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The Displacement of Craniofacial Reference Landmarks During Puberty: A Comparison of Three Superimposition Methods

Z. Mirzen Arat, DDS, PhD;[a] Meliha Rübendüz, DDS, PhD;[b] Ayça Arman Akgül, DDS, PhD[c]

ABSTRACT

In this study, the amount and direction of displacement of reference landmarks located on the cranial base and face were examined and compared according to the superimposition methods of Björk (method A), Steiner (method B), and Ricketts (method C). The material consisted of cephalometric and hand-wrist films of 40 nontreated growing individuals obtained at the beginning (T_1) and at the end of the observation period (T_2). Hand-wrist films were used to evaluate the skeletal maturation of the subjects. The displacement of each landmark was measured according to each superimposition method, and the amounts of displacement in each method were evaluated by paired *t*-test. The repeated measurement analysis of variance test was used to compare the variances of the changes among the methods. Significant changes were observed in landmarks (sella, nasion, basion, pterygomaxillare), which used as references for superimpositions. The direction of displacement of sella and pterygomaxillare points was different among the methods. In the horizontal plane, although most landmarks were displaced in a similar manner in the Björk and Ricketts methods, the vertical displacement of all the landmarks was different. The horizontal displacements of basion, condylion, and gonion were similar according to all three methods. These results indicate that differences regarding the superimposition methods should be taken into consideration in the evaluation of the changes due to growth or treatment.

KEY WORDS: Craniofacial growth, Superimposition methods, Skeletal maturation, Cephalometry.

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INTRODUCTION Return to TOC

The growth and development of the face is an important concern for orthodontists. Without knowledge of normal craniofacial growth, it is impossible to achieve an appropriate treatment plan, treatment approach, or treatment outcome in growing patients.

Changes related to both growth and orthodontic-orthopedic treatments are evaluated by superimposition of serial cephalometric films on the cranial base. The superimpositions on the anatomical structures of the cranial base are highly reliable.[1–6]

However, high-quality films are necessary for this kind of superimposition, and this limits the application of the structural method. Therefore, conventional superimposition methods, such as those suggested by Steiner[7,8] and Ricketts,[9,10] are still being used.[11–14]

Numerous studies concerning the dentofacial changes due to growth and different treatment methods have been published in the literature. Yet, contradictory results have been found using different superimposition methods. Even though the reasons for this conflict are manifold,[3,6,15–18] the main reason is the use of different superimposition methods.

This study was designed to evaluate the effects of various superimposition methods in the interpretation of growth changes in the craniofacial morphology. Thus, the displacement of craniofacial landmarks during the active growth period was compared using the superimposition methods of Björk (method A), Steiner (method B), and Ricketts (method C).

MATERIALS AND METHODS Return to TOC

The material consisted of standardized lateral cephalometric and hand-wrist films of 40 nontreated subjects (28 girls, 12 boys) from a previously collected sample of a longitudinal growth study. All subjects exhibited normal facial profiles with no excessive protrusion or retrusion and normal vertical growth patterns. The occlusions were acceptable with class-I or end-to-end molar relationships, normal overbite and overjet, and with minimal or no crowding.

The observation period was defined on the basis of skeletal maturation, and for this purpose, hand-wrist films were used.[19–21] All the individuals included in this study were in their active growth period. The cephalometric films of the subjects whose developmental stage was between $MP_{3=}$ and S were used as the initial (T_1) and those between MP_{3cap} and RU were evaluated as the final observation records (T_2). The growth that occurred during the observation period was identified according to hand-wrist skeletal maturation criteria. Based on these criteria, the used growth percentage of each individual was calculated using the Atlas of Greulich and Pyle.[22] This used-up growth percentage was called the growth potential. The chronological ages and spent growth potentials of the individuals at the beginning (T_1) and at the end of the observation (T_2) periods are shown in Table 1.

The cephalograms were obtained under standardized conditions (film-focus distance of 155 cm with a midsagittal plane to film [object-film] distance of 12.5 cm). All the cephalometric radiographs were traced by one investigator and then checked for landmark localization by the second. In the event of disagreements, the two landmarks were marked simultaneously on the two films of each subject to obtain maximal agreement. The cephalometric landmarks are shown in Figure 1. Regional superimpositions at the cranial base were performed by hand, using the three methods given below.

- Björk's structural superimposition method (method A)—Cranial and cranial base reference structures were used in the superimposition of the lateral cephalograms. These anatomical reference structures are (1) the contours of the anterior wall of sella tursica, (2) the anterior contours of the median cranial fossa, (3) the intersection of the anterior contour of sella and tuberculum sella, (4) the inner surface of the frontal bone, (5) the contours of the ciribriform plate, (6) the contours of the bilateral frontoethmoidal crests, and (7) the contour of the median border of the cerebral surfaces of the orbital roofs. Changes of the frontoparietal suture, occipital bone, and points articulare and pterygomaxillare were checked to control the superimposition as described by Björk and Skieller[4] (Figure 2a).
- Steiner method (method B)—The most widely accepted and most conventional method of assessing overall dentofacial change involves the superimposition of two serial tracings one over the other on the sella-nasion (S-N) line with registration at sella[7,8] (Figure 2b).
- Ricketts method (method C)—According to Ricketts, the overall changes in facial growth can be observed when superimposing along the basion-nasion (Ba-N) line at the posterosuperior aspect of the pterygomaxillary fissure (PT)[9,10] (Figure 2c).

During the superimposition of the craniofacial structures, the nasion and sella points were transferred from the first film (T_1) to the second film (T_2) to serve as fiducial reference points, and the horizontal (x) and vertical reference planes (y) were constructed using these fixed registration points. The PorDios (Purpose on request Digitizer input-output system, Institute of Orthodontic Computer Science, Arhus, Denmark) cephalometric analysis program was used to measure the projected distances between the landmarks and reference planes (x, y). The differences between the first and the second measurements were recorded as the amount of displacement of the landmarks.

Statistical method

Paired *t*-tests were performed to evaluate the amount of displacement of the landmarks for each superimposition method. The variances of these changes among methods were compared by repeated measurement analysis of variance.

Method error

The ± coordinates of the reference landmarks were recorded using a Houston Hipad Digitizer of 0.125 mm resolution with a double-digitizing process to eliminate the digitizing errors. All procedures of the measurement calculation (landmark identification, superimposition, and digitization) were repeated for all subjects by the same investigator. To assess the reliability of measurements, intraclass correlation coefficients were performed, and the reliability of all parameters was within clinically acceptable limits (0.93–0.99).

RESULTS Return to TOC

The amount and direction of the displacements of the cephalometric landmarks due to growth were evaluated by the three different superimposition methods, and the results are shown in Table 2. Graphic diagrams further illustrate the overall changes (Figure 3a–d).

According to the results, all landmarks, except pterygomaxillare (PT), sella (S), and posterior nasal spine (PNS), were displaced significantly in the same direction in all the superimposition methods. Regarding the Björk method (method A), the horizontal displacement of point sella (S) (−0.52 mm)and the horizontal (1.21 mm) and vertical (0.86 mm) displacements of point nasion (N) were statistically significant, whereas the vertical displacement of point sella (S) was insignificant (Table 2). Basion (Ba), used as a reference in the Ricketts method (method C), showed significant ($P < .001$) displacements both in the horizontal (−1.52 mm) and in the vertical (1.22 mm) directions, whereas pterygomaxillare (PT) showed a significant ($P < .01$) displacement (0.53 mm) only in the vertical direction. A horizontal displacement ($P < .001$) of nasion (N) was observed in the Steiner (1.99 mm) and Ricketts (1.33 mm) methods. Sella (S) showed significant displacements both horizontally (−0.45 mm) and vertically (−0.94 mm) according to the Ricketts method. Basion (Ba) displaced significantly ($P < .001$) in both directions, whereas pterygomaxillare (PT) displaced significantly ($P < .001$) only in the horizontal direction according to the Steiner method.

The displacements of the cephalometric landmarks were compared among the methods, and the results are given in Table 2. In the Björk and Ricketts methods, sella (S) was displaced backward in a similar manner, however, the vertical displacement of this point was different ($P < .001$) (Figure 3b). The horizontal displacement of nasion (N) was similar in the Björk and Ricketts methods. The displacement of this point was different ($P < .001$) between the Björk-Steiner (A × B) and the Steiner-Ricketts (B × C) methods. The downward displacement of nasion (N) was different ($P < .001$) between the Björk-Steiner (A × B) and the Björk-Ricketts (A × C) methods (Figure 3b). Basion (Ba) showed similar amounts of backward displacement in all three methods. The vertical displacement of this point was masked in the Ricketts method, whereas it was statistically similar in the other two methods (Figure 3a). The horizontal displacement of pterygomaxillare (PT) was significant ($P < .001$) only in the Steiner method. Pterygomaxillare (PT) showed no significant displacement according to the Björk method, and any potential movement—if existent—was concealed in the Ricketts method because it was one of the reference points of this method. Therefore, no significant difference was observed between these two methods. The vertical displacement of pterygomaxillare (PT) was different in all three methods (Figure 3b; Table 2). The horizontal displacements of condylion (Cd) and gonion (Go) were similar in all three superimposition methods. On the other hand, the vertical displacement of these points was similar in the Björk and Steiner methods but different between the Steiner-Ricketts (B × C) and Björk-Ricketts (A × C) methods (Figure 3a,c; Table 2).

DISCUSSION Return to TOC

Growth and orthodontic treatment can alter the morphological relationships of the facial structures. Inevitably, there is a strong interaction between them. Guidance of growth and development is one of the fundamentals of orthognathic-functional therapy. It is essential to know the expected amount and direction of growth to distinguish treatment effects from growth changes.

In this study, we aimed to evaluate the growth changes in the craniofacial morphology during puberty comparatively by three commonly used superimposition methods. Skeletal maturation criteria have been used to guarantee a study period of intense growth. During the observation period, a significant amount of growth potential was used up (7.59 ± 0.36%) (Table 1). The growth spurts of the sexes occur at different ages. On using skeletal criteria instead of chronological ages, the confusion arising from this fact has been prevented.

Spatial changes of the face are usually examined by superimposition of serial cephalometric films. The superimposition methods vary according to the reference structures used, and the findings of this study also confirm this variation. According to the structural method of Björk, sella displaced downward and backward and nasion moved in a forward and downward direction (Table 2). The downward displacement of nasion (0.86 mm) was greater than that of sella (0.20 mm). Consequently, in the Steiner superimposition method, all the cephalometric landmarks were displaced forward and upward more than they would in the Björk method.

On the other hand, when the reference landmarks of Ricketts (N, Ba, and PT) are evaluated on the basis of the structural method, the downward displacement of basion (1.22 mm) is more than that of nasion (0.86 mm) (Table 2). Moreover, a vertical displacement of 0.53 mm is observed in pterygomaxillare. In such a condition, superimpositions performed according to the Ricketts method would necessarily conceal the changes in the vertical direction. This situation creates a great contradiction, particularly in the interpretation of responses to orthognathic treatment.[23,24]

The horizontal displacement of most of the landmarks was in similar directions and by similar amounts according to the Björk and Ricketts methods (Table 2). In the vertical direction, all points except sella and pterygomaxillare were displaced in the same direction but by different amounts (Figure 3b). Nielsen[25] also found a similarity for the horizontal displacements of these landmarks. However, the similarity of the behavior of a landmark in a single direction may not be sufficient to state that the results of these methods are similar.

There is a common agreement that points nasion, sella, and basion are not stable.[1–3,17,26–29] This has discouraged the superimpositions on S-N and Ba-N planes.[30–32] The results of the present study also indicate that there are significant displacements of these points both in the horizontal and in the vertical direction due to growth (Figure 3a,b; Table 2). This finding supports the view that the sphenooccipital synchondrosis (SOS) activity continues until late ages.[29,33–37] Coben[37] stated that the SOS activity affects the stability of the anterior cranial base but also claimed that the Ba-Ar relationship remained stable in the posterior cranial base. However, the posterior cranial base elongates in a downward and backward direction.[2,26,33,35,38]

The medial area of the cranial base completes its growth early and, therefore, is essentially more stable than the lateral area.[1,2,5,29] In a recent study, Arat et al[29] stated that the middle cranial base (tuberculum sella-wings) remained stable all through the pubertal growth spurt. These authors also noted that the posterior cranial base (tuberculum sella-basion) demonstrated a significant increase even in the postpubertal stage and that this increase was related to the skeletal growth potential in the peak stage.

Growth spurts within the craniofacial area are often asynchronous. The same asynchrony can be observed even in the cranial base.[1] The cranial base and its components (occipital, sphenoid, ethmoid, and frontal bones) represent a development model consistent with some vital functional demands. The middle cranial base is composed of cartilage and provides protection for vital organs like the midbrain, pituitary glands, and the carotid artery.[9] The anterior and posterior cranial bases demonstrate a skeletal growth rate, whereas the middle cranial base displays a neural growth rate. This may be the reason for the stability of the middle cranial base.

All the results of this study imply that these three superimposition methods yield different interpretations in the evaluation of the craniofacial changes. It is obvious that as long as the reference structure and method of superimposition is not standardized chaos will continue. The American Association of Orthodontics suggested the use of the Steiner method for superimposition, but the liability of sella point and especially nasion has made the validity of this method ambiguous.[39–42] We believe that the middle cranial base (T-W) is more reliable in cephalometric superimpositions than the anterior and posterior borders of the cranial base (points Ba and N). Nevertheless, determining the most reliable superimposition method was not the objective of this study.

There are handicaps of the cephalometric method other than superimposition. The determination, identification, and digitization[3,6,15,43] of the landmarks are drawbacks in the validity of the method. Repeatability or reliability of landmarks and superimpositions is another important matter and was pointed out in the literature.[16–18]

The cephalometric method relies on mathematical criteria. However, the displacements of the landmarks that these measurements rely on are bound by biological rules. Thus, one should always be careful in the interpretation of the findings.

CONCLUSIONS Return to TOC

- All the cephalometric landmarks were displaced by significant amounts during the observation period.
- Sella, nasion, basion, and pterygomaxillare points, which are used as reference landmarks in the superimpositions of Steiner and Ricketts, showed significant amounts of displacement in both directions. This result makes the stability of the main reference points unreliable during puberty.
- The horizontal displacements of most of the cephalometric landmarks are similar in the methods of Björk and Ricketts. This similarity is present in all three methods for the points condylion, basion, and gonion in the horizontal direction.
- In the Steiner method, a more forward and upward rotation of the facial structures should be expected when compared with the structural method of Björk. As for the Ricketts method, there is a probability that the changes in the vertical direction could be concealed.

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TABLE 1. Chronological, Skeletal Ages (years), and Spent Growth Potentials (%) at T_1 and T_2 [a]

N = 40	X ± Sx (T_1)	X ± Sx (T_2)	D ± Sd ($T_2 - T_1$)
Chronological age	11.99 ± 0.18	14.02 ± 0.19	2.03 ± 0.10
Growth potential (%)	89.30 ± 0.43	96.89 ± 0.28	7.59 ± 0.36

[a] X indicates mean; Sx, standard error of mean; D, mean of differences; Sd, standard error of mean differences.

TABLE 2. The Displacement Amounts of Reference Landmarks and their Significance According to Each Method (*t*-test) and the Comparison of Landmark Displacement Among Methods of Björk (A), Steiner (B), and Ricketts (C) by *RMAV*-test

Landmarks	Method A[a] D^{Mest}	±Sd	Method B D^{Mest}	±Sd	Method C D^{Mest}	±Sd	*RMAV*-test A × B	B × C	A × C
Horizontal Displacement (mm)									
N	1, 21***	0.13	1, 99***	0.18	1, 33***	0.17	***	***	NS
Or	0, 57**	0.21	1, 42***	0.66	0, 44*	0.18	***	***	NS
PT	−0, 10	0.12	0, 66***	0.14	0	0	***	***	NS
S	−0, 52***	0.10	0	0	−0, 45**	0.14	***	***	NS
Cd	−1, 17***	0.26	−0, 33	0.28	−1, 71***	0.46	NS	NS	NS
Ba	−1, 52***	0.16	−0, 66***	0.15	−1, 66***	0.19	NS	NS	NS
Go	−2, 82***	0.40	−1, 32***	0.37	−3, 94***	0.35	NS	NS	NS
PNS	−0, 64*	0.16	0, 46*	0.21	1, 02***	0.18	**	NS	**
ANS	0, 64*	0.28	1, 88***	0.18	0, 25	0.21	***	***	NS
A	0, 84**	0.26	2, 16***	0.23	0, 48*	0.20	***	***	***
B	1, 08**	0.35	2, 87***	0.30	0, 52	0.29	***	***	NS
Pg	1, 55**	0.46	3, 53***	0.36	0, 41	0.38	***	***	**
Vertical Displacement (mm)									
N	0, 86**	0.21	0	0	0	0	***	NS	***
Or	1, 39***	0.19	0, 76***	0.21	0, 41	0.24	***	*	***
PT	0, 53**	0.13	0, 19	0.13	−0, 48**	0.14	*	***	***
S	0, 20	0.11	0	0	−0, 94***	0.12	***	***	***
Cd	1, 51***	0.29	1, 53***	0.34	0, 27	0.31	NS	***	***
Ba	1, 22***	0.14	1, 43***	0.18	0	0	NS	***	***
Go	5, 84***	0.36	5, 99***	0.41	4, 08***	0.39	NS	***	***
PNS	2, 60***	0.16	2, 34***	0.18	1, 41***	0.18	*	***	***
ANS	2, 99***	0.26	2, 20***	0.22	1, 97***	0.21	***	NS	***
A	3, 02***	0.31	2, 29***	0.30	2, 10***	0.30	***	NS	***
B	4, 48***	0.43	3, 80***	0.43	3, 64***	0.40	***	NS	***
Pg	4, 56***	0.43	5, 89***	0.45	5, 81***	0.39	**	NS	***

[a] D indicates mean of differences; Sd, standard error of mean differences; NS, nonsignificant.
* $P < .05$, ** $P < .01$, *** $P < .001$.

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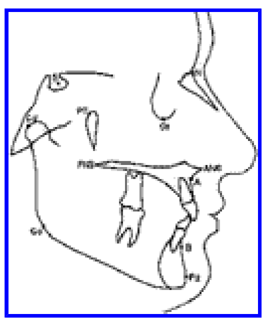
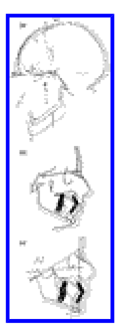


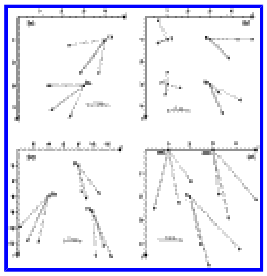
Click on thumbnail for full-sized image.

FIGURE 1. Reference landmarks used in this study



Click on thumbnail for full-sized image.

FIGURE 2. (a) Superimposition according to structural method,[4] (b) superimposition on S-N line,[7] (c) superimposition along the Ba-N line.[10]



Click on thumbnail for full-sized image.

FIGURE 3. The displacements of reference landmarks according to all superimposition methods. Björk method (method A), —— ——; —— Steiner method (method B), and – – – ; Ricketts method (method C), … … …

[a]Department of Orthodontics, School of Dentistry, Ankara University, Ankara, Turkey

[b]Department of Orthodontics, School of Dentistry, Ankara University, Ankara, Turkey

[c]Department of Orthodontics, School of Dentistry, Başkent University, Ankara, Turkey

Corresponding author: Professor Mirzen Arat, DDS, PhD, Ankara Üniversitesi Diş Hekimliği Fakültesi, Ortodonti Anabilim Dali, 06500 Be Şevler, Ankara, Turkey (E-mail: mirzenarat@hotmail.com)