Evaluation of differential growth and orthodontic treatment outcome by regional cephalometric superpositions

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Abstract: Cephalometric superimposition on cranial base is the accepted method for evaluating mandibular displacement during orthodontic treatment and/or growth. However, assessing mandibular position relative to the maxillary base may yield different information. The aim of this study was to evaluate the effects of regional superpositions (cranial versus maxillary) on interpreting mandibular displacement. Both methods were applied to pre- and posttreatment cephalograms of 22 growing children (12 female, 10 male) treated for Class II Division 1 malocclusion. Differences in linear and angular measurements of three mandibular landmarks (pogonion, gnathion, menton) between cranial and maxillary superpositions were statistically significant (p=0.0001). Vertical displacement of these landmarks contributed significantly to the differences (p=0.0001). The contribution of horizontal displacement was not statistically significant. The results support the proposition that, in growing children, posttreatment displacement of mandibular skeletal and dental components should be assessed by both maxillary and cranial base superimpositions. The maxilla is subject to rotational and translational changes during growth that may affect the position of the mandible relative to the maxilla in a way inconsistent with the mandibular displacement perceived upon cranial superposition. Since occlusion is directly associated with the positions of the maxillary and mandibular basal bones, the positions of these bones relative to each other is critical in assessing occlusal changes in individual patients.

Key Words: Cephalometrics, Superposition, Orthodontic treatment, Facial growth

Growth and mechanotherapy contribute to the outcome of orthodontic treatment to different degrees. Differentiating dentofacial changes caused by orthodontic treatment from those induced by growth in a growing patient is nearly impossible using the available technology. Cephalometric superpositions* demonstrate the combined effects of growth and mechanotherapy. Any inference of the probable contribution of one or the other is speculation, although logical conclusions may be formed on the basis of general knowledge of the potential of growth and orthodontic treatment under certain conditions or circumstances.

*Although the terms *superposition* and *superimposition* can be used interchangeably, they have slightly different meanings. In this article, superimposition refers to the general act of superposing figures, while superposition refers to the outcome of the method. Regional superposition assumes that the anatomic structures are made to coincide.

Regional cephalometric superimpositions are performed in order to evaluate three basic components of skeletal and dentoalveolar development: maxillary, mandibular, and overall facial changes.[1-5] To this end, methods of superimposition use relatively stable structures in the cranial base, maxilla, and mandible to evaluate spatial changes over time. The universal regimen of posttreatment evaluation includes the following:

1. Superimposition on cranial base, following one of several accepted methods,[6] yields information about the movement of facial bones away from the cranial structures. Superposition on the best fit of the anterior cranial base uses readily identifiable anatomic structures, unlike other methods that simplify this anatomy into lines (SN, basion-nasion[7]). The reproducibility of specific landmarks connecting these lines, particularly nasion and basion, is affected by the identification error and the influence of growth.[6]

2. Superposition on maxillary structures can be used to evaluate changes in the maxillary dentoalveolar com-

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plex during orthodontic treatment and growth. Björk and Skieller demonstrated the stability of anatomic contours, which favors structural superposition over superimpositions based on the ANS-PNS line.[2,4,5]

3. Mandibular superimposition on relatively stable anatomic structures can be used to evaluate dentoalveolar changes.[3-5]

This recognized regimen does not completely define the movement of the mandible relative to the maxilla. Displacement of mandibular skeletal and dental components in relation to the maxillary base is critical because the resulting information may differ from the conclusions formulated from the cranial superposition.[5] Moorrees and associates[4] have shown the importance of evaluating mandibular changes on maxillary superposition in the analysis of facial growth. Ghafari and Efstratiadis[5] demonstrated the clinical significance of this method by assessing orthodontic treatment results in four patients. Johnston[8] accounted for the differential contribution of the anterior relationship between maxilla and mandible in a pitchfork diagram that illustrates sagittal changes in the buccal occlusion at the level of the functional occlusal plane. The pitchfork analysis attempts to characterize the interaction between growth and treatment at the level of clinical interest, namely the occlusion.

The aim of this study was to evaluate the effects of regional superpositions (cranial versus maxillary) on interpreting mandibular displacement in a group of patients treated for Class II malocclusion. The validity of differentiating outcomes based on both superpositions will thus be examined.

Material and methods

Pre- and posttreatment cephalographs of 22 growing patients (12 female, 10 male) who had been treated for Class II Division 1 malocclusion were randomly collected from the records of the postdoctoral orthodontic clinics at the Columbia University School of Dental and Oral Surgery and the Harvard University / Forsyth Dental Center. The pretreatment ages of the patients ranged from 7.4 to 15.9 years (mean 11.8). All cephalometric tracings were superimposed on anterior cranial base and on the maxilla using the best fit of a maximum number of anatomic structures, as described by Moorrees et al.[4] For each superposition, the pretreatment and posttreatment location of the anatomical landmarks pogonion (Pog), gnathion (Gn), and menton (Me) were evaluated in reference to a coordinate system oriented on the extracranial vertical and registered at the pretreatment location of each landmark. The extracranial vertical registers the patient's so-called natural or upright head position, which denotes a standardized and repro-

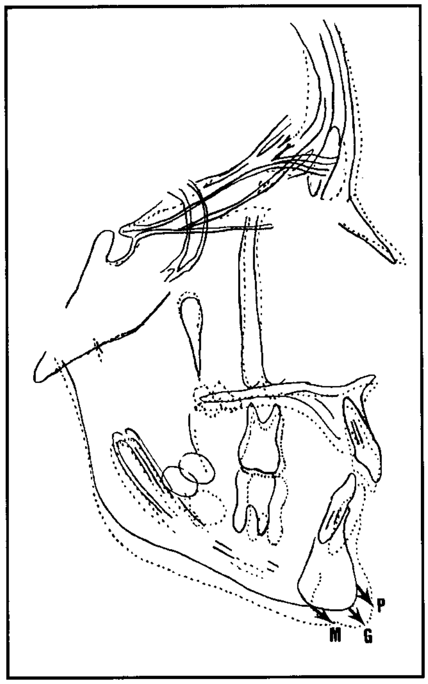

Figure 1
Superimposition of pre- and posttreatment cephalometric tracings on "best anatomic fit" of anterior cranial base. P=pogonion, G=gnathion, M=menton. Note: Treatment of this patient's malocclusion involved the use of an activator, followed by headgear and a lip bumper, prior to fixed appliances.

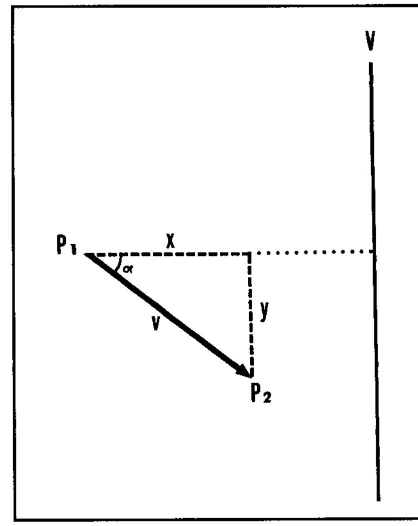

Figure 2
Pretreatment (P1) and posttreatment (P2) positions of pogonion are evaluated in a coordinate system oriented on the vertical V. v is the displacement vector, α is the angle between the vector and the horizontal coordinate, x and y are the horizontal and vertical components of the vector, representing the horizontal and vertical movements of pogonion.

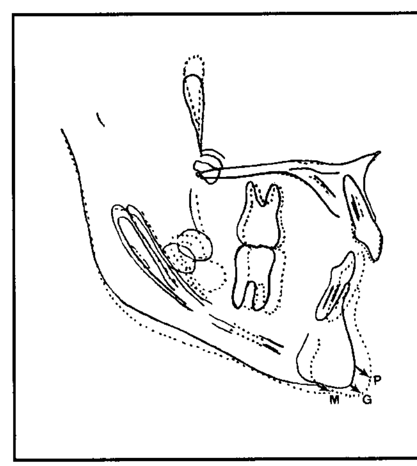

Figure 3
Pre- and posttreatment cephalometric tracings of patient in Figure 1, superposed on maxillary base. Following are the differences in rotation (α) of the displacement vector upon cranial and maxillary superpositions for the three landmarks:

	Cranial base	Maxillary base	Difference
Pogonion	32°	11°	21°
Gnathion	32°	17°	15°
Menton	43°	22°	21°

ducible head posture achieved when the subject is at ease,.sitting or standing upright, and looking straight ahead to a point at eye level.[9] Linear and angular measurements of each landmark's displacement were calculated to evaluate the magnitude and direction of mandibular movement using the following method:[5]

Step 1. On the initial pretreatment cephalometric tracing, a vertical axis "V", parallel to the extracranial vertical, is drawn through nasion.

Step 2. Pre- and posttreatment tracings are superposed on anterior cranial base using the best fit of a maximum number of anatomic structures—namely, the anterior surface of the sella turcica outline, the anterior clinoid processes, the outline of the planum sphenoidale, the lesser wings of the sphenoid, the superior outline of the ethmoid and the contour of the cribriform plate when clearly imaged, the opaque outlines of cortical ridges on the medial and superior surfaces of the orbital roofs, and the cortical layers of the frontal bones (Figure 1).[2,4,5] The individual pattern of trabeculations within the anterior cranial base area facilitates superposition.

The pre- and posttreatment locations of pogonion, gnathion, and menton defined the displacement vector and the angle (α) between this vector and the horizontal coordinate (Figure 2).

Step 3. Pre- and posttreatment tracings are superposed on the maxilla. The maxillary bones are superposed to best fit on the nasal floor, the apex of the palatal vault, and the trabecular area between these structures and the subnasal cortical plate. Trajectories of landmarks Pog, Gn, and Me are drawn, and measurements are performed as described in step 2 (Figure 3) in a coordinate system oriented on the same vertical "V" drawn through nasion on the pretreatment tracing.

Step 4. Values obtained from steps 2 and 3 are compared. Differences in length between displacement vectors are assessed, as are differences between the vector angles, which depict the direction of displacement. The amount of displacement of a landmark is evaluated through its horizontal (x) and vertical (y) components (Figure 2).

Differences between linear and angular measurements were analyzed using paired *t*-tests. Since the differences between vector angles could be positive or negative, depicting forward or backward rotation, a paired *t*-test was conducted on the absolute numbers.

Table 1
Mean displacement vectors (mm) between pre- and posttreatment positions of selected mandibular landmarks

Vector	Superimposition Cranial base		Maxillary base		Difference		p
Pogonion	8.75	(3.37)	6.23	(2.52)	2.52	(1.89)	0.0001
Gnathion	8.93	(3.61)	6.39	(2.50)	2.55	(2.22)	0.0001
Menton	9.27	(3.61)	6.55	(2.60)	2.73	(2.00)	0.0001

n=22,( )=standard deviations

Table 2
Mean horizontal (x) and vertical (y) components of displacement vectors (mm) between pre- and posttreatment positions of selected mandibular landmarks

	Vector	Superimposition Cranial base		Maxillary base		Difference		p
Pogonion	x	1.27	(3.11)	1.27	(3.07)	0.00	(2.75)	NS
	y	7.95	(3.60)	5.00	(3.11)	2.95	(2.09)	0.0001
Gnathion	x	1.50	(3.42)	1.52	(3.25)	-0.02	(2.76)	NS
	y	8.02	(3.54)	5.36	(2.61)	2.66	(2.11)	0.0001
Menton	x	1.18	(3.47)	1.30	(2.93)	-0.11	(2.91)	NS
	y	8.39	(3.70)	5.43	(2.69)	2.95	(2.01)	0.0001

n=22, ( )=standard deviations

Results

Differences between the displacement vectors of pogonion, gnathion, and menton as evaluated using cranial versus maxillary superposition were statistically significant (p=0.0001; Table 1). The vertical displacement of these landmarks contributed significantly to the differences (p=0.0001). Differences in the horizontal displacement were not statistically significant (Table 2). Differences between the vector angles for all three mandibular landmarks upon cranial and maxillary superpositions were statistically significant (p=0.0001) only when the absolute angular numbers were compared (Table 3). When forward (positive) and backward (negative) movements of the vector were accounted for, these differences were not statistically significant. In the majority of patients (>50%), the difference between the vector angles was greater than 10° (Table 4).

Discussion

The results demonstrate that in growing children, posttreatment displacement of mandibular skeletal and dental components may look different, depending on whether they are assessed using maxillary or cranial base superpositions. The implication of this finding is important for interpreting the role of mechanotherapy and/or growth in treating

Table 3
Mean vector angles (degrees) between pre- and posttreatment positions of selected mandibular landmarks

Vector	Superimposition Cranial base		Maxillary base		Difference		p	Absolute difference*		p
Pogonion	80.05	(26.51)	74.32	(33.87)	5.73	(26.18)	NS	18.73	(18.77)	0.0001
Gnathion	80.05	(26.78)	74.41	(30.83)	5.64	(23.10)	NS	17.45	(15.74)	0.0001
Menton	82.91	(24.76)	76.95	(28.96)	5.95	(24.71)	NS	18.68	(16.79)	0.0001

n=22, ( )=standard deviations
* Absolute difference disregards the direction of the difference as forward (positive) or backward (negative).

individual patients. Ghafari and Efstratiadis,[5] using superimposition on cranial base, demonstrated that changes in mandibular rotation may be attributed to treatment mechanics, while the maxillary superposition revealed a major effect of growth in obtaining successful results. They also demonstrated the opposite condition. The tracings in Figures 4 and 5 show how cranial and maxillary superpositions can lead to different conclusions. Figures 1 and 3 show the opposite, that essentially similar conclusions on mandibular displacement can be drawn from both superpositions.

Table 4
Distribution of differences in vector angles (degrees) between cranial and maxillary superimpositions

Vector	< 10°		> 10°*		> 20°	
	n	%	n	%	n	%
Pogonion	10	46	12	55	9	41
Gnathion	9	41	13	59	8	36
Menton	9	41	13	59	8	36

n=22, *includes α>20°

The results of this study suggest that the vertical component of mandibular displacement contributes more than the horizontal component to differences between cranial and maxillary superimpositions. This finding, along with the significant differences in the vector angles, may be related to characteristics of the sample and treated malocclusions. However, in general terms, the findings support the premise that the maxilla is subject to rotational and translational changes during growth.[2,4,5] These changes, particularly maxillary rotation relative to cranial base, in turn may affect the position of the mandible relative to the maxilla in a way inconsistent with the mandibular displacement perceived upon cranial superposition. The maxilla descends away from the cranial base by sutural growth and, to a lesser extent, by modeling resorption of the nasal floor.[2] Several studies[10,11] revealed large individual variations in displacement of the maxilla. The clinical significance of the reported method becomes more critical in view of such variations.

Since occlusion of the teeth is associated directly with the positions of the maxillary and mandibular basal bones, the displacement of these bones relative to each other is critical in assessing occlusal changes in individual patients and must be incorporated in the routine cephalometric superposition protocol. Johnston[8] recognized the practical significance of evaluating growth of the mandible relative to the maxilla, and used maxillary superposition to assess movement of the maxillary molars relative to maxillary basal bone, growth of the mandible relative to the maxilla, and displacement of the maxilla relative to cranial base. This superimposition was one of the steps followed to analyze changes at the occlusal "interface," where all maxillary and mandibular changes are integrated. The other steps include evaluation at the occlusal plane of mandibular molar movement relative to basal bone upon mandibular regional superimposition, and the total molar "correction" relating mandibular to maxillary molar displacement after dental superimposition on the maxillary molars.

Johnston used this scheme to compare occlusal development from flush terminal plane to neutroclusion in 24 children and to distoclusion in 10 children.[8] He demonstrated that mandibular growth relative to the maxilla contributed significantly to differences between groups. He observed similar findings when comparing untreated Class I with untreated Class II occlusions. The basic premise of Johnston's pitchfork analysis is in agreement with the earlier work of Moorrees et al.[4] and the present findings. Whereas the pitchfork analysis used occlusal plane as a registration reference when measuring changes between the jaws, the authors suggest using a coordinate system that differentiates the horizontal and vertical components of each landmark's displacement. Registration on the occlusal plane may underestimate the contribution of the vertical vector of displacement of

Figure 4
Cephalometric tracings of patient treated for Class II Division 1 malocclusion (edgewise mechanics, nonextraction) illustrate difference of interpretation of mandibular displacement between cranial and maxillary superposition. Treatment included the use of a cervical headgear and anterior biteplate. A: Superimposition of pre- and posttreatment tracings on anterior cranial base demonstrates a predominantly downward movement of the mandible, suggesting that correction of the distoclusion was mainly through orthodontic movement. B: Superimposition on maxillary base shows that horizontal, rather than vertical, displacement of the symphyseal landmarks is more evident, indicating that forward mandibular growth contributed significantly to correction of the distoclusion. Following are the differences in rotation (α) of the displacement vector upon cranial and maxillary superpositions for the three landmarks:

	Cranial base	Maxillary base	Difference
Pogonion	74°	11°	63°
Gnathion	68°	18°	50°
Menton	76°	19°	57°

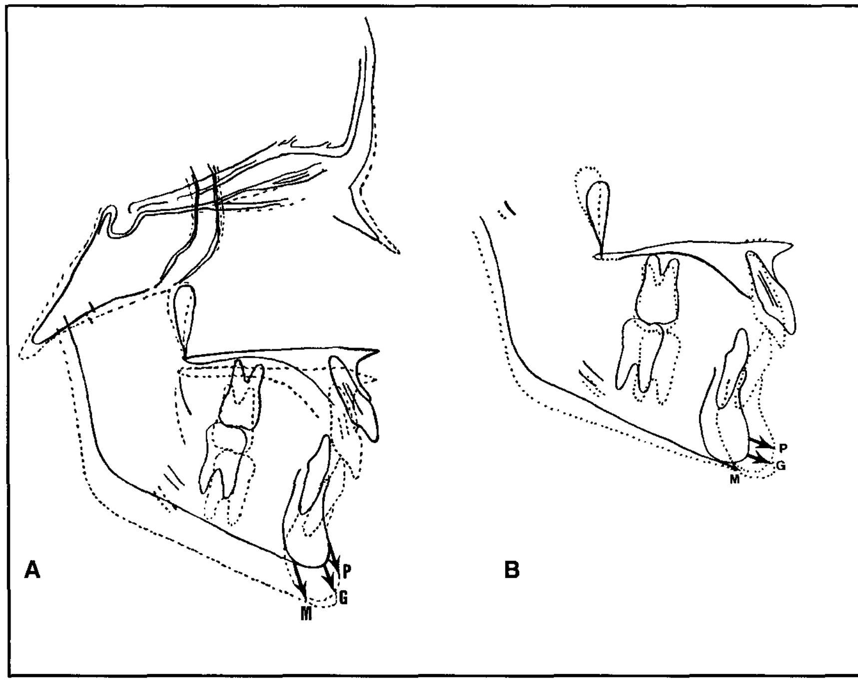

Figure 4

Figure 5
Records of patient treated for Class II Division 1 malocclusion illustrate difference in interpretation of mandibular displacement between cranial and maxillary superposition. Treatment was limited to the maxillary arch and involved the use of headgear. A: Upon superposition on anterior cranial base, differences in directional change (vector angle) disclose a predominantly backward movement of the mandible, suggesting that mechanotherapy was responsible for correction of the malocclusion. B: Maxillary superposition reveals that horizontal movement of the mandible occurred, which contributed, in a minimal to moderate amount, to the correction of the sagittal discrepancy.
Following are the differences in rotation (α) of the displacement vector upon cranial and maxillary superpositions for the three landmarks:

	Cranial base	Maxillary base	Difference
Pogonion	-77°	75°	28°
Gnathion	-80°	75°	25°
Menton	-74°	80°	26°

Negative signs refer to the displacement vector being in the lower left quadrant of the coordinate system. The difference is computed by calculating the deviation in the respective quadrant from 90° (for pogonion: [90°-77°] + [90°-75°] = 13°+15° = 28°)

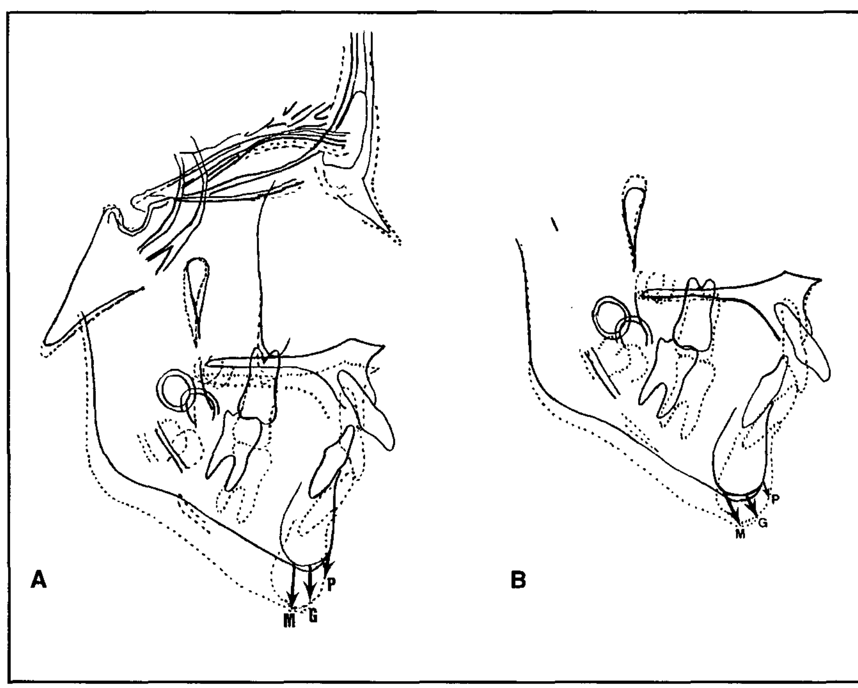

Figure 5

bony landmarks and teeth, notwithstanding the error inherent in defining the functional occlusal or averaging occlusal planes, particularly when comparing pre- and posttreatment records with significant alteration of the occlusal plane. The error inherent in establishing a coordinate system as described in this paper is subject to less variation within each individual series of cephalometric records.

By adding maxillary superposition to the cephalometric evaluation, growth changes occurring at the level of the ramal and condylar areas are emphasized, and those occurring superior to the maxillary plane are somewhat isolated, rendering the interpretation of treatment effects easier to dissociate from general facial growth events. Although the precise contributions of growth and treatment mechanics cannot be determined, our ability to do so may be improved when bony implants are used.

The following regimen is recommended for superposition of serial cephalographs:

1. Superimpose on cranial base (by best anatomic fit or other recognized method) to evaluate maxillary and mandibular displacement;

2. Superimpose on maxillary structures to evaluate changes in the maxillary dentoalveolar complex and mandibular displacement;

3. Superimpose on relatively stable mandibular anatomic structures to evaluate dentoalveolar changes in the mandible.

The displacement of nasion was not evaluated because the focus of the study was the contribution of mandibular displacement to occlusal changes. However, in order to properly assess facial changes, particularly as they contribute to the profile, maxillary and mandibular displacements must be related to the position of nasion.

Conclusions

The results of this study demonstrated that both linear and angular measurements relating the displacement of all three mandibular landmarks (Pog, Gn, Me) were statistically significantly different between the two regional superpositions. These results demonstrate that in growing patients, the posttreatment displacement of mandibular skeletal and dental components should be assessed by superposition on the maxilla and on cranial base. The basic rationale for incorporating this method in the cephalometric superposition regimen are the facts that (1) the maxilla is subject to rotational as well as translational changes that are generally beyond the control of the orthodontist and may obscure the actual displacement of the mandible,[12] and (2) the occlusion of the teeth is associated directly with the positions of the maxillary and mandibular basal bones.

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