIIRR is $Radj - R2$.

It is important to note that the length of the tooth was not changed during the experiment.

Statistics

One-tail and two-tail Student's *t*-tests were used to compare the different results. StatView 5.1 (Cary, NC) for Macintosh was used to analyze the data. $P < .05$ was considered statistically significant.

Method error

Method error analysis was conducted by the two examiners randomly measuring 10 different parameters on both the tooth model and the computer monitor on two separate occasions. The size of the error was calculated using Dahlberg's formula.[21] The method error of the measurements was less than 0.2 mm.

RESULTS

Table 1 presents the total tooth length in four different angles. The length of the tooth model itself was 25.01 ± 0.1 mm and was significantly different from the measured tooth length on the monitor in all four angles (<.001).

Table 2 presents the subtraction results of total tooth lengths in different angles. It reveals that using subtraction with no compensation formula gives a different result with statistical significance than that of the hypothesized mean of zero value ($P < .001$). The calculated values presented in Table 2 consistently increase as the angle between the tooth and the film increases. For example, if during treatment there was a 10° change in the angle between the tooth and the film ie, from 10° to 20°, 1.38 mm of tooth shortening could be calculated and reported. On the contrary, 1.38 mm of tooth elongation could be reported if the angular change is reversed.

Table 3 presents the measured values of the root length and crown length using the buccal CEJ and the median CEJ as bisecting reference points. Again, the larger (from 10° to 40°) the angle between the tooth and the film, the smaller the measured values ($P < .005$).

Table 4 presents the effect of angular changes on the amount of root length changes using formulas 2 and 3. The results of Table 3 are the database for the results of Table

TABLE 3. The Crown Lengths and the Root Lengths According to the Two Defined CEJ's (mm)

The Angle Between the Tooth and the Film (°)	Crown Length According to the Buccal CEJ (mm)	Root Length According to the Buccal CEJ (mm)	Crown Length According to the Median CEJ (mm)	Root Length According to the Median CEJ (mm)
10	10.94 ± 0.09	16.41 ± 0.14	9.75 ± 0.08	17.51 ± 0.06
20	9.66 ± 0.07	16.31 ± 0.06	9.30 ± 0.12	16.63 ± 0.15
30	8.50 ± 0.08	15.64 ± 0.14	8.45 ± 0.08	15.4 ± 0.13
40	7.12 ± 0.13	14.90 ± 0.11	7.95 ± 0.24	13.96 ± 0.16

TABLE 4. Changes in Root Lengths According to Formulas 2 and 3 Using the Defined CEJ's (mm)[a,b]

The Angular Changes Between the Tooth and the Film (°)	Buccal CEJ		Median CEJ	
	Formula 2	Formula 3	Formula 2	Formula 3
From 10 to 20	−2.05 ± 0.32	−0.82 ± 0.95	0.08 ± 0.22	0.45 ± 0.16
From 20 to 30	−1.57 ± 0.23	−0.35 ± 0.18	0.11 ± 0.34	0.73 ± 0.14
From 30 to 40	−2.04 ± 0.28	−0.48 ± 0.25	0.21 ± 0.42	0.81 ± 0.20
From 10 to 30	−3.83 ± 0.27	−1.05 ± 0.19	0.21 ± 0.32	1.17 ± 0.08
From 10 to 40	−6.46 ± 0.21	−1.31 ± 0.22	0.38 ± 0.51	1.97 ± 0.20
From 20 to 40	−3.90 ± 0.12	−0.72 ± 0.24	0.28 ± 0.59	1.53 ± 0.28

[a] Negative signs mean that the root became shorter. Opposite angular changes, ie, from 20 to 10 etc, reverse the sign from minus to plus, meaning that the root became longer.

[b] $P < .005$, see text.

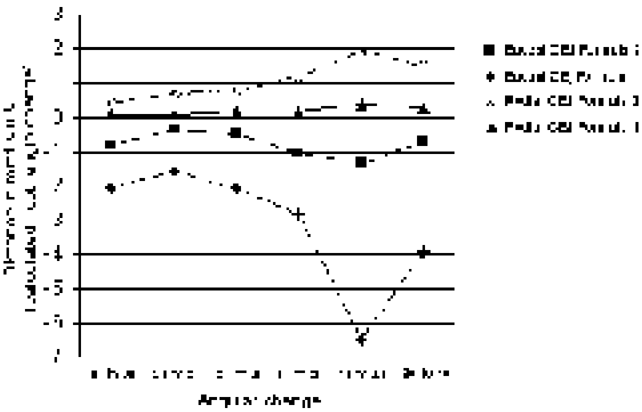

FIGURE 4. The graph represents the average results for each CEJ point using formulas 2 and 3.

FIGURE 5. Holding the film in the mouth of the same patient using the same device, demonstrates two angles between the horizontal line and the device. The left one is more acute.

4. All calculations using the buccal CEJ in both formulas are negative (below the zero line in the graph of Figure 4), whereas using the median CEJ gives the opposite results (above the zero line in the same graph). Therefore, if the angle between the tooth and the film increased and the buccal CEJ was used for studying the amount of root shortening, one can report that the root was shortened, when actually no change occurred in the root length. Of course, angular changes in the reverse direction might lead to a root elongation report. There is a statistical significant difference when all methods were compared ($P < .005$).

DISCUSSION

The literature discussing OIIRR reports that the average amount of root loss after treatment is between 0.45 and 1.5 mm.[3,4,9,16,17,20] This study compares three mathematical procedures to find the best reference point and the best formula to measure root shortening. All changes in tooth and root lengths observed in Tables 2 and 4 are attributed only to angular changes between the tooth and the film. Because the tooth model was not shortened during the experiment, the expected results in all calculations should be zero. Hence, the larger the result (positive or negative) the more inaccurate the method.

The results in Table 1 and the differences in length between the tooth model and its radiographic images are not surprising. When a long body is radiographed in different angles to the film, its length will be changed. Therefore, several formulas are used to compensate for this angulation and magnification changes.

The parallel periapical radiographic technique hides several factors that might affect the picture seen on the film, such as film and patient position (Figure 5), bending of the upper part of the film against the palate (Figure 6),[22–24] and crown-to-root angle. Even with a skilled technician, the same machine, and the same laboratory, the reproducibility of making the same errors in the same directions while taking radiograph is questionable.

The special jig that was individually designed and built for this study overcame most of the above variables and left the angular changes between the tooth and the film as the only parameter affecting the measurements.

The results of this study in Table 2 are contrary to those of Mirrabella et al,[3] and simple subtraction cannot serve as an accurate method to measure root or tooth length changes. This might explain why root elongation in nongrowing patients was reported previously.[3,20,21]

The outcome shown in Table 4 and Figure 4 needs spe-

FIGURE 6. The film as it was radiographed in a skull. No parallelism of the film to the tooth and bending of the film in the palate vault are apparent.

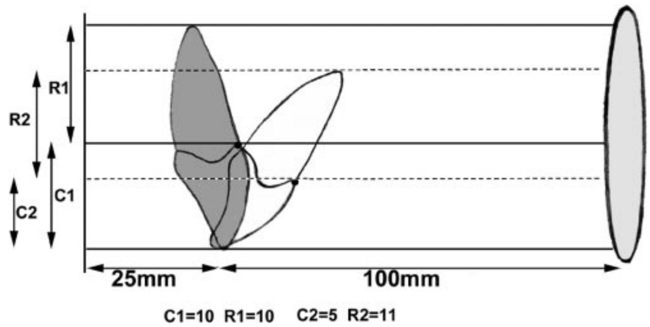

FIGURE 7. The angular change of the tooth with buccal CEJ point serves as a reference to measure the root length changes. C1 and R1 are the measured crown and root of the gray tooth on the film whereas C2 and R2 are the same of the white tooth. The difference is due to angular change only. The units are just as comparative reference. (C1 = 10, R1 = 10, C2 = 5, R2 = 11). It is clear that the ratio between the crowns (C1/C2) and the roots (R1/R2) is not equal.

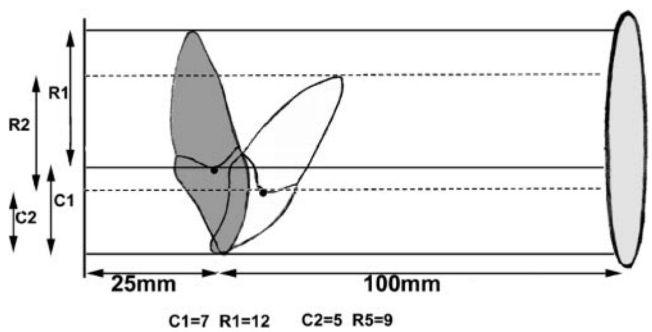

FIGURE 8. The angular change of the tooth with Median CEJ point serves as a reference to measure the root length changes. C1 and R1 are the measured crown and root of the gray tooth on the film whereas C2 and R2 are the same of the white tooth. The difference is due to angular change only. The units are just as comparative reference. (C1 = 12, R1 = 7, C2 = 9, R2 = 5). It is clear that the ratio between the crowns (C1/C2) and the roots (R1/R2) remains almost equal.

cial attention. The differences in the results relating to the CEJ points are because of three-dimensional structure and Euclidian geometric principles. The buccal CEJ lies on the surface of the tooth, whereas the median CEJ is located along the virtual long axis of the tooth. Figures 7 and 8 are two-dimensional schemes that explain the differences between the two CEJ points during angular changes. When the buccal CEJ is the reference point (Figure 7), the ratio C1/C2 is not equal to the ratio R1/R2. However, this ratio is almost equal where the median CEJ (Figure 8) is the bisecting reference point.

The differences in the results relating to formulas 2 and 3 for each CEJ are more complicated. Formula 2, the rule of three, is more accurate when the median CEJ is used. Formula 3 is more accurate when the buccal CEJ is used. For the same angular changes, it is obvious from Figures 7 and 8 that the buccal CEJ reference point moves further than the median CEJ. Therefore, another adjustment is needed to overcome the use of the rule of three, and the formula suggested by McFadden et al[5] compensates better for this change. Instead of using the C1/C2 ratio as in formula 2, the ratio {(C1 + C2)/2}/C1 is used. According to Table 3, when the angle between the tooth and the film increases, C2 is smaller than C1, and, therefore, it is clear that (C1 + C2)/2 is smaller than the C1 value. Consequently, the adjustment ratio {(C1 + C2)/2}/C1 is smaller than C1/C2. Thus, it is not surprising to see that all the results using formula 3 give longer roots when compared with the results using formula 2 for both CEJ points (the lines of formula 3 are graphically above the lines of formula 2 in Figure 4).

The answer to the problematic question, which CEJ point (buccal or median) serves better for calculating the changes of root length in different films and what formula (2 or 3) compensates more accurately for the magnification and angular changes, is given in both Table 4 and Figure 4. In grading the four methods, the best one uses the median CEJ with formula 2, followed by the buccal CEJ using formula 3. The worst method found in this study is to use the buccal CEJ and formula 2.

The results of the study cannot ignore the fact that when the angular changes between the tooth and the film are small (up to 10°) the inaccuracy in using both CEJ points and both formulas is less than one mm.

In another study (accepted for publication), we found that, on a periapical film taken with the paralleling technique, angular changes between the tooth and the film affect the identification of buccal CEJ point but not the mesial CEJ or distal CEJ points. These findings in conjunction with the results of the current study accentuate the importance of using the mesial and the distal CEJ in the study of root shortening during OIIRR.

CONCLUSIONS

Angular changes between the tooth and the film affect the length of the tooth and root as measured on the radiographs. Therefore, simple subtraction of the root or tooth length, as it appeared on two periapical films, before and after treatment, is inaccurate, and may demonstrate shortening or elongation, depending on the direction of these angular changes.

The best method to overcome this inaccuracy and calculate root shortening is by using the median CEJ (the midpoint between the mesial CEJ and distal CEJ points) and the rule of three (formula 2).

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