Original Article

Effects of Orthodontic Treatment on Mandibular Rotation and Displacement in Angle Class II Division 1 Malocclusions

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Abstract: The aim of this retrospective cephalometric study was to investigate the effects of orthodontic treatment on rotation and displacement of the mandible in Angle Class II, division 1 malocclusions. Thirty patients in the treated group (15 boys and 15 girls; mean age at pretreatment, 12.27 ± 1.36 years) were compared with 28 subjects who had untreated Class II, division 1 malocclusions (15 boys and 13 girls; mean age at T1, 12.01 ± 0.07 years). The patients in the first group were treated nonsurgically, without extraction, and without the use of functional appliances. Cephalometric data were obtained from three lateral cephalograms per case representing pretreatment (T1), posttreatment (T2), and at least 2-years postretention (T3). Thirty-seven variables were measured representing craniofacial morphology, tooth measurements, and mandibular displacement. Some variables were obtained from cranial base, maxillary, or mandibular superimposition. Statistical significance was established at $P < .05$, $P < .01$, and $P < .001$. The findings indicated that orthodontic treatment of Class II, division 1 malocclusions induced a more vertical mandibular growth direction associated with an increased vertical displacement of pogonion. Occlusal or vertical movement of maxillary and mandibular molars was not correlated to mandibular rotation or horizontal displacement of pogonion. When compared with controls, the treated group did not exhibit a significant difference in mandibular rotation or occlusal movement of maxillary molars; however, it did show a greater occlusal movement of mandibular molars during treatment. (*Angle Orthod* 2004;74:174–183.)

Key Words: Maxillary prognathism; Mandibular growth direction; Mandibular rotation; Condylar growth; Occlusal movement of molars

INTRODUCTION

Craniofacial growth and mandibular especially growth are important factors in the treatment of Class II malocclusions. Bjork,[1] using implants, revealed the complexity of craniofacial growth and mandibular growth. He reported that jaw displacement is often accompanied by rotation of the bones. Both forward and backward rotations occur, but generally a forward rotation takes place, and mandibular rotation is greater than the maxillary rotation. In addition, he correlated jaw rotations to each other and to the intensity, direction, and curvature of condylar growth.[2]

Odegaard[3,4] carried out implant studies that confirmed Bjork's findings and showed that mandibular rotation was related to the amount and direction of condylar growth. The study also reported that the amount of forward mandibular rotation was reduced by orthodontic treatment.

Isaacson et al[5,6] and Sinclair and Little[7] reported that mandibular displacement is translatory when the increments of vertical condylar growth equal the increments of vertical growth at the maxillary sutures and the maxillary and mandibular alveolar processes. However, if condylar growth exceeds the vertical growth at the sutural-alveolar process area, a forward or closing mandibular rotation would occur and vice versa.

A large number of studies have been done on the effects of orthodontic treatment of Class II, division 1 malocclusions. The findings reported that forward mandibular rotation was decreased,[8–13] forward movement of pogonion inhibited,[8,10,12–18] the Y axis and the mandibular plane angle

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TABLE 1. Treatment Mechanics Applied in the Treated Group ($n = 30$)[a]

Treatment Mechanics	Number of Cases
Cervical headgear	10
Cervical headgear and tandem mechanics	5
Cervical headgear and lip bumper	1
Cervical headgear and Class II intermaxillary elastics	3
Cervical headgear and no appliance in lower arch	2
High pull headgear	3
High pull headgear and Class II intermaxillary elastics	2
Class II intermaxillary elastics	4

[a] Compliance data, headgear forces were not available.

opened,[9,10,12] and anterior facial height increased.[8–12,15,18–23] In addition to skeletal changes, excessive vertical movement of either the maxillary or mandibular molar has been reported.[9–11,18,19,22–26] The consensus of these studies was that excessive vertical movement of the molar contributed to the diminution of forward mandibular rotation.

Whereas most studies concentrated on changes during treatment, some studies examined the changes that occur during retention[10,12,27,28] and a few examined changes during the postretention period.[29,30]

In summary, numerous studies in literature have suggested that orthodontic treatment affects mandibular displacement as well as mandibular rotation. This effect alters mandibular displacement to a more vertical direction, thereby making Class II correction more difficult. However, none of these studies investigated the relationship between mandibular rotation and mandibular displacement.

Most studies determined mandibular rotation by assessing changes in the mandibular plane or Y-axis angle.[7,9–12,15,31] The use of mandibular plane angle may be questionable because Bjork[32,33] demonstrated that the lower border of the mandible is a site of considerable remodeling, and this might influence not only the mandibular plane but also the Y-axis angle. In addition, a tendency of the mandibular plane angle to flatten with age has been reported.[7,34,35] A modified method of determining mandibular rotation will be used in the present study with the desire to gain a clearer picture of total mandibular rotation.

The object of the present investigation is to study the

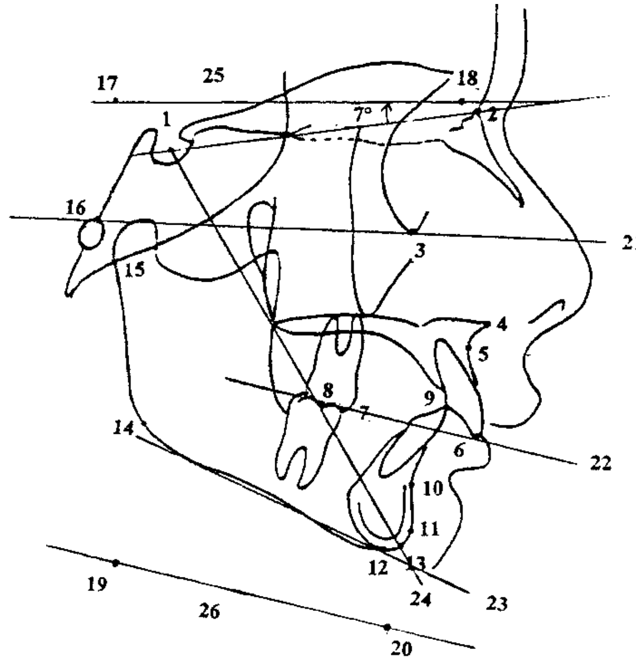

FIGURE 1. Cephalometric landmarks and planes: (1) sella, (2) nasion, (3) orbitale, (4) anterior nasal spine, (5) point A, (6) maxillary incisal edge, (7) maxillary molar cusp tip, (8) mandibular molar cusp tip, (9) mandibular incisal edge, (10) point B, (11) pogonion, (12) menton, (13) gnathion, (14) gonion, (15) articulare, (16) porion, (17) F1—fiduciary point 1, (18) F2—fiduciary point 2, (19) F3—fiduciary point 3, (20) F4—fiduciary point 4, (21) Frankfort plane, (22) functional occlusal plane, (23) mandibular plane, (24) Y axis, (25) F1-F2 fiduciary plane, and (26) F3-F4 fiduciary plane.

effects of orthodontic treatment on mandibular growth, with emphasis on its rotation and displacement by comparing untreated and treated Angle Class II, division 1 malocclusions. It is important to determine the relationship between mandibular rotation and movement of the chin or pogonion. The long-term effect of orthodontic treatment will also be examined.

MATERIALS AND METHODS

Treated group

Records of 30 patients (15 boys, 15 girls) were obtained from the Department of Orthodontics, University of Illinois.

TABLE 2. Ages at T1, T2, and T3 and Interval Lengths for the Treated and Untreated Groups (in years)

	Age at T1		Age at T2		Age at T3		Interval Length T1–T2		Interval Length T2–T3		Interval Length T1–T3	
Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Treated (n = 30)	12.27	1.36	14.93	1.48	20.73	2.02	2.66	1.18	5.8	1.25	8.46	1.49
Male (n = 15)	12.18	1.61	15.25	1.69	21.07	2.26	3.06	1.43	5.82	1.40	8.88	1.69
Female (n = 15)	12.36	1.12	14.61	1.21	20.39	1.76	2.25	0.68	5.77	1.14	8.03	1.15
Untreated (n = 28)	12.01	0.07	14.35	0.55	16.86	1.4	2.33	0.56	2.51	1.25	4.85	1.39
Male (n = 15)	12.01	0.02	14.67	0.52	17.13	1.4	2.66	0.51	2.45	1.16	5.12	1.39
Female (n = 13)	12.02	0.11	13.97	0.30	16.56	1.39	1.94	0.32	2.58	1.39	4.53	1.39

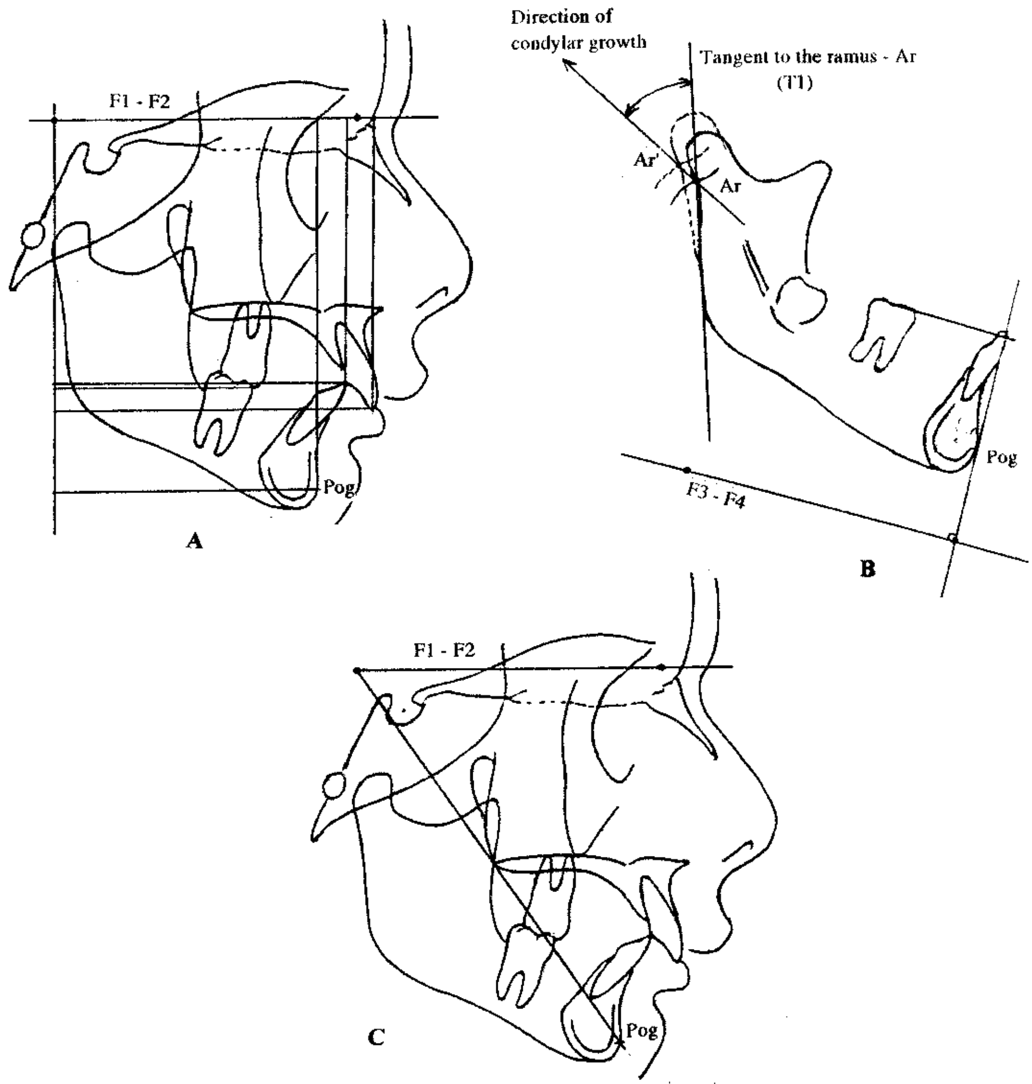

FIGURE 2. Fiduciary coordinate systems. (A) The F1-F2 coordinate system. (B) The F3-F4 coordinate system. (C) Direction of mandibular displacement.

Most patients were white, with two being African American, and all were treated in the postgraduate clinic between 1966 and 1987. Patient record selection was based on the following:

1. The presence of an Angle Class II, division 1 malocclusion with at least an end-to-end Class II molar relationship present at the start of treatment;
2. All patients were treated nonsurgically, without extractions, and without functional appliances. Almost all the cases had full edgewise appliances. The treatment mechanics used in this group are presented in Table 1; however, the force applied by the headgear was not documented. After treatment, all patients were retained with maxillary Hawley appliances. During retention, bite planes were used in 16 cases (53%) and headgear was used in 14 cases (46%). Lower fixed retainers were used in most cases. The retention period ended after the removal of all third molars;
3. None of the patients had congenital anomalies, significant facial asymmetries, or congenitally missing teeth (excluding third molars);
4. The patients were growing at the time of treatment;
5. Pretreatment (T1), posttreatment (T2), and at least 2-years postretention (T3) cephalograms were available for study.

Untreated group

The untreated group consisted of 28 subjects (15 boys, 13 girls) with Class II, division 1 malocclusions who had not undergone any orthodontic treatment. The cephalograms for this group were drawn from copies of the Bolton Growth study available at the Department of Orthodontics,

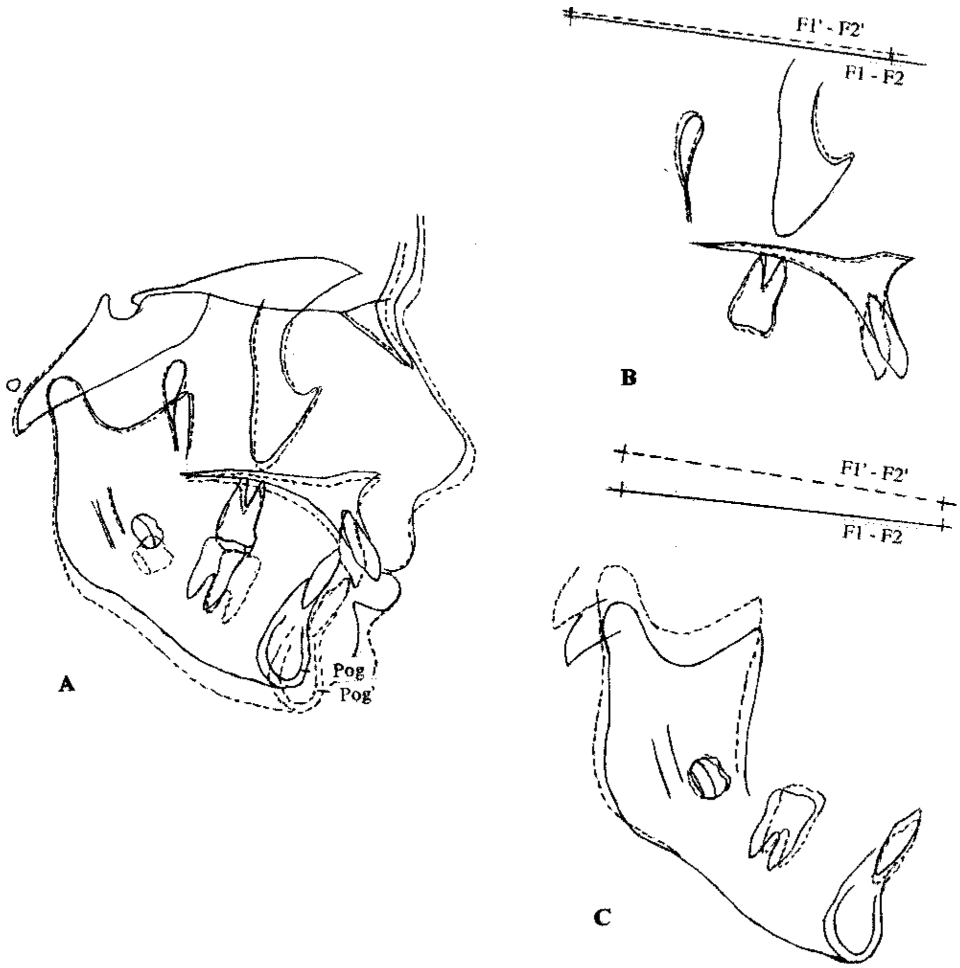

FIGURE 3. (A) Cranial base superimposition. (B) Maxillary superimposition. (C) Mandibular superimposition.

University of Illinois. Table 2 shows the mean age of the untreated and treated groups. The age of the untreated group at T3 did not correspond with the T3 age of the treated group because of the nonavailability of records.

Records and data collection

The principal investigator traced all the lateral cephalograms, and questionable landmarks were checked by a second investigator. The definition and location of the landmarks were in accordance with the literature. Gonion was determined by bisecting the angle formed by the ramus and mandibular planes, whereas gnathion was determined by bisecting the angle formed by the facial and mandibular planes. All bilateral structures were bisected. To minimize the magnification of the cephalograms, BeGole's method of standardization of cephalometric coordinate data was used.[36] All landmarks were digitized, and most variables were computer-generated after correcting for magnification.[37]

Figure 1 illustrates the cephalometric landmarks and planes used.

F1—fiduciary point 1—is the intersection point of a line that is 7° superior to the SN plane[38] and a line through articulare point perpendicular to the former line;

F2—fiduciary point 2—a point constructed three millimeters behind Nasion point and is on a line that is 7° superior to the SN plane;

F3—fiduciary point 3—is the intersection point of a line that is parallel to the functional occlusal plane, inferior to the mandibular plane and a line through Gonion point perpendicular to the former line;

F4—fiduciary point 4—is the intersection point of a line that is parallel to the functional occlusal plane, inferior to the mandibular plane and a line through pogonion point perpendicular to the former line.

The F1-F2 and F3-F4 fiduciary lines were used to construct separate Cartesian coordinate systems. The F1-F2 fiduciary line represented the horizontal axis, and a line through articulare perpendicular to the horizontal axis represented the vertical axis (Figure 2A). The F3-F4 fiduciary line also represented the horizontal axis, and a line through Pogonion perpendicular to the horizontal axis represented the vertical axis (Figure 2B).

TABLE 3. Variables at T1, Treated vs Untreated

Variables	Treated Group (n = 30)		Untreated Group (n = 28)		
	Mean	SD	Mean	SD	t
Craniofacial morphology					
Facial angle (°)	84.84	2.88	83.41	2.94	−1.87
Angle of convexity (°)	8.90	5.03	10.47	4.96	1.19
SNA angle (°)	80.31	3.57	81.23	2.99	1.06
SNB angle (°)	74.94	2.99	75.24	2.46	0.41
ANB angle (°)	5.37	1.81	6.00	1.70	1.34
Mandibular plane angle (°)	25.90	4.30	25.01	4.17	−0.79
Y axis angle (°)	59.96	2.90	60.89	3.66	1.07
Posterior cranial base (S-Ar) (mm)	31.49	2.60	31.78	2.87	0.40
Ramus length (Ar-Go) (mm)	39.14	3.50	39.85	3.53	0.77
S-Ar/Ar-Go (%)	80.83	7.66	80.36	9.92	−0.20
Upper AFH (Na-ANS) (mm)	47.24	3.28	47.72	2.83	0.59
Lower AFH (ANS-Me) (mm)	60.75	5.45	59.02	3.72	−1.39
AFH ratio (UAFH/LAFH) (%)	78.09	6.01	81.11	6.53	1.83
AFH (Na-Me) (mm)	106.11	7.39	104.70	4.92	−0.85
PFH (S-Go) (mm)	65.90	5.17	67.29	4.10	1.13
PFH to AFH ratio (%)	63.22	4.27	64.30	3.36	1.06
Mandibular length (Ar-Pog) (mm)	94.86	5.83	94.21	4.93	−0.45
Corpus length (Go-Gn) (mm)	66.28	4.78	66.23	4.01	−0.03
Tooth measurements					
Overjet (mm)	7.50	2.43	5.12	2.01	−4.03***
Overbite (mm)	4.08	2.52	5.08	1.46	1.86

*** $P < .001$.

Three superimpositions, the cranial base superimposition patterned after Bjork and Skieller,[39] maxillary superimposition following Doppel et al,[40] and Bjork's mandibular structural superimposition[33] (Figure 3) were used in this study. The Frankfort plane and F1-F2 fiduciary line were drawn on the T2-stage cephalograms and transferred to T1- and T3-stage cephalograms using the cranial base superimposition.[41] The F3-F4 fiduciary line was transferred from T2- to T1- and T3-stage cephalograms using the mandibular structural method of superimposition.

Variables measured

Most of the variables were measured at T1, T2 , and T3. Treatment, posttreatment, and overall changes of both groups were determined by the differences T2-T1, T3-T2, and T3-T1 variables.

Four groups of variables were examined in this study, ie, the craniofacial morphology, tooth measurements, jaw rotations, and mandibular measurements. The variables representing craniofacial morphology and tooth measurements were obtained from T1, T2, and T3 tracings. Occlusal or vertical movement of maxillary molar, overjet, and overbite were measured using the F1-F2 Cartesian coordinate system, whereas occlusal movement of mandibular molar was measured from the F3-F4 Cartesian coordinate system (Figure 2A,B).

Jaw rotations were determined from the maxillary or mandibular superimposition and the angular rotation of the F1-F2 fiduciary lines (Figure 3B,C). A counterclockwise rotation (forward or closing) as seen from a subject's right profile was assigned a positive value and a clockwise rotation (backward or opening) was assigned a negative value.

Mandibular measurements consisted of pogonion movement and condylar growth. The extent of pogonion movement was determined from the cranial base superimposition (Figure 3A). The direction of pogonion movement was defined as the angular relationship of the F1-F2 line and the F1-pogonion line (Figure 2C). This was measured on the T1, T2, and T3 cephalograms. An increase in value was designated as positive and indicated a more vertical direction of mandibular displacement. A negative change corresponded with a more horizontal direction of mandibular displacement. Vertical and horizontal displacements of pogonion were measured from the F1-F2 Cartesian coordinate system on each of the T1, T2, and T3 cephalograms (Figure 2A). The amount and direction of condylar growth were patterned after Bjork[2,32] using the mandibular structural method of superimposition. Amount of condylar growth was a millimeter measurement between articulare at T1, T2, and T3 stage tracings. Condylar growth direction was defined as the angular relationship between a line connecting articulare at T1 to articulare at T2 and a tangent to the posterior border of the ramus to articulare of the T1 cephalogram (Figure 2B). This method was also used for the T2 and T3 cephalograms.

Error study

All cephalograms of the treated and untreated groups were retraced, digitized, and measured twice after a minimum of 4 weeks. Paired *t*-tests did not demonstrate any statistically significant differences between the first and second measurements.

Statistical analysis

Descriptive statistics including the mean and standard deviation for each variable (excluding those derived from superimpositions) were calculated at each stage (T1, T2, and T3) for each of the two groups. Paired data *t*-test was used to evaluate intragroup changes, and independent sample *t*-test was used to evaluate intergroup differences at different periods (T1-T2, T2-T3, and T1-T3). Pearson correlation coefficient was used to assess the relationship of selected variables in the treated group during treatment (T1-T2). All statistical analyses were calculated using SAS program. Statistically significant results were indicated at three levels of confidence: $P < .05$ (*); $P < .01$ (**); $P < .001$ (***).

RESULTS

Pretreatment intergroup differences

The T1 cephalograms of two groups were compared (Table 3). The treated group demonstrated a significantly larger overjet (7.5 $\pm$ 2.43 mm) compared with the untreated group (5.12 $\pm$ 2.01 mm).

Treatment changes (T1-T2)

Table 4 shows the results of the *t*-tests for intergroup differences during treatment. Mandibular prognathism did not increase in the treated group, but maxillary prognathism was reduced (SNA $= -1.47°$). This resulted in a decrease of facial convexity and maxillary-mandibular apical base discrepancy ($-4.25°$ and $-1.92°$, respectively). The Y axis and mandibular plane angles increased significantly in the treated group (1.25° and 0.5°, respectively). The anterior facial height change was greater in the treated group, 8.53 mm vs 5.95 mm. Occlusal movement of the maxillary molar in the treated group was not significantly greater than in the untreated group, but occlusal movement of the mandibular molar did exceed that of the untreated group, 2.89 mm vs 1.93 mm. Overjet and overbite decreased significantly in the treated group. Rotation of the maxilla or mandible did not show a significant change during the T1-T2 period. Pogonion movement indicated more vertical displacement during this period in the treated group with the amount of pogonion movement greater (9.06 mm vs 6.89 mm) and its direction more vertical (1.57° vs 0.54°) than in the untreated group.

Posttreatment changes (T2-T3)

Table 4 shows the posttreatment changes. After treatment, growth of the treated group was similar to that of the untreated group. The only intergroup difference was the change in the upper anterior facial height. Overjet and overbite relapsed, with the former losing 20% of its treatment correction, and the latter almost half of its correction. The amount of condylar growth was significantly greater in the treated group, but the observation period for this group was twice as long.

Overall changes (T1-T3)

Table 4 shows the overall changes. Facial convexity decreased almost twice as much in the treated group as in the untreated group, and this decrease ($-5.40°$) was because of a reduction of maxillary prognathism (SNA angle $= -1.35°$). The denture-base relationship (ANB angle) decreased twice as much in the treated group as in the untreated group, $-2.25°$ vs $-1.06°$. The anterior facial height change was significantly larger in the treated group, and the change of the upper anterior facial height component (Na-ANS) was significantly larger (5.60 mm vs 3.40 mm). Occlusal movement of molar teeth did not differ between groups. Overbite and overjet were reduced overall, but overbite correction relapsed considerably (50%), so that the overall change in overbite was not significantly different between groups.

Correlations

Table 5 shows the correlations for the treated group during the treatment period: correlations from 0.25 to 0.50 (or -0.25 to -0.50) indicate a weak relationship, those from 0.50 to 0.75 (or -0.50 to -0.75) a moderate relationship, and those greater than 0.75 (or -0.75) a strong relationship.

Mandibular rotation showed a moderate correlation to the change of mandibular plane angle ($r = -0.75$), the horizontal displacement of pogonion ($r = 0.75$), and the amount and direction of condylar growth ($r = 0.58$ and -0.64, respectively). Vertical displacement of pogonion was strongly correlated to vertical changes in the face. It was highly correlated to the changes of anterior facial height ($r = 0.93$), posterior facial height ($r = 0.82$), the sum of occlusal movement of the teeth ($r = 0.96$), and the amount of movement of pogonion ($r = 0.96$). Horizontal displacement of pogonion was moderately correlated to the change of Y-axis angle ($r = -0.75$), mandibular rotation ($r = 0.75$), and the amount of condylar growth ($r = 0.64$). It was strongly correlated to the change of mandibular plane angle ($r = -0.77$).

DISCUSSION

Sample characteristics

The posttreatment phase of the untreated group was shorter than that of the treated group because of the lack of cephalograms at T3 stage. The treated group was followed for 5.8 years, but the untreated group was observed for 2.51 years. This shortcoming complicates the compar-

TABLE 4. Treatment Changes (T1-T2), Posttreatment Changes (T2-T3), and Overall Changes (T1-T3), Treated vs Untreated

	Treatment Changes (T1-T2)					Posttreatment Changes (T2-T3)				
	Treated Group (n = 30)		Untreated Group (n = 28)			Treated Group (n = 30)		Untreated Group (n = 28)		
Variables	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P
Craniofacial morphology										
Facial angle (°)	0.41	1.49	0.81	1.73		0.13	1.83	0.23	1.09	
Angle of convexity (°)	−4.25	2.61	−1.83	2.22	***	−1.15	2.03	−1.03	1.77	
SNA angle (°)	−1.47	1.56	0.05	1.92	**	0.12	1.55	0.16	1.24	
SNB angle (°)	0.44	1.24	0.7	2.1		0.45	1.33	0.57	1.18	
ANB angle (°)	−1.92	1.17	−0.65	1.35	***	−0.33	0.97	−0.41	0.82	
Mandibular plane angle (°)	0.5	2.16	−1.12	1.99	**	−1.51	1.67	−0.8	1.65	
Y axis angle (°)	1.25	1.45	0.24	1.54	*	0.11	1.68	0.11	1.03	
Pos cranial base (S-Ar) (mm)	2.09	2.23	1.97	1.57		1.34	1.38	0.82	1.21	
Ramus length (Ar-Go) (mm)	4.19	2.35	3.61	2.65		3.29	2.61	2.88	2.37	
(S-Ar)/(Ar-Go) (%)	−2.84	6.15	−2.26	4.97		−2.55	4.84	−2.91	4.57	
Upper AFH (Na-ANS) (mm)	3.53	2.01	2.47	1.74	*	2.07	2.12	0.92	1.05	
Lower AFH (ANS-Me) (mm)	4.51	2.5	3.12	2.34	*	1.65	2.82	1.89	1.67	*
AFH ratio (Na-ANS/ANS-Me) (%)	0.06	3.27	0.05	2.8		0.79	4.18	−0.81	2.42	
AFH (Na-Me) (mm)	8.53	3.84	5.95	3.56	*	3.56	3.59	3.02	2.07	
PFH (S-Go) (mm)	6.47	3.21	5.37	2.92		4.1	3.21	3.6	2.48	
(S-Go)/(Na-Me) (%)	−0.01	3.34	1.43	2.08		1.56	1.54	1.41	1.67	
Mandibular length (Ar-Pog) (mm)	5.89	3.14	5.84	3.5		4.36	3.31	3.16	2.34	
Corpus length (Go-Gn) (mm)	3.16	1.9	3.81	2.15		2.56	2.92	1.65	1.79	
Tooth measurements										
Overjet (mm)	−5.51	2.6	−0.16	0.85	***	0.78	1.11	−0.28	1.08	***
Overbite (mm)	−2.73	2.19	−0.23	1.14	***	1.55	1.27	−0.84	1.55	***
Occlusal maxillary molar movement (mm)	4.54	2.95	4.05	2.21		3.01	2.97	2.21	1.71	
Occlusal mandibular molar movement (mm)	2.89	1.83	1.93	1.75	*	1.05	1.51	1.05	1.14	
Sum occlusal molar movement (mm)	7.44	3.83	5.99	3.49		4.05	4.07	3.25	2.12	
Jaw rotations										
Maxillary rotation (°)	−0.45	2.28	0.53	1.67		0.75	2.11	0.6	1.56	
Mandibular rotation (°)	−0.1	2.2	0.91	2.65		0.9	1.93	0.05	1.72	
Mandibular measurements										
Pogonion movement amount (mm)	9.06	3.99	6.89	3.5	*	5.68	4.94	3.98	2.44	
Pogonion movement direction (°)	1.57	1.24	0.54	1.37	**	0.36	1.82	0.23	0.92	
Pogonion vertical displacement (mm)	8.18	3.67	5.65	3.02	**	3.59	4.31	3.2	2.32	
Pogonion horizontal displacement (mm)	1.54	2.85	2.72	3.53		1.4	3.9	1.57	2.44	
Condylar growth amount (mm)	6.93	3.51	6.39	3.91		5.53	3.34	3.51	2.49	*
Condylar growth direction (°)	17.7	19.9	22.73	16.22		26.16	22.47	30.01	22.61	

[a] * $P < .05$; ** $P < .01$; *** $P < .001$.

ison of these groups, particularly where linear measurements are compared, and caution should be observed in interpreting differences. Although the treatment period was the same for both groups (2.66 and 2.33 years), the posttreatment and overall periods were different.

Methodology

Of all the variables measured, the condylar growth direction had the largest standard deviation. It was measured in relation to the ramus line.[2] During the T1-T2 phase, the range of this variable was 77°, the T2-T3 phase was 83°, and the T1-T3 phase was 61°. The causes of the large variability could be the difficulty of identification of landmark (articulare), error in mandibular superimposition, and the variability in direction of condylar growth, but they are largely because of the close proximity of the points being measured.[28,42–44] Even in the implant studies, large ranges of condylar growth direction were reported, such as 42° (Bjork[32]), 65° (Bjork and Skieller[2]), 30° (Baumrind et al[44]), and 25.09° (Odegaard[3]).

Interpretation of the results

The present study investigated the effects of orthodontic treatment of Class II, division 1 malocclusions on mandibular rotation and mandibular displacement. Our findings indicate that mandibular rotation was not influenced when compared with untreated subjects. This may be partly because of the method used to measure this rotation. Most studies determined mandibular rotation by examining changes in the mandibular plane angle.[7,9–12,15,31] The present

TABLE 4. Extended

Overall Changes (T1-T3)				
Treated Group (n = 30)		Untreated Group (n = 28)		
Mean	SD	Mean	SD	P
0.54	2.47	1.05	2.25	
−5.4	3.15	−2.86	3.1	**
−1.35	1.49	0.22	1.74	***
0.89	1.38	1.27	2.23	
−2.25	1.48	−1.06	1.78	**
−1.01	2.89	−1.92	3.06	
1.37	2.59	0.36	2.12	
3.43	2.5	2.79	2.1	
7.49	3.31	6.49	4.03	
−5.39	6.9	−5.17	6.5	
5.6	2.79	3.4	2.03	**
6.16	3.88	5.02	3.39	
0.85	4.8	−0.76	3.18	
12.09	5.26	8.97	4.95	*
10.58	4.45	8.97	4.62	
1.54	3.81	2.85	3.03	
10.25	4.49	9.01	4.96	
5.72	3.6	5.46	3	
−4.72	2.51	−0.45	1.36	***
−1.18	1.78	−1.08	1.9	
7.55	4.63	6.28	3.26	
4.03	1.96	2.97	2.28	
11.5	6.1	9.24	4.99	
0.3	2.38	1.14	2.32	
0.8	2.94	0.96	3.47	
14.14	6.94	10.59	5.09*	*
1.93	2.59	0.77	1.9	
11.78	6.16	8.87	4.84	
2.94	5.27	4.3	4.91	
12.26	4.85	9.6	5.65	
17.8	13.11	26.28	15.21	*

study used fiduciary lines and Bjork's structural method of superimposition to determine mandibular rotation.[33] Our finding of no significant difference in jaw rotation between the two groups would not have been true if the mandibular plane angle had been used to determine mandibular rotation (Table 4).

During treatment, mandibular displacement was more vertical in the treated group. This finding confirmed the observations of previous studies.[13,28,45–47] This was reflected by both the angular measurement of the direction of pogonion movement and its vertical displacement. Although these differences were observed during the treatment period, they no longer exhibited significant differences compared with controls during the posttreatment period or overall. The increased vertical displacement of pogonion is in accordance with previous studies.[8,10,12–16] These studies also found an inhibition of horizontal displacement of pogonion during treatment. The lack of posttreatment and overall differences of vertical displacement of pogonion between groups is in accordance with Mills et al,[10] but Haas[12] noted that the increased vertical displacement of pogonion persisted in his treated group. However, Haas' study looked at the effects of heavy ''orthopedic'' cervical headgear forces. Horizontal displacement of pogonion showed no significant group difference during any period of the study. This finding was in accordance with what was reported by Wieslander and Tandlakare,[19] Jakobsson,[20] and Wieslander et al.[29]

The occlusal movement of the maxillary molar in the treated group was not significantly greater than in the untreated group during any period of the study, despite the use of cervical headgear in 70% of the cases in this study.

TABLE 5. Pearson Correlation Coefficients (r) for Mandibular Rotation, Pogonion Horizontal and Vertical Displacement of the Treated Group during Treatment (T1-T2)[a]

Measurements	Mandibular Rotation	Pogonion Horizontal Displacement	Pogonion Vertical Displacement
Facial angle	0.56**	0.73***	
Angle of convexity			
SNA angle		0.41*	
SNB angle	0.39*	0.66***	
ANB angle			
Mandibular plane angle	−0.75***	−0.77***	
Y axis angle	−0.63***	−0.75***	0.45*
Overjet			
Overbite			
Upper AFH (Na-ANS)			0.73***
Lower AFH (ANS-Me)			
(Na-ANS)/(ANS-Me)			0.85***
Posterior cranial base (S-Ar)			0.75***
Ramus (Ar-Go)	0.48**	0.66**	0.47*
(S-Ar)/(Ar-Go)			
AFH (Na-Me)			0.93***
PFH (S-Go)	0.44*	0.51**	0.82***
PFH to AFH ratio		0.47**	0.39*
Mandibular length (Ar-Pog)	0.51**	0.67***	0.75***
Corpus length (Go-Gn)	0.43*	0.46**	0.66***
Occlusal maxillary molar movement			0.86***
Occlusal mandibular molar movement	0.37*	0.47**	0.60***
Sum occlusal molar movement			0.96***
Pog vertical displacement			
Pog horizontal displacement	0.75***		
Pog movement direction	−0.59***	−0.64***	0.61***
Pog movement amount			0.96***
Maxillary rotation	0.36*	0.38*	
Mandibular rotation		0.75***	
Condylar growth direction	−0.64***		
Condylar growth amount	0.58***	0.64***	0.69***

* $P < .05$; ** $P < .01$; *** $P < .001$.

This lack of excessive molar extrusion with the use of cervical headgear has been reported in other studies.[10,12,13,18,31,48,49] It should be borne in mind that the determination of occlusal maxillary molar movement in our study included displacement of the maxilla. We decided to use the overall superimposition to estimate the occlusal maxillary molar movement because it was reported in the literature that maxillary sutural-alveolar growth was one of the factors in mandibular rotation.[5,7,17,18] The mandibular molar teeth exhibited a significant increase in occlusal movement during the treatment period. This could be the effect of Class II elastics[9,22,23] or a response to the increase in vertical facial height. After treatment, occlusal movement of the mandibular molars no longer exceeded the movement seen in the untreated group. This finding was in accordance with the findings of Mills et al.[10]

The change of anterior facial height during treatment was greater in the treated group. Our findings were in accordance with previous studies.[8–12,15,18–23] The increased anterior facial height persisted in the treated group during the overall period; however, this finding might be different if the untreated group cephalograms had been available for a comparable period.

Whereas mandibular rotation did show a moderate correlation with horizontal displacement of the mandible ($r = 0.75$), only 56% of the variability in mandibular rotation was explained. If the center of rotation for mandibular rotation was at the condyle, one would expect a stronger correlation than 0.75. This lower correlation probably reflects various centers for mandibular rotation that in turn probably varies between patients and/or treatment mechanics. Mandibular rotation was not significantly correlated to the sum of occlusal molar movement. Similar lack of correlation was also found by Teuscher[13] and Yoon.[42] Moderate correlations were observed between mandibular rotation and the amount and direction of condylar growth ($r = 0.58$ and -0.64, respectively). Odegaard[4] demonstrated higher correlations ($r = 0.64$ and -0.82, respectively), whereas Yoon[42] reported a weak correlation ($r = 0.42$) between mandibular rotation and the amount of the condylar growth.

Vertical displacement of pogonion showed numerous strong correlations, but they all seem to center around increases in vertical facial dimensions. Most of these would be explained by growth in anterior facial height and posterior facial height ($r = 0.93$ and 0.82, respectively). The very strong correlation between the sum of occlusal molar movement and vertical displacement of pogonion ($r = 0.96$) cannot be assumed to be cause and effect because the change of occlusal tooth movement exceeded that of posterior facial height by only 0.97 mm, and the fact that occlusal tooth movement was not correlated to mandibular rotation. It is likely that it reflects concomitant vertical increases in these variables.

Horizontal displacement of pogonion exhibited its highest correlation with mandibular plane angle, with Y-axis changes, and with mandibular rotation. There was no correlation with the sum of occlusal movement of molars, and this agrees with the findings of Teuscher[13] and Yoon.[42] Schudy[50] reported a correlation between pogonion horizontal displacement and the amount of condylar growth ($r = 0.72$). This is in accordance with the findings of the present study, where a slightly weaker ($r = 0.64$) correlation was found. There was also a lack of correlation between horizontal and vertical displacement of pogonion. This finding was also reported by Baumrind et al[44].

CONCLUSIONS

The present investigation led to the following conclusions:

- During treatment, maxillary prognathism was reduced in the treated group, leading to a reduction of facial convexity and maxillary-mandibular apical base discrepancy. Anterior facial height increased in the treated group, whereas overbite and overjet were reduced. These treatment effects were stable after treatment, except for overbite, which relapsed to half of its treatment correction.
- Orthodontic treatment affected mandibular displacement. The treated group exhibited a more vertical mandibular growth direction and a vertical displacement of pogonion. When compared with controls, the treated group did not exhibit a significant difference in mandibular rotation or occlusal movement of maxillary molars; however, it did show a greater occlusal movement of mandibular molars during treatment. These treatment effects no longer persisted at the end of this study.
- The amount of mandibular rotation was correlated with horizontal displacement of pogonion and the amount and direction of condylar growth. However, it did not correlate with the sum of occlusal or vertical movement of maxillary and mandibular molars.

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