Mandibular remodeling measured on cephalograms: 2. A comparison of information from implant and anatomic best-fit superimpositions

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This study quantifies the differences in the perceived pattern of mandibular remodeling when two different methods are used to superimpose roentgenographic images of the mandible. Lateral cephalograms for a group of subjects with metallic implants of the Bjørk type were superimposed twice; first on the metallic implants and then independently on mandibular anatomic structures according to a common "best fit" rule. In this article, we compare the between-superimposition differences in the perceived displacements of condyle, gonion, menton, pogonion, and Point B. Mean differences between the two superimpositional techniques were smaller than had been anticipated. For the 7-year time interval between 8.5 and 15.5 years, the largest mean differences between methods were 2.70 mm in the horizontal direction at condyle, 1.90 mm in the vertical direction at condyle, and 1.52 mm in the vertical direction at gonion. None of the other between-superimposition differences had a mean value in excess of 1 mm. The individual case variability between the two methods was, however, quite considerable, a finding that we believe has bearing on the confidence that can be placed in individual case analyses in clinical orthodontics. A preliminary attempt has been made to represent and discuss the magnitude of this problem. (AM J ORTHOD DENTOFAC ORTHOP 1992;102:227-88.)

This article continues an ongoing evaluation of longitudinal cephalometric records for a group of growing children with metallic implants of the Bjørk type.[1-3] Our strategy in this article and our last one[3] is analogous to that employed previously in the evaluation of maxillary osseous changes.[1,2] It uses cephalograms of patients with implants for two related purposes: (1) to obtain longitudinal in vivo data on patterns of osseous remodeling measured relative to the implants, and (2) to quantify the limitations of common anatomic superimpositional rules as compared with the implant standard.

Recently, we reported on mandibular osseous remodeling relative to superimposition on metallic implants.[3] In this article, we analyze the consequences of using one common rule for anatomic best-fit superimposition on mandibular structures instead of the implant standard.

MATERIALS AND METHODS

The data used in this study are from the same sample and the same records set used in the previous articles of this series[1-3] and were acquired at the same time. Sample demographics are resumrnatized briefly in Table I. The methods of data acquisition have also been previously outlined.[3,4] As in our previous article,[3] the landmarks with which we concern ourselves are condyle, gonion, menton, pogonion, and Point B. Fig. I illustrates the manner in which these landmarks and the frame of reference were defined.

To the extent that superimposition on metallic implants is a valid procedure, differences between measurements of the displacement of landmarks relative to superimposition on implants and the displacement of the same landmarks relative to superimposition according to any particular anatotnic rule constitute reasonable estimates of the error involved in the use of that particular rule. The anatomic rule whose pattern of differences with respect to an implant standard is studied here is defined as follows:

Anatomioal Best Fit of the Mandibular Border—The judges' best estimate of the optimal fit of the two images of the mandible where primary consideration is given to the inner table of the symphysis and the average between the bilateral images representing the lower borders of the mandible while the relationship between the images of the ascending rami is ignored.

Fig. 1. A, Schematic representation of landmark locations. Operational definitions for locating these landmarks may be found in our previous article. 1 B, The coordlnate frame of reference for each case is oriented parallel and perpendicular to the Frankfort plane of the 8.5-year cephalogram. In two separate and independent operations, the images of the mandible at successive time points are superimposed, first on the implants and then according to an anatomic rule. 1C, The origin for measuring the displacement of each landmark relative to each type of superimposition is the location of that landmark on the

8.5-year film. The X and Y axes are parallel and perpendicular to the Frankfort plane on same film.

Table IA. Summary of Sample Demographics at Each Timepoint

Table IB. Summary of Sample Demographics for Between-Timepoint Comparisons

There is a substantial literature[5-9] on techniques of mandibular superimposition. Although we do not contend that the previously mentioned definition is the *best* or *only correct* anatomic ruler, it does have the advantage of conforming closely to the current use of many clinicians. Note, however, that we have chosen in this study to use a rule that omits references to trabecular detail, the third molar crypt, and the inferior alveolar canal (the elements of the "structural method" of mandibular superimposition reported by Bjørk[9]). The reasons for this choice will be indicated in the *Discussion.*

The measurements and coordinate transformations that were performed to produce the findings are explained in Fig. 2. The remainder of this article is based on the logical scheme outlined in the diagrams of Fig. 2.

RESULTS

In this section, we limit ourselves to the tabulation of statistics on the measurements made in the course of this study. As much as possible, we desire to distinguish between these raw findings and the inferences that we draw from them. To this end, we reserve those inferences and our other subjective comments for the *Discussion*..

Fig. 2.1 Rationale for measurements and statistics reported. Mean landmark displacements through time relative to superimposition on implants. A, For a particular subject, a landmark (condyle, for example) is located at "a" on the 8.5-year reference film. A frame of reference is established oriented parallel and perpendicular to Frankfort plane with the landmark at the origin. B, The same landmark is located on another cephalogram from a later time point, and the time point 2 tracing is superimposed on the reference film according to the implant superimpositional rule. This operation carries the landmark to the location represented by the *filled black diamond*, a'. C and D, The same operation is conducted for another subject and the analogous points b and b' are located. E, The data from the two cases from details B and D are now replotted on the same set of X and Y axes. The time point 1 locations for both subjects are *stacked* at the origin. The displacement from the origin of the black diamond for each case represents the displacement of the landmark between time points relative to implant superimposition. F, The condyle outlines are removed to simplify the figure. The means and standard deviations (in the X and Y directions) among the *filled diamonds* for all available subjects are computed. (Such values may be found in Table ll for all landmarks.) The *filled* circle represents graphically the mean displacement of the landmark for all subjects relative to implant superimposition. (Analogous graphic representations of the actual data for all landmarks may be found in Figs. 3 and 5).

To quantify the differences that occur when the anatomic best-fit rule described previously is used in lieu of the implant "gold standard," Table II shows statistics that summarize landmark displacements relative to that implant standard at the 2-, 4-, and 7-year time points. Table 111 shows analogous statistics for the displacement of the same landmarks relative to the anatomic superimposition at the same time points. Finally, Table IV shows casewise statistics on the differences between the values of Tables II and III.

Flg. 2.2. Mean landmark displacements through time relative to anatomic best-fit superimposition. G, In an independent operation similar to that performed in detail R, the time point 2 mandibular image of the first subject is superimposed on the 8.5-year reference film according to the anatomic best-fit rule. The time point 2 location of the landmark, condyle, is now indicated by the *open diamond* at point a''. H, The analogous operation is performed for the second subject. This subject's time point 2 location of condyle is at b''. I, The anatomical superimpositions for all subjects are replotted on the same X and Y axes (like detail E). J, The means and standard deviations are computed similar to detail F. The location of the anatomic superimpositional mean is represented by an open circle. (Analogous numerical values may be found in Table lll for all landmarks, whereas graphic representations of the means may be seen in Figs 3, 5, and B.)

DISCUSSION

This discussion is divided into four parts. The first considers mean differences in perceived displacement of each landmark as between the implant and anatomic superimpositions. The second considers individual case variation at each landmark. The third indicates briefly the reasons for our choice of anatomic rule and their implications. The last briefly states our general conclusions.

We wish to emphasize that the mean differences and individual case differences considered in this study *are entirely assignable to the operation of image superimposition and are entirely unreluted to errors in landmark* *location.* This is true because for each case and time point, the same location for each landmark was used for both the implant superimposition and the anatomic best-fit superimposition.

Part 1. Mean differences as a function of superimpositional rule

A sense of the mean differences in the perceived displacements of the landmarks as a function of superimpositional rule may be had by the examination of Fig. 3, which abstracts data from Tables II and III. The logic underlying this figure and the two tables has been explained in the legends of Figs. 2, A, and 2, B.

[Note: Fig. 3 in this article is the precise analog of Fig. 2 in our analogous article on maxillary changes.[2] However, the symbols identifying the implant means and the anatomic means in the maxillary figure and its legend were inadvertently reversed. The open circles of Fig. 2 in the maxillary article actually represent implant means and the filled circles represent anatomic means. Fortunately, the tables and the remaining figures of the maxillary article are free from errors and are precisely comparable to their analogs in this article.]

The numbered lines connecting the open and filled circles for each landmark at each time poin in Fig. 3 represent the mean differences in the perceived position of the landmark that occur solely as a function of the choice of superimposition rule. In the remainder of this

Fig. 2.3. Individual case superimpositional differences. The calculation of the individual case differences is an operation that requires no new measurements but is done by combining within case data which are already available. K, For the first case. the data on implant superimposition (from detail B) and anatomic best-fit superimposition (from detail G) are plotted on the same X and Y axes. Their common time point 1 position is represented at the origin. L, With the condyle outlines removed to simplify the figure, a line is drawn connecting the implant diamond a' and the anatomic diamond a''. In magnitude and direction, the line segment from a' to a'' represents the error that would have occurred in this case had the anatomic best-fit rule been used to estimate landmark displacement in lieu of the implant standard. We call this value the individual cAse superimpositional difference. M and N, In a manner precisely analogous to K and L, we use the data from details D and H to obtain the individual case superimpositional difference for the second case. O, So as to be able to compare the individual case superimpositional differences from all cases, we plot the data of details L and N (and similar data for other subjects in the sample) on the same X and Y axes. This is analogous to the procedure previously performed in details E and F to produce the data for Table II

and in details I and J to produce the data for Table III. It gives the best sense of the distribution of individual case displacements with respect to the 8.5-year reference film origin. Fig. 5 is the result of performing this operation for all landmarks and cases at the 7-year time interval. P and a, To get a better sense of the magnitude and direction of the deviation of the anatomic superimpositional values from the implant standard at any given time point, the data are replotted with the *filled diamonds* representing the implant values of all cases (a', b') stacked on each other at the origin of a new common coordinate system. This allows us to compare the individual case differences to each other with greater clarity and reduced ambiguity. Fig. 6 is presented in this format, and the statistical values of Table IV should be evaluated in these terms.

Table II. Cumulative Displacements of Condyle, Gonion, Menton, Pogonion and Point B Relative to Superimposition on Implants (means ± standard deviations in mm)

Table III. Cumulative Displacements of Condlye, Gonion, Menton, Pogonion and Point B Relative to Superimposition on Anatomical "Best Fit" (means ± standard deviations in mm)

Fig. 3. Comparison of differences in mean landmark displacement measured by two superimpositional methods. *Left, right, and* lower *middle,* enlarged details for the five individual landmarks. *Filled circles* represent mean displacement measured relative to superimposition on metallic implants. *Opcn circles* represent mean displacement measured relative to superimposition on anatomic best fit of the mandible as defined in this article. The *diagonal* lines connecting the filled and open circles for each landmark at each time point represent mean superimpositional differences, the X and Y components of which are listed as the mean values of Table IV. *Upper middle detail*, schematic 8.5-year mandible showing at scale the mean anatomic displacements of all five landmarks.

article, we use the term *superimpositional difference* to designate such deviations in the perceived position of any landmark at any time point when the anatomic best fit rule is used in place of the implant standard. To the extent that the implant findings are valid and accurate measurements of remodeling, the superimpositional differences reported here are direct measurements of the loss of information that occurs when our particular anatomic rule is used in the absence of implants.

To understand how the concept of mean superimpositional difference operates, consider the relationship among the mean values of condyle in Tables II, III, and IV. At the 7-year time interval, our best estimate of the true mean displacement of condyle with implants is 11.84 mm upward and 1.76 mm backward (Table II). But if we had not had the implants and had used our particular anatomic rule in their stead, we would have estimated the values to have been 15.94 mm and 4.46 mm, respectively (see Table III).

The differences between these two pairs of mean values are 2.70 mm in the horizontal direction and 1.90 mm in the vertical direction. These are the mean X and Y supcrimpositional differences as shown in Table IV.

The mean superimpositional differences are among the more importanl findings of this study. This is because the larger these values are, the less confidence we can have in grouped data drawn from anatomic superimpositions. Since such data constitute a large proportion of all the available information on the effects of orthodontic treatment, it is worthwhile to examine the findings at the several landmarks.

Mean superimpositional differences were greatest at condyle . For the 7-year period from 8.5 to 15.5 years, the anatomic superimposition underestimated the mean upward repositioning of condyle by 2.7 mm, while overestimating its mean backward displacement by 1.9 mm.

At gonion in the horizontal (X) direction, the mean

Table IV. Superimpositional Differences Between the Implant and "Anatomical Best Fit" Methods
(measured at condyle, gonion, menlon, pogonion and point B)

difference was only 0.2 mm. But in the vertical (Y) direction, the anatomic superimposition underestimated the mean upward positioning of gonion by 1.52 mm.

At pogonion, menton, and Point B (the symphyseal landmarks), the mean superimpositional differences were quite small. Over the entire 7-year period of active growth from 8.5 to 15.5 years, the mean differences for none of these three landmarks exceeded 1 mm in either the horizontal or vertical direction.

Perhaps the most important conclusion to be drawn from the present study is that even though we used a rulec that was relatively insensitive, the mean between technique differences were smaller than anticipated. Only at condyle did the mean supetimpositional differences exceed three quarters of a millimeter over the 2-year interval usually associated with active orthodontic treatment. (See column 1 of Table lV.) Even at that landmark, the rate of divergence between the means for the two superimpositional techniques was less than 0.4 mm per year. Fig. 4 illustrates this point graphically and to scale for all landmarks at four time points. The data appear generally consistent with the inference that, unlike the situation encountered earlier in the maxilla,[2] average mandibular remodeling can be fairly well described according to a relatively simple anatomic superimpositional rule. If corrections for the relatively small systematic differences between superimpositions are desired, we believe that the mean superimpositional differences derived from the present sample and listed in Table lV constitute the best (and probably the only) currently available quantitative estimates.

Part 2. Individual differences as a function of superimpositional rule

In Fig. 3, lines were drawn connecting the mean values for the two superimpositions for each landmark at each time point. As was indicated, these lines represent the mean superimpositional differences. The analogous operation can also be carried out for each individual case. The resulting lines connecting the implant and anatomic values for each landmark at each time point then represent the individual case superimpositional differences for the several cases. This idea has been diagrammed and explained in Fig. 2, C, and its legend.

If all the individual case superimpositional differences for any landmark at any time point were exactly the same for all subjects, the task in correcting for the deviations of the anatomic best-fit values from the implant standard would be relatively simple. We could merely adjust each observed anatomic best-fit value by subtracting the appropriate mean superimpositional difference from Table IV. However, the superimpositional differences for different cases are not exactly the same (any more than any other cephalometric measurement is the same in all cases). Instead, there is a distribution,

Fig. 4. Enlarged representations of mean displacements of five landmarks through time for both superimpositional methods. Displayed at scale relative to the same schematic mean 8.5-year mandible. A, Displacement relative to implants. B, Displacement relative to anatomic superimposition. To reduce the complexity of the illustration, data are presented only for the first, fourth, and final time points.

both in magnitude and in direction, of the superimpositional difference values for each landmark at each time point.

Fig. 5 demonstrates this point. Here the individual case superimpositional differences for the l9 cases available at the 8.5 to l5.5-year time interval are represented by lines each of which connects a black (implant) diamond with its associated open (anatomic) diamond. (This is precisely the operation explained schematically in Fig. 2, C, and the five details are precise analogs of detail O in that figure.)

Examintion of the five details shows great variability between landmarks and also between cases at each landmark. As might be expected from Tables ll and Ill, the individual case differences are quite consequential at condyle and gonion but much smaller in the symphyseal region. Within the data for each individual landmark there is substantial vatiability in magnitude and direction with certain interesting trends. If, for example, we examine the orientations of the cases in the condyle detail, we notice that in 16 cases the measured superimpositional difference line connecting each implant gold standard value with its anatomic surrogate runs downward and backward, whereas in the remaining three cases it runs either upward or upward and forward. This is graphic evidence of the consistent tendency of the anatomic superimposition to underestimate upward condylar growth and overestimate backward condylar growth as compared with the implant standard. Analogous tendencies may be discerned at gonion. Another interesting observation, which one may make in Fig. 5, is that the pattern of open diamonds representing the dispersion of anatomic locations for the symphyseal landmarks is more tightly packed than is the analogous pattern for the filled diamonds representing the implant superimpositions of the landmark. This observation may be confirmed by comparing the standard deviations of Table II with those of Table lll. Note that for the symphyseal landmarks, the implant standard deviations listed in Table II are generally larger than the corresponding anatomic values in Table III. This observation is consistent with the idea that there are real between-subject differences in the pattern of growth change that are preserved in the implant superimpositions but "washed out" in the anatomic superimpositions.

The characteristics of individual case superimpositional differences are considered further in Fig. 6. Here the data from each detail in Fig. 5 have been replotted with respect to a new set of X and Y axes in the manner represented schematically in detail Q of Fig. 2, but the lines connecting the anatomic superimposition diamonds to the origin have been removed for simplicity. In each detail, the mean superimpositional difference is represented by the open circle in the midst of the distribution of open diamonds. Its distance from the origin is represented numerically in the mean values of Table IV. The distribution of the individual case anatomic superimpositional values around their mean is reflected in the standard deviations of Table IV. The clinically more important average distance between the anatomic values and their implant analogues stacked at the origin is given in the root mean square error *(rmse)* values of Table IV.

Fig. 5. Individual case superimpositional differences for 19 cases available at 8.5 to 15.5-year time interval. (Like Fig. 2.:2) . Within each detail, each case is represented by an implant value *(filled diamond)* and an anatomical value *(open diamond).* The line connecting these two values represents the individual case superimpositional value. (Case numbers are indicated along the lines where possible. Underscored case numbers indicate treated cases.) In each detail, the implant mean is designated by a *filled circle* and the anatomical mean is indicated by an *open circle.* The heavier line connecting these circles therefore represents the mean superimpositional differenee for the landmark in question.

The *rsme* values of Table IV represent our best estimates of the average individual case superimpositional difference at each landmark and time interval when anatomic superimpositions are used in place of implant superimpositions. The central observation about these values is that they are consequential for all landmarks and time points but greatest at condyle and in the vertical direction at gonion. The *rmse* values for condyle at the 7-year interval are 3.83 in X and 2.75 in Y. The corresponding values at gonion are l.52 mm in the vertical direction but only 0.20 mm in the horizontal direction.

Among the three symphyseal landmarks (menton, pogonion, and Point B), the individual case differences are smaller but still too large to bc overlooked. Even at menton, where the scatter around the mean superimpositional difference is smallest *(rmse X* = 1.46, *rmse Y*= 1.32), individual case values range from -1.4 to + 3.2 mm in the X direction and from -l .2 to +3.4 mm in the Y direction. This reinforces the idea that averages do not tell the whole story when patients receive treatment.

Part 3. On the choice of anatomlc superimpositional rule

It seems appropriate to indicate the reason why we chose to use a relatively simple surface-based rule for anatomic superimposition rather than a "structural" one in the manner of Bjørk. Although we consider information from trabecular patterns, the mandibular canal and the third molar bud to be valuable in the clinical evaluation of individual cases, we have chosen to deemphasize those criteria in this study because of problems in standardizing their use between different cases and over long time spans. lt is well known that x-ray images of the mandibular canal, the molar bud, and the patterns of trabeculation vary in distinctiveness in different subjects and even in the same subject at different time points. For this reason, persons doing superimpositions inevitably weigh the relative contributions of the three criteria differently in different cases and even at different time points within the same case. In the present

Fig. 6. Dispersions of individual case anatomic superimpositional values around their respective implant values. Each detail shows the distribution of individual case superimpositional differences for one landmark at the 7-year time interval. The implant values for all cases are stacked at the origin. This figure is like the schematic detail Q of Figure 2 except that the lines between the open anatomic values and the origin have been omitted to reduce the complexity of the figure. In each detail, the distance from each clear diamond to the origin represents the individual case difference for a single subject.

study, we considered it important that our anatomic rule have thc same operational meaning for all cases at all time points. Hence we opted for the simpler but more general rule specified in the *Materials and Methods* section. To the degree that this simple anatomic rule is weaker than other possible ones, the findings of between-rule differences in this article represent a "worst case statcment" of the maximum errors inherent in the use of anatomic rules for mandibular superimposition.

Part 4. General conclusions

In the analysis of the remodeling of structures located on the mandibular surface, anatomic superimpositions yielded small systematically different mean values from superimpositions on metallic implants. Over the 7-year time interval between ages 8.5 and l5.5 years, the anatomic superimposition underestimated the vertical displacement of condyle by an average of 1.90 mm and exaggerated its backward displacement an average of 2.70 mm.

Over the same time interval, mean upward displacement at gonion was underestimated by an average of 1.52 mm. At none of the other landmarks examined did the mean superimpositional differences exceed 1 mm for the 7 year time interval.

The mean between-superimpositiion differences over shorter time intervals such as those associated with active treatment are proportionately smaller. We believe that for this reason mean findings from well-performed past and current grouped data studies over short time intervals can be accepted with relatively high confidence—certainly with greater confidence than that we can reasonably invest in comparable studies of changes in the maxilla.

Superimpositional errors for individual cases are and will continue to be larger than those for groups. The best available estimates of future individual case superimpositional errors when clinicians use anatomic superimpositions in lieu of implants are the *rsme* values of Table IV. At the 7-year time interval, these values exceeded 1 mm in both the X and the Y direction at all five landmarks; at condyle, they reached magnitudes of 3.8 mm in X and 2.7 mm in Y. For thc 2-year time interval, the comparable values were considerably smaller, ranging from around 0.8 mm in the symphyseal region to approximately twice as much at condyle and gonion.

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