

Change in Root Angulation of Maxillary Molars and Incisors After Orthodontic Treatment

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A handwritten signature in black ink, appearing to read "B. Clum". The signature is written in a cursive style with a long, sweeping underline.

Date: December 9, 2012

University of Washington

**Abstract**

Change in Mesiodistal Root Angulation of Maxillary Second Molars and Lateral Incisors  
Following Orthodontic Treatment

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**Introduction:** Proper root parallelism is an important goal of orthodontic treatment that allows for the best possible functional and esthetic result. Maxillary lateral incisors and second molars are two common teeth for which practitioners fail to achieve acceptable root parallelism. The aim of this study was to investigate angulation changes that non-parallel roots of maxillary lateral incisors and second molars undergo after orthodontic treatment. **Methods:** Records of 68 patients with angled roots of interest were analyzed immediately following orthodontic treatment,  $T_1$  (average age  $16.1 \pm 3.7$  years) and at long-term follow-up,  $T_{\text{Latest}}$  ( $15.4 \pm 4.5$  years). Panoramic radiographs were used to measure the mesiodistal angulations of roots at both time points. Dental casts, lateral cephalometric radiographs, and patient demographic information were used to analyze factors that could be associated with interradicular angulation changes occurring between  $T_1$  and  $T_{\text{Latest}}$ . **Results:** On average, lateral incisors uprighted  $4.79 \pm 3.23$  degrees, and second molars uprighted  $5.52 \pm 5.33$  degrees. Gender (male) and age at  $T_1$  were significantly associated with incisor uprighting. Interradicular angulation at  $T_1$  and increased facial height were significantly associated with uprighting of both incisor and molar roots. **Conclusions:** On average, non-parallel roots of maxillary lateral incisors and second molars tend to upright after orthodontic treatment. Poor interradicular angulation at  $T_1$  and factors involving vertical facial growth leading to tooth eruption are associated with greater

change. Despite angulation improvements on average, some patients did not experience favorable mesiodistal root angulation changes. Therefore, it is recommended that clinicians attempt to parallel roots during orthodontic treatment.

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Finally, I would like to thank my parents for their undying support and emphasis on education as well as my son for the light he brings into my life. And to my ever-supportive, loving, and patient wife: Thank you for everything. I never could have done this without you.

## **DEDICATION**

To my beloved wife, Jenna. I promise.

## INTRODUCTION

One of the aims of orthodontic treatment is to obtain ideal root parallelism.<sup>1,2</sup> Adequate root parallelism helps to achieve proper crown alignment, occlusion, marginal ridge heights, and interproximal contacts.<sup>3</sup> It can also allow for adequate disbursement of occlusal forces within the periodontium.<sup>4</sup>

Maxillary second molars and lateral incisors are two common teeth for which orthodontists fail to achieve acceptable root parallelism. After orthodontics, maxillary second molar roots are often angulated mesially due to incomplete expression of bracket prescription, minimal available arch length in the jaw, and the close proximity of unerupted third molars. Additionally, if maxillary second molar eruption is delayed, these teeth may not be bracketed during orthodontic treatment. In some situations, the most esthetic alignment of the crown of a maxillary lateral incisor may result in mesial angulation of the root.

Although many orthodontists believe that root parallelism is an important aspect of orthodontic treatment, little is known about possible angulation changes that may occur following treatment. Research has been conducted to show that root angulation changes can occur following completion of orthodontic treatment.<sup>5,6</sup> However, there does not appear to be any published research that has investigated any quantifiable mesial or distal root angulation changes that occur in non-parallel maxillary second molars and lateral incisors after orthodontic treatment when adjacent teeth were present.

The purpose of this study is to investigate whether mesiodistal root angulation changes occur after orthodontic treatment in non-parallel maxillary lateral incisors and second molars as well as the factors associated with any measureable changes.

## MATERIALS AND METHODS

### Subjects

Records of 68 patients were collected from the University of Washington Department of Orthodontics Post Retention Archive. The records were selected according to the following criteria:

- At least 1 maxillary lateral incisor or second molar with a mesiodistal interradicular root angulation of at least 10 degrees with an adjacent reference tooth immediately following orthodontic treatment
- No extraction of teeth adjacent to, or in occlusion with, maxillary lateral incisors or second molars (excluding third molars) after orthodontic treatment
- No significant orthodontic relapse of the maxillary dentition
- No abnormal root morphology
- No significant loss of maxillary alveolar bone

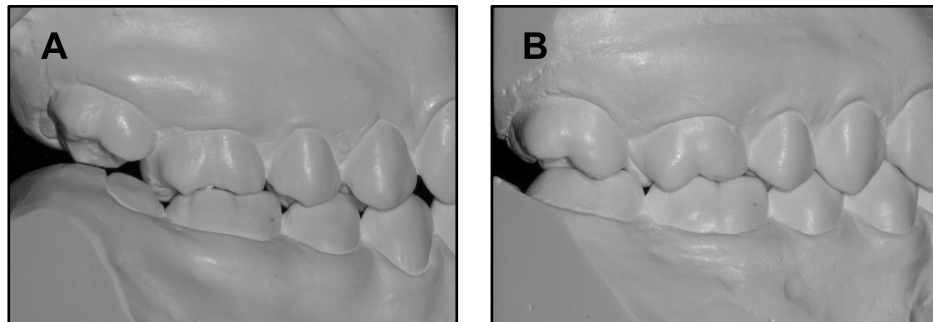
No exclusions were made due to extraction of teeth, orthodontic relapse, abnormal root morphology, or bone loss.

Panoramic and lateral cephalometric radiographs and dental casts were collected for each patient at two time points:  $T_1$ , final orthodontic records immediately after treatment, and  $T_{\text{Latest}}$ , the latest post-retention record available. The average  $T_1$ - $T_{\text{Latest}}$  interval was 15.4 years (8.4-27.3) (**Table I**). Non-identifying demographic information available for all patients in the post-retention archive was searched for age and gender for each selected patient. The institutional review board at the University of Washington approved the record gathering and analysis.

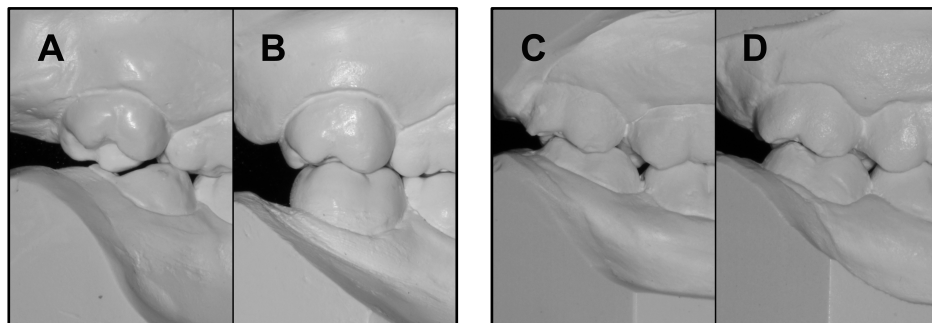
A pilot study was conducted in order to estimate an adequate sample size based on a power calculation. To achieve a power of study of at least 90%, with an effect size of 2.0 and an  $\alpha$  level of 0.05, at least 20 lateral incisors and 59 second molars would be required for the study. A total sample of 24 maxillary lateral incisors and 103 maxillary second molars was analyzed.

### Dental Cast Measurements

Dental casts from both time points were examined to determine the presence of occlusal contact of the study teeth (**Figure 1**). Additionally, the  $T_1$  and  $T_{\text{Latest}}$  dental casts were subjectively compared for improvement in occlusal contacts between the two time points (**Figure 2**).



**Figure 1.** Occlusal Contact. An example of a tooth without occlusal contact at completion of orthodontic treatment (A) and another with contact (B).

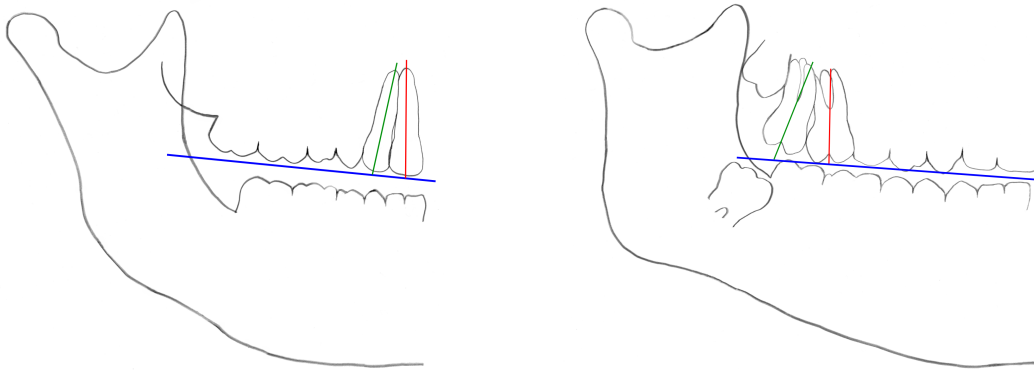


**Figure 2.** Occlusal Contact Improvement. An example of occlusal contact improvement from completion of treatment (A) to follow-up (B) and an example of no occlusal contact improvement from completion of treatment (C) to follow-up (D).

### Radiographic Measurements

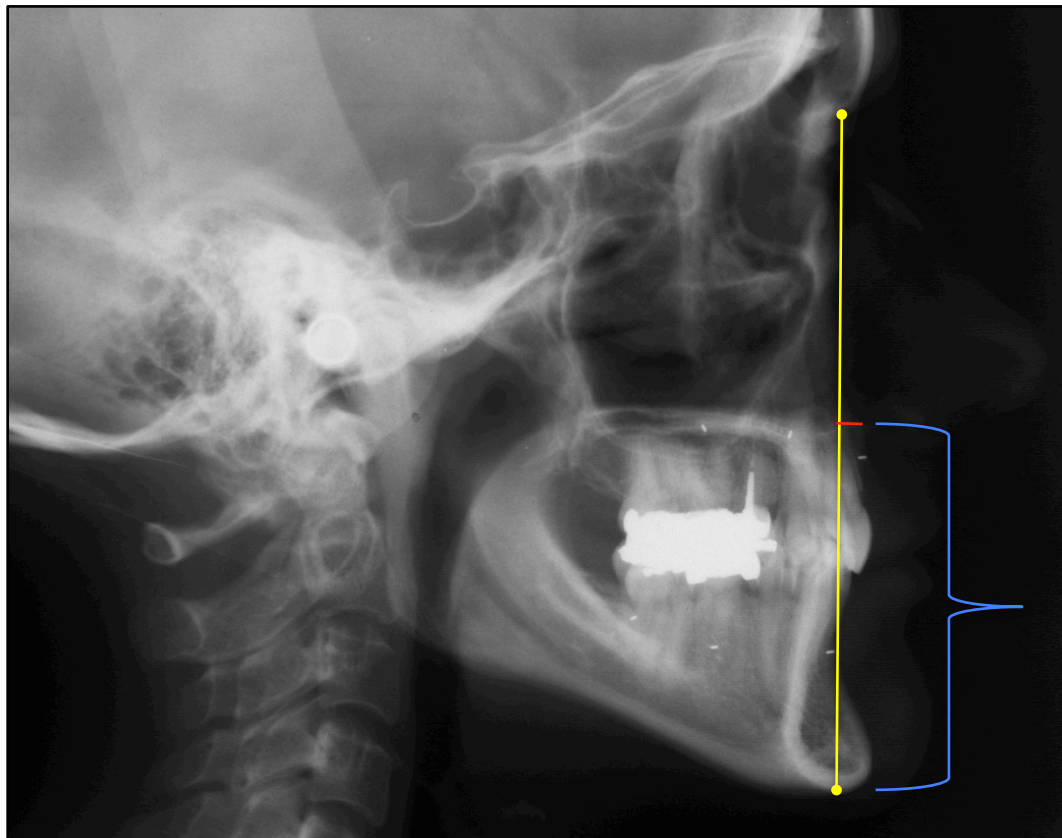
Panoramic radiographs were scanned, imported, and analyzed using ImageJ, a public domain Java image-processing program developed at The National Institutes of Health that can be downloaded from the Internet at <http://rsb.info.nih.gov/ij/download.html>. During the digitization process the images were assigned random numbers to de-identify and randomize the images. The angulation of the maxillary lateral incisors and second molars were measured in relation to the occlusal plane and compared with the same measurement of adjacent reference teeth in order to determine the interradicular angulation between the two teeth.

Central incisors served as reference teeth for lateral incisors and first molars for second molars. To determine the long axes of teeth, the midpoint of the incisal edge or cusp tip and root apex were used for single-rooted teeth. The occlusal aspect of the buccal groove and bi- or trifurcation was used for multi-rooted teeth. Measurements were made to the nearest 0.1 degree (**Figure 3**). Two examiners (B.C.A. and L.G.H.) separately measured the interradicular angulations of 10 randomly selected panoramic images (28 total teeth) on two occasions one week apart to ensure examiner reliability. A single examiner (B.C.A.) evaluated the remaining images at each time point.



**Figure 3.** Interradicular Angulation Measurement. Diagrammatic representation of measurements performed on panoramic radiographs to determine interradicular angulation.

Lateral cephalometric radiographs were measured manually to the nearest 0.5 mm. A line was constructed from Anterior Nasal Spine perpendicular to a line connecting Nasion and Menton. A measurement was made from the intersection of these lines to Menton to determine Lower Facial Height (LFH) (**Figure 4**). A single examiner (B.C.A.) evaluated the LFH at both time points. Measurements for 20 randomly selected images were repeated and recorded one week after initial measurements.



**Figure 4.** Lower Facial Height Measurement. Diagrammatic representation of measurement performed on lateral cephalometric radiographs to determine lower facial height.

### Data Analysis

Incisor and molar angulations were considered separately for all calculations. The interradicular angles were measured on panoramic radiographs at  $T_1$  and  $T_{\text{Latest}}$ . The measurements from the two time points were compared using a paired t-test.

Factors possibly associated with interradicular angulation changes after orthodontic treatment were then analyzed. Because some patients had multiple teeth with interradicular angles greater than 10 degrees, not all individual teeth could be considered as independent. Therefore, a linear Generalized Estimating Equations method was utilized to account for potential dependence between the variables of interest. The following factors were analyzed

individually using univariate regression: gender, age at  $T_1$ , interval from  $T_1$  to  $T_{Latest}$ , change in LFH from  $T_1$  to  $T_{Latest}$ , interradicular angulation at  $T_1$ , whether the tooth was in occlusion at  $T_1$ , whether the tooth came into occlusion between  $T_1$  and  $T_{Latest}$ , whether the occlusal contacts improved from  $T_1$  to  $T_{Latest}$ , whether maxillary third molars were present at  $T_1$ , whether maxillary third molars were removed between  $T_1$  and  $T_{Latest}$ , and whether premolars were extracted as part of orthodontic treatment. Change in LFH from  $T_1$  to  $T_{Latest}$ , interradicular angulation at  $T_1$ , and whether maxillary third molars were removed between  $T_1$  and  $T_{Latest}$  were analyzed together in a single multivariate model in order to account for any overlap of variable effects. All analyses were performed using SPSS 19.0.0.1 ([www.ibm.com/software/analytics/spss/](http://www.ibm.com/software/analytics/spss/)) with a significance level set at 0.05.

### **Measurement Error**

The examiners' reliability was assessed using Pearson's product-moment correlation coefficients ( $r$ ) for repeated measurements and the error of measurement (EM) was calculated using Dahlberg's formula.<sup>7</sup> For the panoramic images, the intra-examiner reliability was 99% for one examiner (B.C.A.) and 96% for the other (L.G.H.) with an EM of 0.01 degrees and 0.02 degrees respectively. The inter-examiner reliability was 96% with an EM of 0.33 degrees. For the cephalometric measurements the intra-examiner reliability was 98% with an EM of 0.01 mm.

## RESULTS

**Table I.** Sample Descriptors – Continuous Factors. Sample descriptive statistics of continuous factors.

	Incisors			Molars		
	Mean	Median	St. Dev.	Mean	Median	St. Dev.
Age at T <sub>1</sub>	17.19	15.92	5.94	15.87	15.17	2.91
Time from T <sub>1</sub> to T <sub>Latest</sub>	16.04	15.04	5.64	15.25	14.58	4.17
Change in Facial Height	3.63	3.00	2.76	2.54	2.00	2.68
Interradicular Angulation at T <sub>1</sub>	11.78	10.90	1.94	19.73	19.40	5.43

**Table II.** Sample Descriptors – Binary Factors. Sample descriptive statistics of binary factors.

	%	
	Incisors	Molars
Gender (Male)	38.0	35.0
Occlusal Contact at T <sub>1</sub> (Yes)	67.0	82.0
Occlusal Contact from T <sub>1</sub> to T <sub>Latest</sub> (Yes)	57.0	100.0
Improved Occlusal Contact (Yes)	33.0	74.0
3rd Molars Present at T <sub>1</sub> (Yes)	87.5	93.2
3rd Molars Removed between T <sub>1</sub> and T <sub>Latest</sub> (Yes)	79.2	79.6
Premolars Extracted During Treatment (Yes)	79.2	47.6

**Change In Interradicular Angulation (Incisors).** At the end of orthodontic treatment (T<sub>1</sub>), the average interradicular angulation between maxillary lateral and central incisors was 11.78° (95% CI [11.00, 12.60]). The average interradicular angulation at T<sub>Latest</sub> was 7.00° (95% CI [5.89, 8.09]). The average change in interradicular angulation between T<sub>1</sub> and T<sub>Latest</sub> was 4.79° (95% CI [3.43, 6.16]; p = 0.000) (**Table III**). On average, distal root movement of the lateral incisors contributed to 0.98° of the overall interradicular angulation change while 3.81° resulted from mesial root movement of the central incisors (**Table IV**).

**Change In Interradicular Angulation (Molars).** At the end of orthodontic treatment (T<sub>1</sub>), the average interradicular angulation between maxillary first and second molars was 19.73° (95% CI [18.68, 20.78]). The average interradicular angulation at T<sub>Latest</sub> was 14.21° (95% CI [13.17,

15.25]). The average change in interradicular angulation between  $T_1$  and  $T_{Latest}$  was  $5.52^\circ$  (95% CI [4.48, 6.56];  $p = 0.000$ ) (**Table III**). The overall molar interradicular change resulted from  $5.87^\circ$  of second molar root distal movement and  $0.35^\circ$  of first molar distal movement (**Table IV**).

When separately considering those patients with premolars extracted as part of orthodontic treatment the average interradicular angulation was  $18.19^\circ$  at  $T_1$  (95% CI [16.70, 19.69]) and  $13.40^\circ$  at  $T_{Latest}$  (95% CI [11.96, 14.85]). The average interradicular angulation change was  $4.79^\circ$  (95% CI [3.30, 6.29];  $p = 0.000$ ) (**Table III**) with  $4.47^\circ$  of distal second molar root movement and  $0.32^\circ$  of mesial first molar root movement (**Table IV**).

For non-extraction patients, the average interradicular angulation at  $T_1$  was  $21.12^\circ$  (95% CI [19.74, 22.50]). The average interradicular angulation at  $T_{Latest}$  was  $14.94^\circ$  (95% CI [13.47, 16.41]), and the average interradicular angulation change was  $6.18^\circ$  (95% CI [4.70, 7.66];  $p = 0.000$ ) (**Table III**). This change was comprised of  $7.06^\circ$  of distal second molar root movement and  $0.89^\circ$  of distal first molar root movement (**Table IV**).

**Table III.** Interradicular Angulation –  $T_1$  vs.  $T_{Latest}$ . The average interradicular angulation between maxillary lateral and central incisors and maxillary second and first molars (overall, premolar extraction, and non-extraction) at  $T_1$  and  $T_{Latest}$ . \* signifies statistical significance ( $p < 0.05$ ).

	N	$T_1$	$T_{Latest}$	Change	P
Incisors	24	$11.78^\circ$	$7.00^\circ$	$4.79^{*}$	0.000
Molars	103	$19.73^\circ$	$14.21^\circ$	$5.52^{*}$	0.000
Premolar Extraction	49	$18.19^\circ$	$13.40^\circ$	$4.79^{*}$	0.000
Non-extraction	54	$21.12^\circ$	$14.94^\circ$	$6.18^{*}$	0.000

**Table IV.** Interradicular Angulation – Sample Teeth vs. Reference Teeth. The average angulation change of sample and reference teeth. Positive numbers indicate distal root movement and negative numbers indicate mesial root movement.

	Individual Teeth		Total Change
	Sample	Reference	
Incisors	0.98°	-3.81°	4.79°
Molars	5.87°	0.35°	5.52°
Premolar Extraction	4.47°	-0.32°	4.79°
Non-extraction	7.06°	0.89°	6.18°

### Factors Associated With Interradicular Angulation Change (Incisors).

*Gender.* Of the 24 lateral incisors, 9 were from male patients and 15 were from female patients. On average, incisors of male patients were significantly associated with 3.23 more degrees of change toward parallel than females (95% CI [1.37, 5.09];  $p = 0.001$ ) (**Table V**).

*Age at  $T_1$ .* The average association of angulation change to age at  $T_1$  was -0.25 degrees (95% CI [-0.37, -0.14];  $p = 0.000$ ) indicating 0.25 less degrees of change toward parallel for every increase of one year in age at  $T_1$  (**Table V**).

*Time from  $T_1$  to  $T_{Latest}$ .* There was not a statistically significant association between time from  $T_1$  to  $T_{Latest}$  and change in interradicular angulation (**Table V**).

*Change in Facial Height from  $T_1$  to  $T_{Latest}$ .* There was not a statistically significant association between change in facial height from  $T_1$  to  $T_{Latest}$  and change in interradicular angulation (**Table V**). However, when controlling for interradicular angulation at  $T_1$  and removal of third molars between  $T_1$  and  $T_{Latest}$ , every millimeter of increase in anterior facial height from  $T_1$  to  $T_{Latest}$  was associated with 0.39 more degrees of interradicular angulation change toward parallel (95% CI [0.11, 0.66];  $p = 0.006$ ) (**Table VI**).

*Interradicular Angulation at  $T_1$ .* On average, for every degree of interradicular angulation away from parallel present at  $T_1$ , 0.88 degrees of increased improvement in interradicular

angulation toward parallel occurred with univariate analysis (95% CI [0.43, 1.33];  $p = 0.000$ ) (**Table V**). This association remained consistent at 0.88 degrees when controlling for change in facial height from  $T_1$  to  $T_{Latest}$  and removal of third molars between  $T_1$  and  $T_{Latest}$  (95% CI [0.45, 1.31]);  $p = 0.000$ ) (**Table VI**).

*Occlusal Contact Present at  $T_1$ .* There was not a statistically significant association between the presence of occlusal contact at  $T_1$  and change in interradicular angulation (**Table V**).

*Occlusal Contact Achieved Between  $T_1$  and  $T_{Latest}$ .* There was not a statistically significant association between achieving occlusal contact between  $T_1$  and  $T_{Latest}$  and change in interradicular angulation (**Table V**).

*Occlusal Contact Improved from  $T_1$  to  $T_{Latest}$ .* On average, the interradicular angulation of teeth subjectively determined to have improvement in the quality of occlusal contact from  $T_1$  to  $T_{Latest}$  changed 2.35 more degrees toward parallel than those that did not appear to improve (95% CI [-0.49, 5.19]) (**Table V**).

*Maxillary Third Molars Present at  $T_1$ .* There was not a statistically significant association between presence of maxillary third molars prior to  $T_1$  and change in interradicular angulation (**Table V**).

*Maxillary Third Molars Removed Between  $T_1$  and  $T_{Latest}$ .* There was not a statistically significant association between removal of maxillary third molars between  $T_1$  and  $T_{Latest}$  and change in interradicular angulation when considered alone or when controlling for change in facial height from  $T_1$  to  $T_{Latest}$  and interradicular angulation at  $T_1$  (**Tables V & VI**).

*Maxillary Premolars Extracted During Orthodontic Treatment.* There was not a statistically significant association between the extraction of maxillary premolars during orthodontic treatment and change in interradicular angulation (**Table V**).

**Table V.** Factors Associated With Interradicular Angulation Change – Univariate (Incisors). The amount of interradicular angulation change between  $T_1$  and  $T_{Latest}$  of maxillary lateral and central incisors associated with different factors when considered separately. \* signifies statistical significance ( $p < 0.05$ ).

	Angulation Change	95% Confidence Interval		P
		Lower	Upper	
Gender (Male)*	3.23°	1.37	5.09	0.001
Age at $T_1$ *	-0.25°	-0.37	-0.14	0.000
Time from $T_1$ to $T_{Latest}$	0.10°	-0.07	0.27	0.260
Change in Facial Height	0.34°	-0.56	0.73	0.093
Interradicular Angulation at $T_1$ *	0.88°	0.43	1.33	0.000
Occlusion at $T_1$ (Yes)	-0.26°	-2.69	2.17	0.834
Occlusion from $T_1$ to $T_{Latest}$ (Yes)	-1.35°	-4.11	1.41	0.337
Improved Occlusion (Yes)	2.35°	-0.49	5.19	0.105
3rd Molars Present at $T_1$	2.24°	-2.22	6.71	0.325
3rd Molars Removed between $T_1$ to $T_{Latest}$	-0.56°	-4.47	3.34	0.777
Premolars Extracted During Treatment	-0.13°	-2.86	2.59	0.923

**Table VI.** Factors Associated With Interradicular Angulation Change – Multivariate (Incisors). The amount of interradicular angulation change from  $T_1$  to  $T_{Latest}$  of maxillary lateral and central incisors when controlling for covariates listed. \* signifies statistical significance ( $p < 0.05$ ).

	Angulation Change	95% Confidence Interval		P
		Lower	Upper	
Change in Facial Height*	0.39°	0.11	0.66	0.006
Interradicular Angulation at $T_1$ *	0.88°	0.45	1.31	0.000
3rd Molars Removed between $T_1$ to $T_{Latest}$	-0.56°	-4.47	3.34	0.777

### **Factors Associate With Interradicular Angulation Change (Molars).**

*Gender.* There was not a statistically significant association between gender and change in interradicular angulation (**Table VII**).

*Age at  $T_1$ .* There was not a statistically significant association between age at  $T_1$  and change in interradicular angulation (**Table VII**).

*Time from  $T_1$  to  $T_{Latest}$ .* There was not a statistically significant association between time from  $T_1$  to  $T_{Latest}$  and change in interradicular angulation (**Table VII**).

*Change in Facial Height from  $T_1$  to  $T_{Latest}$ .* On average, every millimeter of increase in anterior facial height from  $T_1$  to  $T_{Latest}$  was associated with 0.41 degrees of interradicular angulation change toward parallel (95% CI [0.10, 0.72];  $p = 0.009$ ) (**Table VII**). This associated change increased slightly to 0.46 degrees when controlling for interradicular angulation at  $T_1$  and removal of third molars between  $T_1$  and  $T_{Latest}$  (95% CI [0.14, 0.78];  $p = 0.005$ ) (**Table VIII**).

*Interradicular Angulation at  $T_1$ .* On average, for every degree of interradicular angulation away from parallel present at  $T_1$ , 0.49 degrees of increased improvement in interradicular angulation toward parallel was achieved (95% CI [0.33, 0.65];  $p = 0.000$ ) (**Table VII**). This association remained consistent at 0.49 degrees when controlling for change in facial height from  $T_1$  to  $T_{Latest}$  and removal of third molars between  $T_1$  and  $T_{Latest}$  (95% CI [0.31, 0.66];  $p = 0.000$ ) (**Table VIII**).

*Occlusal Contact Present at  $T_1$ .* There was not a statistically significant association between the presence of occlusal contact at  $T_1$  and change in interradicular angulation (**Table VII**).

*Occlusal Contact Achieved Between  $T_1$  and  $T_{Latest}$ .* There was not a statistically significant association between occlusal contact occurring between  $T_1$  and  $T_{Latest}$  and change in interradicular angulation (**Table VII**).

*Occlusal Contact Improved from  $T_1$  to  $T_{Latest}$ .* There was not a statistically significant association between improvement in occlusal contact quality between  $T_1$  and  $T_{Latest}$  and change in interradicular angulation (**Table VII**).

*Maxillary Third Molars Present at  $T_1$ .* There was not a statistically significant association between presence of maxillary third molars prior to  $T_1$  and change in interradicular angulation (**Table VII**).

*Maxillary Third Molars Removed Between  $T_1$  and  $T_{Latest}$ .* Of the 103 molar teeth in the sample, 82 (79.6%) were associated with removal of third molars between  $T_1$  and  $T_{Latest}$ . 75.5% of second molars in patients treated with premolar extraction during orthodontic treatment were associated with third molars removed after treatment while 83.3% of second molars in non-extraction patients were associated with third molar removal after orthodontic treatment. The difference in 3<sup>rd</sup> molar removal rates between patients treated with premolar extraction was not significant ( $p = 0.325$ ) (**Table IX**).

In univariate analysis, second molars in patients whose third molars were removed between  $T_1$  and  $T_{Latest}$  were associated with 3.07 more degrees of change toward parallel than those where third molars were not removed (95% CI [0.42, 5.73]  $p = 0.023$ ) (**Table VII**). However, when controlling for the change in facial height from  $T_1$  to  $T_{Latest}$  and interradicular angulation at  $T_1$ , there was not a significant association between removal of maxillary third molars between  $T_1$  and  $T_{Latest}$  and change in interradicular angulation (**Table VIII**).

*Maxillary Premolars Extracted During Orthodontic Treatment.* There was not a statistically significant association between the extraction of maxillary premolars during orthodontic treatment and change in interradicular angulation (**Table VII**).

**Table VII.** Factors Associated With Interradicular Angulation Change – Univariate (Molars). The amount of interradicular angulation change between  $T_1$  and  $T_{Latest}$  of maxillary second and first molars associated with different factors. \* signifies statistical significance ( $p < 0.05$ ).

	Angulation Change	95% Confidence Interval		P
		Lower	Upper	
Gender (Male)	1.89°	-0.58	4.35	0.134
Age at $T_1$	-0.24°	-0.57	0.08	0.139
Time from $T_1$ to $T_{Latest}$	0.09°	-0.20	0.38	0.528
Change in Facial Height*	0.41°	0.10	0.72	0.009
Interradicular Angulation at $T_1$ *	0.49°	0.33	0.65	0.000
Occlusion at $T_1$ (Yes)	-1.17°	-4.13	1.80	0.440
Occlusion from $T_1$ to $T_{Latest}$ (Yes)	1.17°	-1.80	4.13	0.440
Improved Occlusion (Yes)	0.98°	-1.39	3.36	0.418
3rd Molars Present at $T_1$	1.39°	-3.12	5.89	0.547
3rd Molars Extracted between $T_1$ to $T_{Latest}$ *	3.07°	0.42	5.73	0.023
Premolars Extracted During Treatment	-1.39°	-3.65	0.87	0.228

**Table VIII.** Factors Associated With Interradicular Angulation Change – Multivariate (Molars). The amount of interradicular angulation change from  $T_1$  to  $T_{Latest}$  of maxillary second and first molars when controlling for the covariates listed. \* signifies statistical significance ( $p < 0.05$ ).

	Angulation Change	95% Confidence Interval		P
		Lower	Upper	
Change in Facial Height*	0.46°	0.14	0.78	0.005
Interradicular Angulation at $T_1$ *	0.49°	0.31	0.66	0.000
3rd Molars Removed between $T_1$ to $T_{Latest}$	0.84°	-1.85	3.54	0.540

**Table IX.** Third Molar Extraction Rates. The percentage of second molars in subjects who had third molars removed after orthodontic treatment.

	N	% of 3rd Molars EXT'd	P
Overall	103	79.6%	
Premolars Extracted	49	75.5%	
Non-extraction	54	83.3%	0.325

## DISCUSSION

In the current study, it was found that, on average, the roots of both maxillary incisors and molars had a tendency to upright and become more parallel with the roots of adjacent teeth long-term after orthodontic treatment. Although there do not appear to be any other studies presently published that make direct observations regarding this occurrence, there is published research that may help explain this change in root alignment. Horii<sup>8</sup> evaluated the evolution of the eruption of the permanent mandibular dentition from the tooth-bud stage to full maturation of the dentition. The authors demonstrated how the collective mesiodistal angulations of the dentition transition from a disordered to an ordered state by way of a self-regulatory process that results in a configuration with the long axes of the teeth being parallel. Another study by Kinne<sup>9</sup> showed that, in early serial extraction patients, second premolars were able to erupt so that the extraction spaces were mostly closed while the roots remained nearly parallel. Although the mechanism is not completely understood, teeth seem to demonstrate the innate ability to generally erupt in such a way that the long axes of the teeth are positioned perpendicular to the occlusal plane and parallel to one another. It is likely that this mechanism contributes to the post-treatment root uprighting seen in our sample as well.

While incisors and molars in our sample both demonstrated the tendency to become more parallel following orthodontic treatment, the manner in which the paralleling occurred was different. Lateral and central incisors seemed to improve their interradicular angulation by distal movement of the lateral incisor root and mesial movement of the central incisor root. Whereas second and first molar interradicular angulation improvement resulted completely by distal movement of the second molar roots with the first molar roots also moving slightly to the distal. This pattern of distal molar root movement was less extensive in premolar extraction subjects where most of the parallelism resulted from distal second molar root movement and minor

mesial first molar movement. Non-extraction subjects experienced more distal root movement of the first and second molars than the overall sample. The discrepancy between incisor and molar paralleling is possibly due to their respective locations in the dental arch. Incisors are book-ended by teeth on both sides, which define a set amount of available space. The incisor roots likely move in such a way so as to evenly distribute the space among them within the given space. Molars, on the other hand, are located at the distal aspect of the dental arch. This allows the molar roots to more freely move distally without the restrictive influence of adjacent teeth.

Incisor and molar root uprighting were both associated with vertical facial growth. This finding confirmed the belief postulated by Olsen and Kokich regarding approximation of maxillary central incisor and canine roots after orthodontic treatment in patients who were missing maxillary lateral incisors.<sup>6, 10</sup> The authors suggest that as the lower facial height increases by growth of the mandibular ramus, space opens between the maxillary and mandibular dentitions and allows eruption of the teeth. Perhaps this eruption allows for changes in the angulations of the teeth. Unlike the present study, these authors demonstrated that roots become non-parallel. However, this does not contradict our finding that roots become more parallel, because these authors were investigating teeth adjacent to an edentulous space. In both cases it appears that tooth roots not only change their mesiodistal angulations while erupting into occlusion, but also display the same tendency as further eruption occurs with continued facial growth.

Interradicular angulation at the completion of orthodontic treatment was another factor that was associated with uprighting of both lateral incisor and second molar roots. Nett and Huang investigated six of the eight criteria listed on the American Board of Orthodontics Cast-Radiograph Examination (formerly the Objective Grading System).<sup>11</sup> Of the six criteria investigated (alignment, marginal ridges, buccolingual inclination, occlusal contacts, occlusal

relationships, and overjet), the authors found that all tended to improve with exception of alignment. Additionally, the authors observed a 'regression to the mean' relationship between post-treatment scores and improvement at post-retention where the more poorly-finished cases improved more than well-treated cases.<sup>11, 12</sup> Root parallelism was not investigated in the aforementioned study, but as noted in our study, also followed the same 'regression to the mean' pattern observed in the other aspects of patients treated with orthodontics.

Vertical facial growth, interradicular angulation after orthodontics, and removal of maxillary third molars were combined into a multivariate linear general estimating equations model because of an *a priori* estimate that they best represented the strongest possible influence on post-orthodontic root angulation change. When initially analyzed alone, third molar removal after treatment appeared to be associated with molar root uprighting and improved interradicular angulation. However, in the multivariate, controlled model, this association disappeared. Accordingly, it seems that vertical facial growth and interradicular angulation at end of orthodontics were the factors truly associated with interradicular angulation change after treatment.

Extraction of premolars during orthodontic treatment was not associated with uprighting of lateral incisor or second molar roots in our sample. Interestingly however, the incidence of third molar removal was not significantly different between the premolar extraction and non-extraction groups in our sample. Multiple studies have investigated the frequency of maxillary third molar eruption versus impaction. Two of these studies report third molar impaction in 50-76% of non-extraction patients and 16-56% of those patients in whom premolars were extracted.<sup>13, 14</sup> Both studies report statistically significant differences in third molar impaction rates between the premolar extraction and non-extraction groups at  $p < 0.05$ . These studies may suggest that a relatively large number of third molars were removed in our sample.

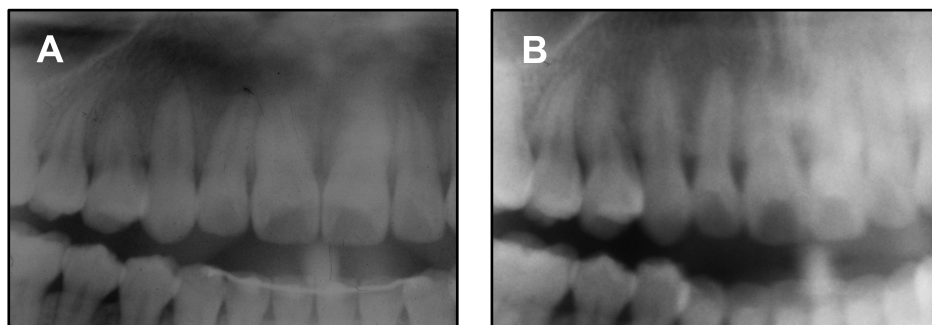
However, without knowing the circumstances or reasoning behind removing the third molars, it is difficult to substantiate this possibility.

A subjective observation of teeth in occlusion at the end of treatment showed a general trend for improvement in occlusal contacts with time. Several studies have examined the change in number of occlusal contacts following orthodontic treatment. In a study comparing occlusal settling when using Hawley retainers vs. clear overlay retainers, a significant increase in the number of occlusal contacts was noted at three months into retention in patients using Hawley retainers.<sup>15</sup> Similar to our study, the greatest increase in occlusal contacts was seen in the posterior dentition. In our study 74% of second molars demonstrated improvement in occlusal contacts whereas only 33% of lateral incisors showed improvement. This discrepancy may be due to the complexity of multi-point posterior tooth occlusal contacts that may be difficult to achieve during active orthodontic treatment. The simpler anterior tooth contacts are probably easier to achieve during treatment. Another study showed that occlusal contacts continued to improve 21 months after treatment.<sup>16</sup> However, Sullivan showed that despite significant improvements after treatment, patients treated with orthodontics might not achieve the same number of occlusal contacts as untreated patients. The authors were unsure of any functional significance that this difference might produce.<sup>17</sup>

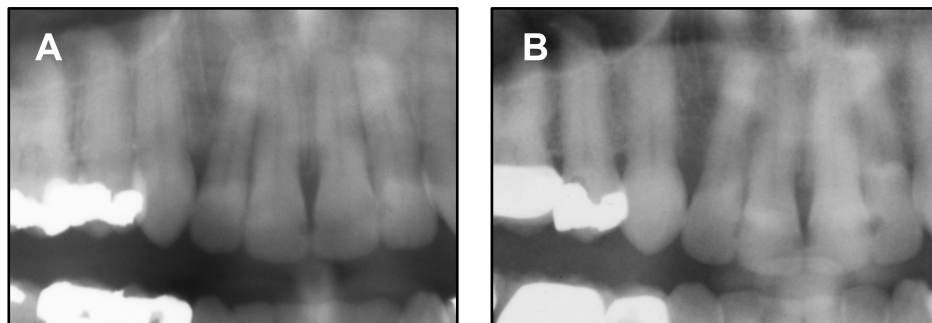
Despite efforts to conduct this study with the most rigorous scientific principles, certain limitations could not be overcome. This retrospective, non-randomized study used subjects acquired from a group of long-term post-retention patients; the generalizability of the study outcomes must be viewed with caution. A future study investigating long-term angulation changes in properly paralleled roots would be useful when contemplating the outcomes of this study. Finally, panoramic radiographs were used to measure the angulation of teeth in this study. Despite their many advantages in orthodontics, it has been well documented that

distortion can occur in panoramic radiographs. While the greatest distortion seems to manifest in the canine regions, distortion has been shown to occur throughout the entire dentition.<sup>2, 18, 19</sup>

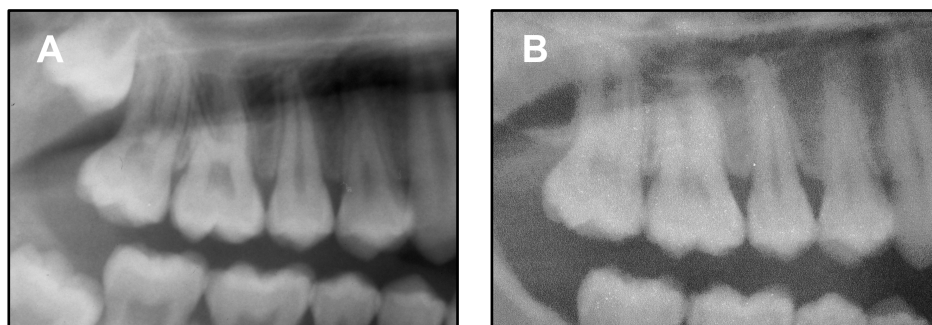
Although this investigation has shown that the root angulations of maxillary lateral incisors and second molars tend to improve after orthodontic treatment, this information does not negate the importance of high-quality orthodontic treatment since not all teeth responded favorably. Several studies have demonstrated the relationship between root proximity and increased risk for periodontal breakdown of interseptal bone.<sup>20-22</sup> Additionally, in most situations, the crown and root of a tooth are related in such a way that when the root is positioned properly the crown is usually aligned correctly. This leads to proper functional occlusion and esthetics. However, there are situations when clinicians are unsuccessful in positioning teeth with ideal root angulations. In these situations, the present study offers information that can aid clinicians in determining which patients are likely to respond favorably and which may not (**Figures 5-8**).



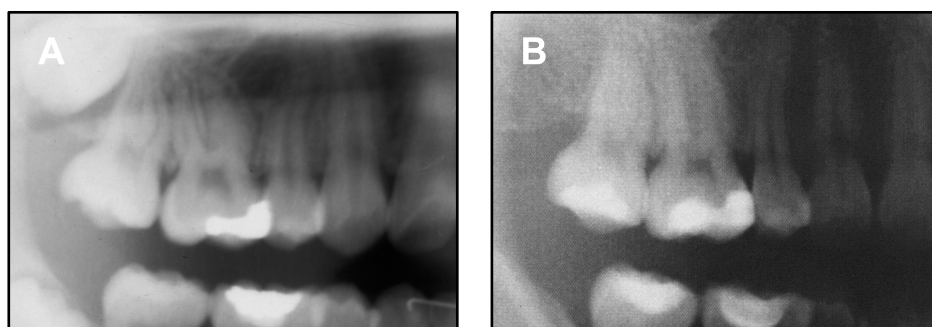
**Figure 5.** Favorable Angulation Change (Incisor). The root of tooth #7 was improperly angled to the mesial at the end of treatment (A). However, at follow-up the root has uprightened into a more parallel relationship with the adjacent teeth (B).



**Figure 6.** Poor Angulation Change (Incisor). The root of #7 was improperly angled to the mesial at the end of treatment (A). At follow-up the root is still angled mesially (B).



**Figure 7.** Favorable Angulation Change (Molar). The root of tooth #2 was improperly angled to the mesial at the end of treatment (A). However, at follow-up the root has uprightened into a more parallel relationship with the adjacent teeth (B).



**Figure 8.** Poor Angulation Change (Molar). The root of #2 was improperly angled to the mesial at the end of treatment (A). At follow-up the root is still angled mesially (B).

## CONCLUSIONS

Based upon the sample studied and the methodology used, the following conclusions can be made:

- Maxillary lateral incisors and second molars with an interradicular angulation of  $\geq 10$  degrees from parallel to adjacent teeth after orthodontic treatment will, on average, become more parallel with time.
- In the anterior region, the uprighting is due to both mesial movement of the central incisor roots and distal movement of the lateral incisor roots, while in the posterior the uprighting is due primarily to distal movement of the roots of the second molar
- Patients with continued vertical facial growth after orthodontic treatment are more likely to have additional root uprighting occur over patients who do not experience growth.
- Patients with poor interradicular angulation at the end of treatment tend to experience more uprighting than patients with good interradicular angulation. However, the roots of these patients are unlikely to reach the same level parallelism as those of patients with less interradicular angulation at the end of treatment.
- Although mesiodistal root angulations improved on average after orthodontic treatment, clinicians should attempt to parallel roots during treatment since not all patients had favorable angulation changes over time.

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