Mandibular remodeling measured on cephalograms. 1. Osseous changes relative to superimposition on metallic implants

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We report the results of a study aimed at quantifying remodeling of mandibular surfaces in a sample of growing children who represent those usually treated by orthodontists in the mixed and early adult dentition. The sample, 31 patients with metallic implants of the Bjork-type, was monitored at annual intervals between 81/2 and 151/2 years of age. (Maxillary remodeling changes for the sample have been reported earlier.) The present article reports findings concerning changes at condyle, gonion, menton, pogonion, and point B as identified on lateral cephalograms. Data are reported in the Frankfort plane frame of reference with the cephalograms from different time points superimposed on the metallic implants. Mean displacement at condyle was larger than that at any other landmark and was similar in magnitude and direction to the observations of Bjork when the difference in orientation of the vertical axis in the two studies is taken into account. The mean displacement of gonion was in an upward and backward direction at an angle of approximately 45° to the Frankfort plane. Mean displacements at menton and pogonion were in a downward and backward direction but were very small. Mean displacement at point B was somewhat greater than that of menton and gonion, oriented in an upward and backward direction. Individual variation for most of the parameters measured was sufficiently large to warrant the inference that caution should be used when mean values are applied to the analysis of individual cases. (AM J ORTHOD DENTOFAC ORTHOP 1992; 102:134-42.)

This article presents quantitative data on dimensional changes at condyle, gonion, and mandibular symphysis in a sample of growing children with metallic implants. Its purpose is to provide previously unavailable information on the normal variability of such changes in a group of subjects typical of those commonly seen for orthodontic treatment in the mixed or early adult dentition.

The fact that our currently available standards for craniofacial growth through time are based on such limited samples and data is evidence of how difficult it is to make accurate measurements of growing children. If the jaws merely expanded uniformly in all directions during growth (as was once thought), the measurement of osseous changes on cephalograms and other standardized x-ray images would be relatively easy. However, the situation is more complex. It has long since been demonstrated that the changes in jaw

size and shape that take place during development are the result of differential apposition of bone on some surfaces and resorption on other surfaces rather than the consequence of simple enlargement with respect to one or more fixed "growth centers."

The absence of truly stable natural reference markers within the jaws complicates the task of investigators who wish to quantify growth changes or to measure the effects of therapeutic intervention in growing children. For this reason, biologists have sought for many years to incorporate extrinsic markers within the growing jaws.[1-3] Thus far the most successful solution has been the metallic implant method developed by Bjork and coworkers.[4-7] Indeed, it would be difficult to overstate Bjork's contribution to our modern understanding of craniofacial development. Unfortunately for orthodontic and craniofacial research, however, the number of treated and untreatcd subjects with metallic implants is small, making it particularly important that the available records be studied with great care. One useful research strategy would be to use the available records of patients with implants in two related ways: first, as a source of longitudinal in vivo data on patterns of osseous mod eling, and second, to test the errors inherent with the different methods of "anatomic" superimposition. In such a strategy, the implant measures for each subject at each time point would be used as a kind of "gold standard" against which other findings could be compared. Repeated comparisons with different anatomic rules would then be required to find the anatomic rule that best corresponds to the "gold standard" values.

In two recent articles,[8,9] we have implemented precisely this strategy to describe growth changes in the maxilla and to determine the limitations of one common maxillary superimpositional rule. In the first article,[8] we supplied quantitative longitudinal in vivo information on remodeling at three osseous landmarks in the maxilla. In the second article,[9] we were able to provide quantitative information on the limitations of the most commonly used rule for maxillary anatomic superimposition as compared with the implant standard. This article is the first of two that seek to achieve the same goals with respect to mandibular superimpositions.

MATERIALS AND METHODS

The data reported in this article were acquired from lateral cephalograms of 31 subjects; 18 had received orthodontic treatment, whereas 13 were untreated. The manner in which these 31 cases were selected from an original sample of 36 subjects has been described previously.[8,9]

The films were evaluated with an updated variant of the UCSF computer-aided head film analysis.[10] Independent de terminations for each landmark and for each of the two kinds of tracing superimpositions were made by James T. Rogers, Research Associate in our laboratory, and by one of the authors (Y.B.B.). Two separate mandibular superimpositions for each film pair were made by each judge. The first super imposition was made entirely on the metallic implants without reference to the mandibular anatomy. The second superimposition ignored the implants and registered entirely on an atomic structures by using one fairly stamdard anatomic rule. Each act of superimposition was performed by overlaying a tracing of a film from one time point on a tracing of the film from the previous time point. Note that this operation is dif ferent from the usual clinical convention in which tracings from all subsequent time points are superimposed on the reference or pretreatment film. In this study we departed from the convention to avoid the large errors that would have been incurred by superimposing tracings from the later (11 1/2 to 15 1/2 year) films on the much smaller 8 1/2-year reference film.

This article reports the results of the implant superimpositions, our best available estimates of osseous changes through time. The relationship between these implant-based estimntes and those obtained with thc anatomic method of superimposition will be reported in a future article.

Mandibular remodeling is characterized here in terms of the displacements of five anatomic landmarks, condyle, gonion, menton, pogonion, and point B (Fig. 1, A). For the purposes of this study, these landmarks are defined as follows:

Condyle: The point on the contour of the image of the mandibular condyle indicating the longest distance from pogonion [after Harvold[11]].

Gonion: The lowest point on the curvature of the angle of mandible where the body of the mandible meets the ramus. Estimates are made for both sides of the mandible. The midpoint between these two estimates is then calculated with the computer.[12]

Menton: The inferiormost point on the mandible at the symphysis.

Pogonion: The anteriormost point on the bony chin measured perpendicular to mandibular plane.

Point B: The deepest point on the curvature of the anterior surface of the mandible between pogonion and the alveolar crest of the lower central incisor measured perpendicular to mandibular plane.

Outlier deletion criteria for each of these landmarks have been established in previous studies.[12,13] Coordinate data are reported in terms of an orthogonal coordinate system in which the X and Y axes for each subject are parallel and perpendicular to the Frankfort plane of the subject's reference film (Fig. 1, *B),* and the origin for each landmark is its location on the reference film (Fig. 1, *C*). The reason for our choice of this coordinate reference frame will be considered in the *Discussion.*

RESULTS

The composition of the sample and the distribution of time points from which data have been encoded are indicated in Table IA. For each subject, the lateral cephalogram taken closest to the age of 81/2 years was used as the time point 1 film. (The age range among these nominal 8 1/2-year films was from 8.02 to 8.98 years.) The data from films taken at subsequent time points have been superimposed on this nominal 8 1/2-year reference film, yielding a longitudinal data set with the data grouped cross-sectionally at annual intervals. The demographics for the films from which data are used in the present article are further summarized in Tables IB and IC. The distribution of cases and time points is identical with that in our earlier reports[8,9] except that information at time point 3 for Case S is missing for this study. Table Il presents means and standard deviations for the cumulative displacement of each of the five landmarks relative to the 8 l/2-year reference cephalogram at the 2-, 4-, and 7-year time intervals. To enable the reader to visualize the trends of displacement of the five landmarks over all cases, the numeric data of Table 11 are also represented graphi cally. Fig. 2 illustrates the mean displacement for each landmark at each time point, and Fig. 3 shows the individual variability at the 7-year time interval.

DISCUSSION

This discussion is organized into five parts. The first examines the mean pattern of change at each landmark. The second discusses individual variation at each landmark. The third considers our choice of anatomically determined coordinate system. The fourth is a comment on aspects of the implant method. The last briefly considers some clinical implications.

Part 1. Mean effects

In Fig. 2, the mean displacements of all five landmarks relative to implant superimposition are represented graphically at a common scale. This allows the reader to obtain at a glance a sense of the relative magnitudes and directions of the modeling changcs at the several landmarks. We consider the five landmarks in turn.

Condyle. The largest dimensional changes were observed at condyle. For a subsample of 19 subjects, mean displacement during the 7-year time interval hetween the ages of 81/2 and 151/2 years, was 17.8 mm upwards and 1.8 mm backwards at an angle of 6° to the vertical. This compares with the report by Bjork[7] of a mean upward and forward displacement at mean angle of 6°. At first consideration, the two findings appear to differ by 12°. However, it is important to note that different frames of reference were used in the two studies. Whereas we defined the Y-axis as a line perpendicular to Frankfort, Bjork's measurements are referenced to a line tangent to the posterior surface of the ramus. The posterior surface of the ramus typically inclines an teroinferiorly with respect to the perpendicular to Frankfort (see Fig. 1, *C*). As a quantitative check, we mea sured the angle between Bjork's vertical axis and our own on the 81/2-year films of a subsample of 10 cases. In this subsample, the mean angle between the two vertical axes was approximately 11°. Thus we feel justified in reporting that when the difference in frame of reference is taken into consideration, the mean direction of condylar growth in our sample closely approximates that reported for Bjork's sample.

Mean rate of growth at condyle was relatively constant through time, diminishing relatively little during the period under study. Vertical growth at condyle averaged almost exactly 2 mm per year between 11/2 and 15 1/2 years of age (a period during which much active orthodontic appliance therapy is completed).

Gonion. Second only to condyle, the largest displacements were seen at gonion. Here, mean backward displacement and mean upward displacement were almost equivalent at each time point. However, it is probably inaccurate to consider the upward displacement through time of the point we identify as gonion to be evidence of resorption, since in growing subjects the physical structure which we call "gonion" at any given time point did not exist at earlier time points. (See, for example, the gonion detail of Fig. 2.) Definitive characterization of resorption at gonion requires evaluation of changes along the surfaces of the lower border and ascending

ramus of the mandible rather than the point displacement approach used in this study.

Symphyseal landmarks. Mean magnitudes of developmental change in the anterior mandible were far smaller than were the changes at gonion and condyle. Menton and pogonion both appear to displace slightly downward and backward, but the mechanisms of change at the two landmarks must clearly be different. The changes at menton are most readily accounted for by apposition on the inferior surface of the symphysis, consistent with the findings of Bjork,[5,7] whereas the displacement of pogonion can probably best be accounted for by slight resorption on the anterior surface of the bony chin, a finding that is consistent with the postmortem studies of Enlow.[14]

Point B appeared on average to displace superiorlyand posteriorly. This finding is consistent with our beliefs about the vertical development of the alveolar processes and the active and passive eruption of the lower anterior teeth. Here, too, there was evidence of resorption on the anterior surface of the mandible.

Part 2. Individual variability

Quantitative data for the individual differences at each landmark are summarized in the standard devia tions of Table II. In general, one standard deviation may be considered a useful approximation of the average error that will be incurred if the mean value is used as a predictor of the value for each individual case in a series of cases.

The raw coordinate data representing the displace ment of each landmark in each case between the first and the eighth time points are shown in the five detail scatterplots of Fig. 3. We now consider briefly the dis tributions of individual case values for the five landmarks.

Condyle. Individual variability at condylc was greater than that at any other landmark studied. At the 7-year time interval, the mean effect in the horizontal direction was a backward displacement of only 1.7 mm, but the range among the 19 cases extended from 7.3 mm backward to 3.4 mm forward. In the vertical direction, the range was even greater (from 10.9 to 26.6 mm). The angle representing growth direction had a range of 30° (compared with the report by Bjork of a range of 42° in a sample of 45 males observed over a 16-year period[5]). This considerable variability should certainly be taken into account when mean values are used to make predictions of condylar growth in individual cases or when cephalometric "evidence of growth at condyle" in individual cases is used to demonstrate the efficacy of specific therapeutic strategies. Horizontal and vertical

deviations from the mean at condyle were essentially uncorrelated ($r = 0.09$, $p < 0.10$).

Gonion. At gonion, variability was less than at condyle but greater than at the symphyseal landmarks. All 19 cases available for study at the 7-year interval showed backward and upward displacement at gonion. Backward displacement ranged from 3.1 to 10.9 mm, whereas upward displacement ranged from 0.4 to 10.5 mm. A particularly striking finding was the high correlation between backward displacement and upward displacement at this landmark ($r = -0.63$, $p < 0.005$). This indicates that the further posteriorly the landmark displaces, the further upward it tends to displace.

Symphyseal landmarks. The patterns of variability at pogonion and menton were rather similar. At each of these landmarks, about a third of the cases had total displacements of 1 mm or less over the entire 7-year period under observation. For neither menton nor pogonion did there appear to be a strong correlation between displacement in the horizontal direction and displacement in the vertical direction. At menton, the correlation between the X and Y changes was $r = -0.19$, ns. At pogonion, it was $r = -0.23$, ns.

The scatter of individual case values at point B was larger than that observed at pogonion or menton. The correlation between changes in the horizontal and vertical directions at point B was stronger than at menton and pogonion ($r = -0.52$, $p < 0.05$), consistent with the idea that the anterior surface of the alveolus remodels resorptively as the incisor crowns erupt.

Part 3. Defining the frame of reference

In our reports on maxillary remodeling, it seemed intuitively reasonable to report findings in terms of an X-axis passing along the ANS-PNS line.[8,9] The analogous operation in the mandible would have been to use the gonion-menton line (i.e., mandibular plane) as the X-axis. The reader may ask why in the present study we opted instead to orient to the Frankfort plane. There were two major reasons for our decision. First, the mandibualr plane intersects much more obliquely with the facial profile than either the Frankfort plane or the ANS-PNS line do. Had we used a coordinate frame of reference oriented obliquely to the facial profile, the changes in facial form implied in our statistics would have become much more difficult to evaluate. Put more positively, we believe that statistics reported in terms of the Frankfort plane convey a better idea of alterations in face form. Second, both the pretreatment orientation and the treatment-associated changes in orientation of mandibular plane are much more variable than the analogous

properties of the Frankfort plane or the ANS-PNS line. For this reason too, we believe that using the gonion-menton line as the X-axis of our coordinate system would have resulted in statistics whose biologic meaning would have been more difficult to assess.

Part 4. Regarding the implants

The aim of this article has been to report new longitudinal data on remodeling of the human mandible from lateral skull cephalograms of subjects with metallic implants. Although the sample is relatively small, it is as large as any other human sample for which similar analyses have been reported. The following generalizations about the implants seem warranted: The mandibular implants appeared more stable when viewed on successive x-ray images than did the maxillary im plants examined in our earlier studies.[8,9] The number of implants that loosen or were lose during the period of these observations approximated 12%. Looseness or migration of implants appeared to be relatively easy to detect.

When viewed in lateral projection, the average horizontal distance between the anteriormost and posteriormost implants in the mandible is at least twice that for maxillary implants. This gives mandibular implant superimpositions much greater robustness against rotational errors than is the case for analogous maxillary superimpositions. Careful inspection reveals, however, that the process of implant superimposition in the mandible is still subject to consequential rotational error.

Part 5. Implications of the findings

An important observation from the clinical point of view is that in our sample average growth at condyle (unlike at gonion) continued at a consequential and relatively undiminished rate at least until the age of 15 1/2 years rather than slowing down at the beginning of the teenage years. Similar late developmental changes in both the sagittal and transverse directions in the maxilla[16,17] and in the sagittal direction in the mandible[5, 7] have been reported hy others. Recently our own group has also reported evidence of late transverse development in the maxilla.[15] We believe that taken together these studies serve to reenforce the need for long term follow-up of orthodontic patients for whom mechanotherapy is completed by the early teenage years.

The mean direction of growth at condyle was generally consistent with the findings of Bjork[5] even though the two samples were defined on the basis of quite different criteria. This tends to support the generalizability of

findings on mandibular rotation by Bjork. However, it is important to note that data on the clinical implications of mandibular rotation are yet to be reported for any sample of treated subjects with implants. Indeed, although several workers[18-22] have attempted to investigate the effects of orthodontic treatment on osseous remodeling patterns, the available data either with or without implants are scant, and further investigations are indicated.

As may be seen from the standard deviations of Table II and the scatter plots of Fig. 3, the magnitude of individual variation was generally consequential at
 all landmarks. In the case of the symphyseal landmarks, the standard deviations tended to exceed the means at almost all time points; at condyle and gonion, the standard deviations were smaller as percentages of the means but larger in absolute value. We conclude that the means from this study provide information useful to our general understanding of developmental change but that their use as quantitative predictors in individual cases would be premature.

REFERENCES

1. Humphry GM. Results of experiments on the growth of the jaws. Br J Dent Sci 1863; 6:548-50.

2. Hulen GR. A method of roentgenographic cephalometry as combined with the use of metallic implants in studying the growth of the mandible in the experimental animal: the dog. [Thesis] Northwestern University, 1948.

3. Robinson IB, Sarnat GB. Growth pattern of the pig mandible. A serial roentgenographic study using metallic implants. Am J Anat 1955; 96:37-64.

4. Bjork A. Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand 1955; 13:9-34.

5. Bjork A. Variations in the growth pattern of the human mandible; longitudinal radiographic study by the implant method. J Dent Res 1963; 42:400-11.

6. Bjork A. The use of metallic implants in the study of facial growth in children: method and application. Am J Phys Anthropol 1963; 29:243-54.

7. Bjork A, Skieller V. Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalomerric implant studies over a period of 25 years. Eur J Orthod 1983; 5:1-46.

8. Baumrind S, Korn EL, Ben-Bassat Y, West EE. Quantitation of maxillary remodeling. 1. A description of osseous changes relative to superimposition on metallic implants. AM J ORTHODDENTOFAC ORTHOP 1987; 91:29-4l.

9. Baumrind S, Korn EL, Ben-Bassat Y, West EE. Quantitation of maxillary remodeling. 2. Masking of remodeling effects when an "anatomical" method of superimposition is used in the absence of metallic implants. AM J ORTHOD DENTOFAC ORTHOP 1987; 91:463-74.

10. Baumrind S, Miller DM. Computer-aided head film analysis: the University of California, San Francisco method. AM J ORTHOD 1980; 78:41-65.

11. Harvold E, Vargervik K. Morphogenetic response to activator treatment. AM J ORTHOD 1971; 60:478-90.

12. Baumrind S, Frantz R. The reliability of head film measurements. 1. Landmark identification. AM J ORTHOD 1971; 60:111-27.

13. Baumrind S, Miller DM, Molthen R. The reliability of head film measurements. 3. Tracing superimpositions. AM J ORTHOD 1976; 70:617-44.

14. Enlow DH, Harris DB. A study of postnatal growth of the human mandible. AM J ORTHOD 1964; 50:25-50.

15. Korn EL. Baumrind S. Transverse development of the human jaws between the ages of 8.5 and 15.5 years studied longitudinally with the use of implants. J Dent Res 1990; 69:1298-306.

16. Krebs A. Midpalatal suture expansion studied by the implant method over a seven year period. Trans Europ Orthod Soc 1964; 40: 131 -42.

17. Skeiller V. Expansion of the midpalatal suture by removable

plates, analyzed by the implant method. Trans Europ Orthod Soc 1964;40: 143.

18. Vargervik K, Harvold E. Response to activator treatment in Class II malocclusions. AM J ORTHOD 1985; 88:242-51.

19. Fotis V, Melsen B, Williams S. Post-treatment changes of skeletal morphology following treatment aimed at restriction of maxillary growth. AM J ORTHOD 1985; 88:288-96.

20. Wieslander L. The effect of orthodontic treatment on the concurrent development of the craniofacial complex. AM J ORTHOD 1963; 49:15-27.

21. Baumrind S, Korn EL, Isaacson RJ, West EE, Molthen R. Quantitative analysis of the orthodontic and orthopedic effects of maxillary traction. AM J ORTHOD 1983;84:384-98.

22. Baumrind S, Korn EL, Isaacson RJ, West EE, Molthen R. Superimpositional assessment of treatment-associated changes in the temporomandibular joint and the mandibular symphysis. AM J ORTHOD 1983; 84:443-65.