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Long-term stability: Postretention changes of the mandibular anterior teeth

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Introduction: Our objectives were to evaluate the long-term posttreatment changes of orthodontically corrected mandibular anterior malalignment and to determine the factors explaining these changes. **Methods:** The sample consisted of 66 subjects (mean age, 15.4 ± 1.7 years) selected from 7 private practices. The teeth had been retained for approximately 3 years and followed for 15.6 ± 5.9 years posttreatment. Longitudinal study models and cephalograms were analyzed to quantify the malalignment and growth changes that occurred. **Results:** Crowding (1.2 ± 0.9 mm) and irregularity (1.5 ± 1.8 mm) showed only small average increases over the postretention period; only 26% of the sample had more than 3.5 mm of postretention irregularity. Variation in crowding explained 16% of the differences among subjects in irregularity. Growth variables (posterior facial height and mandibular rotation) and interarch variables (incisor-mandibular plane angle, interincisal angle, overbite, and overjet) were not significantly related to malalignment. Postretention malalignment changes were related to posttreatment anterior arch perimeter, intercanine width, and arch form, together indicating that narrower arch forms are likely to show greater posttreatment malalignment changes. Patients treated with extractions showed significantly greater malalignment than those treated without extractions; this was related to arch form. Patients who received interproximal restorations after treatment also showed significantly greater postretention malalignment than patients who did not. **Conclusions:** Orthodontic treatment is not inherently unstable. Narrow arch forms and interproximal restorations are potential risk factors for the development of postretention malalignment. (Am J Orthod Dentofacial Orthop 2013;144:420-9)

Mandibular anterior malalignment is the most significant problem in patients having orthodontic treatment.[1-3] Clinically significant incisor irregularity occurs in approximately 40% of the untreated population between 15 and 50 years of age, with approximately 17% exhibiting severe amounts (≥7 mm) of mandibular irregularity.[4] Significant malalignment has also been regularly reported after orthodontic treatment.[5-17] To further challenge orthodontists, treated patients are more aware of their malocclusion than are untreated subjects.[18] Since patients want to maintain straight teeth, a primary objective of the orthodontist must be long-term stability.

When established guidelines of traditional orthodontic treatment have been followed (ie, no excessive flaring or canine expansion), treatment-related factors do not appear to explain postretention malalignment. There also appears to be no relationship between pretreatment and postretention dental malalignment.[5-7] Although excessive incisor proclination during treatment appears to be related to posttreatment retroclination,[19] limited amounts of incisor proclination during treatment show little or no relationship to posttreatment changes.[7,20] Numerous studies have reported postretention decreases in intercanine width, but only one has shown a correlation between the amount of expansion during treatment and the amount of relapse after treatment.[8] The available evidence suggests that when established treatment guidelines have not been violated, postretention malalignment appears to be primarily related to nontreatment factors.

Malalignment of teeth regularly occurs in untreated subjects, even in those with normal occlusions.[9,21-25] Incisor irregularity of untreated subjects shows the greatest rate of increase during adolescence; the rates progressively decrease thereafter.[4,9,21-25] Importantly, the irregularity and crowding increases reported for

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Table I. Longitudinal studies of mandibular anterior malalignment in patients treated by private practice orthodontists

	Ext, nonext, both, or untx	*Initial (posttreatment) age (y)*	*Final (postretention) age (y)*	*ΔII (mm)*	*ΔTSALD (mm)*	*ΔII (mm/y)*	*ΔTSALD (mm/y)*
Treated subjects							
Vaden et al[10]	Ext	15.3	21.6	+0.6	NA	+0.09	NA
Moussa et al[16]	Nonext	15.7	22.0	+0.8	NA	+0.13	NA
Elms et al[6],*	Ext	14.5	23.1	+0.4	NA	+0.05	NA
Ferris et al[17]	Nonext	13.7	24.3	+1.1	NA	+0.10	NA
Driscoll-Gilliland et al[9]	Ext	14.8	26.1	+1.3	−1.0	+0.10	−0.09
Glenn et al[14]	Nonext	14.9	26.7	+1.2	NA	+0.10	NA
Dugoni et al[13]	Nonext	13.6	27.9	+1.6	NA	+0.11	NA
Park et al[15]	Both	14.2	30.3	+1.5	NA	+0.09	NA
Park et al[15]	Both	21.5	37.2	+0.9	NA	+0.06	NA
Vaden et al[10]	Ext	21.6	30.5	+0.8	NA	+0.09	NA
Boley et al[5]	Ext	15.5	31.6	+0.7	NA	+0.06	NA
Current study	Ext	14.7	28.3	+1.8	−1.4	+0.11	−0.09
Current study	Nonext	15.8	32.2	+1.0	−0.9	+0.06	−0.06
Overall treated average	Both	15.8	27.8	+1.1	−1.1	+0.09	−0.08
Untreated subjects							
Sinclair and Little[21]	Untx	9.5	12.5	-0.2	NA	−0.07	NA
Richardson[22]	Untx	12.5	15.5	NA	−1.5	NA	−0.49
Richardson[23]	Untx	13.0	18.0	NA	−2.3	NA	−0.46
Sinclair and Little[21]	Untx	12.5	19.5	+0.7	NA	+0.10	NA
Driscoll-Gilliland et al[9]	Untx	14.3	23.2	+0.9	−1.1	+0.10	−0.12
Richardson and Gormley[24]	Untx	21.0	28.0	NA	−0.2	NA	−0.03
Bondevik[25]	Untx	23.0	34.0	NA	−0.2	NA	−0.02
Bishara et al[26]	Untx	25.0	46.0	NA	−0.3	NA	−0.04
Overall average	Untx	17.4	26.3	+0.8	−0.9	+0.10	−0.19

Increases in malalignment are indicated by − for tooth size-arch length discrepancy (TSALD) and + for incisor irregularity (II).
Ext, Extraction; *nonext*, nonextraction; *both*, both extraction and nonextraction; *untx*, untreated subjects; *Δ*, change.
*Reported interproximal reduction upon removal of fixed retainers.

untreated subjects are similar to the malalignment increases reported in long-term follow-up studies of patients treated in private practices (Table I). This supports the finding of no long-term differences in irregularity and crowding between matched treated and untreated subjects.[9] The similarities of treated and untreated subjects further supports the notion that the commonly reported postretention changes are due to factors not associated with treatment.

There are age-related effects on the development of posttreatment malalignment that indicate an association with growth. Compared with sex, ethnic affiliation, and number of teeth present, age is by far the most important factor explaining incisor irregularity.[4] Vertical facial growth and incisor eruption appear to be the morphologic components most closely related to postretention irregularity.[9,26] Since mandibular rotation influences incisor inclination, and inclination changes might affect space relationships, rotation might affect the development of malalignment, but this relationship has not been previously explored.[27-29] The contained-arch principle suggests that as overbite deepens after treatment, the lingual force imposed on the mandibular incisors from the maxillary incisors tends to squeeze and crowd the mandibular arch.[30] There has been only 1 study substantiating this relationship[6]; other studies have evaluated, but have not been able to support, such a relationship.[8-10]

Irregularity has been reported to worsen for teeth located farther from the mandibular midline, indicating that arch form can also be related to anterior malalignment.[10] It has been suggested that the canines might be "slipping" into a position anterior to the lateral incisor in crowded dentitions, giving the arch a more square appearance.[10] Previous studies evaluating the effects of mandibular arch form on malalignment have been based on linear depth, length, and transverse measurements, which provide only limited information about arch shape and no information about the positional (rotation and displacement) changes of the dentition.[6,8,25] Positional changes could explain the pattern of irregularity observed if alignment is most susceptible at the portions of the arch with the greatest curvature. This is important because the anterior component of occlusal forces might be expected to have its greatest impact at the contacts located at the greatest curvature.[31]

Table II. Years of experience, treatment approach, treatment philosophy, appliances used, and retention protocols of the 7 orthodontists

Orthodontist	*Experience (y)*	*Treatment approach*	*Treatment philosophy*	*Appliances used*	*Retention protocol*
1	45	Standard edgewise	Tweed	Banded	Hawley/3X3
2	44	Standard edgewise	Alexander	Banded/bonded	Hawley/3X3
3	8	Standard edgewise	Gianelly	Bonded	Essix/Essix
4	32	Standard edgewise	Creekmore	Banded/bonded	Hawley/3X3
5	50	Standard edgewise	Tweed	Banded/bonded	Hawley/3X3
6	35	Standard edgewise	Tweed/Alexander	Banded/bonded	Hawley/3X3
7	35	Standard edgewise	Tweed/Alexander	Banded/bonded	Hawley/3X3

Oversized restorations, which also provide an anterior component of force, must be considered as another potential contributing factor.

The aims of this study were to evaluate the long-term posttreatment positional changes of the mandibular teeth and to investigate whether and how growth and intra-arch dental relationships influence these changes. Whether long-term stability is related to novel measures of dental arch shape, including the contact angles between adjacent teeth, and to the angles between dental counterparts in the same jaw, has not been previously established. These relationships should give orthodontists evidence that will enhance their understanding of malalignment, guide them in the treatment of patients, and perhaps provide guidelines for the prevention of future dental malalignment.

MATERIAL AND METHODS

A sample of 66 orthodontically treated patients was collected from 7 orthodontists who used various appliances and mechanics but shared a similar philosophy of maintaining the teeth over the basal bone (ie, they did not excessively procline the incisors or expand the canines). One orthodontist performed interproximal reduction of the mandibular anterior teeth when the retainers were removed. Many patients were treated in the 1960s and 1970s with full banded appliances. It was considered important to include a wide spectrum of treatment approaches and philosophies (Table II).

The records collected included plaster study models, cephalograms, and panoramic radiographs or full-mouth radiographic series. For inclusion in this study, the patients' final posttreatment and long-term postretention records needed to be of acceptable quality. At posttreatment, the patients had to be less than 21 years of age. Postretention records had to be taken a minimum of 5 years posttreatment and 3 years postretention. The patients reported compliance with the retainer protocol, which lasted for 3 years on average. Treatment outcome was not an inclusion criterion. Rejection criteria included pretreatment Class III malocclusions, craniofacial anomalies, orthognathic surgery, circumferential supracrestal fibrotomy, postretention spacing, or abnormal incisor anatomy such as restorations, interproximal reduction, or large lingual marginal ridges. The first 25 patients who met the selection criteria were included in the study.

All posttreatment records were taken within 3 months of debonding or debanding. They were collected at a mean age of 15.4 ± 1.7 years. Postretention records were collected at a mean age of 31.1 ± 6.3 years. The average posttreatment duration was 15.7 ± 6.0 years.

Overjet and overbite were directly measured on the study models with digital calipers, accurate to 0.01 mm.

1. Overjet, measured parallel to the occlusal plane, was the distance from the incisal edge of the most labial maxillary central incisor to the facial surface of the most labial mandibular central incisor.
2. Overbite, measured perpendicular to the occlusal plane, was the overlap of the maxillary to the mandibular central incisors.

Eight additional model measurements were collected from standardized digitized photographs, taken with a single-lens reflex camera and a 100-mm macro lens positioned 27 in from the study models, which were secured in a standardized position. The photos were imported into Dolphin software (version 11.0; Dolphin Imaging & Management Solutions, Chatsworth, Calif), and a customized protocol was used to calculate the following.

1. Intercanine width, measured between the cusp tips of the mandibular canines (Fig 1, *A*).
2. Anterior arch perimeter, measured as the sum of 4 segments, 2 segments on each side. The 2 canine segments were measured from the mesial aspect of the first premolar to the contact of the canine and the lateral incisor. The 2 incisor segments were measured from the contact of the canine and the lateral incisor to the contact of the central incisors on the midline (Fig 1, *A*).

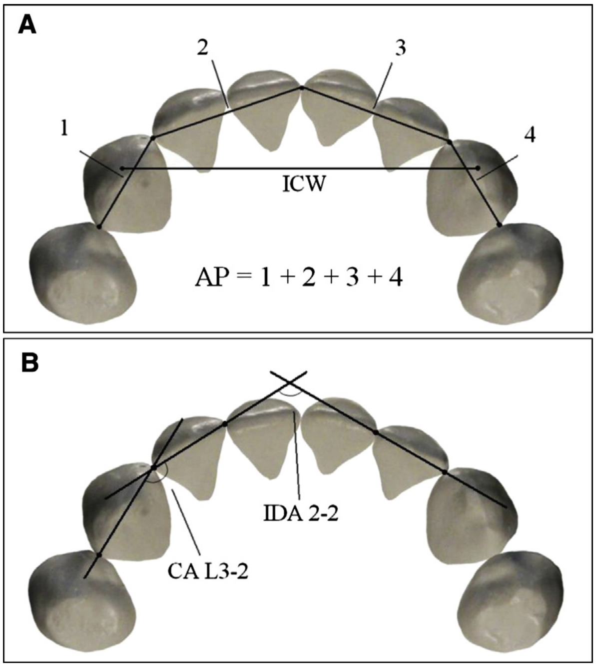

Fig 1. A, Measurements of intercanine width (*ICW*) and anterior arch perimeter (*AP*); **B,** measurement of the contact angles between the left canine and the lateral incisors (*CA L3-2*) and the lateral incisor interdental angle (*ID A2-2*).

3. Tooth size, measured as the sum of the mesiodistal diameter of the 6 anterior mandibular teeth.
4. Contact irregularity, measured between pairs of teeth as the distance between the contact points of the teeth anterior to the first premolars.
5. Contact angle, measured by lines through the mesial and distal contact points of adjacent teeth anterior to and including the first premolars (Fig 1, *B*).
6. Interdental angle, measured as the angle formed by lines through the mesial and distal contact points of the contralateral teeth anterior to and including the first premolars (Fig 1, *B*).
7. Incisor irregularity, calculated as the sum of the 5 contact irregularity measurements of the 6 anterior teeth.
8. Tooth size-arch length discrepancy, calculated as the difference between tooth size and anterior arch perimeter.

The posttreatment and postretention lateral cephalograms were scanned and imported into digitizing software. Sella, gonion, menton, the incisor apices, and the incisor cusp tips were digitized by the principal investigator (S.A.M.) using standard landmark definitions.[32] Structures necessary to superimpose on the cranial base and the mandible were also traced.[27,28] Based on the structures traced and the landmarks digitized, the following measurements were calculated with the Dolphin software.

1. Posterior facial height, measured as the linear distance from sella to gonion.
2. Incisor to mandibular plane angle, measured as the angle formed by the long axis of the mandibular incisor to the mandibular plane.
3. Interincisal angle, measured as the angle formed by the long axis of the mandibular incisor with that of the maxillary incisor.
4. Apparent rotation (as described by Solow and Houston[33]), measured as the angle formed by the postretention and posttreatment mandibular planes after cranial base superimposition.
5. Modeling rotation, measured as the angle formed by the postretention and posttreatment mandibular planes after mandibular superimposition.
6. True rotation, calculated as the difference between apparent rotation and modeling rotation.

The panoramic and full-mouth radiographic series were evaluated to determine whether interproximal dental restorations had been performed. Restorations were counted based on radiopacity.

Statistical analysis

Twenty random plaster models and radiographs were selected and measured twice to determine the intraexaminer reliability. There were no statistically significant systematic errors between replicate measurements. There were also no differences between replicates in the numbers of interproximal restorations. Random errors, measured by Dahlberg's method error statistic,[34] ranged from 0.03 to 0.48 mm for linear measurements and from 0.10° to 0.40° for angular measurements.

Descriptive statistics were calculated at each time point, as well as for changes over the posttreatment period. Because some distributions were significantly skewed or kurtotic, nonparametric statistical comparisons were used. Spearman rank order correlations were used to assess bivariate associations. Mann-Whitney tests were used to evaluate the effects of sex, interproximal restorations, and extraction treatment.

RESULTS

The subjects had small amounts of incisor irregularity (1.48 mm) and minor spacing (0.39 mm) at the end of treatment (Table III). Although irregularity and tooth size-arch length discrepancy increased significantly over time, the average increases in incisor irregularity

Table III. Posttreatment, postretention, and changes of incisor irregularity (II) and tooth size-arch length discrepancy (TSALD)

Malalignment (mm)	Posttreatment (T1)		Postretention (T2)		Change T2-T1	
	Median	IQR	Median	IQR	Median	IQR
II	1.40	1.03	2.75	1.87	1.30*	2.35
TSALD	0.50	0.93	−0.70	0.80	−1.20*	1.22

IQR, Interquartile range.
*Significant (P <0.05) change over time.

Table IV. Posttreatment, postretention, and changes of posterior facial height (SGo), overbite (OB), overjet (OJ), interincisal angle (U1L1), and incisor to mandibular plane angle (IMPA)

Variable	Posttreatment (T1)		Postretention (T2)		Change T2-T1	
	Mean	SD	Mean	SD	Mean	SD
SGo (mm)	73.95	6.56	76.82	6.93	2.87*	2.40
OB (mm)	2.30	0.70	2.83	1.05	0.53*	0.93
OJ (mm)	2.38	0.60	2.80	0.77	0.42*	0.78
U1L1 (°)	128.43	8.25	129.86	8.61	1.43*	5.56
IMPA (°)	91.33	5.68	90.95	6.79	–0.38	3.64

*Significant (P <0.05) change over time.

(1.50 mm) and crowding (−1.22 mm) were minor. Posttreatment and postretention irregularity and tooth size-arch length discrepancy were not significantly correlated. Changes in irregularity were positively correlated with both posttreatment age (r = 0.361, P = 0.003) and posttreatment duration (r = 0.313, P = 0.010). Changes in tooth size-arch length discrepancy were negatively correlated (r = −0.275, P = 0.025) with posttreatment duration. There was a significant negative correlation between postretention tooth size-arch length discrepancy and irregularity (r = −0.603, P <0.001). Tooth size-arch length discrepancy and irregularity changes over time were also significantly intercorrelated (r = −0.406, P = 0.001).

Posterior facial height increased by 2.9 mm, and the mandible underwent 1.34° ± 0.24° of true forward rotation during the posttreatment period (Table IV). One quarter of the true rotation was masked by backward modeling rotation (0.33° ± 1.18°), resulting in −1.01° ± 2.11° of apparent rotation. Although these growth measures were not related to posttreatment duration, posttreatment age was negatively correlated with changes in posterior facial height (r = −.441, P <0.001) and positively correlated with true mandibular rotation (r = 0.281, P = 0.022). Changes in posterior facial height and true rotation were also intercorrelated (r = −0.402, P = 0.001). There were no other significant correlations between these growth variables and the interarch or intra-arch measurements evaluated.

Overbite and overjet increased slightly, but significantly, over time (Table IV). Changes in overbite were positively correlated with changes in overjet (r = 0.408, P = 0.001). The interincisal angle increased by 1.4° at posttreatment. Although the incisor to mandibular plane angle showed no statistically significant change over time (ie, it both increased and decreased), the changes were negatively correlated with the changes in the interincisal angle (r = −0.656, P <0.001). The interarch measures showed no other significant correlations.

Anterior arch perimeter and intercanine width decreased significantly over time (Table V). Changes in anterior arch perimeter and intercanine width were positively intercorrelated (r = 0.426, P <0.001) and were weakly correlated with postretention tooth size-arch length discrepancy (r = 0.275 P = 0.025; and r = 0.388; P = 0.001, respectively); intercanine width changes were negatively correlated with postretention incisor irregularity (r = −0.371, P = 0.002). The changes in anterior arch perimeter and intercanine width were not significantly correlated with any other measures.

The contact irregularities and contact angles showed little or no differences between the right and left sides. Contact irregularities increased progressively for teeth located farther from the midline; these changes, from 0.23 to 0.33 mm, were significant for all contacts except those between the canines and the premolars. The contact angles of the incisors were approximately 161.5° to 164.4°, the contact angles between the canines and the lateral incisors were 10° to 15° smaller, and those between the premolars and the canines were the largest, approximately 171.2° to 173.1°. Only the change in contact angle between the central incisors was statistically significant. The interdental angles were greatest at the central incisors and decreased progressively for the more posterior teeth.

The contact angles of adjacent teeth were interrelated (ie, the contact angle between the premolar and the canine were correlated with the contact angle between the canine and the lateral incisor). The interdental angle between the canines was significantly related to the central and lateral incisors and the premolar interdental angles (r = 0.297, P = 0.015; r = 0.285, P = 0.020; and r = 0.284, P = 0.021, respectively). The posttreatment interdental angle between the lateral incisors showed a significant relationship with the irregularity change (r = −0.256, P = 0.038), so that the

Table V. Posttreatment, postretention, and changes in anterior arch perimeter (AP), intercanine width (ICW), contact irregularity (CI), contact angles (CA), and interdental angles (IDA)

Intra-arch measure	*Posttreatment (T1)*		*Postretention (T2)*		*Change T2-T1*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
AP (mm)	37.63	1.83	35.66	1.72	−1.97*	1.05
ICW (mm)	26.30	1.30	25.19	1.61	−1.10*	1.00
Contact irregularity (mm), distance from anatomical contact points of adjacent teeth						
CI L4-3	0.68	0.57	0.73	0.68	0.05	0.66
CI L3-2	0.42	0.29	0.66	0.58	0.23*	0.61
CI L2-1	0.19	0.19	0.52	0.50	0.33*	0.53
CI 1-1	0.18	0.20	0.49	0.53	0.30*	0.56
CI R2-1	0.23	0.23	0.55	0.52	0.32*	0.53
CI R3-2	0.46	0.35	0.77	0.69	0.31*	0.73
CI R4-3	0.71	0.62	0.72	0.71	0.01	0.94
Contact angles (°), angles formed by lines through the mesial and distal contact points of adjacent teeth						
CA L4-3	172.22	8.66	173.09	9.18	0.87	8.51
CA L3-2	150.08	8.91	149.48	9.27	−0.60	9.31
CA L2-1	161.60	5.31	161.56	9.37	−0.04	8.17
CA 1-1	161.48	4.74	164.38	11.92	2.90*	9.73
CA R2-1	162.94	4.82	163.65	8.95	0.71	8.19
CA R3-2	148.24	8.53	146.45	10.53	−1.79	8.94
CA R4-3	171.22	9.21	171.45	11.42	0.22	7.59
Interdental angles (°), angles formed by lines through the mesial and distal contact points of contralateral teeth						
IDA 1-1	161.48	4.74	164.38	11.92	2.90*	9.73
IDA 2-2	126.02	7.73	129.60	13.15	3.57*	10.28
IDA 3-3	64.34	15.14	65.52	13.05	1.18	9.89
IDA 4-4	47.78	10.30	50.05	13.59	2.27	11.62

*Significant (P <0.05) change over time.

larger the posttreatment interdental angle between the lateral incisors, the less the irregularity change over time. In addition, the posttreatment interdental angle between the canines was positively correlated with the change in tooth size-arch length discrepancy ($r = 0.253$, $P = 0.040$), so that the larger the posttreatment interdental angle between the canines, the less crowding during the posttreatment period.

Although there were no significant sex differences, the extraction group showed significantly more posttreatment spacing than did the nonextraction group (Table VI). Postretention irregularity was also significantly greater for the extraction group than the nonextraction group (0.8 mm), as were the increases in tooth size-arch length discrepancy (0.5 mm) over time. The contact angles for extraction patients were smaller in the anterior region and larger at the premolar canine contacts, indicating a more tapered posttreatment arch form. The extraction patients also had much smaller posttreatment interdental angles between the canines, again indicating a more tapered arch form.

Finally, patients who had interproximal restorations placed after treatment showed significantly greater postretention irregularity (0.9 mm) and significantly greater increases in tooth size-arch length discrepancy (0.4 mm) over the observation period than did those without restorations (Table VII).

DISCUSSION

The mandibular incisors became more crowded and irregular after removal of the retainers. However, the malalignment that developed was relatively small; irregularity increased only by 1.3 mm, and tooth size-arch length discrepancy decreased by only 1.2 mm over the 15.7-year posttreatment period. After controlling for posttreatment duration, these results are consistent with previous long-term follow-up studies pertaining to patients treated by private-practice orthodontists (Table I). Together, these studies indicate that orthodontic treatment is not inherently unstable. In our study, approximately 74% of the subjects showed clinically acceptable postretention irregularity (incisor irregularity ˂3.5 mm), and only 1.5% had severe irregularity (≥6.5 mm). Studies reporting greater posttreatment crowding and irregularity often pertain to patients treated in university training programs.[8,11] Importantly, the majority of patients in our study were treated with full banded appliances; this explains the small amounts of posttreatment spacing (0.39 mm)

Table VI. Group differences in incisor irregularity (II), tooth size-arch length discrepancy (TSALD), arch dimensions, contact angles (CA), and interdental angles (IDA) between subjects treated nonextraction (nonext) and with extractions (ext)

	Posttreatment (T1)					Postretention (T2)					Change T2-T1				
	Nonext		Ext			Nonext		Ext			Nonext		Ext		
Measure	*Mean*	*SD*	*Mean*	*SD*	*Diff*	*Mean*	*SD*	*Mean*	*SD*	*Diff*	*Mean*	*SD*	*Mean*	*SD*	*Diff*
Malalignment (mm)															
II	1.40	0.71	1.52	0.69	NS	2.40	1.74	3.29	1.55	*	1.00	1.78	1.78	1.73	0.051
TSALD	0.11	0.54	0.53	0.69	*	−0.79	0.86	−0.83	0.75	NS	−0.90	0.94	−1.37	0.81	*
Intra-arch (mm)															
AP	37.03	1.71	38.10	1.70	*	35.42	1.63	35.96	1.71	NS	−1.62	0.77	−2.15	1.11	NS
ICW	26.47	1.52	26.26	1.13	NS	25.74	1.66	24.88	1.59	NS	−0.73	1.02	−1.38	0.93	†
Contact angle (°)															
CA L4-3	169.56	9.14	173.93	8.38	*	170.73	10.97	175.07	7.67	NS	1.17	10.40	1.13	7.47	NS
CA L3-2	152.75	7.30	148.85	9.67	*	152.92	7.26	147.54	10.19	*	0.17	7.20	−1.31	10.76	NS
CA L2-1	161.47	6.05	161.43	5.00	NS	158.93	9.06	162.95	9.60	NS	−2.53	6.70	1.52	9.02	*
CA 1-1	163.32	5.27	160.33	4.08	*	169.52	11.87	161.77	11.42	*	6.20	10.14	1.44	9.34	*
CA R2-1	163.24	5.95	162.94	4.19	NS	161.05	9.48	165.24	8.72	*	−2.19	7.79	2.30	8.23	*
CA R3-2	152.81	7.44	145.37	8.24	†	150.92	10.26	143.33	9.60	†	−1.89	10.07	−2.03	8.14	NS
CA R4-3	167.49	6.94	173.94	9.77	†	167.83	10.94	174.08	10.79	*	0.34	6.62	0.15	8.02	NS
Interdental angle (°)															
IDA 1-1	163.32	5.27	160.33	4.08	*	169.52	11.87	161.77	11.42	*	6.20	10.14	1.44	9.34	*
IDA 2-2	128.03	8.51	124.70	7.43	NS	129.50	15.65	129.96	12.17	NS	1.48	10.66	5.23	10.32	NS
IDA 3-3	73.59	11.75	58.92	14.80	‡	73.34	10.20	60.83	12.29	‡	−0.25	8.69	1.92	10.95	NS
IDA 4-4	50.64	9.47	46.79	10.71	NS	51.89	18.25	49.98	8.92	NS	1.25	12.00	3.19	11.47	NS

Diff, Difference; *NS*, not significant.
$^{*}P < 0.05$; $^{\dagger}P < 0.01$; $^{\ddagger}P < 0.001$.

Table VII. Group differences in incisor irregularity (II) and tooth size-arch length discrepancy (TSALD) between subjects with no interproximal restorations posttreatment (no IP) and those with interproximal restorations performed posttreatment (IP)

	Posttreatment (T1)					Posttetention (T2)					Change T2-T1				
	No IP		IP			No IP		IP			No IP		IP		
Measure	*Mean*	*SD*	*Mean*	*SD*	*Diff*	*Mean*	*SD*	*Mean*	*SD*	*Diff*	*Mean*	*SD*	*Mean*	*SD*	*Diff*
Malalignment (mm)															
II	1.40	0.64	1.67	0.73	NS	2.72	1.62	3.59	1.61	*	1.32	1.77	1.92	1.72	NS
TSALD	0.31	0.65	0.59	0.74	NS	−0.78	0.83	−0.94	0.74	NS	−1.09	0.90	−1.52	0.96	*

Diff, Difference; *NS*, not significant.
$^{*}P < 0.05$.

and irregularity (1.48 mm). Previous studies of banded patients have reported similar posttreatment findings.[5,6,10,13,14]

Incisor irregularity and tooth size-arch length discrepancy were interrelated, but only one explains some variation of the other, indicating that they measure different attributes. The postretention correlation accounted for about 36% of the variation; the changes in irregularity accounted for approximately 16% of the variation in tooth size-arch length discrepancy changes over time. A study specifically designed to evaluate their pretreatment association showed that irregularity explained approximately 25% of the variation of tooth size-arch length discrepancy.[35] Since most of the variation remains unexplained, these 2 important outcome measures must be sensitive to different sources of malalignment. The main difference lies in the sensitivity of irregularity to rotational changes of the teeth. Whereas the mandibular incisors are often perceived as flat teeth, larger in their mesiodistal than faciolingual dimensions, their faciolingual dimensions are actually similar or slightly greater.[36] Thus, pure rotation of an incisor produces considerable changes in irregularity, with essentially no change in the tooth size-arch length discrepancy. Moreover, simple displacements of incisors that retain space affect irregularity considerably more than tooth size-arch length discrepancy. Such rotations and displacements, which often occur, help to explain why changes in irregularity are generally larger than changes in tooth size-arch length discrepancy, and why these measures are not more closely related.

Anterior malalignment in the mandible increased progressively for teeth located farther from the midline. This pattern was evident at posttreatment and postretention. It was first reported by Vaden et al[10] at pretreatment, posttreatment, and recall. Interestingly, the canine-lateral incisor contact angles were the smallest and the only angles that tended to decrease over time. Whether due to mesial drift caused by the transseptal fiber system[37] or by the anterior component of occlusal force,[31] anteriorly directed forces might be expected to have their greatest effects at the portions of the dental arch with the greatest curvature (canine-lateral incisor contacts). This suggests that the canine-lateral incisor contact has the greatest potential for slippage.

Posterior facial height increased, and mandibular rotations occurred posttreatment, but neither change was related to incisor inclination or mandibular anterior malalignment. It has been shown that posterior facial height continues to increase through the 20s and well into the 40s; this is consistent with our findings.[26,38] However, other studies have shown malalignment to be related to age,[4,10,11,15] vertical facial growth,[9,26] and incisor eruption.[9] In our study, only limited amounts of vertical growth and mandibular rotation occurred; these might explain why no associations between growth, rotation, and malalignment were identified.

The postretention increases in overbite, overjet, and interincisal angle were small and unrelated to postretention mandibular anterior malalignment. Others have reported similar types and magnitudes of change.[6,8-10,20] The fact that these 3 measures, along with the incisor to mandibular plane angle, were not related to mandibular anterior malalignment is consistent with previous studies and argues against the contained-arch principle.[8-10] It also does not support the claim that final posttreatment overbite and overjet are keys to long-term stability.[6]

The small posttreatment decreases in anterior arch perimeter and intercanine width were weakly related to postretention malalignment. Decreases in arch perimeter were slightly larger than previously reported; this is most likely due to posttreatment spacing.[8,9,26] This possibility is supported by the fact that the decreases in intercanine width were within the range of changes previously reported.[6,8,10,14,26] The changes in arch perimeter and intercanine width were related to posttreatment malalignment, indicating that patients with the greatest postretention malalignment had the greatest decreases in arch space from anterior movements of the teeth.

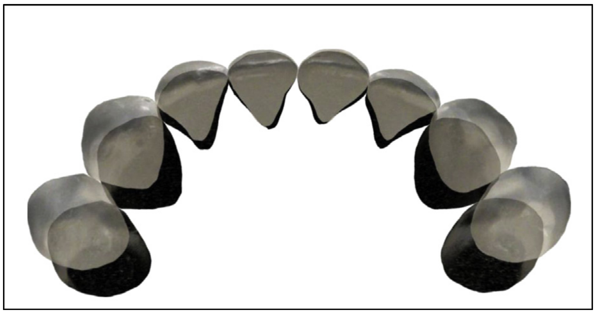

Fig 2. Representative example of the posttreatment nonextraction arch form (*light*) superimposed on the posttreatment extraction arch form.

The posttreatment rotational position of the mandibular canines was highly variable. More importantly, only the rotational position of the canines was related to the rotational position of the other teeth, so that the larger the interdental angle of the canines, the larger the other interdental angles, and thus the broader the arch form. The fact that these relationships existed only for the canines indicates that their rotational position plays an essential role in determining the overall anterior arch form. The stability of posttreatment canine rotational position might be due to the canines' greater root surface area.

Mandibular arch form tends to become more rectangular over time, with a "cornering effect" between the lateral incisors and the canines (Fig 2). Vaden et al[10] described a similar "squaring" of the arch form after treatment. Our results indicate that the incisor region flattened by 3° to 4° at postretention. Simultaneously, the contact angles between the canines and the lateral incisors decreased as the teeth moved forward (ie, as intercanine width and anterior arch perimeter decreased). It has been suggested that the squaring effect was caused by the canine "slipping" anteriorly to the lateral incisor.[10] In most subjects in our study, the lateral incisors rotated distofacially as the canines and the premolars moved mesiolingually. This further emphasizes the importance of the positional relationship of the canines and the lateral incisors.

A broader anterior arch immediately after treatment was related to increased stability. The larger the posttreatment rotational positions of the mandibular lateral incisors (ie, the flatter they were), the smaller the posttreatment increase in irregularity. Additionally, the posttreatment rotational position of the canines was related to the malalignment changes, so that the larger the canine interdental angle, the smaller the postretention crowding. Since the contact angles of a broad anterior arch are greater than those in a tapered arch, mesially directed forces might be expected to have less effect on adjacent teeth, perhaps resulting in less malalignment.

Importantly, these findings should not be used as a justification for producing broader dental arches orthodontically. We did not include patients treated with even moderate expansion of the mandibular arch. A shared philosophy of the orthodontists who provided the patients for this study was to maintain the teeth over basal bone, similar to the prosthetic concept when setting denture teeth. This suggests that the broader posttreatment arch forms in this study were most likely broader before treatment. The link between dental malalignment and decreased jaw size was previously established.[39] The clinical implication of these findings is that orthopedic treatments (eg, midsymphyseal distraction osteogenesis) producing broader dental arches, with teeth upright over basal bone, might enhance long-term stability.

Interestingly, our results showed greater postretention malalignment in patients treated with extractions than nonextraction. Other studies comparing the postretention changes of extraction vs nonextraction treatments found no differences in irregularity.[8,12,40] The tooth size-arch length discrepancy differences were small (<0.5 mm) and probably due to the posttreatment differences in the anterior arch form between the extraction and nonextraction patients (Fig 2). All anterior contact angles were larger in the nonextraction group, particularly at the canine-lateral incisor contact, indicating a broader arch form, which was related to increased stability, as previously discussed. Since a primary consideration for extraction therapy is the available space in the dental arch, it seems reasonable that patients treated with extractions had more tapered bony arches than those treated without extractions. In other words, the increased crowding was probably due to the patients' more tapered arches rather than to the extractions.

Patients who received interproximal restorations during the posttreatment period displayed greater amounts of anterior malalignment than those who did not. In patients with interproximal restorations, irregularity was 0.9 mm greater postretention, and crowding increased by more than 0.4 mm. The restorative process, including the interproximal wedges used, or the restorations themselves, might apply forces that cause mesial movement of the dentition; this could, as previously described, cause malalignment of the anterior teeth. Clinically, these results imply that restorative dentists must be careful not to produce oversized interproximal restorations to avoid contributing to mandibular anterior dental malalignment.

These results provide new and important factors that help to explain postretention stability and instability. This study supports the notion that there is no 1 major factor that explains malalignment. Rather, there are several factors, each having small but significant effects. It has been previously shown that growth and eruption play important roles,[4,9-11,15,26] as do the patient's sex and ethnic affiliation.[4] Whether subjects have premolars or molars in the mouth also appears to be related to irregularity.[4] Circumferential supracrestal fibrotomy procedures[41] and interproximal recontouring also play roles.[42] This study showed that arch form and interproximal restorations are also related to postretention malalignment. Although the recommendation to patients should be lifelong retention for the prevention of malalignment, this study, as well as previous studies, clearly shows that orthodontic treatment is not inherently unstable in the long term. Stability is not merely a rare accident; it is possible and occurs more often than is commonly recognized.

CONCLUSIONS

1. Orthodontic treatment that follows established guidelines is not inherently unstable in the long term.
2. Incisor irregularity and tooth size-arch length discrepancy are primarily related to different attributes of malalignment.
3. Mandibular irregularity progressively increases for teeth located farther from the midline.
4. The mandibular arch form becomes more square over time, with a "cornering effect" at the canine-lateral incisor contact.
5. A broader anterior arch form is related to increased long-term stability.
6. Interproximal restorations are risk factors for post-retention anterior malalignment.

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