CONTINUING EDUCATION ARTICLE

A retrospective study of Angle Class I malocclusions treated orthodontically without extractions using two palatal expansion methods

Mozhgan Azizi, DDS, MS,[a] Michael K. Shrout, DMD,[b] Andrew J. Haas, DDS, MS,[c] Carl M. Russell, DMD, PhD,[d] and Edward H. Hamilton, Jr, DDS[e]
Augusta, Ga

The correction and relapse of mandibular anterior crowding was evaluated in a population of 58 patients with Angle Class I malocclusion who were treated orthodontically without extraction of permanent teeth. The subjects were retrospectively evaluated from records taken before treatment, posttreatment, and postretention. The postretention period averaged 8 years (minimum of 4 and maximum of 20 years). All cases in Groups A and B were given orthopedic treatment to develop the maxillary apical base in the transverse and anteroposterior planes. Group A was treated with expansion of the inner bow of the face bow appliance (Kloehn), and Group B was treated with the Haas palatal expansion appliance. Both groups were then treated orthodontically with tandem mechanics. The response variables measured were: overbite, overjet, intercanine distance, intermolar distance, and irregularity index. Study groups A and B were not significantly different for subject age, retention, or postretention time. Moreover, the groups did not show significant difference for any of the response variables before treatment. However, there was a statistically significant difference in the treatment times ($P = .0133$). A statistically significant treatment effect was observed for most response variables in the groups. Overbite, overjet, and irregularity index were significantly reduced, intermolar distance was significantly increased, and intercanine distance showed no significant change in Groups A and B. In the postretention period, there was a tendency for variables to change slightly toward their before treatment values but no compromise of orthodontic correction was noted. The irregularity index in Group A was corrected from 4.8 to 1.1 mm and remained at 1.1 mm in the postretention period. The irregularity index in Group B was corrected from 5.1 to 1.2 mm ($P = .0001$) and changed slightly from 1.2 to 1.7 mm ($P = .0540$) in the postretention period. We concluded that mandibular incisors tended to become more crowded postretention. However, in contrast to previous reports, we calculate this relapse to be small. Neither before treatment nor posttreatment variables were predictive of relapse. (Am J Orthod Dentofacial Orthop 1999;116:101-7)

Mandibular anterior crowding is a condition well known to all dental professionals. It is often noted by untrained persons and can be a component of a patient's esthetic concerns at the inception of treatment. Because patients with such treatment needs may be more sensitive to their dental esthetics, the occurrence of unacceptable crowding after orthodontic treatment may cause strain on the doctor-patient relationship.

Angle believed the ideal dentition was a full complement of teeth.[1] This view was opposed by other investigators who believed in extraction of permanent teeth, leading many orthodontists to use extraction as a necessary adjunct in the treatment of malocclusion.[2] Until the work of Little et al[3-5] this philosophy did not consider the incidence of incisor relapse after the extraction therapy. Premolar extraction to permit alignment of crowded teeth has been an accepted procedure for decades and continues as a common treatment modality for patients with crowded arches. Some believed if canines were moved posteriorly into the premolar extraction space, they could be expanded buccally to the limits offered by their new location.[6,7] Others state the lower canines may hold the key to stability of the mandibular dental arch and that no other dental relationship has as much relapse tendency as the

[a]Orthodontic Department, School of Dentistry, Medical College of Georgia.
[b]Associate Professor in Oral Diagnosis and Patient Services, School of Dentistry, and Associate Professor in Oral Biology, School of Graduate Studies, Medical College of Georgia.
[c]Associate Professor in Orthodontics, University of Illinois, and in private practice, Cuyahoga Falls, Ohio.
[d]Associate Professor, Medical College of Georgia.
[e]Professor and Interim Chair, Orthodontic Department, School of Dentistry, Medical College of Georgia.
Reprint requests to: Michael K. Shrout, DMD, Associate Professor in Oral Diagnosis and Patient Services, School of Dentistry, Associate Professor in Oral Biology, School of Graduate Studies, Medical College of Georgia, Augusta, GA 30912-1241

0889-5406/99/$8.00 + 0 **8/1/92015**

mandibular incisors. If the mandibular canines were moved laterally to accommodate crowded incisors, relapse would follow unless the canines were positioned posteriorly in a wider portion of the mandible as is done in extraction cases.[8] Therefore, when a tooth is totally blocked out as a result of space deficiency, nonextraction treatment may place the tooth in an unstable position, which may predispose it to relapse.[4]

Sinclair and Little,[9] in a study evaluating the nature and extent of the developmental process in the normal dentition, observed a decrease in arch length and intercanine width; stability in measurements of intermolar width, overjet and overbite; and, an increase in the incisor irregularity. They concluded that changes found in untreated subjects were similar in nature, but to a lesser extent, than postretention changes found in a sample of orthodontically treated cases.[9] Fastlicht[10] compared untreated and orthodontically treated subjects. He found more mandibular crowding in the untreated dentition than in the treated group and concluded that orthodontic treatment increases the stability of dental arches. Muchnic[11] investigated incisor crowding in the mandibular dental arch that demonstrated crowding occurs regardless of orthodontic treatment in the growing child and adult. Sanin and Savara[12] in a study of 150 white children noted that mandibular anterior crowding occurs during development when the mandibular arch is relatively small compared with incisor size early in eruption and changes in incisor alignment are mostly related to mandibular growth and repositioning of the incisors. That is, latant horizontal growth of the mandible without a concomitant growth of the maxillae restricts and therefore crowds the lower incisors.[12]

Expectation of a crowding potential led Angle to state “patients’ characteristics and treatment responses should be taken into consideration in setting retention time”.[1] A study demonstrating the importance of long-term retention by Sadowsky and Sakols[13] indicated orthodontists should be aware of protracted changes in dental relationships many years after treatment. A high incidence of incisor relapse has been reported in cases treated with first premolar extraction.[14]

Some investigators believe continued retention is indicated during adolescence, when greater bone growth and remodeling is expected, and should continue until the effect of these changes diminish. Muchnic[11] suggested this period of slow-down corresponds with the third molars eruption timing. Others have studied the role third molars play in mandibular crowding and found the presence of the lower third molars did not appear to have any significant influence on posttreatment changes in arch length, lower molar position, lower incisor position, or lower incisor crowding.[10,15] These studies demonstrate the conflicting philosophies concerning extraction versus nonextraction treatment in orthodontics.

Little[4] reported the success of maintaining satisfactory alignment was less than 30%; nearly 20% demonstrated marked lower anterior crowding many years after removal of retainers. In addition, the degree of incisor irregularity increased between 10 and 20 years postretention.[16] The majority of previous long-term studies of anterior crowding relapse have been on extraction cases. It has been suggested that different results might be seen in the relapse pattern of nonextraction cases.[17] Indeed, there was an 89% chance of unacceptable relapse in nonextraction cases and a 70% to 89% chance of unacceptable relapse in cases treated with premolar extraction therapy.[4,18]

Another important factor related to crowding and relapse potential is arch width determined by the intercanine and intermolar distance. A recent study suggested that prolonged retention time may be an important factor for the stability of both the transverse dimension and mandibular incisor alignment.[19] A 1974 study by Shapiro[20] noted a difference in results of intermolar width stability when comparing extraction and nonextraction therapy. The extraction cases exhibited a decreased intermolar width during treatment that continued to decrease after retention. In the nonextraction cases, the intermolar width was maintained or increased. The intercanine width tended to decrease during the postretention period.[20] In another study,[21] intercanine width increased during expansion treatment and had a tendency to return to pretreatment width in both the nonextraction and the extraction cases. However, with stabilization, approximately 89.2% of the patients experienced a net increase in the intermolar width.[21] Investigators have found the most frequent cause for mandibular incisor instability was overexpansion of canines during treatment[7,22]; stable results could only be gained when the mandibular intercanine and intermolar widths were maintained.[6] Yet it has also been shown that maintenance of the pretreatment intercanine distance during treatment did not guarantee alignment stability of the mandibular incisors posttreatment.[23] Walter[24] concluded dental arches can be expanded without much relapse declaring: “The statement that the dental arch length cannot be permanently widened or lengthened is incorrect.” Other studies support that statement.[25,26]

The stability of rapid maxillary palatal expansion has been discussed over the years. Brodie[27] stated: “The interaction of the forces of the tongue and the buccal musculature, which have antagonistic effects, dictate the size and form of the arches as well as the

Table I. Distribution of ages and time periods of observation (years)

Variable	Group*	Mean	SD	Minimum	Maximum	P value†
Age at BT	A	14.8	5.5	9.8	31.8	.8305
	B	14.5	3.8	10.3	24.9	
Treatment time	A	2.2	0.5	1.1	3.1	**.0133**
	B	2.7	0.9	1.3	4.9	
Retention time	A	7.1	1.7	1.4	10.7	.4323
	B	6.8	1.3	2.6	9.7	
Postretention time	A	8.2	4.0	4.3	19.3	.6925
	B	7.8	3.6	4.0	18.4	

*Group A, N = 32; B, N = 26.
†2-Sample *t* test.

axial inclination of the teeth at rest." Haas[28-31] observed that after rapid palatal expansion (RPE) unassisted expansion occurred in the mandibular dental arch. It was suggested this response was due to the forces of occlusion being altered by the maxillary expansion, to the degree that normal lingual force vectors on the mandibular buccal are lost. Even more significant is the modification in muscle balance. As the maxillae widen, the influence of the buccinator muscle to the mandibular buccal is diminished; the lingual influence to these teeth is increased by displacement of the tongue inferiorly into the mandibular environment, as a result of the thickness of the appliance. A later RPE study by Sandstrom et al[32] concluded that the stability of the expanded mandibular arch width may be the result of an altered muscular balance exerted on the dentition by the buccinator muscles, which had been carried laterally by the maxillary expansion, or it may also be attributed to the altered forces of occlusion.

It has been argued that the arch width added by opening the midpalatal suture can be considered permanent because the midpalatal repair involved new bone formation. The permanence of change added by tooth movement and alveolar bending, on the other hand, is questionable.[28] Two works[29,31] strongly demonstrate that RPE accomplished by a tissue-borne appliance with reinforced dental anchorage can produce an orthopedic (skeletal) change with excellent stability of both the orthopedic and orthodontic corrections.

The purpose of this study was to measure the treatment effects and long-term stability of mandibular incisor correction in a group of subjects treated by one orthodontist using an expanded face bow (Kloehn) appliance, a tissue-born rapid palatal expansion appliance, or both.

METHODS

This retrospective study examined records of patients over a 30 year period. The subjects were not randomly assigned to treatment modalities but were picked on the basis of availability and the criteria previously listed. Subjects were obtained from the archival records of one author's (A.J.H.) Cuyahoga Falls, Ohio, practice. Subjects had been treated for Angle Class I malocclusion without extraction of permanent teeth, using tandem treatment mechanics whereby the maxillary molars were restricted by a headgear from moving anteriorly. The mandibular molars were restricted from moving anteriorly with Class III elastics placed in tandem with the headgear while the remaining dentofacial skeleton grew forward, therefore, preserving and creating arch-length for use in decreasing the amount of crowding.

All cases in Groups A and B were subjected to orthopedic treatment to develop the maxillary apical base in the transverse and anteroposterior planes: Group A via expansion of the inner bow of the face bow appliance (Kloehn) and Group B by way of the Haas palatal expansion appliance. Both groups were then treated orthodontically with tandem mechanics. In Group A, the orthopedic and orthodontic treatments were concurrent; in Group B, the orthodontic (tandem) treatment followed the orthopedic (RPE). The essential feature of tandem mechanics is the coupling of force placed on the maxillary and mandibular arches. The maxillary arch was subjected to a distalizing force through headgear attached to the first molars. A Class III elastic was attached from the posterior end of the inner bow as it exits the molar tube to a hook in the canine region of a continuous lower arch wire. On this continuous lower arch, an open coil spring was placed from the canine region to the banded first molar. The lower arch wire engaged the banded first molars and was tied to the mandibular anterior teeth (a sling tie) to avoid gingival irritation. Such biomechanics work in tandem providing a distalizing force to all four quadrants whereas the incisors advance with corpus growth effecting a gain in dental arch length

Table II. Distribution of variables before treatment (BT) in mm

Variable	*Group**	*Mean*	*SD*	*Minimum*	*Maximum*	*P value†*
Overbite	A	3.6	1.2	1.0	6.0	.074
	B	3.0	1.4	0.5	5.4	
Overjet	A	2.2	1.1	0.4	4.3	.231
	B	1.9	0.9	0.6	4.3	
Intercanine distance	A	25.8	1.7	23.3	29.7	.607
	B	26.0	2.1	22.9	31.4	
Intermolar distance	A	43.7	3.3	36.6	52.0	.299
	B	44.7	4.0	37.7	53.0	
Irregularity index	A	4.8	3.1	0.7	13.3	.741
	B	5.1	2.7	0.7	12.3	

*Group A, N = 32; Group B, N = 26.
†2-Sample *t* test.

Table III. Distribution of variables at the end of observation (PR) in mm

Variable	*Group**	*Mean*	*SD*	*Minimum*	*Maximum*	*P value†*
Overbite	A	2.6	0.9	1.0	4.6	.0862
	B	2.1	1.0	0.8	4.2	
Overjet	A	1.1	0.4	0.3	2.2	.7076
	B	1.0	0.5	0.4	1.8	
Intercanine distance	A	26.3	1.3	24.2	29.5	.7120
	B	26.4	1.9	22.9	30.5	
Intermolar distance	A	45.4	2.9	40.5	51.4	.2299
	B	46.5	3.7	39.9	55.1	
Irregularity Index	A	1.1	0.9	0.0	4.2	.0535
	B	1.7	1.1	0.0	5.2	

*Group A, N = 32; Group B, N = 26.
†2-Sample *t* test.

Dental casts and treatment records for each subject were selected using criteria provided, without other known bias, by an assistant and shipped to the Medical College of Georgia Department of Orthodontics from the Ohio office. Gender, age at the time treatment began, treatment time, retention time, and follow-up time after retention were recorded for each study case.

Dental casts were made before treatment, immediately after treatment, and at least 4 years after the retention period. To qualify for the study, each case was required to have the following: mandibular permanent canines present at pretreatment, a full complement of teeth (eg, no missing permanent teeth), Angle Class I molar and canine relationships, and no anterior open bite. In addition, only cases with the following criteria were selected for the study[12]: overbite (OB), defined as the mean vertical overlap of upper and lower central incisors, greater than zero; overjet (OJ), defined as the horizontal distance parallel to the occlusal plane from the lingual surface of the most labial maxillary incisor to the labial surface of the most lingual mandibular central incisor, (0 to 6 mm); the intercanine (IC) distance (0 to 30 mm), defined as the distance between the cusp tips of the mandibular canines (or estimated cusp tips in cases of wear facets); the intermolar (IM) width (0 to 50 mm), defined as the distance between the mesiobuccal cusp tips of the mandibular first permanent molars (or estimated cusp tips in cases of wear facets); and, an irregularity index of 0 to 10 mm.

The irregularity index (IR) has been previously described,[33] briefly, it is the summed displacement of the anatomic contact points of the lower anterior teeth. "Irregularity Index is not an arch-length assessment, but rather a guide to quantifying mandibular anterior crowding."[33] It is measured as: $IR = IR1 + IR2 + IR3 + IR4 + IR5$, where IR is the total irregularity. IR1 is measured from the mesial contact point of the left canine to the distal contact point of the left lateral; IR2 is from the mesial contact point of the left lateral to the distal contact point of the left central incisor; IR3 is from the mesial of the left central incisor to the mesial of the right central incisor; IR4 is from the distal of the right central to the mesial of the right lateral incisor; IR5 is from the distal of right lateral incisor to the mesial of the right canine.

The irregularity index scoring method represents a

Table IV. Distribution of changes in variable (BT-PR)

Variable	*Group**	*Mean*	*SD*	*Minimum*	*Maximum*	*P value†*	*P value‡*
Overbite	A	–1.0	0.9	–3.2	2.1	**.0001**	.4996
	B	–0.8	1.2	–3.6	1.2	**.0021**	
Overjet	A	–1.1	1.0	–3.0	0.8	**.0001**	.2994
	B	–0.8	1.0	–3.4	0.8	**.0003**	
Intercanine distance	A	0.5	1.5	–2.0	3.4	.0649	.8074
	B	0.4	1.5	–3.1	5.0	.1686	
Intermolar distance	A	1.7	2.2	–1.8	5.7	**.0001**	.9400
	B	1.8	2.1	–2.6	6.0	**.0003**	
Irregularity index	A	–3.7	3.1	–11.1	1.8	**.0001**	.7357
	B	–3.4	3.0	–11.8	2.0	**.0001**	

*Group A, N = 32; Group B, N = 26.
†Paired *t* test.
‡2-Sample *t* test.

planar distance between the vertical projection of the anatomic contact points of adjacent teeth. Any vertical discrepancies of contact points are not measured or included. To ensure recording horizontal displacement, the caliper was consistently parallel to the occlusal plane while obtaining each measurement. The mesiodistal spacing was disregarded if teeth were in proper arch form. However, if displacement of the teeth in conjunction with spacing occurred, then only the labiolingual displacement from proper arch form was recorded. For accurate measurements of mandibular incisors, the dial caliper used in this study was calibrated to one-hundredth of a millimeter.[34]

The following categories have been assigned to ranges of irregularity[34]: 0 = perfect alignment; 1 to 3 = minimal irregularity; 4 to 6 = moderate irregularity; 7 to 9 = severe irregularity; >10 = very severe irregularity.

It was noticed that the primary study pool included subjects who were past the growing age. Therefore, to assess whether growth and development affected outcomes, this pool was reduced to include a data group of only growing-aged patients (9 to 14 years old); subjects older than 14 years of age were eliminated. The data were reevaluated with 35 subjects: 21 in group A and 14 in group B.

To assess reliability, a second examiner was trained. This examiner made all five of measurements on 20 randomly selected cases. Reliability was assessed by intraclass correlation, paired *t* test, and Bradley-Blackwood test.[35] None of the measures exhibited a significant mean or variance difference. The intraclass correlation coefficient exceeded 0.94 for three of the measures. For overjet the intraclass correlation was 0.73; for intercanine distance it was 0.81. The intraclass correlation coefficients were conservative estimates because they were calculated for interexaminer variation. Thus, there was an outside measure of objectivity and repeatability in the measurements.

RESULTS

There were 58 cases (45 female and 13 male) selected on the basis of the entry criteria previously described; all were white. Group A consisted of 32 cases, 26 females and 6 males; Group B consisted of 26 cases, 19 females and 7 males. The mean age before treatment (BT) was 14.8 years (SD 5.5) for Group A and 14.5 years (SD 3.8) Group B. The age distributions at BT were not significantly different between Groups A and B (P = .8305). A summary of the BT distributions of age, treatment time, retention time, and postretention time for Groups A and B is provided in Table I. Only the difference in treatment time (approximately 6 months) was significant (P = .0133).

In retrospective studies, detection of bias is important. One way of examining the data for biased selection of patients for Groups A and B is to look at distributions of the study variables at BT. The distributions of the study variables (overbite, overjet, intercanine distance, intermolar distance, irregularity index) are given in Table II. None of the P values for differences in distributions are significant.

Table III provides the study variables at the end of the observation period. None of the study variable distributions is statistically significantly different between Groups A and B. For overbite, the 0.5 mm difference (A, 2.6 mm: B, 2.1 mm) is not significant (P = .0862). For irregularity index, the 0.6 mm difference (A, 1.1 mm; B, 1.7 mm) approaches significance at P = .0535. This effect will be revisited later with an analysis of changes in study variables from BT.

The effects of orthodontic treatment observed after treatment, retention, and postretention periods (BT to PR) are shown in Table IV. The longitudinal changes in

Table V. Mean values for the various study variables and the difference between Group A and Group B at observation times. (Subtracting Group B from Group A) (mm).

	Overbite	*Overjet*	*Intercanine distance*	*Intermolar distance*	*Irregularity index*
Before treatment	3.3	2.0	26.9	44.1	4.9
A – B	0.6	0.4	–0.2	–1.0	–0.2
Posttreatment	1.8	0.9	27.2	45.6	1.2
A – B	0.1	-0.2	0.1	-1.1	-0.1
Postretention (PR)	2.3	1.1	26.2	45.8	1.3
A – B	0.6	0.1	–0.1	–1.2	–0.6

this table provide the mean, standard deviation, minimum, and maximum values for the change in each variable. In addition, the mean change was tested to see if it was significantly greater or less than zero (paired *t* test), an indicator that variables are changing during the periods of observation. Though a small amount of relapse occurred, overbite, overjet, intermolar distance, and irregularity index changes were significantly different from zero in the period BT to PR (*P* values < .003). Intercanine distance relapsed enough to yield an overall change of 0.5 and 0.4 mm in Groups A and B (*P* = .049, .1686), respectively. These values were not significantly different from zero.

Table V complements Table IV to show the difference between Groups A and B across the three time points of observation. In Table V, a pattern across time was observable, note that *P* values with significant changes are in bold type. Overbite, overjet, and irregularity index demonstrated a relatively large reduction by treatment (BT to PT), followed by a relatively small amount or no relapse (PT to PR). Intercanine and intermolar distances increased as a result of treatment. Intercanine distance relapsed to near pretreatment levels. Intermolar distance remained nearly constant at posttreatment levels. Reanalysis of the data after the primary study pool had been reduced to only growing patients (35 subjects) yielded results that were very similar to the original analysis.

DISCUSSION

The analysis of data indicated that overjet and overbite in groups A and B showed very similar patterns as far as treatment effects and relapse. Both overjet and overbite decreased during the treatment. Group A relapsed more than B; the total reduction of the amount of OB and OJ was 1.0 and 1.5 mm for Group A, 0.8 and 0.8 mm for Group B. These results are significant (Table IV) and support studies in which intermolar width, overjet, and overbite displayed considerable long-term stability.[13,17] In the present study, there was very little change in the intermolar and intercanine distance in both groups (3.0 mm of increase in the total width). Intermolar distance relapsed 1.0 mm posttreatment indicating a net increase of IM width (2.0 mm) that remained stable throughout the PR follow-up time. The intercanine distance relapsed by 80%, which agrees with the previous relapse potential of IC width after expansion studies. However, the RPE group relapsed less than the group expanded with headgear only. The total change in the IC width was a net increase of 1.0 mm from BT-PR. Irregularity index decreased dramatically during treatment from 4.5 mm to 1.3 mm indicating a net correction of about 3.2 mm at the end of treatment. There was a mild relapse (0.06 in group A and 0.34 in group B) in the irregularity index. This finding did not agree with a previous study which suggested that the chance of unacceptable relapse is 89% in orthodontically treated nonextraction cases.[4]

The results of the present study agree with previous works that state that, with time, potential for continued relapse of postretention crowding increases. The degree of postretention anterior crowding was not predictable from pretreatment variables. The finding was consistent with a study[36] that indicated greater relapse with more years of retention; but, there was no relationship between the number of years in retention and the variables used in the study. The present findings, however, indicated significantly less relapse than would be expected based on findings of previous studies. Possible explanations for the stable results we observed include (1) the treatment modality (maxillary apical base expansion and tandem mechanics), (2) long-term retention, and (3) a single clinician (potential reduction in variability of patient selection and treatment).

Just as gnathologists are beset with canine disclusion, the orthodontists are tormented with finding a treatment modality that will assure long-term postretention stability of mandibular incisors. The results reported in this study strongly support the supposition that a maxillary apical base expansion and tandem treatment philosophy and extended retention offer a solution to this dilemma. We are unaware of comparable results in the literature.

CONCLUSIONS

This study involved evaluation of nonextraction therapy with dental casts that exhibited Angle Class I molar and canine relationship from a sample of 58 orthodontically treated cases followed for an average of 8 years. It was concluded that mandibular incisors tended to become more crowded postretention. However, in contrast to many published reports, the postretention irregularity index in this study remained quite constant through the postretention follow-up. None of the 58 postretention records measured in this study relapsed beyond the minimal acceptable standards established in the Little irregularity index categories. This seems to establish a new standard for stability of Class I nonextraction treatment compared with previously published articles concerning relapse in the literature. This relapse was observed to be small. Neither pretreatment nor posttreatment variables were predictive of relapse.

REFERENCES

1. Angle EH. Treatment of malocclusion of the teeth. 7th ed. Philadelphia: S.S. White Dental Mfg Co; 1907.
2. Tweed CW. The application of the principles of the edgewise arch in the treatment of malocclusions: I. Angle Orthod 1941:5-12.
3. Little R, Riedel R, Stein A. Mandibular arch length increase during the mixed dentition: postretention evaluation of stability and relapse. Am J Orthod Dentofacial Orthop, 1990;97:393-404.
4. Little R, Wallen T, Riedel R. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. Am J Orthod 1981;80:349-65.
5. Little R. Stability and relapse of dental arch alignment. Br J Orthod 1990;17:235-41 .
6. Strang RHW. The fallacy of denture expansion as a treatment procedure. Angle Orthod 1949:12-22.
7. Rossouw PE, Preston CB, Lombard CJ, Truter JW. A longitudinal evaluation of the anterior border of the dentition. Am J Orthod Dentofacial Orthop 1993;104:146-52.
8. King E. Relapse of orthodontic treatment. Angle Orthod 1974;44:300-15.
9. Sinclair P, Little R. Maturation of untreated normal occlusions. Am J Orthod 1983;83:114-23.
10. Fastlicht J. Crowding of mandibular incisors. Am J Orthod 1968;58:156-63.
11. Muchnic H.Retention or continuing treatment. Am J Orthod 1970;57:23-34.
12. Sanin C, Savara B. Factors that affect the alignment of the mandibular incisors: a longitudinal study. Am J Orthod 1973;64:248-57.
13. Sadowsky C, Sakols E. Long-term assessment of orthodontic relapse Am J Orthod 1982;82:456-63.
14. Shields T, Little R, Chapko M. Stability and relapse of mandibular anterior alignment: a cephalometric appraisal of first-premolar extraction cases treated by traditional edgewise orthodontics. Am J Orthod 1985;87:27-38.
15. Kaplan R. Mandibular third molars and post retention crowding. Am J Orthod 1974;66:411-30.
16. Little R, Riede R, Artun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. Am J Orthod 1988;93:423-8.
17. Glenn G, Sinclair P, Alexander R. Nonextraction orthodontic therapy: posttreatment dental and skeletal stability. Am J Orthod 1987;92:321-8.
18. Persson M, Persson EC, Skagius S. Long-term spontaneous changes following removal of all first premolars in Class I cases with crowding. Eur J Orthod 1989;11:271-82.
19. Sadowsky C, Schneider B, BeGole E, Tahir E. Long-term stability after orthodontic treatment: nonextraction with prolonged retention Am J Orthod 1994;106:243-9.
20. Shapiro P. Mandibular dental arch form and dimension. Am J Orthod 1974;66:58-70.
21. Gardner S, Chaconas S. Postretention changes following orthodontic therapy. Am J Orthod 1976;46:151-61.
22. McCauley DR. The cuspid and its function in retention. Am J Orthod 1944;30:196-205.
23. Gallerano R. Mandibular anterior crowding: a post retention study [MSD Thesis]. University of Washington, 1976.
24. Walter DC. Changes in the form and dimensions of dental arches resulting from orthodontic treatment. Angle Orthod 1953;23:3-18.
25. Weinberg M, Sadowsky C. Resolution of mandibular arch crowding in growing patients with Class I malocclusions treated nonextraction. Am J Orthod Dentofacial Orthop 1996;110:359-64.
26. Germane N, Lindauer SJ, Rubenstein LK, Revere JH, Isaacson RJ. Increase in arch perimeter due to orthodontic expansion. Am J Orthod Dentofacial Orthop 1991;100:421-7.
27. Brodie AG. The fourth dimension of orthodontia. Angle Orthod 1954;24:15-30.
28. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. Angle Orthod 1961;31:73-89.
29. Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthod 1965;35:200-17.
30. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. Am J Orthod 1970;57:219-54.
31. Haas AJ. Long-term posttreatment evaluation of rapid palatal expansion. Angle Orthod 1980;50:189-217.
32. Sandstrom R, Klapper L, Papaconstantinou S. Expansion of the lower arch concurrent with rapid maxillary expansion. Am J Orthod 1988;94:296-302.
33. Little R. The irregularity index: a quantitative score of mandibular anterior alignment. Am J Orthod 1975;68:554-63.
34. Peck H, Peck S. An index for assessing tooth shape deviations as applied to the mandibular incisors. Am J Orthod 1972;61:384-401.
35. Bradley EL. Blackwood LG. Comparing paired data: a simultaneous test for means and variances. American Statistician. 1990;43:234-5.
36. Katz R. The long term stability of mandibular arch length and width changes following rapid maxillary expansion [MSD Thesis]. The Ohio State University, 1990.