1-1-2006

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Published version. *The Angle Orthodontist*, Vol. 76, No. 1 (January 2006): 72-76. Permalink.

Original Article

Soft Tissue to Hard Tissue Advancement Ratios for Mandibular Elongation Using Distraction Osteogenesis in Children

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Abstract: Distraction osteogenesis is extensively used for the elongation of hypoplastic mandibles in children, yet the soft tissue profile response to this is not well understood. The pre- and posttreatment lateral cephalometric radiographs of 27 pediatric patients who underwent bilateral mandibular elongation using distraction osteogenesis were analyzed retrospectively to correlate horizontal soft tissue advancement with horizontal underlying bone advancement at B point and pogonion. Horizontal advancement (in millimeters) of bone and overlying soft tissue at these points was collected from the radiographs of each patient, and linear regression analysis was performed to determine the relationship of hard to soft tissue horizontal advancement at these points. A 1:0.90 mean ratio of bone to soft tissue advancement was observed at B point/labiomental sulcus and at pogonion/soft tissue pogonion (linear regression analysis demonstrated slopes [β_1 values] of 0.94 and 0.92, respectively). These ratios were consistent throughout the sample population and are highly predictive of the soft tissue response that can be anticipated. Magnitude of advancement, age, and sex of the patient had no effect on these ratios in our population. This study assists with our understanding of the soft tissue response that accompanies bony elongation during distraction osteogenesis which will allow us to more effectively treatment plan the orthodontic and surgical intervention that will optimize the patients' functional and esthetic outcome. (*Angle Orthod* 2006;76:72–76.)

Key Words: Osteodistraction; Soft tissue

INTRODUCTION

Distraction osteogenesis has become an accepted method for mandibular elongation for children and adults afflicted with specific mandibular hypoplasias that might not be amenable to traditional osteotomies.[1–3] Distraction has allowed us to treat large magnitude disabling hypoplasias of the mandible without bone grafting, while inducing adjacent soft tissue development at the distraction site.[4,5] The nature of the distraction technique also allows these large-scale functional and anatomic corrections to be completed on children who might not be amenable to traditional grafting or osteotomy techniques or who might have hypoplasia in excess of the capabilities of these techniques.[6]

Although these procedures are used in children for the functional correction of airway, mastication, or speech abnormalities (or all), the facial profile is altered by the mandibular elongation. Many of these patients also require concomitant or staged reconstruction of the forehead, midface, or chin regions (or all), with associated changes in profile esthetics. For these reasons, an understanding of the amount (ratio) of soft tissue advancement that can be expected to accompany a given hard tissue advancement of the mandible undergoing distraction will improve our ability to pre-

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Accepted: February 2005. Submitted: February 2005.

dict the profile change that will accompany the functional correction. This will allow more accurate planning of the other required surgical and orthodontic treatment to not only correct the functional abnormality but optimize facial balance and profile esthetics.

The importance of soft tissue response to underlying bone movement was highlighted for orthognathic surgery in the 1970s and 1980s. Our ability to predict the soft tissue response for a particular movement of the maxilla or mandible allows us to plan the orthodontic intervention that will most appropriately set up the case for surgery. Furthermore, decisions about relative movements of the maxilla, mandible, chin, nose, or zygoma (or all) are more accurately made when we can predict how the overlying soft tissue will respond to surgical manipulation of these elements. The ratio of horizontal hard tissue movement to soft tissue movement for mandibular advancements using bilateral sagittal split ramus osteotomy has been evaluated in many studies. Although there is some minor variation among these reports, in general, a near 1:1 ratio is observed at B point, pogonion, gnathion, and menton, with less predictable ratios being recorded for the incisor and lower lip regions.[7–13] To date, no similar body of work has been completed for mandibular elongation using distraction osteogenesis.

Some evaluation of profile changes related to the use of midfacial distraction has been completed. Harada et al[14] compared the soft tissue changes that accompany midfacial advancement in nine cleft patients treated with distraction vs the soft tissue changes of nine cleft patients treated with conventional midfacial advancement. They found larger increases in nasolabial angle and subnasal length as well as a greater ratio of soft tissue advancement for the distraction group when compared with the conventional midfacial advancement group. Wen-Ching et al[15] also evaluated midfacial soft tissue changes in a group of cleft palate patients and found qualitative changes that were consistent with the Harada group findings. In addition, they found soft tissue to hard tissue ratios for midfacial advancement that were somewhat comparable with conventional advancements in noncleft patients and much better than those ratios observed for cleft patients undergoing traditional midfacial advancement.

Further investigation of hard tissue to soft tissue ratios for distraction osteogenesis reconstruction of the maxilla and mandible is needed to improve the accuracy of orthodontic and surgical treatment planning for these procedures. Our objective is to characterize the soft tissue response to bony advancement using distraction osteogenesis by evaluating the changes that soft tissues of the chin region have in response to bilateral elongation of the mandible.

MATERIALS AND METHODS

The lateral cephalometric radiographs of 27 pediatric patients who underwent bilateral mandibular elongation using distraction osteogenesis between January 1996 and June 2003 were analyzed retrospectively. The average patient age at the time of treatment was seven years seven months, with a range of two years seven months to 17 years zero months. There were 16 boys and 11 girls. All had severe mandibular hypoplasia with associated airway compromise or other dysfunction resulting from this hypoplasia (or both). These patients all underwent a combination of ramus elongation coupled with body lengthening of the mandible, which resulted in an anterior (horizontal) displacement of B point and pogonion.

Immediate predistraction and postconsolidation (device removal) lateral cephalometric radiographs were evaluated. These centric occlusion radiographs were taken on the same machine with a standardized technique. One individual traced and marked these radiographs using a standardized technique to assure anatomic point placement reproducibility. Horizontal movement of B point and its associated soft tissue landmark labiomental sulcus (LMS) and hard and soft tissue pogonion (Pg, Pgs) were measured for each individual by superimposing composite acetate tracings over a one-third mm grid applied parallel to Frankfort horizontal. Composite acetate tracings were generated by superimposing cranial base anatomic landmarks of the predistraction and postconsolidation tracings, using the American Board of Orthodontics Phase III Guidelines for Craniofacial Composite tracings. Horizontal changes at each of the four points were measured to the one-third mm using the grid and recorded. Hard to soft tissue ratios were calculated for each set of millimeter advancement values for each pair of points (the B point/LMS pair and the Pg/Pgs pair).

All statistical analyses were run using SAS.[16] Summary statistics are presented in terms of means and standard deviations. A *t*-test was used to test for age differences by sex and B point to LMS ratio and Pg to Pgs ratio differences by sex. Pearson's product moment correlation test was used to examine the relationship between each of the two ratios and age. Simple linear regression was used to examine relationships between bone advancement at B point and soft tissue advancement at LMS, bone advancement at Pg and soft tissue advancement at Pgs, and the B point to LMS and Pg to Pgs ratios. Multivariate linear regression was run further adjusting for age and sex.

RESULTS

The raw data, including the patient's age, sex, horizontal advancement in millimeters for B point/LMS

TABLE 1. Columns 2, 3, and 4 Show Amount of Advancement Parallel to Frankfort Horizontal for B Point and LMS and the Ratio of These Two Segments for Each Patient. Columns 5, 6, and 7 Show Amount of Advancement Parallel to Frankfort Horizontal for Pg and Pgs and the Ratio of These Two Segments for Each Patient[a]

Sex/Age	Bone Advancement at B Point (mm)	Soft Tissue Advancement at LMS (mm)	Ratio of B Point to LMS	Bone Advancement at Pg (mm)	Soft Tissue Advancement at Pgs (mm)	Ratio of Pg to Pgs
M 16 y 1 mo	18.33	17.33	1:0.95	21.33	19.67	1:0.92
M 11 y 11 mo	16.67	16.33	1:0.98	17.00	16.33	1:0.96
M 9 y 8 mo	6.00	6.00	1:1	10.00	9.33	1:0.93
M 9 y 6 mo	5.33	5.00	1:0.94	9.67	8.67	1:0.90
M 8 y 9 mo	11.00	10.00	1:0.91	12.33	11.33	1:0.92
M 6 y 5 mo	9.67	9.00	1:0.93	8.00	7.00	1:0.88
M 5 y 11 mo	11.67	11.33	1:0.97	13.67	12.67	1:0.93
M 5 y 10 mo	8.00	7.67	1:0.96	7.67	8.00	1:1.04
M 5 y 4 mo	4.00	4.00	1:1	5.67	5.00	1:0.88
M 4 y 10 mo	15.00	13.33	1:0.89	16.00	14.67	1:0.92
M 4 y 1 mo	19.33	17.00	1:0.88	24.33	21.33	1:0.88
M 4 y 1 mo	8.00	6.67	1:0.83	11.33	9.67	1:0.85
M 4 y 0 mo	4.00	2.67	1:0.67	6.00	4.33	1:0.72
M 3 y 5 mo	10.33	9.33	1:0.90	16.00	14.67	1:0.92
M 2 y 11 mo	9.00	8.67	1:0.96	10.00	10.0	1:1
M 2 y 8 mo	10.00	9.67	1:0.97	11.33	10.33	1:0.91
F 17 y 0 mo	6.00	5.33	1:0.89	6.33	6.00	1:0.95
F 15 y 7 mo	8.33	6.00	1:0.72	6.67	7.00	1:1.05
F 13 y 6 mo	5.00	3.33	1:0.67	6.00	5.67	1:0.95
F 13 y 1 mo	4.00	4.00	1:1	4.67	3.67	1:0.79
F 8 y 6 mo	12.33	10.67	1:0.87	14.33	12.67	1:0.89
F 8 y 5 mo	5.00	3.67	1:0.73	5.00	4.33	1:0.87
F 7 y 3 mo	7.00	5.67	1:0.81	7.67	5.67	1:0.74
F 5 y 5 mo	5.00	5.00	1:1	5.33	4.67	1:0.88
F 4 y 1 mo	5.00	5.33	1:1.07	6.00	6.67	1:0.11
F 3 y 5 mo	9.00	9.33	1:1.04	13.00	13.00	1:1
F 2 y 7 mo	5.67	4.67	1:0.82	5.00	3.33	1:0.67
Mean	8.84	8.04	1:0.90	10.38	9.47	1:0.90
Standard deviation	4.39	4.19	0.11	5.22	4.86	0.11

[a] LMS indicates labiomental sulcus; Pg, pogonion; and Pgs, soft-tissue pogonion.

and Pg/Pgs and the corresponding ratios, as well as overall means and standard deviations, are reported in Table 1.

A total of 27 children between the ages of 2.6 and 17.0 years are included in these analyses. Fifty-nine percent (n = 16) of the subjects were boys, and 41% (n = 11) were girls. No significant difference was found between the mean age of boys and girls (mean ages: 6.6 and 9.0, respectively, *P* value = .17); the overall average age was 8.8 (SD = 4.4). The range of advancement at B point was 4–19.33 mm (mean = 8.84, SD = 4.39), with a range of associated soft tissue advancement at the LMS of 3.33–17 mm (mean = 8.04, SD = 4.19). For bony pogonion, the advancement range was 5–21.33 mm (mean = 10.38, SD = 5.22) with associated soft tissue pogonion advancing in a range of 3.33–21.33 mm (mean = 9.47, SD = 4.86). The mean ratio of hard tissue to soft tissue advancement was 1:0.90 (SD = 0.11) at B point/LMS and also 1:0.90 (SD = 0.11) at Pg/Pgs. There were no significant correlations between either the B point to LMS ratio or the Pg to Pgs ratio and age (*P* = .32 and *P* = .39, respectively). No significant differences were found in the mean ratios by sex either (B point to LMS ratio, *P* = .27; the Pg to Pgs ratio, *P* = .78).

The results of simple linear regression are shown in Table 2. The slopes (β_1 values) shown in columns two and three are indicative of the ratios of bone advancement to soft tissue advancement at these points. The slope of B point to LMS movement was 0.94, and the slope of hard to soft tissue pogonion was 0.92. Stated more simply, linear regression analysis demonstrates that for every one mm of horizontal advancement of bone at B point or pogonion, the associated overlying soft tissue is expected to advance 0.94 and 0.92 mm, respectively. These values are consistent with the mean advancement ratio of 1:0.9. The *P* values and *r*-squared values signify the strong predictive values of these models. The *r*-squared value in column four suggests that the B point to LMS ratio is not a strong predictor of the pogonion ratio. Although the slope of 0.42 nearly reaches statistical significance (*P* = .051), the *r*-square value of 0.14 indicates that only 14% of the variation in the pogonion ratio is explained by the B

TABLE 2. Results of Simple Linear Regression[a]

	Dependent Variable = Soft Tissue Advancement Independent Variable = Bone Advancement		Dependent Variable = LMS/B Point Ratio IndependentVariable = Pgs/Pg Ratio
	LMS and B Point	Pgs/Pg	
β_1 (*P* value)	.940 (<.0001)	.922 (<.0001)	.418 (.051)
r-square	0.972	0.979	0.1439

[a] LMS indicates labiomental sulcus.

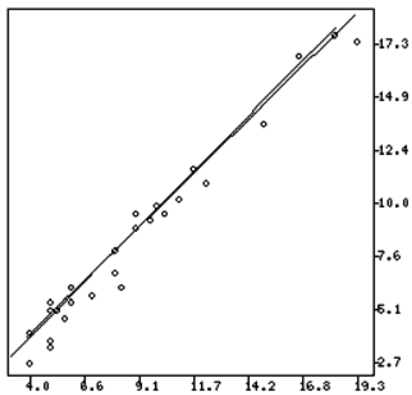

FIGURE 1. Scatterplot diagram for simple linear regression analysis of B point to labiomental sulcus (LMS) horizontal movement in millimeters for the 27 patients studied. The line slope is indicative of a ratio of B point to LMS movement of 0.94.

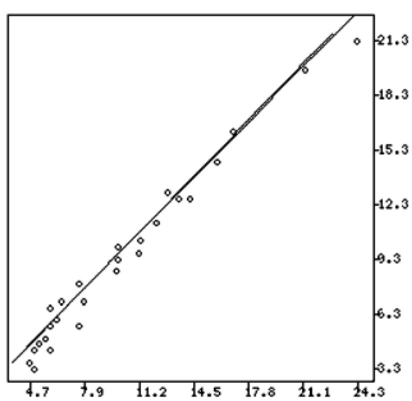

FIGURE 2. Scatterplot diagram for simple linear regression analysis of pogonion (Pg) to soft tissue pogonion (Pgs) horizontal movement in millimeters for the 27 patients studied. The line slope is indicative of a ratio of Pg to Pgs movement of 0.92.

point to LMS ratio. Scatterplot analyses of this data are presented in Figures 1 and 2.

The results of the multivariate linear regression are shown in Table 3. Neither sex nor age was significant in any of the models, and the increases in the *r*-squared values are small, particularly for the models comparing horizontal bony movement with soft tissue movement, indicating that neither the child's age nor sex adds much predictive value to our models.

DISCUSSION

The ratio of hard tissue to soft tissue movement for mandibular elongation using distraction osteogenesis in children consistently approximates 1:0.9 for anatomic landmarks at and inferior to B point/LMS. Compared with similar studies completed in adult orthognathic surgery populations, this falls just short of the 1:1 hard to soft tissue ratio that is observed there. This minor difference is surprising because we would expect that the expanding soft tissue envelope that occurs with distraction osteogenesis would allow for a match of the 1:1 ratio that is observed with advancement using traditional osteotomies. Further, midfacial distraction advancement in cleft patients has shown greater relative advancement of soft tissue for a given amount of bone advancement when compared with nondistraction midfacial advancement cleft patients.[14,15]

Although it might seem logical that the greater magnitude of advancement for distraction patients over osteotomy patients might be responsible for this slightly lower 1:0.9 ratio, there are individuals in our sample who do not support this hypothesis. A review of our data from Table 1 reveals that of the 54 hard to soft tissue pairs, 11 have a ratio at or in excess of 1:1. The

TABLE 3. Results of Multiple Linear Regression[a]

	Dependent Variable = Soft Tissue Advancement Independent Variable = Bone Advancement		Dependent Variable = LMS/B Point Ratio Independent Variable = Pgs/Pg Ratio
	LMS and B Point	Pgs and Pg	
β_1 (*P* value)	.924 (<.0001)	.920 (<.0001)	.453 (.04)
β_{male} (*P* value)	.327 (.33)	.079 (.82)	.028 (.50)
β_{age} (*P* value)	−.017 (.63)	.031 (.38)	−.01 (.24)
r-square	0.974	0.980	0.230

[a] LMS indicates labiomental sulcus.

bony movements for these 11 sites are 4, 4, 5, 5, 6, 6, 6.67, 7.67, 9, 10, and 13 mm, respectively. And although these values fall in the orthognathic surgery range of advancement (supporting our hypothesis), distraction advancements of as little as five mm in our group had a ratio value of 1:0.73. Indeed, many of the advancements in our data set that fall below 12 mm have ratios less than 1:0.9, although advancements in the same range in the orthognathic surgery literature would show a near 1:1 ratio. Furthermore, the five largest magnitude bony advancements in our sample, 24.33, 21.33, 19.33, 18.33, and 17 mm, were associated with the ratios 1:0.88, 1:0.92, 1:0.88, 1:0.95, and 1:0.96, respectively.

On inspection of the data, the magnitude of the distraction advancement of the mandible does not solely explain variations in the ratio between distraction patients, which makes magnitude a less likely culprit in the difference between distraction and traditional osteotomy ratios. The linear regression analysis also demonstrates little variation (therefore high predictability) regardless of the magnitude of distraction advancement. The difference may lie in the fact that we are comparing skeletally mature osteotomy patients with growing distraction patients. It might be possible that in growing patients mandibular elongation may have a modulating influence on bone and soft tissue remodeling in the symphyseal area that moderates the hard tissue to soft tissue ratio. A study comparing the adult soft tissue response of bilateral mandibular distraction elongation vs bilateral sagittal advancement might help to answer this question.

Regardless, a minor but consistent difference in ratio is observed for distraction in children (approximating 1:0.9) vs sagittal advancement in adults (1:1) that is of little real clinical significance for small advancements. However, for larger distraction advancements, a 1:0.9 ratio indicates that one mm of soft tissue advancement is lost for every 10 mm of bony advancement. In an era when 40+ mm mandibular elongations are becoming more common, this slightly lower ratio becomes more relevant, especially when planning concomitant chin and midface procedures. It also highlights the importance of determining whether this 1:0.9 ratio holds up in the adult distraction population.

CONCLUSIONS

- A 1:0.9 mean ratio for bone to soft tissue advancement was observed at B point/LMS and at Pg/Pgs in our sample of pediatric patients undergoing bilateral mandibular elongation using distraction osteogenesis. These means are consistent with the linear regression slope (β_1) values of 0.94 and 0.92 for these point pairs, respectively. These ratios were consistent throughout the sample population and are highly predictive of the soft tissue response that can be anticipated with distraction mandibular elongation in children.
- Further investigation with distraction mandibular elongation in adults is needed to see whether these ratios also apply to this group.

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