Original Article

Facial divergence and mandibular crowding in treated subjects

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ABSTRACT

Objective: To understand the relationships between facial divergence, vertical growth, and postretention mandibular crowding.

Materials and Methods: Seventy-five white extraction patients were evaluated immediately posttreatment (15.4 years) and again 16.6 years later. Hyperdivergent subjects, subjects with open bite or severe deep bites were not evaluated. Changes in incisor irregularity and tooth-size arch-length discrepancies (TSALD) were evaluated and correlated with measures of divergence and skeletal growth.

Results: Incisor irregularity increased 0.9 mm and TSALD increased 0.7 mm after treatment; 68% of the subjects had less than 3.5 mm incisor irregularity at postretention. Male patients showed significantly more growth than female patients did. Female patients, who were significantly more hyperdivergent than male patients, showed weak to moderately weak associations between posttreatment facial divergence and crowding. Female posttreatment changes in anterior face height, lower incisor eruption, and changes in arch depth were also related to crowding; male patients showed moderate relationships between posttreatment changes in arch width and crowding.

Conclusions: Greater vertical growth, incisor eruption, and especially facial divergence are related to greater posttreatment mandibular crowding. (*Angle Orthod.* 2013;83:381–388.)

KEY WORDS: Crowding; Posttreatment; Postretention; Premolar extraction; Hyperdivergence; Growth

INTRODUCTION

Although improved oral health, function, and social approval are all benefits of orthodontic treatment, patients typically present to maximize appearances.[1–3] This explains why dissatisfaction with crowded and irregular anterior teeth is the most cited reason for seeking treatment.[4–6]

Retention is currently the only way to ensure satisfactory posttreatment alignment[7] and patient satisfaction with orthodontic treatment.[8,9] However, the use of permanent retention instills complacency among orthodontists and transfers ownership of the occlusion to the patient. Understanding the factors affecting stability and relapse makes it possible to prevent posttreatment crowding by adjusting treatment tactics[10–12] and individualizing retention protocols.

Longitudinal studies have shown that mandibular crowding increases over time.[7,13–16] The increases are greatest during adolescence and slow down during early adulthood.[7,17,18] Since crowding occurs in both treated and untreated individuals,[13,14] it may be the result of facial growth changes and not treatment-related relapse.[13,17,19] Crowding has been associated with vertical growth, lower incisor eruption, and increased vertical dentoalveolar eruption.[13,20,21]

Crowding and facial divergence might be expected to be associated because divergence increases anterior vertical dentoalveolar eruption. Hyperdivergence results in retroclination of the incisors, which

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Table 1. Age Distribution of Male and Female Patients

	Male (n = 31)		Female (n = 44)		Diff
	Median	IQR	Median	IQR	*P*
Posttreatment ages	15.92	15.08 to 16.58	15.25	14.83 to 15.71	.018*
Postretention ages	33.17	27.50 to 39.67	30.92	26.79 to 35.46	.326
Age difference (T2–T1)	16.83	10.75 to 23.08	15.50	11.50 to 19.71	.469

* Significant at $P < .05$.

may cause crowding by reducing the arch length.[22,23] While some studies have related increased crowding with hyperdivergence,[24–28] others have found no associations.[29,30] In the only long-term posttreatment study evaluating this relationship, greater prevalence of postretention incisor irregularity was found among hyperdivergent than hypodivergent patients.[28]

The purpose of the present study was to determine whether facial divergence relates to posttreatment crowding. Longitudinal evaluations with larger sample size maximize the possibility of identifying weaker relationships. It was important to exclude hypodivergent subjects who exhibit different dental compensatory mechanisms than hyperdivergent individuals[22]; open bites and severe deep bites were also excluded because altered anterior tooth contacts could affect the dental compensations that occur.

MATERIALS AND METHODS

Selection Criteria

This study evaluated 75 treated subjects with long-term postretention records. The subjects were selected based on: (1) being white and 14–18 years of age at the end of treatment; (2) having Class I molar relationships; (3) having had four premolars extracted; (4) not having had orthognathic surgery, syndromes, significant asymmetries, or hypodivergence; (5) having fully erupted permanent dentitions without missing (other than third molars and four premolars), impacted, or supernumerary teeth; (6) not having excessive cuspal wear; (7) not having open bites or excessively deep bites; (8) having acceptable quality records, including a Panorex or full mouth series, lateral cephalograms, and models; and (9) having postretention records at least 5 years postretention. Using age and sex specific standards[31] subjects with posttreatment mandibular plane angles (S-N/Go-Me) more than 1 standard deviation below the mean were excluded. The models were screened to eliminate individuals with open bite (>0 mm) or severe deep bites (<−4 mm). The study was approved by the Institutional Review Board at Saint Louis University.

The sample, which included 31 male and 44 female patients, was 15.4 years (interquartile range [IQR] 14.8–16.3 years) and 32.0 years (IQR 26.9–36.7 years) of age at posttreatment and postretention, respectively (Table 1). Male patients were significantly older (0.67 years) than female patients immediately after treatment. The patients were treated with edgewise mechanics according to the Tweed philosophy, using extractions to resolve crowding and incisor protrusion (83% had four first premolars extracted, 5% had second premolars extracted, and the remainder had other premolar extraction combinations). Banded 3-to-3 retainers were used for 2–3 years.

Cephalometric Analysis

Cephalograms were traced on 0.003-inch acetate paper and 14 landmarks were identified.[31] The tracings were scanned, uploaded into Dolphin Imaging (version 11.0, Chatsworth, Calif), and digitized at 7× magnification. Fourteen measurements were calculated (Table 2).

Model Analysis

Standardized photographs, incorporating a 100-mm calibration ruler, were uploaded into Dolphin Imaging (version 11.0) for custom digitization. Photographs have been shown[32] to provide measurements as reliable as those taken directly from study models. Twenty-one dental landmarks[33] were digitized at 3× magnification. Seven dental measurements were calculated, including:

(1) Intercanine width (ICW), measured between cusp tips of the lower canines.
(2) Intermolar width (IMW), measured between central pits of the lower first molars.
(3) Arch depth (AD), the distance measured from the contact of the mandibular central incisors perpendicular to a line connecting the mesial contacts of the first molars.
(4) Anterior tooth width (TW), the sum of the mesiodistal dimension of the lower teeth from canine to canine.
(5) Anterior arch perimeter (AP), the sum of two posterior segments, taken from the distal contact of the canine to the distal contact of the lateral incisor, and two anterior segments, from the distal contact of the lateral incisor to the midpoint between the central incisors.

Table 2. Cephalometric and Model Measurements, Along With Method Errors (n = 24)

Measurement	Interpretation (Abbreviation)	Units	Method Error
N-Me	Anterior face height (AFH)	mm	0.65
N-ANS	Upper face height (UFH)	mm	0.56
ANS-Me	Lower face height (LFH)	mm	0.55
S-Go	Posterior face height (PFH)	mm	0.51
Ar-Go	Ramus height (RH)	mm	0.60
L1-GoMe	L1 dentoalveolar height (L1DAH)	mm	0.79
L1-Me	L1 dentoalveolar height (L1Me)	mm	0.79
SN-GoMe	Mandibular plane angle (MPA)	degrees	0.62
PP-GoMe	Palatal plane to mandibular plane angle (PMA)	degrees	0.78
L1/APg	Lower incisor protrusion	degrees	0.82
IMPA	Lower incisor inclination	degrees	1.38
Overbite	Vertical distance between U1 and L1 tips (OB)	mm	0.76
Overjet	Horizontal distance between U1 and L1 tips (OJ)	mm	0.53
ICW	Intercanine width	mm	0.19
IMW	Intermolar width	mm	0.10
Arch depth	Arch depth	mm	0.09
II	Incisor irregularity	mm	0.26
TSALD	Tooth-size arch-length discrepancy	mm	0.46

(6) Anterior tooth-size arch-length discrepancy (TSALD), the difference between AP and TW.
(7) Little's irregularity index (II), the sum of the contact point displacements of the six anterior teeth.

Reliability of Measurements

To reduce measurement errors, all cephalograms were traced and digitized by one investigator. Method errors,[34] which were based on 24 replicates, for the cephalometric measures ranged from 0.51 to 0.79 mm and 0.62° to 0.82°, except the IMPA, which was 1.38°; method errors for the model measurements ranged from 0.09 to 0.46 mm (Table 2). Systematic error, evaluated using the Wilcoxon test, was not statistically significant.

Statistical Analysis

Nonparametric statistics were used because the skewness and kurtosis statistics showed that the primary outcome variables (II and TSALD) and several other variables were not normally distributed. Medians and interquartile ranges (IQRs) were used to describe the variables. In order to determine whether sex differences could help to explain the results, the Mann-Whitney *U*-test was used to evaluate differences between male and female patients. Changes over time were evaluated using the Wilcoxon signed rank tests. Correlations were calculated using Spearman rank-order correlations. The calculations were performed using SPSS Statistics software (version 17.0, SPSS, Chicago, Ill), with the significance level set at .05.

RESULTS

There were no statistically significant sex difference in II and TSALD. After treatment, both sexes showed minor II (2.00 mm) and mild TSALD (−0.20 mm). Over time, II and TSALD increased significantly ($P < .001$), 0.90 mm and 0.70 mm, respectively (Table 3). Approximately 32% of the samples had II greater than 3.5 mm at postretention. Some individuals displayed almost no change in crowding (25% showed less than 0.2 mm) or even developed spacing. Postretention irregularity (3.10 mm) and TSALD (−1.00 mm) were small. Posttreatment II and TSALD were not interrelated ($r = 0.097$, $P = .435$); they were moderately correlated postretention ($r = -0.612$, $P < .001$); the correlation between the changes that occurred between II and TSALD over time was low ($r = -0.322$, $P = .008$).

All of the posttreatment linear measures were significantly larger in male than in female patients (Table 4). Female patients were significantly more hyperdivergent than were male patients, with larger mandibular plane (3.4°) and palatomandibular plane

Table 3. Crowding in Treated Groups

	Posttreatment		Postretention		Change (n = 67)	
Variable	Median	IQR	Median	IQR	Median	IQR
II	2.00	1.50 to 2.50	3.10	2.40 to 3.80	0.90*	0.20 to 2.10
TSALD	−0.20	−0.70 to 0.20	−1.00	−1.40 to 0.60	−0.70*	−1.40 to 0.30

* Significant ($P < .001$) change over time.

Table 4. Comparison of Posttreatment (T1) Skeletal Measures in Male and Female Patients in Treated Groups

	Male		Female		Diff
Variable	Median	IQR	Median	IQR	*P*
AFH	127.90	122.90 to 132.30	121.75	117.73 to 124.10	<.001
UFH	57.80	55.50 to 59.10	53.60	52.25 to 55.60	<.001
LFH	71.80	69.10 to 75.60	69.30	66.08 to 72.88	.026
PFH	83.30	78.90 to 87.80	75.30	73.00 to 77.45	<.001
RH	49.30	45.70 to 53.80	44.80	43.13 to 47.30	<.001
L1DAH	42.20	41.10 to 44.20	40.15	38.68 to 41.85	.002
L1Me	43.00	41.80 to 45.50	41.10	39.50 to 43.00	.005
LFH/AFH	0.57	0.55 to 0.58	0.57	0.56 to 0.59	.078
PFH/AFH	0.66	0.63 to 0.68	0.63	0.61 to 0.65	.001
MPA	33.80	30.90 to 36.30	37.20	34.83 to 40.85	<.001
PMA	24.20	21.50 to 27.40	28.70	26.20 to 32.45	.001

(4.5°) angles, and smaller posterior to anterior facial height ratios (3%).

Significant increases over time occurred for most measures (Table 5). Male patients showed significantly greater increases in posterior face height (2.5 mm) and ramus height (2.1 mm), and more closure in the MPA (2.2°) and PMA (1.6°) angles than female patients. Lower to anterior face height ratios (LFH/AFH) were maintained over time and showed no significant sex differences.

Male patients had significantly larger intercanine (1.05 mm) and intermolar widths (1.20 mm) than female patients (Table 6). There were no significant sex differences in the posttreatment dental changes that occurred (Table 7), except for intermolar width, which increased slightly (0.20 mm) in male patients and decreased slightly (−0.40 mm) in female patients. There were statistically significant increases in overbite and overjet and significant decreases in L1/APg, ICW, and arch depth.

Associations

Sex specific correlations showed no associations for male patients, but female patients showed a significant association between posttreatment AFH and postretention II changes. Female patients also showed moderate correlations between postretention irregularity changes and posttreatment PFH/AFH, mandibular plane angle, and palatomandibular angle (Table 8). Female patients also showed significant correlations between TSALD changes and posttreatment PFH/AFH and MPA.

Female patients who showed the greatest posttreatment increases in anterior facial height and the greatest lower incisor eruption (L1DAH and L1Me) also showed the greatest increases in TSALD (Table 9). Male patients showed no correlations between crowding and the posttreatment skeletal changes that occurred. Changes in IMPA were positively related to increases in II in female patients only. Male and female patients who underwent greater decreases in arch widths also showed greater increases in II and greater decreases in TSALD. Posttreatment decreases in arch depth and TSALD were moderately correlated in male patients.

DISCUSSION

Both II and TSALD must be measured in studies evaluating crowding because they represent different aspects of crowding. Correlations between postretention

Table 5. Comparison of Skeletal Changes (T2–T1) in Male and Female Patients in Treated Groups

	Male (n = 30)		Female (n = 44)		Diff
Variable	Median	IQR	Median	IQR	*P*
Δ AFH	3.10*	0.90 to 5.53	4.45*	1.65 to 5.48	.516
Δ UFH	1.25*	−0.13 to 2.95	1.65*	0.70 to 2.80	.484
Δ LFH	1.85*	0.45 to 3.03	2.15*	0.20 to 3.28	.656
Δ PFH	5.40*	3.50 to 8.20	2.95*	1.68 to 4.58	<.001
Δ RH	4.60*	3.20 to 6.30	2.50*	1.03 to 3.10	<.001
Δ L1DAH	2.05*	0.60 to 2.75	1.70*	1.33 to 2.50	.671
Δ L1Me	2.30*	0.35 to 3.10	1.85*	1.25 to 2.48	.589
Δ LFH/AFH	−0.002	−0.008 to 0.006	−0.001	−0.009 to 0.004	.800
Δ PFH/AFH	0.026*	0.015 to 0.040	0.009	−0.003 to 0.015	<.001
Δ MPA	−2.80*	−3.93 to −0.93	−0.65*	−1.60 to 0.55	<.001
Δ PMA	−2.00*	−4.20 to −0.73	−0.40*	−1.85 to 0.40	.005

* Significant ($P < .05$) change over time.

Table 6. Comparison of Posttreatment (T1) Dental Measures in Male and Female Patients in Treated Groups

	Male (n = 26)		Female (n = 41)		Diff
Variable	Median	IQR	Median	IQR	*P*
OB	1.50	1.20 to 2.10	1.85	1.10 to 2.38	.734
OJ	2.60	1.90 to 2.80	2.20	1.80 to 2.58	.100
L1/APg	1.50	0.30 to 2.40	1.45	0.45 to 2.58	.609
IMPA	90.60	87.90 to 95.40	90.50	86.05 to 95.45	.423
ICW	26.95	26.30 to 27.60	25.90	25.00 to 26.70	.002
IMW	36.80	35.78 to 37.98	35.60	34.40 to 37.05	.018
Arch depth	−17.75	−18.88 to −16.70	−17.10	−17.90 to −15.85	.053
II	2.00	1.475 to 2.525	2.00	1.60 to 2.60	.584
TSALD	−0.30	−0.53 to 0.23	−0.20	−0.70 to 0.20	.918

II and TSALD were moderate to moderately high (r = 0.61 and 0.78). Similar correlations have been reported for pretreatment[35,36] and postretention[37] crowding. Importantly, one measure explains less than half of the variation of the other measure. This difference is clinically important because irregularity is "sensitive" to axial displacements and rotational changes of teeth, whereas TSALD reflects the difference between space required and space available.

Increases in mandibular crowding commonly occur after retention has been discontinued. Generally, the treated sample maintained satisfactory stability 16.6 years after treatment; 93% of the subjects exhibited only minor TSALD (<4 mm) and 68% had satisfactory II (<3.5 mm). They showed small, but significant, posttreatment increases in irregularity (0.9 mm) and TSALD (−0.7 mm). Crowding that occurred was similar to amounts of II previously reported (0.34–1.3 mm) for patients treated with extractions in private practices.[13,18,38,39] It is difficult to know whether sample characteristics, the treatment rendered, the retention protocol, band spaces remaining after treatment, or band space after removal of fixed retainers contributed to the lower levels of crowding observed in the present study.

The present study was limited by the lack of an untreated control group, due to the difficulty of securing longitudinal cephalograms and models of untreated adolescents and adults. However, the crowding that occurred posttreatment in this and other studies from private practitioners, was similar to, or on the low end of, values reported for untreated samples (II ranges from 0.47–2.58 mm; TSALD ranges from 0.1–2.78 mm).[13–15,40–45] This is important because it suggests that the crowding that occurred was probably not related to treatment itself, but to other nontreatment related factors that are not exclusive to orthodontic patients.

Male and female patients exhibited similar amounts of posttreatment crowding. A lack of sex differences in crowding has been previously reported for treated[13,41,46] and untreated[13,15,43] individuals. Based on a large cross-sectional sample of 9044 individuals, Buschang and Shulman[17] found significantly larger II (0.48 mm) among male than female patients. If a difference exists, it is likely small and can only be identified using large samples.

Generally, female patients were more divergent than male patients and remained more divergent over time. Female patients had significantly larger mandibular plane angles and anterior to posterior facial height ratios than male patients. Female patients have been previously shown to be more divergent than male patients.[47–50] Sex differences could be due to the fact that male patients exhibited greater increases in posterior face height and ramus height than female patients. These sex differences pertain mainly to growth in the posterior aspects of the face; LFH/AFH

Table 7. Comparison of Dental Changes (T2–T1) of Male and Female Patients in Treated Groups

	Male (n = 26)		Female (n = 41)		Diff
Variable	Median	IQR	Median	IQR	*P*
Δ OB	0.75*	−0.13 to 2.15	1.65*	0.80 to 2.20	.108
Δ OJ	0.15	−0.43 to 0.95	0.50	0.10 to 1.08	.086
Δ L1/APg	−0.50	−1.33 to 0.90	−0.50	−1.10 to 0.40	.893
Δ IMPA	−0.85	−2.70 to 3.15	0.25	−3.40 to 3.13	.692
Δ ICW	−1.45*	−1.78 to −0.75	−1.70*	−2.30 to −0.75	.325
Δ IMW	0.20	−0.43 to 1.03	−0.40	−0.90 to 0.30	.008
Δ Arch depth	−1.20*	−1.83 to −0.70	−1.90*	−2.30 to −0.95	.113
Δ II	0.75*	−0.03 to 1.98	1.10*	0.40 to 2.15	.367
Δ TSALD	−0.65*	−1.15 to −0.28	−0.70*	−1.65 to −0.25	.685

* Significant (P < .05) change over time.

Table 8. Correlations Between Change in Crowding (T2–T1) and Posttreatment Skeletal Measures (T1) in Treated Subjects[a]

	Male (n = 26)				Female (n = 41)			
	Δ II		Δ TSALD		Δ II		Δ TSALD	
Variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
AFH	−0.111	.591	−0.085	.681	0.342	.029	−0.265	.094
PFH/AFH	−0.116	.571	0.064	.756	−0.327	.037	0.414	.007
MPA	0.104	.615	−0.028	.893	0.398	.010	−0.361	.021
PMA	0.002	.992	0.048	.815	0.447	.003	−0.194	.224

[a] II indicates incisor irregularity; TSALD, tooth-size arch-length discrepancy.

showed relatively minor changes in both sexes. This indicates that female patients are more divergent because they have less posterior growth, and not because they have greater posterior mandibular rotation.

Female patients with increased facial divergence were more likely to exhibit posttreatment crowding than female patients with average divergence. This association was significant in female patients, but not in male patients, probably because they exhibited greater mandibular divergence. The changes in divergence were not related to the crowding that occurred, most likely because these dimensions showed relatively small changes over time. Although some studies have not found a relation,[29,30] others have found that differences in crowding were related to facial divergence.[24–27] Importantly, the associations between crowding and divergence were not strong, indicating that it is just one of many factors that must be considered.

Divergence might be at least partially related to crowding due to changes in the transverse dimension. Both male and female patients whose arches became more narrow after treatment exhibited greater posttreatment crowding. Since narrow arches limit the space available for the teeth, this could increase the risk of crowding.[37,51]

Vertical eruption of the lower incisors was also associated with posttreatment crowding. Female patients with greater amounts of lower incisor eruption had greater increases in TSALD. In female patients, L1DAH explained 20% and L1Me explained 41% of the variation in crowding. Relationships between increased eruption and crowding have been previously demonstrated.[13,20] A relationship between TSALD and increases in the anterior face height is reasonable because height increases might be expected to result in greater incisor eruption.

CONCLUSIONS

Within the limits of this study based on a single sample of 75 white adolescents followed longitudinally after treatment for approximately 16.6 years:

- Posttreatment crowding was generally acceptable and showed only small increases in patients who had been out of retention for approximately 13–14 years.
- Posttreatment cephalometric and dental arch measures were larger and grew more in male patients than female patients.
- Although male patients showed no relationships, female patients with the greatest posttreatment increases in facial divergence exhibited the greatest posttreatment crowding.
- Female patients with greatest posttreatment lower incisor eruption and greatest increases in anterior facial growth showed the greatest increases in crowding.
- Posttreatment increases in crowding were related to posttreatment decreases in arch widths in both male and female patients.

Table 9. Correlations Between Change in Crowding (T3–T2) and Change in Skeletal Measures (T3–T2) in Treated Subjects[a]

	Male (n = 26)				Female (n = 41)			
	Δ II		Δ TSALD		Δ II		Δ TSALD	
Variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Δ AFH	−0.106	.615	0.122	.562	0.246	.122	−0.343	.028
Δ L1DAH	0.227	.276	−0.227	.275	−0.003	.986	−0.445	.004
Δ L1Me	0.350	.086	−0.260	.210	0.092	.567	−0.643	<.001
Δ IMPA	−0.204	.328	−0.039	.853	0.015	.927	0.376	.016
Δ Arch depth	0.069	.738	0.174	.396	−0.254	.109	0.575	<.001
Δ ICW	0.410	.037	0.568	.002	0.431	.005	0.291	.065
Δ IMW	−0.508	.008	0.701	<.001	−0.138	.391	−0.021	.896

[a] II indicates incisor irregularity; TSALD, tooth-size arch-length discrepancy.

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