Original Article

A predictive model of "favorable" and "unfavorable" anteroposterior skeletal relations among Class Is and Class IIs

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ABSTRACT
Objectives: To validate the use of the sagittal distance between ANS and Pg (ANSPg) as a measure of favorable and unfavorable anteroposterior skeletal relations and to identify multivariate cephalometric measures that could be used to predict favorable and unfavorable relations at 15 years of age.
Materials and Methods: This longitudinal study included 226 untreated adolescents evaluated at 10 and 15 years of age. Patients were grouped as "favorable" or "unfavorable" based on the ANSPg (measured parallel to S-N -7°) at 15 years of age ($ANSPg_{15}$). $ANSPg_{15}$ was validated based on its correlation with changes in ANSPg between 10 and 15 years of age, as well as its relationships with established measures of growth potential. Multiple regression and discriminant analyses were performed to predict $ANSPg_{15}$ from measures at 10 years of age.
Results: $ANSPg_{15}$ and the change in ANSPg between 10 and 15 years of age were significantly correlated ($R = -0.661$; $P \leq .001$), with 77% of patients in whom relationships improved (ie, distance decreased) exhibiting favorable relationships at 15 years of age. Established measures of growth potential were significantly ($P < .001$) correlated with $ANSPg_{15}$ and showed significant differences between patients with favorable and unfavorable relations. Multiple regression showed that the Y-axis, ANS-N-Pg, and symphyseal angle measured at 10 years explained approximately 60% ($R = 0.78$) of the variation in $ANSPg_{15}$. Based on these three variables, discriminant function correctly predicted favorable or unfavorable relations of $ANSPg_{15}$ 77% of the time.
Conclusions: $ANSPg_{15}$ was a valid measure for determining favorable and unfavorable anteroposterior skeletal relationships that could be predicted with moderately high levels of accuracy. (*Angle Orthod.* 2021;91:604–610.)

KEY WORDS: Growth; Prediction; AP relationships; Human; Cephalometric

INTRODUCTION

The dentofacial complex of growing orthodontic patients continuously changes.[1] To develop meaningful treatment plans, orthodontists need to determine how much growth is left and whether it will be favorable for solving the orthodontic problems. Such knowledge allows orthodontists to work smarter by effectively incorporating growth into their treatment plans.[2] Knowing whether patients have favorable or unfavorable growth tendencies also helps orthodontists distinguish between growth and treatment changes. All of this depends on the ability to predict.

Early predictions were based on pattern extension, which applied the same average growth changes to patients, and on the notion that facial growth patterns are established early and continue unchanged.[3,4] This idea led to the development of age- and sex-specific templates.[5] Later studies developed separate templates for sagittal, average, and vertical growers.[6] More recently, multilevel models were used to develop individualized curves that predicted growth with high levels of success.[7,8] However, these models are complicated and perform best with longitudinal data.

For clinical applications, orthodontists need to predict anteroposterior (AP) maxillomandibular rela-

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tionships. At the most basic level, they need to predict whether patients are expected to develop favorable or unfavorable relations. Favorable and unfavorable AP growth changes have been associated with decreases and increases, respectively, in the sagittal distance between ANS and Pg.[9] Unlike A- and B-point, ANS and Pg are not influenced by tooth movements, making them better measures of skeletal change.

Various morphologic attributes have been introduced to characterize favorable and unfavorable growth patterns (Table 1). Downs[10] emphasized the importance of the Y-axis, the mandibular plane angle, and facial convexity in determining a balanced profile. Ricketts[11] confirmed the use of those measures, as well as the gonial angle, condylar inclination, and cranial base angulation. Björk[12] and Skieller et al.[13] identified the posterior to anterior face height ratio and the angulation of the symphysis as important determinants of favorable and unfavorable growth potential. The symphyseal width to height ratio has also been used to classify growth patterns.[14]

The purpose of the present study was twofold. First, we sought to validate the use of the sagittal distance between ANS and Pg (ANSPg) to measure favorable or unfavorable AP skeletal relationships. Second, we sought to determine whether morphologic characteristics evaluated at 10 years of age were related to ANSPg at 15 years of age ($ANSPg_{15}$). The goal was to predict favorable and unfavorable AP skeletal relationships so that clinicians could make better decisions before initiating treatment. Favorable growth patterns help orthodontists correct skeletal and dental malocclusions.

Table 1. Traditional Measures Used to Characterize Favorable and Unfavorable Growth Patterns of Patients With Class I and Class II Relationships

Measure	Favorable	Unfavorable
Mandibular plane angle	Smaller	Larger
Y-axis	Smaller	Larger
Posterior to anterior face height ratio	Larger	Smaller
ANS-N-Pg	Smaller	Larger
Condylar inclination	Superior/anterior	Posterior
Gonial angle	Smaller	Larger
Symphyseal angle	Smaller	Larger
Symphyseal width to height ratio	Larger	Smaller
Palatal plane angle	Smaller	Larger
Cranial base angle	Smaller	Larger

MATERIALS AND METHODS

This retrospective longitudinal study included 226 untreated patients (106 boys, 116 girls). The data pertained to French-Canadian children from three school districts representing the socioeconomic backgrounds of the Montreal area at large.[15] Children were judged to be French-Canadian based on having at least three French-Canadian grandparents. Only children with normal Class I occlusion or untreated Class I and Class II dental malocclusions, as determined from their dental models, were included in this study. Approval to conduct this study was obtained from the Texas A&M University human ethical review committee.

Patients were selected based on available and suitable lateral cephalograms at T1 (10.4 $\pm$ 1 years of age) and T2 (15.3 $\pm$ 0.6 years of age) collected by the Human Growth Research Center, University of Montréal.[15] The ages 10 and 15 were chosen because these are the ages of most orthodontic patients. All cephalograms were hand-traced and digitized by the same technician. Twelve landmarks were identified on each tracing (Table 2; Figure 1). Cartesian coordinates (X, Y) were used to describe the sagittal and vertical positions of the landmarks, registering on Sella. All measurements were corrected for radiographic enlargement. Reliability of the sagittal and vertical landmark locations ranged between 95% and 98%.[9]

To describe the patients' AP relationships, the maxillary skeletal base was defined by ANS, and the mandibular skeletal base was defined by Pg. These landmarks are (1) commonly used to describe maxillary and mandibular positions, (2) relatively independent of changes in tooth position, and (3) easily located on lateral cephalograms.[9] To measure changes in landmark position, each patient's cephalograms were superimposed on stable natural structures in the anterior cranial base and cranium,[16] the reliability of which was greater than 98%.[17] The sagittal distances between ANS and Pg were measured parallel to the natural structure reference line (T1 S-N minus 7°). Ten predictor variables were calculated (Table 1). They were chosen based on their ability to characterize adolescent facial growth patterns.[10–14]

Statistical Analyses

None of the variables violated the assumption of normality. Independent *t*-tests were used to determine between-group differences. Patients were categorized as having favorable or unfavorable skeletal relations based on whether $ANSPg_{15}$ was smaller or larger than sex-specific mean values, respectively. Bivariate correlations were used to estimate the associations between the predictor variables and sagittal relationships.

Multiple stepwise regression was used to predict $ANSPg_{15}$. Sex and the 10 predictor variables were included in the regressions. Before performing the multiple regressions, 20% of the sample was randomly chosen, removed from the analyses, and used to validate the regression equations. Based on the variables identified using the multiple regressions, discriminant functions were performed to predict group

Table 2. Measurement Names, Definitions, and Abbreviations

Name	Definition	Abbreviation
Landmarks		
Anterior nasal spine	Most anterior point of the maxilla	ANS
B point	Point of deepest curvature between infradentale and pogonion	B
Basion	Midpoint of the anterior margin of the foramen magnum	Ba
C point	Point of deepest curvature of the lingual portion of the mandibular symphysis	C
Condylion	Most superior point of the mandibular condyle	Co
Gonion	Bisection of the angle formed by tangents to the posterior ramal border and the inferior mandibular border	Go
Infradentale	The intersection point of the anterior lower incisor and the crestal bone	Id
Menton	The most inferior point of the mandibular symphysis	Me
Nasion	Junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose	N
Pogonion	Most anterior point of the bony chin	Pg
Sella	Center of the sella turcica of the sphenoid bone	S
Measurements		
Mandibular plane angle	Angle formed by the intersection of line Go-Me with line S-N	MPA
Y-axis	Angle formed by the intersection of line S-Gn and S-N	Y-Axis
Posterior to anterior face height	Ratio of the distance from S to Go divided by the distance from N to Me	PAFH
ANS-N-Pg	Angle formed between the points ANS, N, and Pg	ANS-N-Pg
Condylar Inclination	Angle formed between the line Go-S and S-N	CondInc
Gonial angle	Angle formed between Ar, Go, and Me	GonAng
Symphyseal ratio	Ratio of the distance from C to Pg divided by the distance from Id to Me	SymWH
Symphyseal angle	Angle formed between Id, B, and Pg	SymAng
Palatal plane angle	Angle formed between the line ANS-PNS and S-N	PPA
Cranial base angle	Angle formed between N, S, and Ba	NSBa

membership of patients classified as having favorable and unfavorable relationships. A leave-one-out validation procedure was performed.

RESULTS

There was a statistically significant increase in the sagittal distance between ANS and Pg in girls between 10 and 15 years of age, indicating a worsening of their relationships (Table 3). ANSPg did not change among boys. The AP sagittal relationships were significantly worse among 15-year-old girls than boys. Based on sex-specific mean values of $ANSPg_{15}$, favorable and unfavorable skeletal relationships were estimated (Figure 2). The average sagittal distance between ANS and Pg was 8.2 mm smaller among individuals with favorable than unfavorable relations.

Validation of $ANSPg_{15}$

Of the individuals for whom distances between ANS and Pg increased (ie, improved AP relations), 76% had

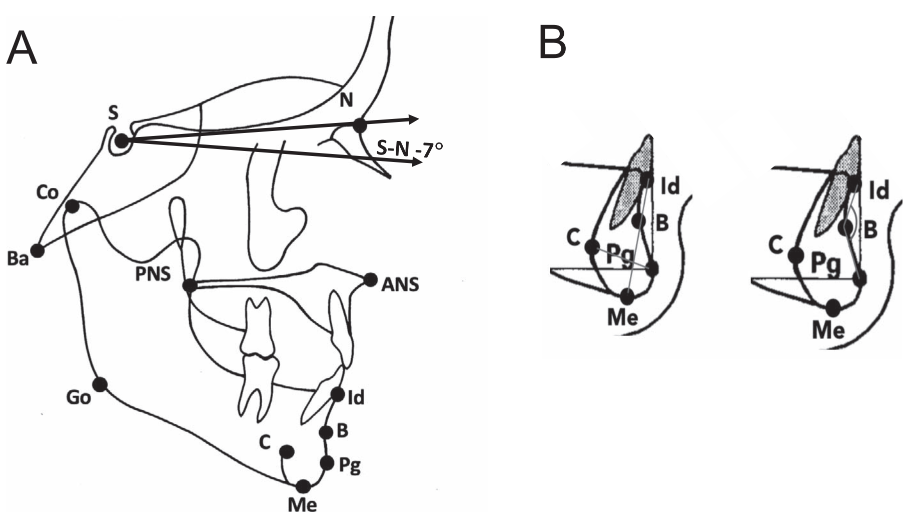

Figure 1. (A) Landmarks digitized along with the natural structure reference line, and (B) predictor variables of symphyseal ratio (SymWH) and (SymAng) angle.

Table 3. Changes in Anteroposterior Relationships (ΔANSPg) and Anteroposterior Relationships at 15 Years ($ANSPg_{15}$) in Girls and Boys, Measured in Millimeters[a]

	Male		Female		
	Mean	SD	Mean	SD	*P*
ΔANSPg	–0.10	2.88	1.10	2.88	.002
$ANSPg_{15}$	12.8	5.03	14.7	5.05	.004

[a] $ANSPg_{15}$ indicates sagittal distance between ANS and Pg at 15 years of age; ΔANSPg, change in the sagittal distance between ANS and Pg.

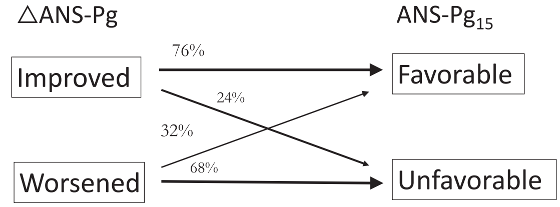

Figure 3. Percentages of individuals at 15 years of age with favorable or unfavorable relations whose AP relations improved (distances decreased) or worsened (distances increased) between 10 and 15 years of age.

favorable skeletal relations at 15 years of age; 68% of those in whom relations worsened had unfavorable relations (Figure 3). All of the predictor variables measured at 10 years of age showed statistically significant ($P < .01$) differences between individuals categorized as having favorable or unfavorable AP skeletal relationships at 15 years of age (Table 4). In addition, the predictor variables showed statistically significant correlations with $ANSPg_{15}$, with the MPA, Y-axis, ANS-N-Pg, gonial angle, and symphyseal angle showing the strongest associations (Figure 4).

Predictions of $ANSPg_{15}$

Stepwise multiple regression showed that the Y-axis, ANS-N-Pg, and symphyseal angle at 10 years of age were significantly correlated with $ANSPg_{15}$ (Table 5). The correlation (0.78) explained 60% of the variation in $ANSPg_{15}$. The contributions of the Y-axis and ANS-N-Pg were similar and larger than the contribution of the symphyseal angle. The following formula predicted $ANSPg_{15}$:

$$ANSPg_{15} = -20.343 + 0.6038*Y\text{-}axis_{10} + 0.6601*ANS\text{-}N\text{-}Pg_{10} - 0.09788*SymAng_{10}$$

The regression showed that $ANSPg_{15}$ was larger in 10-year-old patients who had larger Y-axes, larger angles of convexity (ANS-N-Pg), and smaller symphyseal angles (SymAngs). When the regression equation was applied to the validation sample, it yielded a correlation of 0.72 ($P < .001$), which closely approximated the correlation obtained with the larger sample.

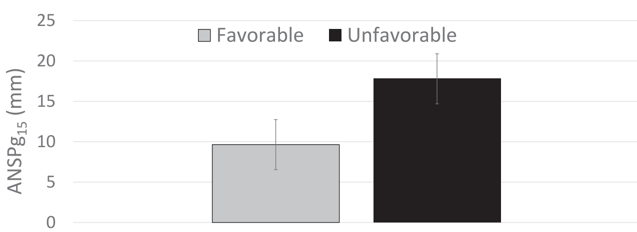

Figure 2. Means ± standard deviations of participants with favorable and unfavorable $ANSPg_{15}$ relations.

Excluding the predictor variables of the first regression, the second regression identified the mandibular plane angle (MPA), cranial base angle (NSB), and symphyseal ratio (SymWH). In combination, these variables explained 44% of the variation in $ANSPg_{15}$:

$$ANSPg_{15} = -33.2426 + 0.5141*MPA_{10} + 0.293*NSBa_{10} - 19.2822*SymWH_{10}$$

The equation indicated that $ANSPg_{15}$ was larger in 10-year-olds who had larger MPAs, larger NSBs, and narrower symphyses (SymWH). When applied to the validation sample, the correlation between the predicted and actual values of $ANSPg_{15}$ was 0.60.

Discriminant function was able to predict those individuals who exhibited favorable and unfavorable relationships at 15 years of age (Table 6). The predictor variables ($Y\text{-}axis_{10}$, $ANS\text{-}N\text{-}Pg_{10}$, and $SymAng_{10}$) identified in the first stepwise multiple regression yielded a moderately significant discriminant function (Wilks' Lambda = 0.671; $P \leq .001$), correctly classifying 80.4% of the patients. The leave-one-out validation correctly classified 78.4% of the patients. The following formula determined a patient's group affiliation:

$$\text{Group membership} = -7.75 + (0.153*YAxis) + (0.225*ANS\text{-}N\text{-}Pg) - (.035*SymAng)$$

where values greater than 0 predicted an unfavorable group membership, and values less than 0 predicted favorable group membership.

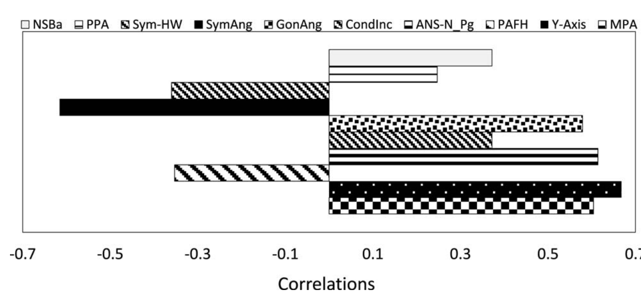

Figure 4. Correlations between $ANSPg_{15}$ and the 10 predictor variables (all $P < .001$).

Table 4. Differences in T1 Predictor Variables of Patients Who Exhibited Favorable or Unfavorable Relationships at T2 ($ANSPg_{15}$)[a]

	Unfavorable $ANSPg_{15}$		Favorable $ANSPg_{15}$		
	Mean	SD	Mean	SD	*P*
MPA, °	38.1	4.1	34.4	3.9	<.001
Y-axis, °	70.0	2.8	66.9	2.6	<.001
PAFH, %	60.5	4.9	63.1	5.3	<.001
ANS-N-Pg, °	10.6	2.3	7.7	2.7	<.001
CondInc, °	83.8	3.8	81.6	3.7	<.001
GonAng, °	122.3	6.8	116.3	6.2	<.001
SymWH, %	50.1	6.1	53.3	6.1	<.001
SymAng, °	129.8	9.9	139.9	9.7	<.001
PPA, °	7.9	2.8	6.9	2.7	.009
NSBa, °	132.4	3.8	129.4	4.4	<.001

[a] $ANSPg_{15}$ indicates sagittal distance between ANS and Pg at 15 years of age; CondInc, condylar; GonAng, gonial angle; MPA, mandibular plane angle; NSBa, cranial base angle; PAGH, posterior to anterior; PPA, palatal plane angle; SymAng, symphyseal angle; SymWH, symphyseal ratio.

The three predictor variables identified by the second stepwise multiple regression were able to correctly discriminate between favorable and unfavorable T2 sagittal relationships 70.3% of the time. The leave-one-out cross-validation correctly classified 69.8% of the patients:

Group membership = –18.049 + (0.171*MPA) – (0.4.53*SymWH) + (0.109*NSB)

DISCUSSION

The sagittal distance between ANS and Pg provided a valid measure of favorable and unfavorable AP skeletal relations. It was a valid measure because more than 3/4 of individuals with favorable relations at 15 years of age exhibited decreases in ANSPg (ie, improved AP relations). Similarly, most patients whose AP relationships worsened were classified as having unfavorable patterns at age 15. In addition, measures for 10-year-olds previously established by others to classify patients' growth patterns were correlated with and were able to distinguish between patients who had favorable or unfavorable AP relations at 15 years of age. These reasons support the use of the distance between ANS and Pg as a valid measure of favorable and unfavorable AP skeletal relations.

Sagittal skeletal relationships of adolescent girls worsened between 10 and 15 years of age, while those relationships did not worsen in boys. While no previous study has examined sex differences in AP skeletal base relationship changes during adolescence, greater decreases of ANB have been reported for boys, resulting in smaller ANB angles among 17-year-old boys than girls.[7] Additionally, sagittal movements of pogonion have been reported after age 13 years for boys, but not for girls.[7,18] Worsening of sagittal skeletal base relationships among adolescent girls could be explained by their more limited anterior chin movements.

Changes in adolescents between 10 and 15 years in the distance between ANS and Pg were closely related to the AP relationships individuals had at 15 years of age. It was previously established that mandibular, rather than maxillary, growth determined whether the distance ANSPg increased or decreased, and that individuals whose AP relations worsened also had vertical relationships that worsened, and vice versa.[9] In other words, individuals with unfavorable AP relations at 15 years of age are probably more likely to be hyperdivergent, which supports the between-group differences and correlations in the present study.

Perhaps most importantly, the results showed that it is possible to predict sagittal relationships at age 15 based on cephalometric variables at age 10. It was previously shown that 86% of the variation in mandibular rotation could be explained among extreme growers.[13] The present study could explain only 60% of the variation. The amount of variation explained in the present study was also less than growth predictions based on multilevel modeling,[7,8] which are more complex and difficult to apply. Correlations produced in the present study were similar to those reported by some,[19] and substantially greater than those reported by others.[20] Importantly, the predictions in the present study were all substantially better than those reported for pattern extension.[5,6,21]

Table 5. Multiple Regression of T1 Predictor Variables for the Dependent Variable $ANSPg_{15}$[a]

Step	Constant	Variable 1	Variable 2	Variable 3	*R*	R^2
Multiple regression 1 – validation correlation = 0.723 (*P* < .001), N = 53						
		Y-axis	ANS-N-Pg	SymAng	0.779	0.598
Unstandardized	–20.343	0.6038	0.6601	–0.09788		
Standardized		0.366	0.371	–0.213		
Multiple regression 2 validation correlation = 0.599 (*P* < .001), N = 53						
		MPA	NSB	SymWH	0.661	0.437
Unstandardized	–33.2426	0.5141	0.2930	–19.2822		
Standardized		0.439	0.234	–0.233		

[a] $ANSPg_{15}$ indicates sagittal distance between ANS and Pg at 15 years of age; MPA, mandibular plane angle; NSB, ??; SymAng, symphyseal angle; SymWH, symphyseal ratio.

Table 6. Discriminant Function Between Patients With Favorable and Unfavorable T2 Relationships ($ANSPg_{15}$)[a]

Discriminant Coefficients				Wilks' Lambda		Classification	Validation
Constant	Variable 1	Variable 2	Variable 3	Estimate	*P*	% Correct	% Correct
–7.75	Y-axis (0.153)	ANS-N-Pg (0.225)	SymAng (–0.035)	0.646	<.001	76.7	74.4
–18.049	MPA (0.171)	SymWH (–4.53)	NSB (0.109)	0.781	<.001	70.3	69.8

[a] $ANSPg_{15}$ indicates sagittal distance between ANS and Pg at 15 years of age; MPA, mandibular plane angle; NSBa, ??; SymAng, symphyseal angle; SymWH, symphyseal ratio.

Based on only three predictor variables, it was possible to correctly classify individuals as having a favorable or unfavorable growth pattern. In the present study, the patient's Y-axis, ANS-N-Pg, and symphyseal angle made it possible to correctly classify the patient 77% of the time. These three variables, which pertained to three different and relatively independent aspects of the patients' facial pattern, combined to increase prediction accuracy. The accuracy achieved in the current study was greater than that previously reported for binary craniofacial predictions. Based on seven predictor variables evaluated at 10 years of age, favorable or unfavorable sagittal relationships were correctly classified in only 60% of 15-year-old patients with Class III malocclusion.[22]

The validation samples and one-out validation procedures showed that the predictive models developed in the current study were externally valid. Auconi et al.[22] reported that their discriminant analysis correctly classified 60% of individuals, but they did not validate their results. The large number of predictor variables that they used might make validation difficult. In contrast, the models developed in the current study were based on only three predictor variables, possibly explaining their stability.

Orthodontic treatment typically takes place while the jaws are growing. Accurate determination of favorable or unfavorable growth is possible in almost 4 of 5 patients, depending on each patient's vertical and sagittal relationships, along with characteristics of the bony chin. If AP growth is favorable, the orthodontist requires less dental movement to correct Class II molar/canine relationships.[23] Patients with favorable growth patterns are also better candidates for functional appliance therapy.[24]

CONCLUSIONS

- The $ANSPg_{15}$ provided a valid measure for distinguishing between favorable and unfavorable adolescent growth potential.
- During adolescence, sagittal skeletal relationships worsened in girls but not in boys.
- The Y-axis, ANS-N-Pg, and symphyseal angle at 10 years of age combined to explain 60% of the variation of the sagittal relationship of ANSPg at age 15.
- In combination, these same variables were able to classify individuals correctly as having favorable or unfavorable sagittal relationships 77% of the time.

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