CRANIAL-BASE MORPHOLOGY IN CHILDREN WITH CLASS III MALOCCLUSION

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The association between cranial-base morphology and Class III malocclusion is not fully understood. The purpose of this study was to investigate the morphologic characteristics of the cranial base in children with Class III malocclusion. Lateral cephalograms from 100 children with Class III malocclusion were compared with those from 100 subjects with normal occlusion. Ten landmarks on the cranial base were identified and digitized. Cephalometric assessment using seven angular and 18 linear measurements was performed by univariate and multivariate analyses. The results revealed that the greatest between-group differences occurred in the posterior cranial-base region. It was concluded that shortening and angular bending of the cranial base, and a diminished angle between the cranial base and mandibular ramus, may lead to Class III malocclusion associated with Class III facial morphology. The association between cranial-base morphology and other types of malocclusion needs clarification. Further study of regional changes in the cranial base, with geometric morphometric analysis, is warranted.

Key Words: cephalometric analysis, children, Class III malocclusion, cranial base, morphology
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A Class III malocclusion, defined by the mandibular first permanent molar being "mesial" (i.e. more forward than normal in its relationship to the maxillary first molar), is largely a skeletal type of occlusal variation. Studies indicate that 63–73% of Class III malocclusions are of a skeletal type [1,2]. Such skeletal cases result from growth disharmony between the mandible and maxilla, thus producing a concave facial profile. A skeletal Class III malocclusion can exhibit mandibular protrusion, maxillary retrusion, or a combination of the two [2,3].

The association between cranial-base morphology and Class III malocclusion is not fully understood. Contradictory results were noted in previous studies of the morphologic characteristics of Class III cranial-base configuration [4–6]. The number of landmarks selected was often limited, and attempts were made to characterize global craniofacial morphology rather than regional changes in the cranial base itself. Cephalometric analysis using more cranial-base landmarks may provide more precise information about the type of cranial-base changes contributing to a Class III configuration.

The purpose of this study was to investigate morphologic characteristics of the cranial base in children with Class III malocclusion. It was also hoped that the data might provide baseline material for subsequent studies of Class III malocclusion.

MATERIALS AND METHODS

Lateral cephalograms from 100 children (aged 9.4–11.5 years) with Class III malocclusions were compared with those from 100 subjects with normal occlusions. The study groups included an equal number of males and females. Radiographs were obtained from files at the Department of Orthodontics, Kaohsiung Medical University. The

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cephalograms were traced by a single investigator, and checked by another. Ten landmarks on the cranial base were identified and digitized (Figure 1). Cephalometric analysis using seven angular and 18 linear measurements was performed (Figure 2). The enlargement factor on the lateral cephalograms was 10%, which was then corrected to natural size.

Cephalometric measurements for the two groups were compared by a t test for independent samples. Statistical significance was indicated by a p value of < 0.05. After the t test, measurements were compared using a multivariate Hotelling's T^2 test.

To assess errors involved in cephalometric tracing and digitizing, 30 randomly selected, lateral cephalograms were traced and digitized. The same cephalograms were retraced and redigitized under the same conditions 1 week later. Correlations between the two cephalograms were then analyzed for both angular and linear measurements [7]. Method error (ME) was calculated by the Dahlberg formula:

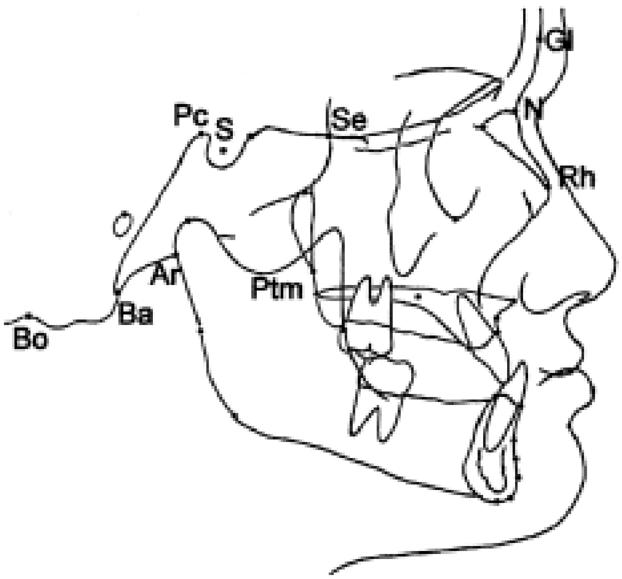

Figure 1. *Lateral cephalograms showing the position of the 10 landmarks used to define the cranial base in this study: Ar = articulare (intersection of the condyle and the posterior cranial base); Ba = basion (lowest point on the anterior border of the foramen magnum); Bo = Bolton point (highest point behind the occipital condyle); Gl = glabella (most prominent point on the frontal bone); N = nasion (most anterior point on the frontonasal suture); Pc = posterior clinoid process (most superior point on the clinoid process); Ptm = pterygomaxillary fissure (most inferior point on the outline of the pterygomaxillary fissure); Rh = rhinion (tip of the nasal bone); S = sella (center of the sella turcica); Se = sphenoidale (intersection of the greater wings of the sphenoid and the anterior cranial base).*

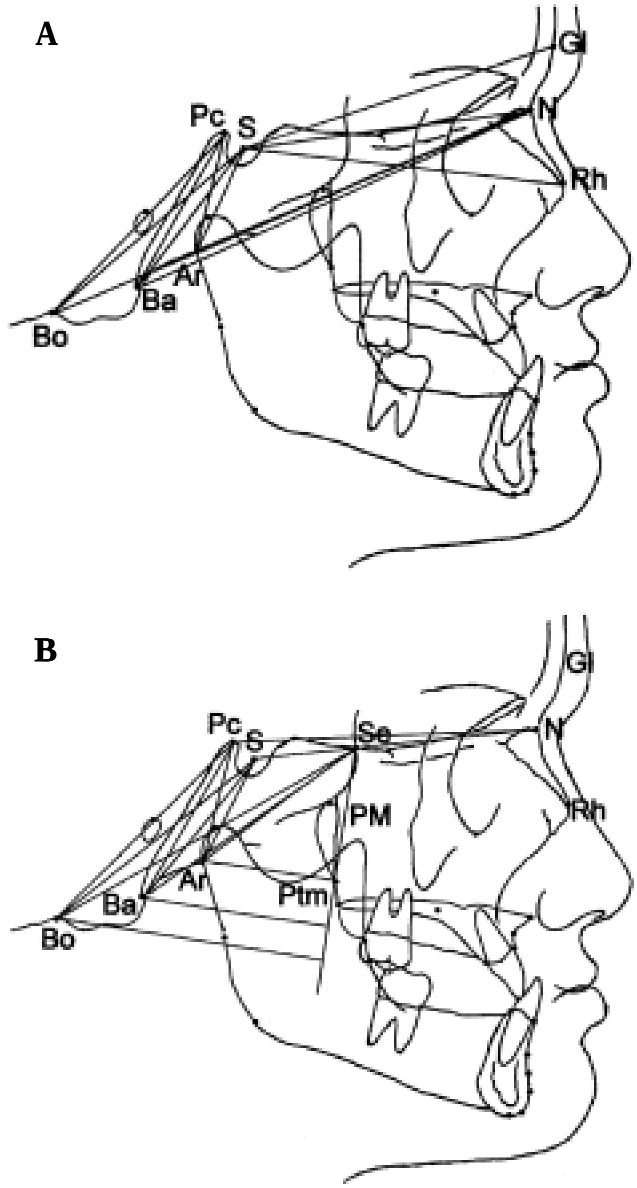

Figure 2. *Cranial linear and angular variables used for cephalometric analysis. (A) Linear variables (mm): N-Ar; N-Ba; N-Bo; S-N; S-Gl; S-Rh; S-Ar; S-Ba; S-Bo; Pc-Ar; Pc-Ba; Pc-Bo. (B) Posterior-maxillary (PM) plane: Se-Ptm. Linear variables (mm): Ar-PM; Ba-PM; Bo-PM; Se-Ar; Se-Ba; Se-Bo. Angular variables (°): N-S-Ar; N-S-Ba; N-S-Bo; Gl-N-Rh. (*Abbreviations as listed in Figure 1).

$ME = \sqrt{\sum d^2/2n}$; where d is the difference between two measurements in a pair; and n is the number of double measurements. MEs were 0.16–0.29 mm for linear measurements, and 0.26–0.60° for angular measurements. The reliability coefficients had been previously assessed [8] and ranged from 0.973 to 1.000, indicating a high level of reliability.

RESULTS

For the total cranial base, the lengths N-Ar (nasion-articulare), N-Ba (nasion-basion), and N-Bo (nasion-Bolton), were significantly shorter in individuals with Class III malocclusion than with normal occlusion ($p < 0.0001$, $p < 0.01$, and $p < 0.01$, respectively; Table 1).

For the anterior cranial base, the lengths S-N (sella-nasion) and S-Gl (sella-glabella) were significantly shorter in the Class III malocclusion group than in the normal-occlusion group ($p < 0.05$; Table 1). However, the upper midfacial length S-Rh (sella-rhinion) did not differ significantly between the two groups (Table 1).

For the posterior cranial base, the lengths S-Ar, Pc-Ar (posterior clinoid process-articulare), Pc-Ba, and Pc-Bo, were significantly shorter in the Class III malocclusion group than in the normal-occlusion group ($p < 0.001$, $p < 0.0001$, $p < 0.05$, and $p < 0.05$, respectively; Table 1).

From the posterior-maxillary (PM) plane or Se-Ptm (sphenoidale-pterygomaxillary fissure) line, the junction between the anterior and middle cranial fossae, the lengths Ar-PM, Ba-PM, Bo-PM, Se-Ar, Se-Ba, and Se-Bo, were significantly shorter in the Class III malocclusion group than in the normal-occlusion group ($p < 0.0001$, $p < 0.01$, $p < 0.001$, $p < 0.0001$, $p < 0.05$, and $p < 0.05$, respectively; Table 1).

The saddle angles (N-S-Ar and N-Pc-Ar) appeared to be more acute in the Class III malocclusion group than in the normal-occlusion group ($p < 0.05$ and $p < 0.01$, respectively; Table 1), although the cranial-base angles (N-S-Ba, N-Pc-Ba,

Table 1. Cephalometric measurements of cranial-base morphology in children with normal occlusion or class III malocclusion

	Normal occlusion (n = 100)	Class III malocclusion (n = 100)	Difference	p
Linear measurements (mm)				
N-Ar	92.0 ± 3.9	89.3 ± 4.2	2.7	< 0.0001*
N-Ba	104.7 ± 4.3	103.0 ± 4.5	1.8	0.0051†
N-Bo	122.6 ± 4.9	120.6 ± 4.7	2.0	0.0038†
S-N	67.7 ± 2.7	66.9 ± 2.8	0.8	0.0397‡
S-Gl	73.6 ± 3.0	72.7 ± 3.0	0.9	0.0313‡
S-Rh	77.6 ± 2.9	76.8 ± 3.7	0.8	0.1091
S-Ar	35.6 ± 3.1	33.9 ± 3.3	1.7	0.0003*
S-Ba	47.7 ± 3.3	46.8 ± 3.7	0.9	0.0844
S-Bo	61.9 ± 3.5	60.9 ± 3.8	1.0	0.0723
Pc-Ar	38.6 ± 3.2	36.7 ± 3.4	2.0	< 0.0001*
Pc-Ba	50.0 ± 3.5	48.7 ± 3.9	1.3	0.0142‡
Pc-Bo	62.7 ± 3.7	61.4 ± 4.1	1.4	0.0135‡
Ar-PM	34.1 ± 3.2	32.3 ± 2.7	1.8	< 0.0001*
Ba-PM	42.5 ± 3.3	41.0 ± 3.8	1.5	0.0042†
Bo-PM	59.7 ± 4.3	57.6 ± 4.7	2.6	0.0009*
Se-Ar	55.0 ± 3.7	52.4 ± 3.8	2.6	< 0.0001*
Se-Ba	68.0 ± 3.6	66.4 ± 4.2	1.6	0.0035†
Se-Bo	84.7 ± 4.2	83.0 ± 4.2	1.7	0.0039†
Angular measurements (°)				
N-S-Ar	122.9 ± 4.3	121.4 ± 4.8	1.6	0.0151‡
N-S-Ba	129.8 ± 4.5	129.2 ± 4.6	0.6	0.3228
N-S-Bo	142.5 ± 4.1	141.5 ± 4.1	1.0	0.1068
N-Pc-Ar	109.9 ± 4.2	107.9 ± 4.6	2.1	0.0013†
N-Pc-Ba	118.4 ± 4.3	117.7 ± 4.7	0.7	0.2471
N-Pc-Bo	132.3 ± 4.0	131.4 ± 4.2	0.9	0.1449
Gl-N-Rh	147.5 ± 4.9	149.2 ± 5.3	–1.7	0.0193‡

*$p < 0.001$; †$p < 0.01$; ‡$p < 0.05$. Data are presented as mean ± standard deviation. Ar = articulare (intersection of the condyle and the posterior cranial base); Ba = basion (lowest point on the anterior border of the foramen magnum); Bo = Bolton point (highest point behind the occipital condyle); Gl = glabella (most prominent point on the frontal bone); N = nasion (most anterior point on the frontonasal suture); Pc = posterior clinoid process (most superior point on the clinoid process); Rh = rhinion (tip of the nasal bone); S = sella (center of the sella turcica); Se = sphenoidale (intersection of the greater wings of the sphenoid and the anterior cranial base); PM = posterior maxillary.

N-S-Bo, and N-Pc-Bo) were not significantly different between the two groups. However, the frontonasal angle (Gl-N-Rh) appeared to be more obtuse in the Class III than normal group ($p < 0.05$; Table 1).

Multivariate Hotelling's T^2 tests indicated that statistical differences existed between the Class III malocclusion group and control for both angular and linear measurements of cranial-base morphology ($p < 0.0001$ and $p = 0.0001$, respectively; Table 2).

Discussion

The floor of the cranium develops in phylogenetic association with the brain [9]. A larger human cerebrum expands around a much smaller midventral segment (the medulla, pons, hypothalamus, and optic chiasma) [9]. This causes a bending of the whole underside of the brain and results in a flexure of the cranial base [9]. The foramen magnum in the typical mammalian skull is located at the posterior aspect of the cranium. In humans, it is in the midventral part of the expanded cranial floor at an approximate balance point for upright head support on a vertical spine [9]. As humans assumed a bipedal posture, complex phylogenic migration of muscles occurred and provided an effective balance for the head over the upright vertebral column [10].

The results of this study revealed that statistically significant differences in cranial-base morphology existed between children with Class III malocclusion and children with normal occlusion. The greatest differences were noted in the posterior cranial-base region, where marked shortening was evident. Previous cephalometric studies in individuals with Class III malocclusion have suggested that decreased angulation between the anterior and posterior cranial base (i.e. alteration of saddle angle) displaces the temporomandibular joint forwards, resulting in a prognathic facial profile [11–13]. Cohlmia et al indicated that skeletal and dental Class III patients have significantly more condyles positioned anteriorly on tomographic assessment [14]. Similarly, using axial computerized tomography, Seren et al reported relative condylar protrusion associated with anterior mandibular displacement in Class III malocclusion [15]. Decreased angulation between the anterior and posterior cranial base, particularly associated with the Ar, was also noted in the current study. Thus, anterior displacement of the temporomandibular joint appears to be demonstrable in children with Class III malocclusion.

Cranial-base angulation is considered to result from spheno-occipital synchondrosis [16,17]. The basilar portion of the occipital bone, also called the basiocciput, extends forwards and upwards from the foramen magnum and meets the body of the sphenoid bone at the spheno-occipital synchondrosis. The basiocciput is related to the petrous portion of each temporal bone along the petro-occipital synchondrosis and fissure [18]. Morphometric study indicates that the morphogenetic basis for anterior displacement of the mandible lies within the posterior cranial base, presumably coinciding with early cessation of growth activity within the petro-occipital complex [19]. Hoyte provides support for the belief that developmental mechanisms in the petro-occipital complex account for such anterior mandibular displacement [20]. Thus, divergent growth activities produce a Class III malocclusion, as demonstrated in animal models of midfacial retrognathic mice [21]. It is conceivable that insufficient proliferation within the posterior cranial-base cartilage could lead to the changes in form that are constituents of the Class III condition. The resulting prognathic face, characterized by shortening and angular bending of the cranial base, and a diminished angle between the cranial base and mandibular ramus [13], provides an indication of apparent cranial-base kyphosis, associated with the appearance of a Class III facial morphology [19].

The shape of the cranial base appears to be established during fetal development [22–24], and remains relatively stable during postnatal growth [25,26]. Kerr found that saddle angle was one of the few craniofacial parameters that varied little during the growth period from age 5 to 15 years [27]. An extensive longitudinal study by Bhatia and Leighton confirmed such stability in both sexes, although there was wide inter-individual variability for the different types of occlusion [28]. A prominent feature of this early growth is progressive flattening of the cranial base during late prenatal development [22,23,29,30]. Therefore, the Class III cranial-base morphology may be established very early in development, possibly at the

Table 2. Hotelling's T^2 test for angular and linear measurements of mean cranial-base morphology in children with Class III malocclusion versus those with normal occlusion

Angular measurement	*p*	Linear measurement	*p*
4.8675	< 0.0001	2.9713	0.0001

prenatal stage [31]. Moreover, such morphology may arise, not because of increased cranial-base flexion, but rather because of deficient orthocephalization, or failure of the cranial base to flatten anteroposteriorly. However, cranial-base flexure is not the only factor involved in determining malocclusion. Scott suggested that several factors determine or influence the jaw position and, consequently, occlusion in individual cases [32,33]. Three principal factors involved are the cranial-base angle, the extent to which the mandible and maxilla are moved forward in relation to the cranium, and the amount of surface bone deposition along the facial profile from nasion to menton [32,33]. In the current study, besides the more acute saddle angles in the cranial base, individuals with Class III malocclusion had a more obtuse frontonasal angle, presumably associated with a flatter midfacial profile.

The anterior cranial base provides the template that establishes the horizontal length of the midfacial complex, which is also relatively short in Class III malocclusion [34]. Therefore, the cranial base has a role in the final positioning of the midface and mandible that could account for the clinical presentation of mandibular protrusion and/or maxillary retrusion in individuals with Class III malocclusion. However, because of conflicting data in the literature [4–6], it seems that anterior cranial-base length may not play an important role in the pathogenesis of Class III malocclusion. The nasion may be quite variable in its position during growth and, thus, may contribute to the contradictory findings [27,35]. Another possible explanation for such findings is that the foramen cecum is the anterior anatomic limit of the anterior cranial base [36], and the nasion may not be appropriate for characterizing anterior cranial-base configuration.

In conclusion, shortening and angular bending of the cranial base, and a diminished angle between the cranial base and mandibular ramus, may be associated with the formation of a Class III malocclusion, and with the appearance of a Class III facial morphology. The association between cranial-base morphology and other types of malocclusion requires clarification. Further advanced study of regional changes in the cranial base, with geometric morphometric analysis, is now warranted.

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三級異常咬合兒童顱底形態的研究

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顱底形態與三級異常咬合之間的關係，吾人尚未十分清楚。本研究的目的，在於探討三級異常咬合兒童顱底形態的特徵。比較 **100** 名三級異常咬合兒童與 **100** 名正常咬合兒童的側面測顱放射圖形，進行單變項分析與多變項分析的統計檢定，主要結果顯示後顱底呈現最大的差異。結論如下：顱底的長度縮短與角度彎折以及顱底與下顎枝之間的角度減小，導致三級異常咬合以及相關臉形的形成。顱底形態與其他類型異常咬合之間的關係，尚待釐清；值得進一步進行幾何形態學分析的研究，以便更清楚地找出顱底局部變異的位置所在。

關鍵詞：測顱分析，兒童，三級異常咬合，顱底，形態

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