ORIGINAL ARTICLE

Role of cranial base flexure in developing sagittal jaw discrepancies

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The aim of this longitudinal cephalometric study was to investigate skeletal features in patients with small and large cranial base angles. Two groups of untreated subjects were formed on the basis of a small and large cranial base angle N-S-Ar at the age of 5 years: the large cranial base angle group (n = 22) consisted of subjects with an N-S-Ar angle larger than 125° (mean, 128.1°), and the small cranial base angle group (n = 20) included subjects with an N-S-Ar angle of less than 120° (mean, 117.6°). Cephalometric data of the 2 groups were analyzed at subject ages 5 and 12 years. At both ages, the groups showed significant differences of the variables SNA, SNB, individualized ANB, and Y axis. The unadjusted ANB angle and the angle of convexity N-A-Pg were not significantly different between the 2 groups. According to the individualized norm of the ANB angle, subjects with a large cranial base angle in the primary dentition demonstrated a skeletal Class II tendency both at the initial observation and at the longitudinal follow-up. On the basis of cephalometric variables at 12 years of age, it was possible to classify 88.1% of the initial large and small cranial base angle individuals, indicating a constancy of the skeletal pattern during the longitudinal follow-up. The relationship between cranial base flexure and skeletal pattern of the jaws seems to be established before the age of 5 years. (Am J Orthod Dentofacial Orthop 2002;122:386-91)

The correlation of cranial base and malocclusion was discussed early by Renfroe,[1] Björk,[2,3] Moss,[4] and Ricketts.[5] Although differences in the flexure of the cranial base have been ascribed to mainly genetic factors, Solow and Tallgren[6] and Solow and Greve[7] indicated that changes in head posture, caused for example by respiratory obstruction of the nasopharyngeal airway, could be an environmental factor capable of influencing cranial base flexion. Hopkin et al[8] stated that in the assessment of orthodontic problems involving anteroposterior malrelationships of the jaws and arches, recognition must be given to the determining role of the cranial base. According to Scott,[9] 3 main factors influence facial prognathism: opening of the cranial base angle, the relative forward movement of components like maxilla and mandible to the cranium, and the amount of surface deposition along the facial profile between nasion and menton. The saddle angle is characterized by rather large interindividual variation as indicated by a standard deviation of 5° or more.[10] Whereas George[11] observed a decrease of this angle from birth through the first years of life, Lewis and Roche[12] found marked constancy within subjects after the age of 2 years, and Kerr[13] considered it 1 of the few craniofacial constants with very little variation during the growth period from 5 to 15 years of age. Melsen[14] and Solow[15] explained the average stability as a result of a balance between the backward rotation of the basioccipital bone and its forward relocation by resorption on the cerebral and apposition on the pharyngeal surfaces. Smaller linear and angular dimensions have been shown for Class III patients,[4,8,16-18] whereas Class II subjects demonstrated an increased cranial base angle,[1,16-18] leading to a more posterior position of the mandible.[19]

The significance of cranial base flexure as an early factor in the etiology of malocclusion remains controversial. Varrela[20,21] investigated characteristics of a sample of Class II patients between 3 and 7 years of age and did not find the cranial base to be different in these patients compared with a Class I control group. The author concluded that the cranial base is not an early etiologic factor in Class II skeletal relationships. When comparing Class I and Class II skeletal patterns, Wilhelm et al[22] did not observe any differences for the

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Table I. Descriptive statistics and statistical comparison of groups I and II at age 5 years

	Group I (large N-S-Ar) (n = 20)			Group II (small N-S-Ar) (n = 22)			Mann-Whitney test	
Cephalometric measurements	Median	Mean	SD	Median	Mean	SD	Z	P
N-S-Ba (°)	133.9	134.4	3.0	126.2	126.3	3.0	−5.289	.000***
GoAr-SN (°)	86.1	86.1	5.2	84.9	84.2	3.9	−1.386	.166
S-N-A (°)	78.9	79.2	3.0	82.8	82.8	2.8	−3.426	.001**
S-N-B (°)	74.8	74.9	2.4	78.4	78.6	2.8	−4.258	.000***
A-N-B (°)	4.1	4.3	1.8	4.2	4.2	1.7	−0.038	.970
Individualized A-N-B (°)	3.4	3.3	1.3	1.8	1.7	1.8	−2.871	.004**
N-A-Pg (°)	8.7	9.3	4.2	10.2	9.3	3.7	−0.327	.743
N-S-Gn (°)	68.6	68.3	2.6	65.1	65.0	2.9	−3.489	.000***
S-N MP (°)	34.3	34.3	3.0	33.1	33.4	5.5	−0.982	.326
PP MP (°)	25.8	26.7	3.2	27.4	28.0	5.1	−0.403	.687
Ar-Go-Me (°)	129.2	128.3	5.6	127.7	129.2	6.3	−0.340	.734
Ar-Go-N (°)	56.5	56.8	4.0	55.8	56.1	3.5	−0.579	.562
N-Go-Me (°)	70.9	71.5	3.0	72.1	73.1	4.7	−1.184	.236
Ar-N (mm)	80.4	80.6	3.0	78.1	78.5	3.4	−1.977	.048*
S-Ar (mm)	27.0	27.2	1.7	25.7	26.3	2.0	−1.890	.059
S-N (mm)	60.2	61.0	3.0	61.5	62.8	3.0	−2.003	.045*
Go-Me (mm)	54.5	54.4	2.3	55.3	55.2	3.3	−1.222	.222
Ar-Go (mm)	35.9	36.0	3.2	36.9	36.1	2.5	−0.189	.850
S-Go (mm)	58.8	59.0	3.7	54.9	59.8	2.8	−0.567	.571
N-Me (mm)	92.4	92.9	5.0	93.3	92.9	3.4	−0.101	.920

$*P < .05$; $**P < .01$, $***P < .001$.

cranial base measurements between the 2 groups. Anderson and Popovich[23] studied subjects with small and large cranial base flexure at the age of 6 years. During the longitudinal follow-up it was found that the group with the flatter cranial base flexure had Angle Class II occlusion 45% more frequently (59% vs 14%). In the group with the closed cranial base angle, the condyles were more forward and downward, but no Class III occlusions were found. Kerr and Hirst[24] investigated longitudinal growth changes and concluded that the cranial base angle at 5 years of age is an accurate predictor of the occlusal type at 15 years of age in 73% of the subjects.

The aim of the present study was to assess early skeletal features in patients with small and large cranial base angles. Furthermore, this study tried to evaluate the influence of variations of the cranial base angle N-S-Ar at the primary dentition stage on the sagittal jaw relationship on the basis of a longitudinal follow-up of untreated subjects from 5 to 12 years of age.

MATERIAL AND METHODS

Sample

The records were obtained from the Child Research Council in Denver, Colo, and included longitudinal data from annual lateral radiographs of 82 subjects from 5 to 12 years of age. All subjects were of white origin and had not received orthodontic treatment. On the basis of cranial base angle N-S-Ar at the age of 5 years, 2 groups were formed: the large N-S-Ar group I (n = 22) included subjects with an N-S-Ar angle larger than 125° (mean, 128.1°), and the small N-S-Ar group II (n = 20) consisted of subjects with an N-S-Ar angle of less than 120° (mean, 117.6°). The skeletal characteristics of the 2 groups at the age of 5 years are given in Table I.

Cephalometric analysis

The following landmarks were used for cephalometric analysis: point A (A), point B (B), sella (S), nasion (N), articulare (Ar), basion (Ba), gonion intersection (Go), menton (Me), anterior nasal spine (ANS), posterior nasal spine (PNS), gnathion (Gn), and pogonion (Pg). All cephalometric landmarks were traced with a cross-wires cursor to achieve digitization of landmarks with the Dentofacial Planner system (Dentofacial; Toronto, Ontario, Canada).

The following measurements were used:

- Linear measurements for the assessment of cranial base dimensions: Ar-N, S-Ar, S-N.
- Linear measurements for the assessment of mandibular dimension: Go-Me, Ar-Go.
- Linear measurements for the assessment of vertical growth: S-Go, N-Me.

- Angular measurements for the assessment of cranial base flexure: N-S-Ar, N-S-Ba.
- Angular measurements for the assessment of the sagittal growth pattern: SNA, SNB, ANB, individualized ANB (deviation from the individualized norm of the ANB according to Järvinen[25]), N-A-Pg (angle of convexity).
- Angular measurements for the assessment of the vertical growth: S-N MP (sella nasion line to mandibular plane Go-Me), S-N PP (sella nasion line to palatal plane ANS-PNS), PP MP (palatal plane ANS–PNS to mandibular plane Go-Me), N-S-Gn (Y axis).
- Angular measurements for the assessment of mandibular morphology: Ar-Go-Me (gonial angle), Ar-Go-Me (upper gonial angle), N-Go-Me (lower gonial angle), GoAr-SN (ramus tangent Go-Ar to sella nasion line S-N).

To determine the sagittal growth pattern, we applied Järvinen's method[25] of calculating an individualized ANB; this method takes into account that besides the actual apical base difference, horizontal and vertical variations of the point N and the variations in the inclination between the jaws and the cranial base affect the angle ANB. By using a regression model that includes the SNA and mandibular plane to sella nasion line angles, we can explain much of the ANB variation that is due to the above-mentioned factors and establish individual norms.

Dahlberg's formula[26] was used to calculate the method error on 25 randomly selected radiographs. The method error was found to be 0.5° for the angular measurements and 0.5 mm for the linear measurements.

Statistical analysis

For each cephalometric variable and each group median, mean and SD were calculated at subject ages 5 and 12 years. The cephalometric data of the 2 groups at age 12 years were compared by a Mann-Whitney *U* test for independent samples ($P < .05$). In order to determine which measurements at 12 years of age were most associated with our initial separation into high and low cranial base angle subjects at age 5 years, a discriminant analysis was chosen: a stepwise variable selection procedure was computed to assess whether some variables were more important in differentiating between the 2 groups. The efficiency of the discriminant model was measured by examining the eigenvalues and the canonical correlation. The angles N-S-Ar and N-S-Ba were not included in this model. For the procedure an F level of 4.0 to enter and 3.9 to remove was used. Also, the classifying power of the selected variables was tested.

RESULTS

Descriptive data of the cephalometric analysis and the results of the Mann-Whitney test for groups I (large N-S-Ar angle) and II (small N-S-Ar angle) at ages 5 and 12 years are reported in Tables I and II, respectively.

The groups selected on the basis of high and low cranial base angles N-S-Ar at age 5 years showed significant differences for sagittal skeletal parameters: the larger N-S-Ar group I was characterized by smaller SNA ($P < .01$) and SNB ($P < .001$) angles. Whereas the angle of convexity N-A-Pg showed a mean of 9.3° in both high and low cranial base angle subjects and the unadjusted ANB was similar for both groups (4.3° for the large N-S-Ar group and 4.2° for the small N-S-Ar group), the individualized norm of the ANB according to Järvinen[25] showed more of a skeletal Class II tendency in group I ($P < .01$). This indicates that vertical factors are involved as well: a small cranial base angle was associated with a smaller Y axis (mean, 65.0° vs 68.3°; $P < .01$).

Many of the differences between the 2 groups at age 5 years were still present at age 12 years: group II showed a smaller SNA ($P < .01$), SNB ($P < .01$), and individualized ANB ($P < .05$), as well as a smaller measurement for Y axis (65.8° vs 67.9°; $P < .05$).

Discriminant analysis

The stepwise variable procedure identified 4 variables at 12 years of age that differentiated the 2 groups: the first variable that entered the model was SNB, followed by the distances sella-articulare, sella-nasion, and articulare-nasion. Using these variables, we were able to classify correctly 37 of the 42 subjects (88.1%) of the 2 groups. The eigenvalue of the model was 1.68, and 63% of the total variance was attributable to differences between the groups (canonical correlation $r = .792$; $r^2 = .627$).

DISCUSSION

The methodology used in the present study was similar to that of Anderson and Popovich,[23] who formed 2 groups based on cranial base flexure (N-S-Bolton point) at age 6 years. Although the angle N-S-Ar that we used does not accurately represent the form of the cranial base,[27] Björk[3] demonstrated high levels of correlation between N-S-Ba and N-S-Ar, and Sarnäs[28] and Solow,[15] between N-S-Ba, N-S-Ar, and N-S-Condylion. Therefore, the method chosen should

Table II. Descriptive statistics and statistical comparison of groups I and II at age 12 years

	Group I (large N-S-Ar) (n = 20)			*Group II (small N-S-Ar) (n = 22)*			*Mann-Whitney test*	
Cephalometric measurements	*Median*	*Mean*	*SD*	*Median*	*Mean*	*SD*	*Z*	P
N-S-Ba (°)	133.1	133.2	3.6	126.9	126.9	3.6	−4.408	.000***
GoAr-SN (°)	88.7	88.7	4.7	88.1	88.2	4.0	−0.504	.614
S-N-A (°)	80.5	80.1	2.9	83.8	82.7	2.9	−2.645	.008**
S-N-B (°)	76.6	76.8	2.4	79.2	79.4	3.4	−2.632	.008**
A-N-B (°)	3.1	3.3	1.9	3.6	3.3	2.0	−0.101	.920
Individualized A-N-B (°)	2.7	2.3	1.3	1.0	1.1	2.1	−2.241	.025*
N-A-Pg (°)	4.8	4.9	4.9	5.7	5.7	5.1	−0.579	.562
N-S-Gn (°)	68.2	67.9	2.2	66.0	65.8	3.1	−2.580	.023*
S-N MP (°)	31.7	32.1	3.9	31.2	32.3	5.6	−0.025	.960
PP MP (°)	23.8	23.4	4.8	24.6	25.9	5.1	−1.171	.241
Ar-Go-Me (°)	121.3	123.4	6.3	120.6	124.1	7.0	−0.025	.980
Ar-Go-N (°)	52.6	52.7	3.4	51.1	51.5	3.0	−0.995	.320
N-Go-Me (°)	70.7	70.6	3.7	72.1	72.6	5.4	−1.096	.273
Ar-N (mm)	91.4	91.1	3.6	89.2	88.7	4.3	−0.411	.087
S-Ar (mm)	32.7	33.0	1.9	2.0	32.1	2.5	−1.411	.158
S-N (mm)	66.6	66.9	2.9	7.9	68.0	3.3	−0.995	.320
Go-Me (mm)	67.4	67.2	3.5	68.3	68.0	4.2	−0.970	.332
Ar-Go (mm)	43.4	43.0	3.7	42.8	42.6	2.7	−0.617	.537
S-Go (mm)	72.2	71.5	4.3	71.5	71.7	3.5	−0.000	1.000
N-Me (mm)	108.6	108.5	5.3	109.4	109.3	4.5	−0.504	.614

$^*P < .05$; $^{***}P < .001$.

be valid to investigate skeletal patterns associated with variations of the cranial base flexure.

It has been suggested that cranial base flexure influences mandibular prognathism by determining the anteroposterior position of the condyle relative to the facial profile.[29] Kerr and Hirst[24] found the cranial base angle at 5 years of age to determine the fundamental jaw relationship at 15 years of age and also to be an accurate predictor of ultimate facial type in, on average, 69% of the subjects. In the present study, the discriminant analysis of cephalometric variables at 12 years correctly classified more than 90% of the subjects in the groups formed at 5 years of age. The 2 groups that were formed on the basis of early presence of a large and small cranial base angle N-S-Ar showed specific characteristics at 5 years of age. Although these traits were present early, the larger or smaller cranial base angle did not appear to progressively amplify the skeletal pattern; indeed, the skeletal characteristics changed very little between 5 and 12 years in both groups, and a constancy of the skeletal pattern during the longitudinal follow-up was shown. The most rapid growth of the cranial base occurs between birth and 2 years of age.[30] It might be assumed that changes that alter growth and development of the cranial base would be reflected in facial growth, especially during this period.[22] On the basis of these findings and the results of our study, it can be postulated that the relationship between sagittal jaw position and cranial base flexure is established before age 5 years and that the skeletal pattern remains constant during the longitudinal follow-up, with only a limited influence on the further development of sagittal jaw discrepancies between 5 and 12 years.

Anderson and Popovich[23] found more Class II occlusions in large cranial base angle subjects. These authors looked at the dental characteristics for their group selection. Varrela,[20] when investigating early characteristics of a sample of Class II occlusion patients, found no cranial base etiology in the Class II group. The relationship between skeletal pattern and malocclusion is debatable because although malocclusion appears to be acquired, craniofacial form seems to be under fundamental genetic control.[31,32] Factors like mastication, breathing, posture, or habits can affect craniofacial form in the etiology of Class II malocclusion.[21] In a recent study, Wilhelm et al[22] compared the cranial base in Class I and Class II skeletal patterns. They made the group selection on the basis of overjet, ANB angle, and Harvold unit length difference at age 14 years and found no significant differences between the skeletal classes for any of the cranial base measurements. The present study also focused on the skeletal pattern; at the initial observation and at the longitudinal follow-up, the large cranial base angle group showed smaller SNA and SNB angles, indicating a difference in facial type between the 2 groups. Björk[33,34] identified angular deflection of the cranial base as 1 of the key factors influencing facial prognathism. Järvinen[27,35] noted that the value of the angle SNA can be affected by the configuration of the cranial base and stated that at least part of the correlation between N-S-Ar and SNA has a topographic causation. When comparing the sagittal jaw relationship in our study, no significant differences for the angle of convexity N-A-Pg and the ANB angle were present between the 2 cranial base angle groups. The unadjusted angle ANB has been found to have several shortcomings[36-44]; therefore, Järvinen's method[25] of individualizing the ANB norm was applied. The large cranial base angle group had average ANB values of 3.3° and 2.3° above the individualized norms at 5 and 12 years of age, respectively; this was significantly higher than the small cranial base angle group ($P < .01$ at 5 years; $P < .05$ at 12 years) and indicated a skeletal Class II tendency. Although they were statistically significant, the differences in deviation from the individualized ANB norm between the 2 groups were small from a clinical standpoint (average, 1.2° at age 12 years). Therefore, it can be concluded that the flexure of the cranial base is associated with a specific facial pattern but has only a limited effect on the development of sagittal jaw discrepancies.

Other cephalometric characteristics resulting from the skeletal type might influence sagittal jaw position and relationship. Bacon et al[10] found a flattening of the saddle angle associated with a decrease of the posterior cranial base angle N-Ba-S, an elongation of the posterior part of the cranial base at Ba-point, and an enlarged distance N-Ar, favoring an increased sagittal discrepancy of the jaws. In the present study, the subjects with a large N-S-Ar angle also showed an elongation in the posterior part of the cranial base, as indicated by a larger distance S-Ar. A compensating mechanism associated with cranial base flexure was described by Anderson and Popovich[45]: the angle between the posterior cranial base and the ramus of the mandible closes in a highly correlated compensation for opening of the cranial base flexure. This tends to maintain the angle between the ramus and the anterior cranial base. Therefore, with a more obtuse cranial base angle, the mandible swings only slightly down and forward. The present study confirmed the effectiveness of this compensating mechanism: the angle between ramus and anterior cranial base GoAr-SN did not show any significant differences between the 2 groups.

CONCLUSIONS

- Early differences between the 2 groups selected on the basis of a small and large cranial base angle N-S-Ar at 5 years of age included the angles SNA and SNB, individualized ANB, Y axis, and the distances, Ar-N and S-N.
- The presence of a large or small cranial base angle N-S-Ar had a rather limited effect on the development of sagittal jaw discrepancies during the longitudinal follow-up. The ANB angle and the angle of convexity N-A-Pg were not significantly different between the 2 groups. In subjects with a large cranial base angle, the individualized ANB angle indicated a skeletal Class II tendency at the initial observation and at the longitudinal follow-up.
- On the basis of variables SNB, S-Ar, S-N, and Ar-N, at the age of 12 years, it was possible to classify 88.1% of the initial large and small cranial base angle subjects, indicating a constancy of the skeletal pattern during the longitudinal follow-up. The relationship between cranial base flexure and skeletal pattern of the jaws seems to be established before the age of 5 years.

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