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An International Journal of Orthodontics and Dentofacial Orthopedics
78th Anniversary 1930-2008

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The Angle Orthodontist: **Vol. 71, No. 6, pp. 433–441.**

Effects of Patient Age and Sex on Treatment: Correction of Class II Malocclusion with the Begg Technique

Edward F. Harris, PhD[a]

ABSTRACT

When children are treated orthodontically during a phase of active growth—notably adolescence—there is the opportunity to harness growth to achieve some of the correction, especially in the sagittal plane in which differential jaw growth can harmonize dental relationships. All correction must be from tooth movement when there is no growth. Three questions were addressed in the present study: (1) how much orthodontic correction is achieved by bone growth? (2) do the proportions of tooth and bone movement depend on patient age? and (3) do the jaws of boys and girls grow at discernibly different rates during treatment? A sample of 139 children aged 9 to 17 years at the start of treatment with Class II division 1 malocclusions was studied cephalometrically using Johnston analysis. Maxillary and mandibular growth were highest in the youngest children, with rates decreasing to effectively zero in the oldest adolescents. Means adjusted for age were significantly higher for boys than for girls for upper and lower jaw growth. Age had little influence on the amount of tooth movement except for a marked decline with age in the mesial movement of the maxillary first molar, which was greatest in the youngest patients of both sexes. The amount of orthodontic correction was independent of age, but in the youngest quartile of the sample, most of the correction (87%) was due to differential jaw growth in the youngest quartile of the sample, and the rest (13%) resulted from tooth movement, whereas in the oldest quartile, most of the correction was due to tooth movement (64% tooth movement and 36% bone growth). Overall, the influence of age and sex had significant influences on multiple skeletodental variables, suggesting that research designs need to account for these demographic sources of variability. Although all cases were treated to a Class I occlusion, the nature of the correction was affected measurably by the patient's age and sex.

KEY WORDS: Facial growth, Tooth movement, Adolescence, Lightwire technique.

Accepted: May 2001.

INTRODUCTION Return to TOC

Malocclusions can be treated successfully in patients of almost any age, but the nature of the correction—predominately bone growth or predominately tooth movement—depends on the amount of growth during treatment. In turn, growth velocities are tied to the patient's age and are greatest in adolescence and typically larger in peripubertal boys than girls. It is a common theme that orthodontists wish to treat “ with growth” so that one or the other of the supporting bony bases can be constrained or propulsed to improve the patients' profile and not simply to change dental relationships.[1]

Facial dimensions exhibit peripubertal growth spurts,[2–5] though it appears that the peak velocities are only approximately synchronous[6] and that the spurt is more apparent in peripheral compared with deep facial structures.[7] As with stature,[8–10] adolescent growth spurts in facial dimensions occur roughly 2 years earlier in girls than in boys, and the growth spurt is more obvious in boys, in whom it contributes more to adult size.

How does adolescent growth influence the nature of the orthodontic correction? Does the relative role of jaw growth vs tooth movement depend on the patient's age or sex? Does the greater growth of boys influence the nature of the correction? The present study analyzed a sample of adolescents with Class II division 1 malocclusion to address these questions.

MATERIALS AND METHODS Return to TOC

We studied white American children between the ages of 9 and 17 years at the start of treatment with Class II division 1 malocclusions. All were treated with the Begg lightwire technique,[11,12] and all had intact dentitions at the start of treatment (ignoring third molars), although some combination of four premolars was extracted in all patients to address anterior crowding or bimaxillary protrusion. Cases (N = 139, consisting of 64 boys and 75 girls) were recruited from private practitioners and a graduate orthodontic program. We did not select cases based on the severity of the Class II malocclusion, but all were treated to an acceptable Class I molar relationship.

The patient's chronologic age was used as the index of maturity rather than some measure of bone or dental age. The controlling consideration was that so few practicing orthodontists actually take a hand-wrist radiograph let alone interpret it[13] that, although there is little question that a measure of physiologic age would account for more of the variance in degree of maturity than calendar age would,[3,4,14–19] biological age is of little relevance if it is effectively limited to the research setting and is not routinely used in clinical practice. It should also be appreciated that the common perception that bong age is strongly associated with growth rates is based primarily on studies of linear body dimensions, such as stature and leg length; associations are more modest for facial dimensions.[20] Moreover, using calendar age provides a worst-case scenario because if calendar age is shown to have significant influences on the nature of the orthodontic correction, then bone or dental measures of age will almost certainly have much more obvious influences.

Cephalometry

Skeletodental changes between the pretreatment and posttreatment examinations were assessed using the Johnston analysis.[21–24] This cephalometric method evaluates parasagittal changes in the jaws and first molars relative to the mean functional occlusal plane (Figure 1) to assess the sources of the orthodontic correction.

In brief, tracings of the pretreatment and posttreatment cephalograms are overlaid and registered on trabecular details in the palate that are visible in both cephalograms, also ensuring that the lingual cortical outlines are superimposed.[25,26] Actual calculations are computer generated by digitizing relevant points on the superimposed tracings. The functional occlusal planes are averaged, providing the mean functional occlusal plane (MFOP) that is used as the common reference axis.[21,22] Tooth and skeletal movements are measured relative to the MFOP, which is one reason why the analysis is pointedly focused on mesiodistal changes; the analysis is largely insensitive to cranial-caudal changes. Other analyses can be used to assess vertical changes. Johnston[21] contends,

> Although the face undergoes widespread change during orthodontic treatment, only effects that are felt at the level of the occlusion have a direct impact on the molar and incisor relationships. The occlusion, therefore, represents the “bottom line,” the site at which change in the upper and lower jaws comes together and is integrated.

Mesiodistal movement of the maxillary first molar (U6 movement) is partitioned into change due to tipping (ie, change in axial inclination relative to the MFOP) and change due to translation. The same partitioning is done for movement of the mandibular first molar (L6).

Growth of the maxillae is measured using the same registration and noting the apparent shift in the radiographic shadows of the greater wings of the sphenoid bone (SE) as they cross the cranial floor (planum sphenoidale), which actually quantifies the dorsoventral change of the maxillae.

Mandibular change is measured as the change in the centroid of the mandibular symphyseal outline.[25,27] A dot is placed on the pretreatment tracing denoting the geometric center of the symphysis by visual best fit, then this dot is transferred to the posttreatment tracing with registration on the trabecular pattern and inner borders of the cortical outline. Mandibular growth is the change in position of the centroid and SE (sphenoethmoidale) relative to the MFOP. This straight-line distance is partitioned into a vertical and horizontal vector vis-à-vis the MFOP. Johnston[21] also quantifies the relative growth of the two jaws, termed apical base change (ABCH), which is the amount of mandibular growth minus the amount of maxillary growth.

Throughout the analysis, changes contributing to correction of a Class II malocclusion are given positive signs, whereas negative signs denote a worsening of the Class II condition (see Johnston[21] and references therein for details).

A significant conceptual strength of Johnston's "pitchfork" diagram that encapsulates the results (Figure 1) of the analysis is that all of the values for skeletal and dental contributions to the sagittal correction of the malocclusion sum to total molar correction (TMC). It is an internally thorough-going diagram, with TMC being the outcome and the other values defining the sources of the molar correction.

It also is possible to assess the treatment changes in the central incisors. The change in their axial inclinations relative to the MFOP and how much the incisal edges move mesiodistally vis-à-vis the MFOP can be added to the diagram,[22] but the incisor changes do not combine with the other variables in the diagram since they have no relation to TMC. We present the incisor changes in the tables, but, for clarity, we have not added them to the pitchfork diagrams.

Statistics

Analysis of covariance (ANCOVA) was used to test for sex differences in the amounts of in-treatment change and to determine whether growth velocity changed systematically with age within the adolescent period.[28,29] Computations were made using SAS algorithms (SAS Inc, Cary, NC),[30] with the conventional α level of .05. The proportions of total variance due to age and sex were calculated with multiple linear regression.[31] Age and sex were entered into each test, whether statistically significant or not, to calculate the partial coefficients of variation (r^2) between age and sex and the dependent variable.

ANCOVA addresses 2 questions: (1) whether the slopes regressing the dependent variable on age are statistically different between boys and girls (ie, heterogeneity of slopes) and, if not, (2) whether age is significantly associated with the dependent variable. A third question implied by the analysis (H_O: boys = girls for the dependent variable) is of less interest because the two sexes will have at least slightly different age distributions and different means in this—and most—research designs. In ANCOVA analysis, the variance due to age is removed from the treatment effect (leaving the residual variance the same as if no covariate were in the model), but this does not adjust for differences in age distributions.[28] It is customary, then, to adjust the means by the method of least squares to the grand mean and then to test for differences between the adjusted means.[29,32] The stronger the association between age and the dependent variable, the greater the effect of adjustment on the treatment means. Tests of significance for the adjusted means have been reported by Sokal and Rohlf[29] and others.

The mean time between pretreatment and posttreatment records was 2.6 years (SD, 0.9 years), and, intuitively, it was anticipated that longer treatment would be positively associated with greater growth and greater orthodontic change. In fact, these suppositions were not true for this data set. For those variables with significant age dependence, age at the start of treatment was a stronger predictor of the amount of in-treatment change (due to growth *and* treatment) than was duration of treatment. Moreover, once starting age was accounted for in the statistical sense, time in treatment did not account for significant additional variation. It seems, then, that time in treatment is a poor indicator of the severity or difficulty of the malocclusion, at least as judged by the skeletodental criteria in this analysis.

RESULTS

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Descriptive statistics and results of ANCOVA tests are combined in Table 1. Results of 1-sample *t*-tests also are included in the table, testing whether the in-treatment change differed significantly from zero (vs the mean overlapping zero, which would indicate that the sample did not preferentially change in either direction during treatment).

Jaw Growth

The Johnston analysis measures parasagittal growth of the maxilla and mandible, and mandibular growth is partitioned into horizontal and vertical components (Table 1). Growth velocities diminished significantly with age in each of these four variables. That is, forward growth of the maxilla and downward and forward growth of the mandible were greatest in the youngest patients and velocities slowed progressively into late adolescence (Figure 2). Mesial growth of the maxilla was about 2 mm in 10-year-olds and decreased to less than 1 mm by age 16 to 17 years. The mandible grew forward about 4 mm in 10-year-olds, and the growth slowed to effectively zero by age 16 to 17 years. A polynomial (curvilinear) model was tested for these growth patterns, but it did not significantly improve the fit to the data. Tests of the age-adjusted means for boys and girls (Table 2) disclosed that all four of these dimensions of jaw growth were significantly greater in boys than in girls. Mandibular growth—the extent of mesial movement of the mandibular symphysis relative to the anterior cranial base—was 33% greater in boys than in girls. The straight-line change in D point relative to the maxilla grew 46% more in boys than in girls. ABCH, the excess of mandibular growth relative to maxillary growth, was 45% greater in boys than in girls. The vertical change in point D, which is effectively lower face height, increased 77% more during treatment in boys than in girls, reflecting the common observation that greater growth of boys in the vertical plane most distinguishes the sexes during adolescence.[20,33,34] Of note, these were the only statistically significant sex differences among the 15 variables tested. These tests (Table 2) in combination with the ANCOVA results revealed that the amounts of growth (adjusted for age) were larger in boys than in girls (roughly half again as large), but that the decline of growth with age was equivalent in boys and girls.

The question arises as to whether mesial growth of the two jaws was improved more in younger, actively growing adolescents. This net improvement, termed ABCH, is the amount the mandible grows forward in excess of the maxilla. Adjusted means showed that, statistically, ABCH was significantly greater in boys than in girls (Table 2) ($P = .04$), which corresponded to a difference between male and female means of 45%. These rates diminished significantly with age but equivalently in both sexes (Figure 3). The typical patient experienced an improvement in the skeletal profile of about 5 mm at 9 to 10 years of age, with ABCH declining to zero in later adolescence ($r^2 = 7\%$).

Tooth Movement

Maxillary molar. U6 “movement” is composed of tipping and bodily movements (Table 1). In the present study, U6 was not tipped in the average adolescent (angulation, 0.8°; $P = .16$), but this tooth was moved forward bodily an average of 2.8 mm. The amount of bodily change depended significantly on patient age ($r^2 = 11\%$; $P < .001$): U6 was allowed to slide mesially significantly more in younger adolescents than in older adolescents (Figure 4). U6 moved mesially about 4 mm in young patients (aged approximately 10 years) but only 1 to 2 mm in patients aged 16 to 18 years. It therefore seems that molar anchorage was more carefully preserved in the older patients. Patient age accounted for about one-eighth (14%) of the variation in U6 movement ($P < .001$). On the other hand, patient sex had no discernible influence on how much U6 was tipped or displaced.

Mandibular molar. L6 was tipped (distal crown tipping) about 4.5° in the typical patient, which translated to a distal crown repositioning of about 1 mm ($P < .001$). It is likely that this tipping was caused by the tip-back bends in the archwire.[11] Systematic tipping was not seen in the upper molar. Removing the effect of tipping, L6 was actually moved forward bodily 5.0 mm on average, but, in contrast to U6, neither tipping nor bodily movement of L6 was influenced by patient age or sex in these Begg cases (Figure 4). Combining distal crown tipping with mesial bodily movement, L6 was moved mesially an average of 3.9 mm regardless of the patient's age or sex (Figure 1).

Molar relationship. Although both U6 and L6 were moved mesially in most patients, L6 moved farther on a case-by-case basis (Figure 1); the mean difference was 0.8 mm farther for L6, thus providing some of the Class I molar correction. This mean improvement of 0.8 mm was the same in boys and girls and was independent of the age at which treatment was initiated ($P = .22$).

DISCUSSION Return to TOC

Somatic growth is faster during adolescence than during any other phase of life after infancy,[35,36] so the clinician should be able to work “ with growth” in adolescents and to use growth to augment corrections, rather than relying wholly on tooth movement. It has also been noted that the treatment of nongrowing adults differs from that of adolescents because it is harder to maintain the occlusal plane in adults because they are effectively not growing, and correction at this age depends almost exclusively on tooth movement.[23,37,38] It appears that peak velocities of facial dimensions occur around 14 years of age in boys and appreciably earlier (around 11 to 12 years of age) in girls, with progressively declining rates thereafter.[2,4,6,36]

Skeletodental Correction

Because the supporting bones of the dental arches are actively growing in adolescence, it was anticipated that correcting the Class II malocclusion would involve some combination of skeletal and dental changes.[21] This was evident for the whole sample (Figure 1) in which three-fourths of the total molar correction was due to skeletal changes. The maxilla grew forward 2.1 mm on average, but this was exceeded by a mandibular growth of 4.7 mm, producing a net sagittal improvement of 2.6 mm, which was 77% of TMC. On average, then, tooth movement accounted for just 23% of the correction. Specifically, U6 slipped forward 3.1 mm, but this movement was exceeded by a forward movement of L6 of 3.9 mm, for a net gain of 0.8 mm, which was one-fourth of the mean TMC in this sample.

These overall averages disclose the importance of skeletal growth, but they obscure the effects of age at treatment since facial growth slowed significantly across the age span of 9 to 17 years studied here, and the rate of maxillary growth was slower than the rate of mandibular growth at all ages (Figure 2). Additionally, the degree of U6 slippage was less in older adolescents (Table 1), so the contributions of skeletal and dental changes are multidimensional and hard to visualize. Figure 5 provides a simple evaluation of the effect of patient age on the nature of the correction. We sequenced the total sample (N = 139) by age at the start of treatment (sexes pooled) and compared the youngest and oldest quartiles. The younger group had an age range of 9.1 to 11.6 years, and the older group had an age range of 14.0 to 16.9 years. Comparison of these extremes helps clarify the effects of growth in the younger group, which is probably close to peak velocity, and that in the older, predominately postpubertal group.[4]

There was significantly more maxillary and mandibular growth in the younger group than the older group, notably so in the mandible (6.2 vs 2.5 mm), and, as a result, the ABCH was about 3 times greater in the younger group (3.5 vs 1.2 mm). L6 movements were about the same in the two groups, but there was only half as much mesial slippage of U6 in the older group (1.7 vs 3.6 mm). The key issue in this comparison was that skeletal changes, specifically mandibular growth in excess of maxillary growth, produced 87% of TMC in the younger group. Mesial movement of L6 in excess of U6 movement (0.5 mm) produced the other 13% of the correction. Growth, then, accounted for over four-fifths of the correction in children between 9 and 12 years of age.

In the older quartile, although the adolescents were just a few years older (approximately 14 to 17 years of age), the relative skeletodental contributions were quite different (Figure 5). Skeletal growth, although still substantive, dropped to 36% of TMC, and dental changes then made up the bulk of the correction at 64%. Prior work has shown that this rapid drop in skeletal “assistance” in correcting the malocclusion projects asymptotically to effectively zero, at least by a patient's mid-20s.[23] Without growth, all of the correction must occur through tooth movement, which has obvious ramifications for the high and increasing proportion of adults in many orthodontic practices.[13,39]

Sexual Dimorphism

Adult faces are significantly larger in men than in women, and much of this difference is attained during adolescence.[33,40,41] But, as gauged with the Johnston analysis, these absolute size differences have only a localized influence on the orthodontic correction of Class II division 1 malocclusions in adolescents. Influential sex differences were localized to mandibular growth (Table 2); the mandible grew forward and downward significantly more in boys than in girls. In contrast, forward growth of the maxilla was the same in both sexes, so that there was a marginally significant difference in ABCH ($P = .04$). That is, the mandible grew forward *relative to the maxilla* more in boys than in girls (3.2 vs 2.2 mm), which yielded a greater skeletal correction in boys. The 4 variables reflecting mandibular growth were the only variables suggesting a sex difference in how the Class II malocclusion was corrected in these adolescents (Tables 1 and 2).

Molar Correction

All of the cases studied were treated with 4-premolar extractions. Extractions are a quantum event,[42,43] and one obtains either about 7 mm of arch space with a premolar extraction or none at all without it. Thus, it should be anticipated that the maxillary molars will slide mesially somewhat to close excess extraction space, even though this movement detracts from the Class I molar relationship. What was seen, though, was that U6 moved forward about 3 mm in the average patient—and substantially more in younger patients (Figure 4). A patient's age accounted for 14% of the variation in the amount of U6 movement. In contrast, the amount of mesial movement of L6 did not depend on age, and, at a mean of 3.9 mm, orthodontic movement of L6 exceeded that of the upper molars except in the youngest patients in whom the correction was obtained instead by disproportionate mandibular growth.

Unexplained Variation

This report focuses on the effects of age and sex on the nature of the Class II correction, but it also highlights potential problems in research design within and among studies. Many of the coefficients of determination for the variables studied are near zero (Table 1), but others, notably those in the mandible, exceed 10% (R^2 for age plus sex for change in D point was 31%.). If a researcher matches samples for orthodontic criteria but ignores age (which is an indicator of the patient's status relative to the somatic growth pattern) and sex, this unrecognized, potentially substantial variation, is hidden in the residual (unexplained) variance in the statistical design. This decreases the ratio of among-to-within group variances and reduces the chance of finding statistical differences if they exist. Conversely, differences among results of assumedly comparable studies may be due to demographic differences in sample composition—which are rarely fully described. Johnston[21] also addresses these issues.

The present results are strongly confirmatory of prior work in this area. Researchers have often reported that growth—which aids treatment—is greater in younger patients than in slower-growing, more mature older patients.[14,17,18,44–49] The perspective is that correction via bone growth is preferable because it is probably more stable over the long term and because it improves the facial profile, not just the occlusion.

Johnston[21] compared the nature of the orthodontic correction in several treated and untreated samples. Generally, the age ranges of the samples were sharply constrained, and age differences among the samples were adjusted through the use of *expected growth units* based on the work of Schulhof and Bagha[50] using the Ricketts short-range growth forecasting method. Johnston's summary finding was that the orthodontic correction in young patients was due primarily to ABCH ("in conjunction with the elimination of dentoalveolar compensation"). In older adolescent patients, correction was primarily due to tooth movement.

Harris et al[23,37] contrasted 2 groups of patients, one consisting of young adolescents at the start of treatment (mean age, 12 years) and the other of young adults (mean age, 28 years). The studies included only female cases because it was not practical to obtain an adequate sample of male cases. The adults exhibited almost no in-treatment growth; parasagittal correction was almost wholly due to tooth movement, and it was difficult to maintain vertical control in this group. Long-term stability appeared to be the same in these two age groups, however.[51]

The present study deals with the age range of 9 to 17 years as a continuum and contrasts male and female growth rates by way of statistical design. None of the variables disclosed a growth spurt suggestive of the peripubertal growth spurt so well documented for stature as well as for the maxilla[52] and the mandible.[27] Given that the mean treatment time was 2.5 years in this study, one would expect the " spurt" to be attenuated compared with per annum growth rates; however, in each case, a linear model fit the data better than did a curvilinear model.

Overview

We return now to the 3 questions raised at the beginning of this paper. Peripubertal growth is characterized by sequential phases of acceleration, deceleration, and cessation. The present study shows that orthodontic treatment early in the second decade of life involves significantly greater components of skeletal than dental movement. In the age span of 9 to 17 years assessed here, there were linear declines with age in the contribution of skeletal growth to the parasagittal orthodontic correction and, as an accommodation, the amount of tooth movement increased with age. The greater adolescent growth seen in boys did little to affect the orthodontic correction relative to that in girls because much of the growth was proportional and did not alter relative size. The important exception was mandibular growth, which was much greater in boys than in girls, and mesial mandibular growth in these cases tended to exceed maxillary growth in boys (but not in girls), thereby improving sagittal relationships.

Brodie and coworkers[53] suggested long ago, "There seems to be a definite correlation between success of treatment and growth."[54] They observed that "the best esthetic results were obtained in those [cases] where growth was more active,"[55] and that growth and development account "for a considerable part of the changes which take place during orthodontic treatment."[55] The present research is a contribution toward quantifying these sources of variation.

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TABLE 1. Descriptive Statistics, Results of Analysis of Covariance, and Components of Variation[a]

			One-Sample	Analysis of Covariance						Coefficients of Determination	
				Sex		Age		Age by Sex			
Variable	Mean	SD	*t*-Test	F Ratio	*P*	F Ratio	*P*	F Ratio	*P*	Sex R^2	Age R^2
Jaw growth											
Change in FOP	−0.7°	4.70°	1.9	2.3	.131	1.4	.245	2.5	.117	0.1	1.4
Maxillary growth	−2.1	2.44	10.0*	0.3	.605	11.8	.001	0.1	.790	0.6	3.2
Mandibular growth	4.7	4.39	12.7*	0.2	.673	12.4	.001	0.0	.849	2.4	7.9
Change in D point	5.7	2.63	25.6*	0.8	.373	29.2	<.001	0.0	.855	15.7	15.1
Apical base change	2.6	2.92	10.7*	0.3	.605	11.8	<.001	0.1	.790	2.8	7.4
Vertical change in D	−4.1	2.78	17.3*	1.5	.219	22.2	<.001	0.3	.589	15.9	11.8
Maxillary first molar (U6)											
Change in angulation	−0.8°	6.63°	1.4	0.7	.419	0.9	.330	1.0	.313	1.6	0.1
Linear conversion	−0.3	1.39	2.8*	0.6	.456	1.0	.313	0.9	.343	1.7	0.1
Movement[b]	−3.1	2.18	16.7*	1.3	.256	22.9	<.001	1.1	.299	0.5	13.6
Bodily movement	−2.8	2.03	16.0*	3.1	.081	19.1	<.001	3.2	.074	0.0	11.2
Mandibular first molar (L6)											
Change in angulation	−4.5°	6.35°	8.3*	1.3	.248	0.3	.597	1.5	.220	0.2	0.0
Linear conversion	−1.1	1.36	9.7*	1.4	.242	0.3	.609	1.6	.214	0.2	0.0
Movement[b]	3.9	2.04	22.4*	2.5	.115	1.4	.239	2.7	.102	0.1	0.7
Bodily movement	5.0	1.98	29.8*	0.7	.417	0.7	.393	0.7	.411	0.0	0.4
Molar relationship											
Total molar correction	3.4	1.85	21.9*	1.6	.202	1.2	.222	1.2	.284	2.1	0.8

[a] Coefficients of determination are the percentages of total variation in the sketetodental variable explained by the patients' sex and age at the start of treatment (partial R^2 from regression analysis); FOP, functional occlusal plane.

[b] Tipping plus translation.

* $P < .05$ (test of whether the mean change differed from zero); descriptive statistics are for sexes pooled (n = 139).

TABLE 2. Least-Squares Descriptive Statistics[a]

	Boys		Girls		
Variable	Mean	SEM	Mean	SEM	Sex Difference *P*
Jaw growth					
Change in FOP	−0.62	0.585	−0.91	0.540	.717
Maxillary growth	−2.27	0.302	−1.89	0.279	.357
Mandibular growth	5.46	0.526	4.09	0.486	.048
Change in D point	6.91	0.277	4.72	0.256	<.001
Apical base change	3.18	0.350	2.20	0.323	.041
Vertical change in D	−5.32	0.299	−3.01	0.276	<.001
Maxillary first molar (U6)					
Change in angulation	−1.70	0.826	0.05	0.762	.122
Linear conversion	−0.53	0.173	−0.15	0.160	.114
Movement	−3.26	0.255	−2.96	0.236	.382
Bodily movement	−2.73	0.239	−2.80	0.221	.825
Mandibular first molar (L6)					
Change in angulation	−4.73	0.799	−4.21	0.737	.633
Linear conversion	−1.17	0.171	−1.06	0.158	.618
Movement	3.83	0.255	3.95	0.235	.710
Bodily movement	5.00	0.249	5.01	0.230	.969
Molar relationship					
Total molar correction	3.75	0.230	3.20	0.212	.080

[a] Least-squares means are the group averages having removed effects of the covariate, age at start of treatment. Sample size was 139. SEM is standard error of the mean.

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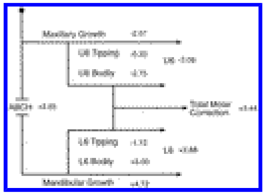

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FIGURE 1. The “pitchfork” diagram in the Johnston analysis partitions the skeletodental sources of the orthodontic correction. All measurements are made parallel to the mean functional occlusal plane (MFOP), which is the average of the pretreatment and posttreatment FOPs with superimposition of the cephalometric tracings on the lingual cortical plate of the palate and registration on the fine structure internal to the maxilla common to the pretreatment and posttreatment films. Results of the present study (with sexes and ages pooled) are shown in the diagram. By convention, positive values denote changes that aid correction of a Class II to a Class I molar relationship, such as mesial growth of the mandible. Maxillary and mandibular growth are the amounts of forward growth of the 2 jaws during treatment relative to the anterior cranial base (*note* that maxillary growth is negative because it detracts from the Class I correction). Total crown movement of the maxillary first molar (U6) is partitioned into the contributions from tipping vs bodily movement, and the same partitioning is done for the mandibular molar (L6). Apical base change (ABCH) is the difference between the forward growth of the 2 jaws; a positive value indicates that mandibular growth exceeded maxillary growth, thus assisting in the Class II correction. The average patient in the present study experienced more mandibular growth than maxillary growth (ABCH, +2.65 mm). There was forward crown tipping of U6 (−0.33 mm), but most of the U6 movement was forward translation (−2.75 mm). Mandibular forward translation was twice that of U6 (L6 bodily movement, 5.00 mm). Growth of the 2 jaws (−2.07 plus +4.72 = 2.65 mm) plus dental movement (−3.09 plus +3.88 mm) sum to the total molar correction of 3.44 mm. In our patient sample, skeletal growth produced 77% of the total molar correction, whereas molar movement was responsible for 23%

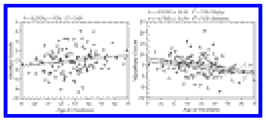

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FIGURE 2. Scatterplots of mesiodistal growth of the maxilla (left) and mesiodistal growth of the mandible (right). Both are measured relative to the anterior cranial base. The sign of the changes was based on whether the change aided a Class I correction; mesial growth of the maxilla is reflected by negative values, whereas mesial growth of the mandible is reflected by positive values. Maxillary growth slowed significantly across the age span of 9 to 17 years; the few positive values appeared to be due to orthopedic effects of Class II elastics. Forward growth of the mandible was also significantly slower in older adolescents; negative values were probably due to downward-backward autorotation in some cases. Mandibular growth was significantly faster in boys (closed symbols) than in girls (open symbols)—as shown by the difference in intercepts—although the slopes were the same

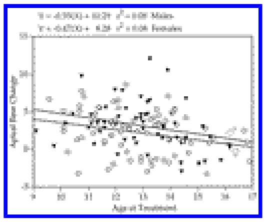

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FIGURE 3. Apical base change (ABCH) was calculated as the mesial growth of the mandible minus the mesial growth of the maxilla. Therefore, positive values reflect improvements in the bony denture bases that aided in achieving a Class I sagittal molar relationship. ABCH was greatest in the youngest patients and decreased significantly as the age at the start of treatment increased. The rate of growth was significantly greater in boys (closed symbols) than in girls (open symbols) as indicated by the larger Y-intercept, although the slopes were the same in the 2 sexes

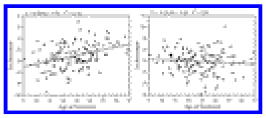

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FIGURE 4. Bivariate plots showing the significant association between patient age at the start of treatment and the amount of slippage of U6 during treatment (left) (F = 22.9, $P < .001$) and the statistical independence of age with L6 movement (right) (F = 1.4, $P = .24$). Negative values represent mesial movement for U6 and distal movement for L6, since these directions of change detract from attaining a Class I

molar relationship

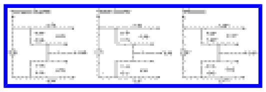

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FIGURE 5. Pitchfork diagrams illustrating the different mix of skeletal and dental contributions to the correction of a Class II to a Class I molar relationship between the youngest and oldest quartiles from the total sample of patients treated with Begg lightwire technique. Differences (right) were highly significant (** indicates $P < .001$) for skeletal growth and amount of mesial bodily movement of U6. Skeletal changes accounted for 87% of the total molar correction in the youngest quartile but only 36% in the oldest quartile. Conversely, most of the correction in these older adolescents (64%) had to be achieved by tooth movement per se

[a] Departments of Orthodontics and Pediatric Dentistry and Community Health, University of Tennessee, Memphis, Tenn.

Corresponding author: Edward F. Harris, PhD, Department of Orthodontics, University of Tennessee, 875 Union Ave, Memphis, TN 38163 (E-mail: eharris@utmem.edu).