Childhood and adolescent changes of skeletal relationships

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If we had a better understanding of developing skeletal relationships, it would be possible to make more informed decisions about the timing and type of orthopedic and orthodontic interventions. Reference data for mandibular and maxillary growth, which are essential for making diagnoses based on expected etiologies and planning effective preventative strategies, allow orthodontists to better communicate relevant information and take a more knowledgeable and scientific approach to patient care.[1]

While good epidemiological data are not available, there is indirect evidence for a high prevalence of skeletal dysmorphology. The US Public Health Service[2,3] reported that the incidence of Class II Division 1 dental malocclusion decreases from 35% for children 6 to 11 years to 32% for adolescents 12 to 17 years of age. Approximately 75% of individuals with Class II Division 1 dental malocclusion also have corresponding skeletal malocclusion.[4,5] Based on an estimate of 47,000,000 children in the United States between 5 and 17 years old,[6] 32% of whom have dental malocclusions (NCHS), over 11 million children with Class II skeletal malocclusions might be expected. Reference data for untreated subjects de-

Abstract

This paper describes the development of anteroposterior (AP) and vertical (VER) skeletal relationships. A mixed-longitudinal sample of 49 females and 50 males was followed during childhood and adolescence. Childhood growth changes were assessed from 6 to 10 years for females and 8 to 12 years for males. Adolescent changes were evaluated from 9 to 13 years for females and 11 to15 years for males. Anteroposterior relationships were described by the horizontal distance between ANS and Pg. Vertical relationships were described by the vertical distance between Pg and Go. Subsamples were defined based on overall changes (AP and VER) that were either greater than or less than average. The results showed that AP and VER relationships were not stable during growth. AP relationships changed over time due to differential growth movements of the mandible (as opposed to the maxilla). There was greater potential for horizontal discrepancies to decrease during childhood than during adolescense. The potential for AP discrepancies to increase was greater during adolescence. The VER relationships increased in the majority of subjects. The subsample whose vertical discrepancies increased most showed less inferior movement of gonion and more inferior movement of pogonion. Inferior movements of Pg and Go were greater during adolescence than childhood.

With a commentary by Robert J. Isaacson

Key Words

Cephalometrics • Growth • Skeletal relations • Reference data

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Table 1
Definition of landmarks and reference lines used in the analysis

Landmark	Definition
Sella (S)	Center of the pituitary fossa of the sphenoid bone
Nasion (N)	Junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose
Anterior nasal spine (ANS)	Tip of the median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening
Gonion (Go)	Midpoint of the angle of the mandible, found by bisecting the angle formed by the mandibular plane and the mandibular ramus
Pogonion (Pg)	Most anterior point on the contour of the bony chin, determined by a tangent through nasion
Posterior cranial base (PCB)	Fiducial posterior point on the cranial base transferred from the first tracing to subsequent tracings following superimposition
Anterior cranial base (ACB)	Fiducial anterior point on the cranial base transferred from the first tracing to subsequent tracings following superimposition.
Reference line (RL)	The reference plane S-N minus 7°, registered on sella

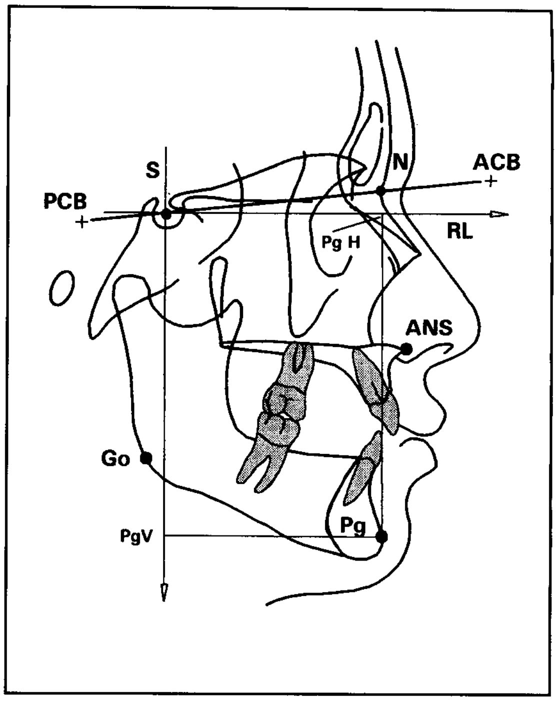

Figure 1

Figure 1
Cephalometric landmarks and references axes. Registering on sella, horizontal and vertical relationships are evaluated parallel with and perpendicular to RL (S-N minus 7 degrees).

veloping both normal and abnormal relationships are needed to identify these children.

Methodological improvements are necessary to understand the development of skeletal relationships. First, relationships should be described as a continuous range of phenotypes with known probabilities of incidence, so that dysmorphology can be based on the sampling distributions rather than arbitrary categories, as suggested for dental malocclusions.[7] Second, true skeletal base, rather than dental landmarks, should be used; dental landmarks are sensitive to incisor position,[8] which changes with dental malocclusion. Third, horizontal and vertical components of skeletal relationships must be evaluated simultaneously and described.[9,10] Fourth, skeletal relationships must be broken down into component parts. Comparisons based on more complex relationships (e.g., ANB angle, Wits appraisal, etc.) are inconsistent and less sensitive.[11] Fifth, variance estimates for developing skeletal discrepancies must include subjects with normal occlusion and malocclusion. Finally, and perhaps most importantly, longitudinal samples of adequate size are required to discern long-term developmental tendencies.[12,13] Studies fulfilling these requirements are limited; the lack of longitudinal data is particularly important.

Based on the foregoing methodological considerations, this study describes the childhood and adolescent development of anteroposterior and vertical skeletal relationships. Our goal was to evaluate the stability of skeletal relationships and their component parts. Specifically, we will address the following questions:

1. Do the changes in skeletal relationships differ with age?
2. Are developmental changes of AP relationships determined either by maxillary or mandibular growth?
3. Are anterior or posterior growth changes more closely associated with the development of vertical relationships?

Materials and methods

The data pertain to untreated French-Canadian children, drawn from three school districts in Montreal and its suburbs, representing the socioeconomic stratification of the larger population.[14] This nonorthodontic sample encompassed the entire range of phenotypic variation. A sample of 49 females and 50 males, with longitudinal cephalograms taken annually between 6 and 15 years of age, was selected based on available cephalograms. There were approximately equal numbers of subjects with Class I and Class II dental malocclusion. Four observations (T1 to T4) were evaluated for each subject to describe childhood and adolescent changes. Based on estimated ages for the onset and maximum (peak) adolescent facial growth velocities,[15] a 4-year adolescent period of observation was defined 3 years prior to and 1 year after peak velocity (i.e., T3 and T4 records were taken at 9 and 13 years, respectively, for females and at 11 and 15 years for males). Using a 1-year overlap between periods, the 4-year childhood period (T1-T2) was defined from 6 to 10 years for females and from 8 to 12 years for males.

The cephalograms were traced, digitized, and superimposed by one person. Five landmarks were identified on each tracing (Table 1, Figure 1). The maxillary skeletal base was defined by ANS; the mandibular base was defined by Go and Pg. These landmarks were chosen because (1) they are commonly used to describe maxillary and mandibular growth, (2) unlike A-point and B-point, they are less influenced by tooth movements, and (3) they can be reliably located. Sella (S) and nasion (N) were also identified. Reliability of the five landmarks ranged between 95% and 98%. Each subject's serial tracings were superimposed on natural structures in the anterior cranial base and cranium, as described by Björk and Skieller;[16] anterior (ACB) and posterior (PCB) cranial base fiducial landmarks were transferred to the subsequent tracing. Reliability for the cranial base superimposition was greater than 98%.[17]

Rectangular coordinates were used to describe the horizontal and vertical positions of the four maxillary and mandibular landmarks. All measurements were adjusted for magnification. Changes were evaluated relative to the original sella, located on the transferred natural structure reference line (RL), constructed from S-N minus 7 degrees (Figure 1). For example, the horizontal distance of pogonion to sella was measured parallel with RL (Pg H) and the vertical distance of pogonion to sella was measured perpendicular to RL (Pg V).

To better evaluate the development of skeletal relationships, two subsamples were defined based on the overall (T1 to T4) changes of the subjects' anteroposterior and vertical skeletal relationships that were greater or less than average. Anteroposterior (AP) relationships were defined by changes in the horizontal distance between ANS and Pg. Since the average AP change for both males and females was less than 0.6 mm, the two subsamples essentially compared subjects whose AP relationships increased (AP+) with those that decreased (AP-). Changes of vertical (VER) relationships were defined by changes in the vertical distance between Pg and Go. Subsamples with lesser and greater than average (approximately 6 mm) overall changes in vertical relationships were classified as VER+ and VER++, respectively.

Table 2
Changes (mm) of anteroposterior relationships and horizontal positions of Pg and ANS

Variables	N	Childhood Mean	SD	Adolescence Mean	SD	prob
Females						
AP (ANS-Pg)	42	-0.21	2.16	0.86	2.22	0.011
Pg	43	2.98	2.35	2.16	2.52	0.058
ANS	42	2.72	1.50	2.95	1.42	0.408
Males						
AP (ANS-Pg)	49	-0.33	2.28	0.91	2.38	0.006
Pg	50	3.21	2.43	2.42	3.07	0.083
ANS	49	2.89	1.58	3.39	2.22	0.167

Results

Children and adolescents showed significantly different patterns of AP development (Table 2). While AP relationships improved slightly during childhood, they worsened during adolescence. Movements of pogonion showed more individual variation than ANS. Movements of ANS during adolescence and childhood were not statistically different. Anterior movements of pogonion were approximately 0.8 mm less during adolescence than childhood, with differences approaching significant levels.

Individuals whose AP relationships improved showed different patterns of development compared with those whose AP relationships worsened (Table 3). The subsample whose AP relationships worsened (AP+) showed most of the effect during adolescence. Based on the observed standard deviations, approximately 15% of the adolescents increased their skeletal discrepancies by more than 4.0 mm. Conversely, AP relationships improved most during childhood. It was not uncommon for children to show more

Table 3
Horizontal growth changes (mm) for subsamples with greater than (+) and less than (-) mean overall (6 to 13 yrs) AP changes

Variables	Subsample	Childhood Mean	Childhood SD	Adolescence Mean	Adolescence SD	prob
Females						
AP	+	1.53	1.81	2.22	1.71	0.801
AP	-	-1.53	1.32	-0.15	2.01	0.136
prob		<0.001		<0.001		
Pg	+	1.64	2.25	0.63	2.08	0.526
Pg	-	3.92	1.98	3.17	2.23	0.779
prob		0.006		0.005		
ANS	+	3.18	1.31	2.85	1.19	0.948
ANS	-	2.38	1.57	3.02	1.59	0.461
prob		0.440		0.999		
Males						
AP	+	0.72	1.80	2.35	1.73	0.035
AP	-	-1.63	2.16	-0.85	2.18	0.861
prob		<0.001		<0.001		
Pg	+	2.09	2.08	1.19	2.69	0.612
Pg	-	4.61	2.18	4.06	2.82	0.969
prob		<0.001		0.006		
ANS	+	2.81	1.31	3.54	2.23	0.639
ANS	-	2.98	1.57	3.21	2.24	0.998
prob		0.998		0.995		

prob - with Bonferroni corrections

Table 4
Changes (mm) of vertical relationships and vertical positions of Pg and Go

Variables	N	Childhood Mean	Childhood SD	Adolescence Mean	Adolescence SD	prob
Females						
VER	41	3.15	2.01	2.49	2.13	0.054
Pg	43	7.65	2.16	7.99	1.87	0.347
Go	41	4.50	1.56	5.58	1.92	0.001
Males						
VER	48	2.56	2.18	3.54	2.29	0.024
Pg	50	7.50	2.05	10.43	3.20	<0.001
Go	48	4.92	2.27	6.78	2.62	<0.001

than 3.0 mm improvement in AP relationships. Subjects whose discrepancies increased showed 2 to 3 mm less anterior movement of pogonion than the sample whose relationships improved. There were no significant differences in the anterior movement of ANS between individuals whose AP relationships increased or decreased. In other words, movements of pogonion rather than ANS accounted for the differences between the two subsamples. There were no significant differences between childhood and adolescent growth changes for either landmark.

Females showed greater changes of vertical relationships during childhood and males showed greater changes during adolescence (Table 4). Vertical relationships increased because there was 2.5 to 3.5 mm more inferior movement of pogonion than gonion. Absolute vertical growth changes were significantly greater during adolescence than childhood.

Table 5 shows more inferior movement of pogonion and less inferior movement of gonion for the individuals whose overall vertical relationships increased more than average (VER++). Differences between the two subsamples were statistically significant only for childhood movements of pogonion. Vertical changes of pogonion and gonion were greater during adolescence than childhood.

Finally, AP and vertical growth changes were related (Table 6). Approximately 29% of the females and 34% of the males showed greater than average changes of both AP and vertical relationships. Of those whose AP relationships improved, 34 to 37% tended to have less than average increases in vertical relationships. Product-moment correlations between overall AP and vertical changes were moderate for females (R=0.68; p<0.001) and males (R=0.59; p<0.001), indicating that the subjects with the greatest increases of AP discrepancies were likely to also show the greatest increases of vertical discrepancies.

Discussion

The results imply that skeletal malocclusions are not stable. Skeletal relationships change, depending on the age and sex of the patient as well as the type of malocclusion. Following shifts during the early mixed dentition,[9,18,19] untreated occlusal relationships have been reported to remain stable.[20-21] Evaluating actual dental relationships rather than dental classes, Harris and Berhents[22] showed a progressive worsening of dental relationships in Class II and Class III cases, indicating that molar classifications remain stable because the relational changes are directional.

Classes of skeletal malocclusion also appear to be stable[12,23] while the actual measured relationships change. Approximately 50% of our subjects showed increases and 50% showed decreases in the distance between ANS and Pg. It was not unusual for AP relationships to worsen by over 4 mm during adolescence. Nanda and Merrill[11] recently showed a decrease in the linear distance between A-point and pogonion for Class I subjects between 6 and 18 years of age. Their adjusted values compare closely to changes observed for the group where relationships decreased. Buschang and coworkers[24] previously showed that untreated French-Canadian children with Class II dental malocclusion displayed less mandibular growth than Class I children.

ANS, rather than A-point, was used for describing AP skeletal relationships because it provides a better measure of apical base changes. Measurement reliability was also better for ANS than A-point. Finally, ANS is not directly affected by the replacement and movements of the incisors, while A-point may be.[8] In untreated individuals, ANS and A-point actually showed similar growth patterns between 8 and 25 years of age;[25] differences were small and mostly vertical in nature, as previously reported.[26-27]

The maxillary growth of the French-Canadian children compares well with Danish children (Björk's sample).[25] ANS moved forward approximately 5 mm over the combined childhood and adolescent periods. Over 16% of subjects showed more than 4 to 5 mm anterior movement of ANS during childhood alone. Bony apposition at ANS amounts to less than 1 mm during adolescence and cannot account for the observed[25] changes in maxillary position. Related perhaps to the early fusion of the sphenoethmoidal sychondrosis and changing growth patterns of the nasal septum, it has been assumed that there is less anterior maxillary displacement during adolescence than childhood. Our results do not support such a contention; they support implant studies[16,25] demonstrating anterior maxillary displacement both during childhood and adolescence.

The results also demonstrated that changes in AP relationships are determined primarily by differences in the horizontal growth of the mandible. Horizontal maxillary growth could not account for the differences between subjects whose AP relationships increased or decreased. This substantiates that excessive anterior growth of the maxilla is not the primary determinant in the development of AP discrepancies. The results provide longitudinal support for cross-sectional

Table 5
Vertical growth changes (mm) for subsamples with greater than (++) and less than (+) mean overall VER changes

		Childhood		Adolescence		
Variables	Subsample	Mean	SD	Mean	SD	prob
Females						
VER	+	1.63	1.01	1.01	1.31	0.649
VER	++	4.60	1.61	3.82	1.84	0.709
prob		<0.001		<0.001		
Pg	+	6.63	1.63	7.34	1.93	0.707
Pg	++	8.63	2.25	8.68	1.65	0.998
prob		0.012		0.120		
Go	+	4.99	1.48	6.33	1.91	0.041
Go	++	4.03	1.53	4.86	1.68	0.288
prob		0.256		0.076		
Males						
VER	+	1.34	1.62	1.98	1.60	0.822
VER	++	3.89	1.93	5.24	1.62	0.265
prob		<0.001		<0.001		
Pg	+	6.58	1.86	9.58	2.86	<0.001
Pg	++	8.47	1.87	11.13	3.44	0.006
prob		0.023		0.454		
Go	+	5.23	2.63	7.59	2.26	<0.001
Go	++	4.57	1.80	5.89	2.74	0.130
prob		0.892		0.130		

prob - with Bonferroni corrections

Table 6
Crosstabulation of subjects (%) in the AP and VERT subsamples

		VER	
		+	++
Females (chi-square prob=0.04)			
AP	+	12.2	29.3
	-	36.6	22.0
Males (chi-square prob=0.01)			
AP	+	19.1	34.0
	-	34.0	12.8

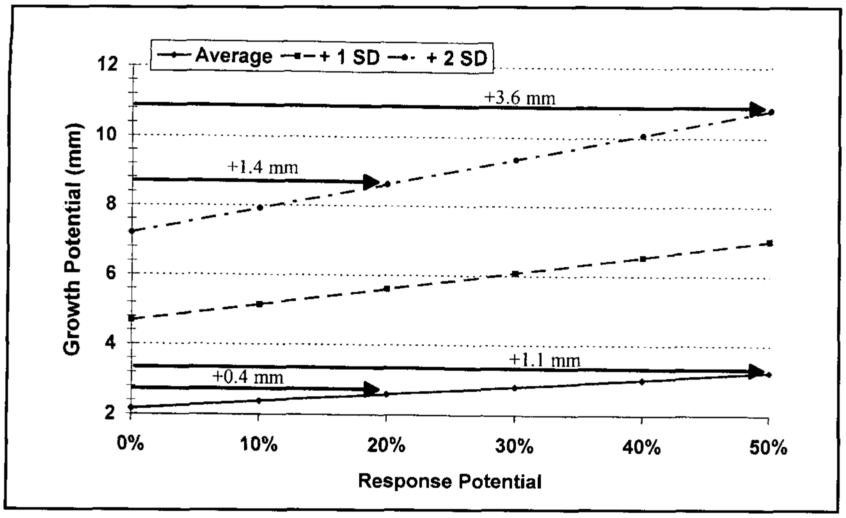

Figure 2
Simulation of response potential for three hypothetical girls with average and above average growth potential.

studies suggesting that Class II malocclusion is most often due to retrognathic, short, mandibles and orthognathic maxillae.[10,28-29] This does not mean that Class II skeletal malocclusion cannot be related to excessive development of the maxillary apical base.[30] The combined anterior growth of ANS and posterior growth of PNS of this sample was significantly greater in the AP+ group than in the AP- group, suggesting that excessive posterior growth at PNS may influence a subject's potential for mandibular rotation.

The results also provide a different perspective for evaluating treatment effects. Based on the subsample that became more retrognathic, orthopedic appliances would have to augment anterior mandibular growth and displacement over a typical treatment period just to maintain AP relationships. In other words, skeletal relationships for many children might be expected to deteriorate up to 5 mm during the typical course of treatment. This may explain why patients often do not respond favorably to orthopedic therapy. The treatment plans for patients whose AP relationships worsen must incorporate the expected improvement plus the anticipated developmental deficit.

AP relationships changed at different rates during development, with most of the improvement occurring during childhood. Nanda and Merrill[11] showed that the linear distance between A-point and pogonion for Class I subjects also decreased more between 6 and 12 years than between 12 and 18 years of age. This suggests that therapy to stimulate or restrict AP mandibular growth might best be performed during childhood,[31-33] when the greatest potential exists for modifications in the AP plane. In contrast, most AP discrepancies develop during adolescence due to limited mandibular growth. Individuals who became more retrognathic had twice as much mandibular growth potential during childhood as in adolescence.

Assuming that the response potential to appliance therapy depends on an individual's growth potential,[34] Figure 2 shows three hypothetical adolescent girls with average and above average horizontal growth potential. If therapy supplements growth by 20%, the girl with growth potential two standard deviations above average would gain 1.4 mm and the average grower would gain 0.4 mm. Assuming a 50% supplemental effect, the same two girls would exhibit 1.1 mm and 3.6 mm of extra growth, respectively. If treatment is expected to be successful, a 2 mm correction in AP relationships requires either a high individual growth potential or an extremely high response potential. The outcome for individuals with less than average growth potential might be extremely limited or possibly detrimental.

Growth changes of both the anterior and posterior mandible must be considered to understand the development of vertical discrepancies. Even though pogonion showed considerably more inferior movement than gonion, it should not be inferred that the mandibular plane steepened. In fact, the mandibular plane remained stable or it flattened because gonion moved both downward and substantially backward. The vertical distances between Pg and Go increased most in subjects with less inferior movement of gonion and more inferior movement of pogonion. Growth differences between hyper- and hypodivergent facial types are well accepted for anterior height.[35-39] While a reduction in posterior height has also been suggested as a contributing factor to the hyperdivergent phenotype,[40-43] Nanda[13] could not establish longitudinal differences in posterior height between untreated openbite and deepbite subjects. Our results imply that posterior facial height deficiencies are involved in the development of vertical discrepancies. The discrepancies between our results and Nanda's are due to the different measurements used.

Finally, the results showed only moderate relationships between AP and vertical changes. Approximately 30% of the children had coincidental deterioration of the vertical and horizontal relationships. They represent the segment of the population at greatest risk; their discrepancies develop during childhood and become more fully expressed during adolescence. In contrast, 34% to 37% of the children showed improvements of AP relationships and limited vertical changes; they represent the typical low-angle Class I type of growth pattern. A minority (12 to 19%) showed increasing AP discrepancies and less than average increases of vertical relationships. They had insufficient mandibular growth to maintain the AP relationships. Interestingly, 13 to 22% of the children showed improvement of AP relationships even though their vertical discrepancies increased more than expected. This group could include individuals with skeletal growth problems overlooked by diagnosis based on dental criteria.

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Commentary: Childhood and adolescent changes of skeletal relationships

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This is an important paper. The authors have factored out the amounts of anteroposterior (AP) and vertical skeletal growth occurring during childhood and adolescence. The results provide some very interesting and clinically relevant conclusions and some ideas for altering therapy based on an assessment of individual growth potential.

This paper describes growth as the AP and vertical displacement of the mandible and the maxilla relative to cranial base. For example, they view mandibular growth as how much anteroposterior and how much vertical displacement of the mandible occurs compared with the same parameters for the maxilla. It is the relative, not absolute, amounts of AP and vertical change occurring at the mandible compared with the same changes occurring in the maxilla.

In the AP direction, the authors compare ANS to pogonion and make some interesting observations. No one will be surprised to hear that anterior movements of pogonion accounted for most of the skeletal Class I improvement. However, the finding of anteroposterior skeletal relationships becoming more Class I during childhood than during adolescence is going to catch some attention. The clinical implications for early treatment and the interpretations of early treatment data are apparent.

Of comparable treatment interest, the report that anterior movement of ANS occurs during *both childhood* and adolescence addresses a long-standing clinical concern in treatment timing. While the paper does not explicitly state this, anterior displacement of ANS clearly depends on the direction of growth at the maxillary sutures. The observation that a subsample existed whose AP relationships worsened at a greater rate during adolescence confirms clinical experiences. The conclusion that, for this group, orthopedic appliances must augment mandibular growth just to maintain the AP relationship is an explicit consideration that has clinical utility and needs documentation in our literature. What practitioner has not concluded that an appliance is not being worn when in fact growth proportion was the real problem? We cannot sort this out without the information and approach of this paper.

The paper deals very forthrightly with the idea of relative AP displacement of the maxilla and the mandible, but the data in the vertical direction is less clear. The paper reports the measuring of vertical jaw growth using projections to pogonion and gonion from a cranial base reference. It was disappointing that the same idea of proportional change they used in the AP direction was not carried forward in the description of vertical growth. The relative growth contributions resulting in the vertical displacement of gonion and pogonion result in jaw rotations. This is not comprehensively addressed. For example, in the lateral view, mandibular rotation results from dissimilar amounts of vertical growth in the anterior face (at the sutures of the maxilla and the dentoalveolar processes), as compared with vertical growth in the posterior face (in the condylar and fossa regions).

Considering pogonion and gonion individually, the authors define pogonion as the most anterior point on the chin. This is reliably found AP on an individual film. However, is the pogonion found at age 8 or 10 identical to pogonion at age 14 or 16, after it has moved to a new vertical position and after substantial deposition inferiorly on the chin? An error in this decision will not affect measured values in the AP direction, but can affect vertical measurements. Pogonion has its greatest strength as an AP measure.

The very significant resorptive remodeling at gonion during forward mandibular rotation virtually insures that the gonion point found in childhood is different from gonion in adolescence. However, gonion was always reliably found according to the stated definition. The data in this study most probably profoundly understates the vertical distance from the cranial base reference line to the original gonion. Think of this as vertical condylar growth displacing the original gonion inferiorly. Simultaneously, resorption—attempting to mask the forward mandibular rotation and maintain the spatial relationship of the mandibular line to the cranial base—takes the original gonion away, creating a new point that is also called gonion.

If they understate gonion, the same error flaws the mandibular rotational data suggested by Table 5. This is probably the least valid data reported in the paper. All the comments regarding landmark identification validity are based on conclusions referenced from the 21 implanted cases reported by Björk and Skieller (Am J Orthod 1972;62:339). This classic paper uses implants to show the actual remodeling changes of many surface landmarks, including those used in this study. The time periods involved are nearly identical. The Björk and Skieller data provides information that could confirm or alter the clinical conclusions reached in the present study.

The major flaw in the data is the question of the validity of all the landmarks employed. Surface landmarks are subject to significant remodeling changes, as explained by long-term implant studies (Björk and Skieller 1972). If they superimposed the childhood and adolescent films (tracings) with the maxilla on the maxilla and the mandible on the mandible, analogous to Björk and Skieller's work, the validity of surface landmarks becomes apparent. An alternative proposal to improve the validity of the landmarks used in long-term studies such as this does exist.

How can they achieve this without implants? Implant studies show that, in an AP direction, ANS is significantly remodeled during the growth period of this study, but the change is greater in the vertical direction and smaller in an AP direction. Pogonion is also quite stable in the AP direction. Thus the AP data in this study are probably the most reliable data presented. In the vertical direction, implant studies show more surface remodeling changes. As noted above, pogonion probably moves, but mostly in a vertical direction. Gonion, however, is commonly heavily remodeled, therefore a less useful point in vertical measurements. What can be done to improve clinical analysis where we measure landmarks on the surface of a mandible?

Björk suggested superimposing the mandible on itself using the internal border of the symphysis, which is easy to find. The other structures he proposed (mandibular canal and third molar tooth buds before root formation) are hard to find and use. Alternatively, a point exists on the mandibular surface below the mandibular first molar where resorption crosses over to deposition, and almost no remodeling occurs. This point is a second point for mandibular superimposing that is easy to find and does not remodel (Am J Orthod Dentofac Orthop 1996;109:193). Using the inferior border of the symphysis and the crossover point below the first molar provides two points for superimposition of the mandible on itself, analogous to implants. This allows separation of the changes resulting from growth and displacement of the mandible from cranial base and local surface remodeling changes—a separation not possible when using surface landmarks that remodel.

This is a great longitudinal sample of records of 99 untreated children. Annual cephalograms taken on a population representing the entire range of phenotypic variation are a treasure that will not likely be duplicated in the future. The cranial base superimpositions are ideal. The use of ANS and pogonion to assess AP skeletal growth yielded new and important data. The problem of assessing vertical growth, jaw rotation, and its associated remodeling needs further work. The records exist and are traced. Knowing more about proportional vertical jaw growth could be exceedingly useful, and would avoid the potential pitfalls of surface remodeling graphically shown with implants in Björk and Skieller's 1972 publication. The authors have made a powerful contribution in this article. I urge them to undertake further work, such as that suggested in this commentary, and to fully exploit this rich resource of records.