Spring 2015

Short lower anterior face height: phenotypic diversity

Julie Marie Wees
University of Iowa

Follow this and additional works at: https://ir.uiowa.edu/etd
Part of the Orthodontics and Orthodontology Commons

SHORT LOWER ANTERIOR FACE HEIGHT: PHENOTYPIC DIVERSITY

by

Julie Marie Wees

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Orthodontics
in the Graduate College of
The University of Iowa

May 2015

Thesis Supervisor: Professor Thomas E. Southard

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Julie Marie Wees

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Orthodontics at the May 2015 graduation.

Thesis Committee:

Thomas E. Southard, Thesis Supervisor

Steven D. Marshall

Nathan E. Holton

Sreedevi Srinivasan

ACKNOWLEDGMENTS

I would like to thank my husband, Paul, for his immeasurable support and encouragement during residency. I would also like to thank Drs. Tom Southard, Steve Marshall, Nathan Holton, and Sreedevi Srinivasan for their knowledge and input while serving on my thesis committee.

ABSTRACT

Introduction: Individuals with short lower anterior facial height (LAFH), reduced mandibular plane angle, and excessive overbite resulting from upward and forward mandibular rotation are traditionally classified as skeletal deep bites. Our purpose was to explore phenotypic variation within short LAFH individuals using geometric morphometric methods.

Methods: Cephalograms of 101 individuals (64 female, 37 male; age range: 7-62 years) with LAFH to total anterior facial height (TAFH), ratio (LAFH/TAFH), at or below 52.6% were studied. Principal component analysis, cluster analysis, and canonical variate analysis captured phenotypic variation and identified homogenous groups. **Results:** Four principal components were identified which accounted for 49% of the variation within the skeletal vertical and sagittal dimensions, flexure of the gonial angle, and incisor angulation. Cluster analysis resulted in 3 discrete short LAFH subpenotypes. **Conclusions:** Within the selected population of short LAFH individuals, we found: A range of morphologic variation. Convergent and divergent facial patterns with concomitant variation in gonial angle and ramus height. Anteriorly directed condylar morphology correlated with characteristics of extreme forward mandibular rotation; less anteriorly directed condylar morphology correlated with characteristics of backward mandibular rotation. Overbite magnitude is independent of vertical skeletal relationship and/or characteristics of forward mandibular rotation.

PUBLIC ABSTRACT

The term short lower anterior face height is one used to describe individuals with a shorter dimension of their face as measured vertically between the base of the nose and the chin. This facial pattern can make certain aspects of straightening the teeth and achieving an attractive smile using braces somewhat more difficult depending on the individual. There are not currently many scientific studies about facial patterns found within people sharing the trait of a short lower face. The purpose of this study was to explore possible different characteristics that might differentiate people with short face heights and see how these differences may help orthodontists achieve esthetic results during and after treatment with braces. We did this by finding the same 28 points on x-rays of 101 people using a method called geometric morphometrics. The results tell us that even within a group of people who should be similar (all of them having short lower face height), we see a lot of differences. These findings enable orthodontists to make more accurate diagnoses of their patients, ideally resulting in a better, more individualized plan for the orthodontic care of each patient.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

INTRODUCTION

The proper diagnosis and classification of individual patients is of paramount importance for successful treatment planning in orthodontics. Such a diagnosis includes careful evaluation of the dento-facial complex in the anteroposterior, transverse, and vertical dimensions. Skeletal dysplasia in any dimension typically complicates treatment, and may implicitly warrant or preclude certain treatments. Malocclusions of a skeletal nature can be especially difficult to treat, and therefore are particularly important to diagnose correctly.

In a study of cephalo-facio-dental relationships, Sassouni reported a definitive correlation between facial patterns and anterior vertical facial proportions. (1955) Wylie and Johnson, in a 1952 study, reported that in well-balanced individuals, total facial height (nasion-menton) is divided into 45% of nasal height or upper facial height (nasion-anterior nasal spine) and 55% of dental height or lower facial height (anterior nasal spine-menton). (1952) Schudy expounded upon the importance of vertical growth and its contribution to anteroposterior growth, overall facial types and degree of overbite. (1964) He introduced the terms “facial divergence” as well as “hyperdivergent” and “hypodivergent” as classifications of extremes along the vertical spectrum.

The term “skeletal deep bite” or “hypodivergent”, used to describe one of the distinct types of dysplastic vertical facial forms is typically characterized by a short lower anterior facial height (anterior nasal spine to menton), a concave profile, and nearly parallel cephalometric facial planes. (Sassouni 1964, 1969) (Nielsen, 1991) The etiology of such a vertical malocclusion is multifactorial. In studies using the implant method, Björk and Björk and Skieller demonstrated that the direction and amount of mandibular growth varies widely between individuals. (Björk 1955, Björk and Skieller 1972). Patients with upward and forward growth of the condyle often display reduced anterior facial height. A greater degree of forward mandibular rotation with a tendency toward more closure at the gonial angle is also characteristic of vertical skeletal deficiency. (Björk 1969, 1983)(Solow, 1988) Vertical growth of the face also depends on temporal fossa growth, degree of maxillary descent, and eruption of posterior teeth. Differences between anterior and posterior facial height development can also affect the vertical pattern of development. (Schudy 1964, Isaacson 1977, Baccetti 1997). When growth is balanced between anterior facial height (AFH) and posterior facial height (PFH), the mandible should translate during growth without rotation. However, if the PFH growth (determined by growth at the condyles and temporomandibular fossa) outpaces the growth in AFH (due largely to sutural lowering of the maxilla and dentoalveolar growth), exaggerated forward rotation of the mandible can occur, contributing to a shorter lower anterior facial height and overall deep bite facial pattern. (Björk 1983, Isaacson 1977, Schudy 1964)

Numerous authors have reported on the morphological differences between skeletal deep bite and skeletal open bite subjects. (Schudy 1964, Björk 1969, Sassouni and Nanda 1964, Nanda 1988, Fields et al. 1984) Variation within a group of long face patients was explored in a study by Schendel and Carlotti. (1985) In a 1978 study identifying parameters for diagnosis of short face patients, Opdebeeck and Bell described two subgroups distinguishing short face patients, however, further elucidation of phenotypic subgroups and variation within short face subjects is absent from the literature.

The purpose of this study was to extract phenotypes that can best describe the variation seen within a group of individuals presenting with short lower anterior face height using multivariate data reduction methods and geometric morphometrics.

REVIEW OF THE LITERATURE

The review of the literature revealed that studies pertaining specifically to skeletal deep bite are somewhat limited, which was an impetus for the study. The review will consist of an overview of the growth and development of the cranial base, maxilla, and mandible, with emphasis on growth in the vertical dimension. It will also include an overview of methods of assessment and treatment of vertical facial hypoplasia and a description of hypodivergent morphology in particular.

Cranial Base Growth

In prenatal life and throughout childhood, the chondrocranium (consisting mainly of cartilage) develops to accommodate the growing brain. Eventually in the cranial base, ossification occurs and growth is limited to chondrogenesis at the synchondroses. Membranous bone formation as well as sutural growth account for the formation of the cranial vault as well as the lateral and frontal portions of the cranial fossae, sutural growth being the major mechanism for growth. During development, resorption at the inner (meningeal) surface occurs with concurrent deposition along the outer surfaces, allowing for changes in the contour of the cranial vault. (Björk 1955)(Enlow 1982) The middle part of the cranial base grows until about 13 to 15 years of age in girls and until 15 to 17 years of age in boys, with remodeling at the rim of the foramen magnum also occurring during this period of time. Growth at the laterally positioned temporal lobes of the brain, as well as the concomitant skeletal remodeling of this region continues until adolescence. This growth is correlated with the forward and lateral/downward positioning of the temporomandibular fossa, which can influence the growth of the face. (Baccetti 1997, Bastir 2006)

Maxillary Growth

In the maxilla, growth occurs by apposition of bone at the sutures between the maxilla and the cranial base and by surface remodeling. (Enlow 1982) The sutures are located posteriorly and superiorly to the nasomaxillary complex. Primary displacement from the apposition of bone along the sutures displaces the maxilla in a downward and forward direction. Apposition also occurs in the posterior maxilla and in the area of the maxillary tuberosity, to account for the eruption of the primary and permanent dentition. The anterior maxilla is an area for bony resorption. The palate is relocated inferiorly through resorption on the nasal side accompanied by deposition on the oral side

In a 1966 study, Björk used the implant method to expound upon the overall pattern of maxillary growth. Metallic implants were placed within the maxilla to allow for highly accurate cephalometric superimpositions. His sample consisted of forty-five normal Danish males, with a lateral cephalogram taken annually. Forward growth in length is sutural toward the palatine bone, accompanied by periosteal apposition at the maxillary tuberosity. The downward descent of the maxilla takes place at the sutural articulations of the frontal and zygomatic processes and by periosteal apposition on the lower border of the alveolar processes. Björk also concluded that the expression of growth varies greatly between individuals, ranging from largely horizontal to almost completely vertical. The data from this and similar studies demonstrate how sutural growth and remodeling of the alveolar process take place simultaneously during the growth period; one-third of the growth attributed to sutural growth, and the remaining two-thirds to growth of the alveolus. (Baumrind 1996, Björk 1976)

Mandibular Growth

The mandible grows by both endochondral and periosteal activity. (Enlow 1982) The body of the mandible grows in length due to large amounts of bony apposition at the posterior border of the ramus. The bone on the anterior border of the ramus undergoes resorption during this time to allow for the eruption of the developing dentition. Cartilage covers the articular surface of the condyle. The condylar cartilage provides for growth of the condylar process and ramus by chondrogenesis and endochondral ossification. This partially accounts for growth in the height of the mandible. The condyle also adapts to repositioning, articular functioning, and mechanical loading through the process of remodeling. The pattern of mandibular growth is generally characterized by upward and slightly forward condylar growth, accompanied by resorption on the lower aspect of the gonial angle and some apposition below the symphysis, causing downward and forward translation of the mandibular body.

Björk and Björk and Skieller demonstrated through their implant studies the importance of the direction and amount of condylar growth for the development of certain patterns of growth. (Björk 1955,1969 Björk and Skieller 1972) Although the condylar head typically grows in an upward and slightly forward direction, variation in growth can contribute to vertical skeletal dysplasia. The growth of the condyle may be directed posteriorly, contributing to possible backward mandibular rotation and an overall hyperdivergent facial pattern. Conversely, excessive vertical or forward condylar growth may be a factor in the development of a hypodivergent facial growth pattern. A study by Buschang and Gandini evaluated 186 adolescents at 10 and 15 years of age and found significant superior and posterior growth at the condyle and ramus, which was greater in males than females. (2002)

Extreme vertical growth patterns are not only affected by condylar growth but can also be the result of differences between the anterior facial height (AFH) and posterior facial height (PFH). (Schudy 1964, Sassouni 1964) Differences in development between AFH and PFH lead to rotational growth or mandibular positional changes. (Isaacson 1977) An increase AFH has been attributed to greater sutural lowering of the maxilla as well as pronounced eruption of the posterior teeth. PFH is determined by lowering of the temporomandibular fossa and condylar growth. When condylar growth outpaces maxillary descent and eruption of the posterior teeth, forward rotation of the mandible occurs. Conversely, if dentoalveolar growth and growth of the maxillary sutures is greater than the growth at the condyles, backward rotation of the mandible is the result. (Schudy 1964)(Björk 1963, 1972, 1983, Solow 1984)

The center of rotation along the occlusal plane is also an important factor in those presenting with a tendency toward forward rotation. Björk demonstrated that the ideal center of mandibular rotation is located at the incisors. If the center of intramatrix rotation is located at the condyle or even in the region of the premolars in patients with an unstable anterior occlusion, a more extreme upward and forward mandibular rotation with underdevelopment of the anterior facial height can occur. (Björk 1969)

The Hypodivergent Facial Form

Two marked extremes of vertical facial forms have been described in the literature as "skeletal open bite"(hyperdivergent) and "skeletal deep bite" (hypodivergent). (Sassouni 1969, Schudy 1964) Although there are numerous studies concerning diagnosis and treatment of hyperdivergent individuals, it should be noted that the literature concerning the hypodivergent patient in particular was found to be quite limited.

The facial form of the deep bite patient is typically characterized by more convergent horizontal facial planes and presents with a reduced lower anterior facial height to total facial height ratio (N-Me). (Nielsen 1991) The patient often times presents with a concave profile, a deep labiomental sulcus, and an overclosed appearance.

In a study of the facial morphology of three groups of subjects, low angle, average, and high angle, Isaacson et al. found that high angle and low angle subjects had similar upper facial height development. (Isaacson 1971) Vertical height as measured from the palatal plane to the maxillary molars was significantly higher in the high angle subject group when compared to the other two groups, indicating that dentoalveolar eruption is greater in high angle cases. Janson et al. corroborated these findings in a study, where investigators found that dentoalveolar height was greater in patients with long anterior facial heights, and significantly shorter than in normal patients or in subjects with short lower anterior facial heights. (Janson 1994) The maxillary molars usually contribute more than the mandibular molars toward an overall increase in lower face height. Schudy contends that the downward movement of the maxillary molar teeth within the facial complex is the most important growth factor in reducing the amount of overbite, and the most important factor in establishing facial height. (Schudy 1968)

Differences in posterior dental eruption have been attributed to weaker musculature in high angle cases compared to stronger musculature in the low angle cases. (Möller 1966, Ingervall 1974) A common finding is that the masseter and medial pterygoid muscles have larger cross-sections in those with short lower anterior facial heights and small gonial angles compared to longer-faced individuals. (Kiliaridis 1991) Möller, Ingervall, and Ingervall and Thilander described the facial shape of individuals with great bite force or with high masticatory muscle activity as rectangular. (Möller 1966, Ingervall 1976, Ingervall and Thilander 1974) The facial morphology in these individuals was characterized by short anterior face height, anterior inclination of the mandible, convergence of the facial planes and a curved mandible. Ingervall found that strong muscles seemed to bring about forward rotation of the mandible, reducing the height of the lower anterior part of the face. (Ingervall 1978) In contrast, Van Spronsen at al. reported no significant correlations between either anterior facial height or posterior facial height and jaw elevator cross sectional areas. (Van Spronsen 1991) Future studies are needed in this area as no clear consensus has been reached.

Sassouni reported that in skeletal deep bite patients, the posterior vertical chain of muscles (masseter, medial pterygoid, temporal) is attached more anteriorly on the mandible and stretches in nearly a straight line vertically. The molars are directly under the impact of the masticatory forces of this muscle group, transmitting a greater depressive action to the posterior dentition (Sassouni 1969) Haskell et al reported that the superficial masseter was angled much more anteriorly in a hyperdivergent specimen when compared to a hypodivergent specimen. (Haskell 1986) However, Van Spronsen observed that the orientation of mandibular muscles could be quite similar despite differences in vertical facial morphology. (Van Spronsen 1996) The issue of whether masseter angulation is constant relative to the occlusal plane remains controversial.

Many investigators have reported on the proportion of upper or lower facial height to total facial height. (Coben 1955, Goldsman 1958, Opdebeeck 1978,) According to Wylie, upper facial height (N-ANS) should be 45 percent of total facial height (N-Me), and lower facial height should be 55 percent of the total height in a well-balanced face. (Wylie 1952) These values are similar to those reported by Strang and Thompson (ANS-Me, 55%), Goldsman (1958) (ANS-Go, 54.6%), Weinberg and Kronman (ANS-Go, 54.8%), Coben (ANS-Me, 54.6%), and Schudy

(1964) (ANS-Me, 54.6%). Lower anterior facial height has been reported to be greater in skeletal open bite patients when compared to norms, and decreased in patients termed skeletal deep bite.

Vertical Diagnosis

Studies have yet to produce irrefutable predictors of dysplastic vertical growth rather than the more typical and ideal downward and forward direction of growth. Morphological features thought to be indicative of vertical growth patterns include the angulation of the lower border of the mandible, the measurement of the gonial angle, the ramus length and inclination, the ratio of anterior face height (AFH) to posterior face height (PFH), the percentage of lower anterior facial height related to total anterior facial height, the degree of maxillary descent, the amount of molar eruption, and the amount and direction of condylar growth. Skieller at al. suggested that mandibular morphology might be used to predict the direction of any residual growth based on characteristics established by previous development. He suggested that the inclination of the mandibular symphysis, the shape of the lower border of the mandible, and the thickness of the cortical bone below the symphysis could act as morphological descriptors used to anticipate future growth. (Skieller 1984) Björk summarized seven criteria used to assess a difference between backward rotators and forward rotators including inclination of the condylar head, curvature of the mandibular canal, shape of the lower border of the mandible, inclination of the symphysis, interincisal angle, intermolar angles, and lower anterior facial height. (Björk 1969) The predictive value of the above criteria has yet to be established.

Tweed emphasized the importance of the mandibular plane angle in diagnosis. He suggested that the steeper the plane, the poorer the overall prognosis for improvement of facial esthetics. (Tweed 1946) In an analysis of his own cases, Tweed concluded that the best results were obtained in those cases with a Frankfort mandibular plane angle of 25˚. As reported by several investigators, the horizontal facial planes tend to be more divergent in persons with open bite and long lower face height than in deep-bite subjects with small lower face height and more convergent facial planes. (Muller 1963, Sassouni 1964, 1969, Isaacson 1977) For some investigators and clinicians, it is often assumed that values of mandibular plane angles can serve as prognostic indicators for direction and proportion of facial growth. However, Baumrind et al. and Skieller and Björk have suggested that a high mandibular plane angle is not a good predictor for growth. (Baumrind 1984, Skieller 1984) In a study of subject with long and short faces, Nanda suggested that although the palatal plane was found to be significantly different between the open bite and deep bite subjects, the inclinations of the occlusal and mandibular planes were not significantly different between the two facial types. He found that during comparable phases of development, the mandibular plane, the occlusal plane, and the gonial angle steadily decreased in both open bite and deep bite subjects. Nanda contends that the larger values for the mandibular plane in open bite patients are likely due to the spatial orientation of the palatal plane, while mandibular position and rotation is secondary to the maxilla. (Nanda 1990) The mandibular plane is constantly remodeling, with apposition of bone on the posterior inferior part of the corpus with or without remodeling at the lower border of the symphysis. The mechanism of adjustment in response to displacement of the mandible is change in the gonial angle, changes in dentoalveolar growth and intramatrix mandibular rotation. (Enlow 1982, Björk 1969)

Many investigators have reported that an obtuse gonial angle is associated with a skeletal open bite, while a more acute gonial angle is characteristic of a skeletal deep bite. (Opdebeeck 1978, Sassouni 1964, Trouten 1983, Jensen 1954) Björk, however, did not find the gonial angle to be a diagnostic factor between the two types of vertical extremes. (Björk 1947) Enlow contended that the gonial angle undergoes a compensatory counterrotation during facial growth to account for backward mandibular rotation, resulting in a reduction of the gonial angle with time. (Enlow 1982) Mair and Hunter found that the gonial angle was significantly correlated with mandibular growth during treatment, and also concluded that the inclination of the mandibular ramus was also significant. (Mair 1992) Conversely, Björk and Skieller reported that the ramal inclination does not change but rather maintains a constant relationship with the mandibular corpus during growth. (Björk 1972)

Extreme vertical growth patterns have also been attributed to the result in difference between anterior facial height, measured from Nasion to Menton (AFH) and posterior facial height, measured from Sella to Gonion (PFH). Differences height development in either region can lead to rotations or positional changes of the mandible. AFH is determined by sutural lowering of the nasomaxillary complex as well as dentoalveolar eruption. PFH is established through lowering of the temporomandibular fossa and condylar growth. (Isaacson 1977) There is some dissonance in the literature regarding the role of the posterior dimension in the etiology of vertical dysplasia. Björk demonstrated that an open bite is associated with a large ramus while Sassouni and Schudy reported that open bite is associated with a shorter ramal height. (Björk 1947, Sassouni 1964, Schudy 1964) These findings differ yet from those of Wylie and Fields et al. who reported a comparable PFH in open bite and deep bite subjects. (Wylie 1946, Fields 1984)

Treatment

Owing to the difficulty in changing skeletal facial patterns with traditional orthodontic therapy, clinicians have traditionally focused on improving and correcting the malocclusion as opposed to addressing the vertical dysplasia in non-growing skeletal deep bite patients. This is essentially accomplished in the same manner as treatment in a patient with a dental deep bite, that is, through arch leveling (eruption of premolars associated with backward mandibular rotation), intrusion of incisors, proclination of incisors, and molar extrusion. Most orthodontic mechanics are extrusive in nature. In an analysis of treated cases, Engel at al. has shown that an attempt to increase lower anterior facial height through the eruption of posterior teeth and resulting mandibular rotation is prone to relapse, ultimately resulting in a shortening of the face and increase in overbite. Deep bite patients with an underlying skeletal deep bite, presents the practitioner with the problem of a high probability of relapse, reported to be secondary to the influence of the musculature. (Spyropolous 1976) Traditionally, practitioners have advocated for nonextraction treatment, when possible, for skeletal deep bite patients as this approach has been shown to significantly increase lower anterior facial height when compared to treatment with extractions. (Chua 1993) The same study also reported that there was no appreciable difference in the lower anterior face heights of the extraction group, suggesting that extraction alone may not be effective in reducing lower anterior face height.

In a patient with remaining growth, orthopedics can be considered to enhance lowering of the nasomaxillary complex, increasing eruption of the maxillary and mandibular dentoalveolar segments resulting in downward mandibular rotation and a longer lower anterior face height. Cervical-pull headgear, used in class II correction, has been shown to reduce forward movement of A point, and causes a downward tipping of the anterior aspect of the palatal plane with slight extrusion of the maxillary molars. (Klien 1957) In an implant study, Melsen also identified a downward and backward rotation of the palatal plane with corresponding backward mandibular rotation. However, posttreatment, maxillary and mandibular growth exhibited a forward direction, indicating that the effects of cervical-pull headgear on overall growth patterns are temporary. (Melsen 1978)

Surgical treatment of the skeletal deep bite patient with vertical maxillary deficiency requires downward repositioning of the maxilla, typically with a LeFort I osteotomy. (Epker 1978) The amount of maxillary repositioning depends largely on the incisal and gingival display of the individual patient. As the maxilla is positioned inferiorly, backward mandibular rotation will occur, further increasing the lower anterior facial height. Sagittal surgical movements of the maxilla or mandible can be considered in conjunction with the LeFort downfracture as needed to address the overall resulting dental and skeletal anteroposterior positions. In a class II patient with adequate incisal display, a sagittal split osteotomy with clockwise rotation of the distal segment can increase lower facial height. A maximum increase of lower facial height can be obtained by leveling the mandibular arch post-surgically. Mandibular advancement prior to leveling the curve of Spee will result in an occlusion that is tripoded on the anterior teeth and bilaterally on the molars. (Bell 1984)

MATERIALS AND METHODS

The sample consisted of pre-treatment lateral cephalometric radiographs made from all healthy subjects (n= 101; 64 female, 37 male; age range: 7-62 years) who had presented for treatment at the University of Iowa Department of Orthodontics with a lower anterior facial height to total facial height ratio (LAFH/TFH, Figure 1) equal to or less than 52.6%. Exclusion criteria were any of the following: presence of facial syndromes, or poor quality records. The study protocol was reviewed and approved by the institutional review board at the University of Iowa.

A series of k=28 two-dimensional coordinate landmarks were collected using the lateral cephalometric radiographs. These landmarks spanned the upper and lower facial skeleton, and midline and lateral components of the cranial base. Coordinate landmarks are described in Table 1 and illustrated in Fig. 2. All data were collected using ImageJ (Rasbund 1997-2014). For any landmark that did not lie on the midsagittal plane, the midpoint between the right and left points was used. All images were initially traced in Dolphin Imaging

To assess for intraobserver reliability in landmark data collection, n=10 subjects were digitized on two separate occasions. Intraobserver error was assessed first by calculating the intraclass correlation for the x and y coordinates for each landmark used in the analysis. Next, we calculated the millimetric distance between homologous landmarks for each individual.

Coordinate landmark data were superimposed using Procrustes analysis, used in order to isolate size and shape variation from the individual landmark configurations. This is accomplished by first translating the centroid landmark configurations (i.e., the average of all the x coordinates and the average of all the y coordinates) to a common origin. Next, all subjects are scaled for size using individual centroid size values. Centroid size is defined as the sum of the squared distances between the centroid and each landmark in a configuration. Finally, the individual configurations are rotated using a least-squares criterion.

In order to maximize the number of individuals who met the minimum criteria for inclusion in our study, it was necessary to include a wide age-range. As such, a certain amount of morphological variation in our sample is going to be due to the effects of allometry (i.e., size correlated shape variation). Given that our research is not inherently developmental in nature, it was necessary to parse out allometric variation while retaining any variation that is not due to developmental differences in the sample. To do this, we used multivariate regression of our Procrustes shape variables on centroid size. Following this analysis, the regression residuals (i.e., shape variation that was not explained by centroid size) were extracted and used for all remaining analyses.

To assess patterns of morphological variation across individuals with skeletal deep bite, we first used principal components analysis (PCA) of allometry-corrected shape data. This method allows us to identify major axes of variation across the sample.

By convention, we examined components that accounted for more than 5% of the total sample variation. Morphological variation along these components was illustrated using wireframe models.

Next, we used cluster analysis to identify subgroups of relatively homogenous morphology within the category subjects presenting with short lower anterior facial height and to describe the morphological variation that defines these subgroups. Using individual principal component scores from all principal components (i.e. 100% of sample variation), we first used a hierarchical cluster analysis with Ward's method as a distance measure. Given that we had no *a priori* prediction regarding the number of clusters that were potentially represented in the total sample, this initial analysis was used as an exploratory technique to identify groups of relatively homogenous individuals based on morphological variation in craniomandibular shape. From the resulting agglomeration schedule, we identified the number of discrete clusters represented within the sample. Next, we used K-means clustering to define k number of clusters based on the results from the agglomeration schedule. Using the group assignments from the K-means clustering, we conducted a canonical variate analysis (CVA) of allometry-corrected shape data to examine the morphological variation that best separates the clusters.

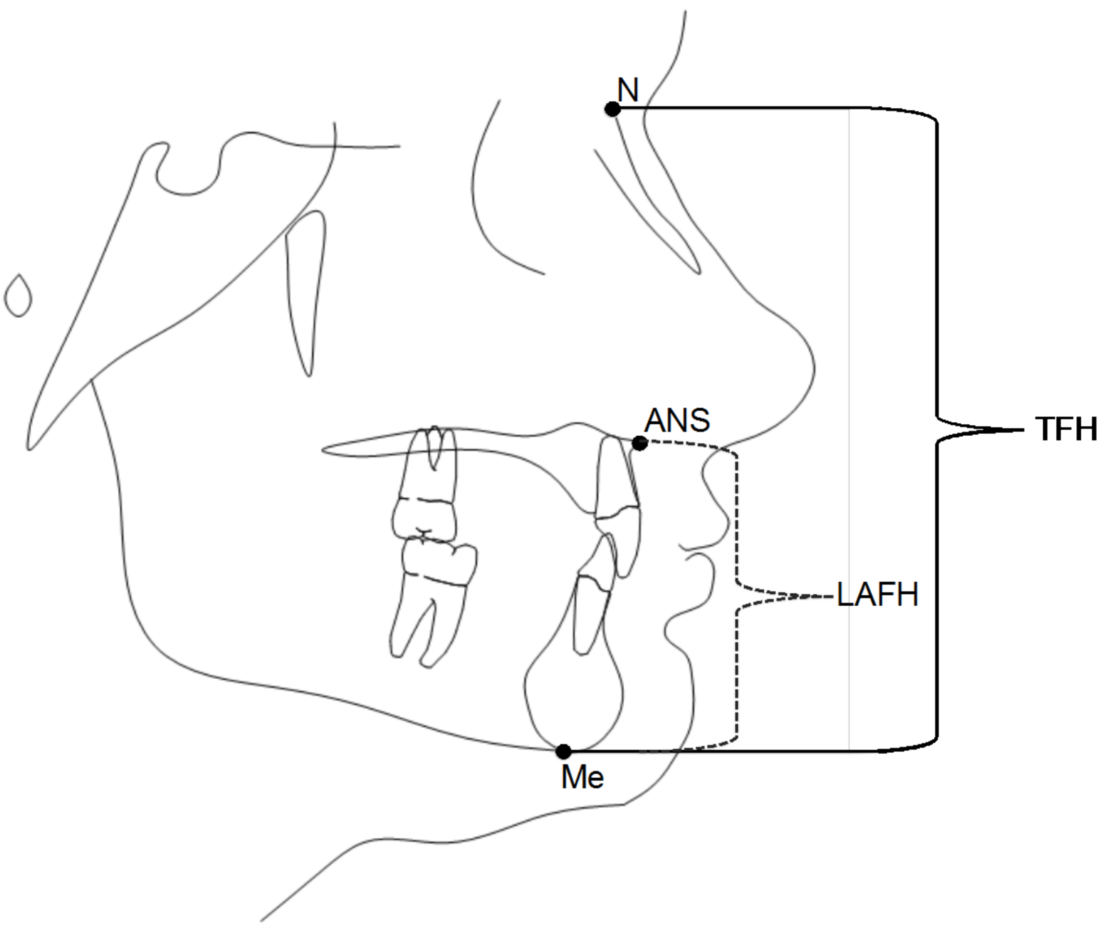

Figure 1. Measurements used to quantify lower anterior facial height (LAFH)

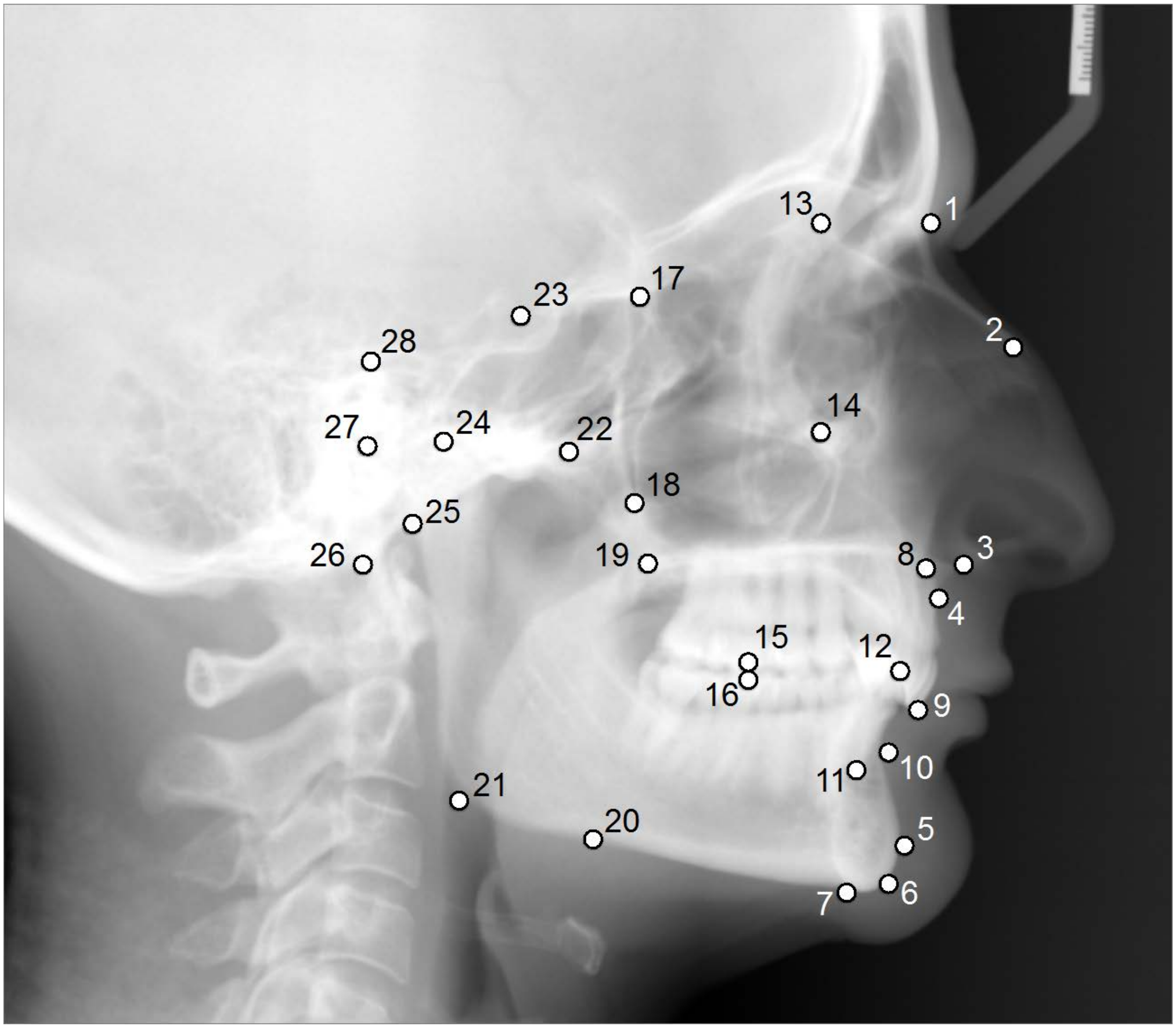

Figure 2. Landmarks used to quantify shape variation

Table 1. Cephalometric landmarks used to quantify shape variation

Landmark number	Landmark name
1	nasion
2	rhinion
3	anterior nasal spine
4	A point
5	pogonion
6	gnathion
7	menton
8	maxillary incisor root
9	maxillary incisor
10	B point
11	mandibular incisor root
12	mandibular incisor
13	anterior ethmoid
14	orbitale
15	maxillary first molar
16	mandibular first molar
17	greater wing of the sphenoid
18	pterygomaxillary fissure
19	posterior nasal spine
20	antegonion
21	gonion
22	floor of the midcranial fossa
23	sella
24	condylion
25	articulare
26	basion
27	porion
28	superior aspect of the petrosal bone

RESULTS

The results of the reliability study indicated good agreement between observations. Intraclass correlations for the x and y coordinates for each landmark ranged from r =0.80-0.99 with an average correlation coefficient of r =0.94. With regard to Euclidian distances values, the average distance for homologous landmarks between the two observations was only 2.32 mm (s.d.=1.26).

The principal component analysis of allometry-corrected shape data resulted in four principal components that each explained greater than 5% of the variance and accounted for 49% of the total variation within the sample (Fig 3). PC1 explained approximately 18% of the shape variation in the sample, and was associated primarily with variation in the vertical dimension. As evidenced from the wireframe models in Fig. 4, which represent the total range of variation along the axis, PC1 contrasts individuals with relatively longer anterior facial height with individuals who have relatively shorter anterior facial height. Individuals with a comparatively longer anterior vertical dimension are characterized by steeper mandibular planes and an increase in lower anterior facial height. This pattern is further associated with a relatively shorter mandible and a more vertically positioned condylar head. By comparison, individuals with relatively shorter anterior vertical dimensions exhibited a flatter mandibular plane and a more anteriorly positioned condylar head.

Variation in relative vertical facial dimensions was also evident in the upper facial skeleton and the cranial base. Individuals with a relative elongation of the anterior skeletal dimension also exhibited a relative increase in upper face height as evidenced by the superior displacement of nasion, and a dorsal rotation of the cranial base. In contrast, individuals with shorter anterior vertical facial dimensions were characterized by the opposite pattern. In spite of the vertical skeletal variation along PC1, there is little variation in the degree of overbite.

PC2 accounted for 16% of the variation within the sample. The range of shape variation along this component, illustrated in Fig. 4, largely contrasted skeletal and dental class II subjects from skeletal and dental class III subjects. Shape variation along this component was associated with anterior-posterior facial dimensions and the spatial relationship between the maxillary and mandibular regions. Class II skeletal deep bite subjects exhibited a relative anterior displacement of the anterior nasal spine and A point relative to the posterior nasal spine and pterygomaxillary fissure. Anterior projection of the upper facial skeleton was further evident in the anterior displacement of the nasal bones. This pattern was coupled with a relatively retrognathic mandible. Moreover, class II subjects demonstrated a greater degree of overbite. Class III subjects, in contrast, exhibited the opposite pattern.

PC3 and PC4 accounted for approximately 8% and 7% of the morphological variation respectively. PC3 (Fig. 5) described variation in the relative size of the posterior skeleton and posterior cranial base. In particular, there was variation in the vertical dimension of the posterior skeleton as evidenced by vertical displacements of gonion and the antegonial notch relative to the rest of the facial skeleton, which exhibited little variation along this component. In addition to the height of the posterior facial skeleton, there was variation in the relative anterior-posterior dimensions of the posterior cranial base region as evidenced by the displacement of basion, the superior aspect of the petrosal bone, and porion. There was also significant variation in the gonial angle along this component. Variation along PC4 was related largely to the degree of incisor proclination or retroclination in the sample. Individuals with greater retroclination exhibited greater dental overbite, while individuals with greater proclination presented with relatively minimal overbite.

With regard to phenotypic clustering of subjects with deep bite, we initially identified four discrete clusters based on the agglomeration schedule for the hierarchical cluster analysis (Fig. 6). However, after running the k-means cluster analysis to partition the sample into four clusters, one contained a sample of only n=6 individuals. Therefore, we ran the analysis to determine cluster assignments using only three clusters, which resulted in clusters with samples sizes of n=32 (cluster 1), n=21 (cluster 2), and n=48(cluster 3).

Using CVA, we assessed the shape variation that separated our three clusters. The first CV, which explained 59% of the variation, largely separated clusters 1 and 2 with cluster 3 located between these two extremes as indicated in the scatter plot in Fig. 7. The range of variation along this axis, illustrated in Fig 7, is associated with the vertical dimensions of the anterior facial skeleton, with cluster 1 exhibiting a more convergent facial shape with anterior mandibular rotation. Cluster 2, in contrast, exhibits a more divergent facial shape with a pattern of posterior mandibular rotation. Morphological differences between these skeletal patterns are largely independent of the vertical relationship between the upper and lower incisors.

CV2 explained 41% of the variation and separates cluster 3 from clusters 1 and 2, the latter two exhibiting complete overlap on the CV2 axis. Variation along this component, which is illustrated in Fig. 7, is primarily related to differences towards more of a class II skeletal and dental pattern (cluster 3) and a tendency for more of a class III skeletal and dental pattern (clusters 1 and 2).

Collectively, the results of our analysis suggest that the three clusters can be defined as follows. Cluster 1 exhibits relatively a shorter upper and lower anterior vertical facial dimensions. Moreover, subjects in Cluster 1 are characterized by a skeletal and dental class III relationship associated with a high degree of mandibular prognathism (Fig. 8). Individuals in Cluster 2 exhibit longer anterior vertical facial dimensions. This is evident in both the upper and lower anterior facial skeleton and is associated with a dorsal rotation of the cranial base and a steep mandibular plane. These subjects are characterized by a greater degree of posterior mandibular rotation and present with a more pronounced antegonial notch and reduced chin prominence. Cluster 3 is primarily characterized by short anterior vertical facial dimensions and a retrusive mandible and a class II molar relationship. Individuals in Cluster 3 are further characterized by a relatively greater mandibular ramus height resulting in flatter mandibular plane angle.

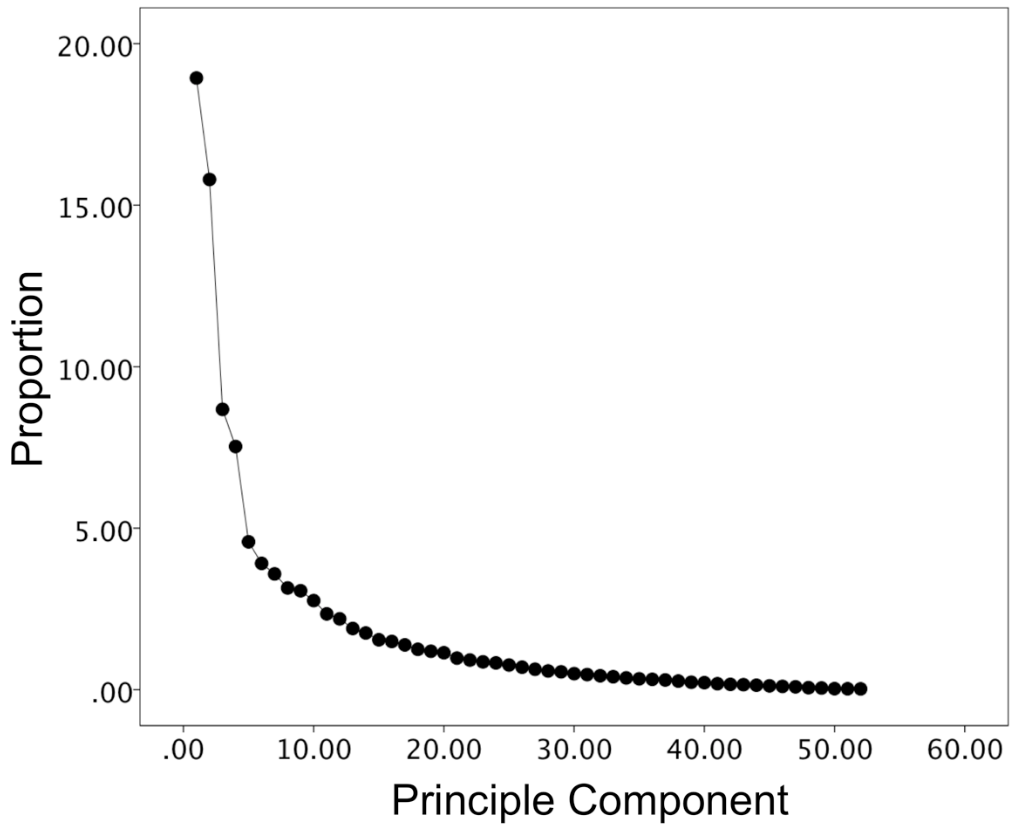

Figure 3. Scree plot illustrating variation explained by principal component analysis (PCA)

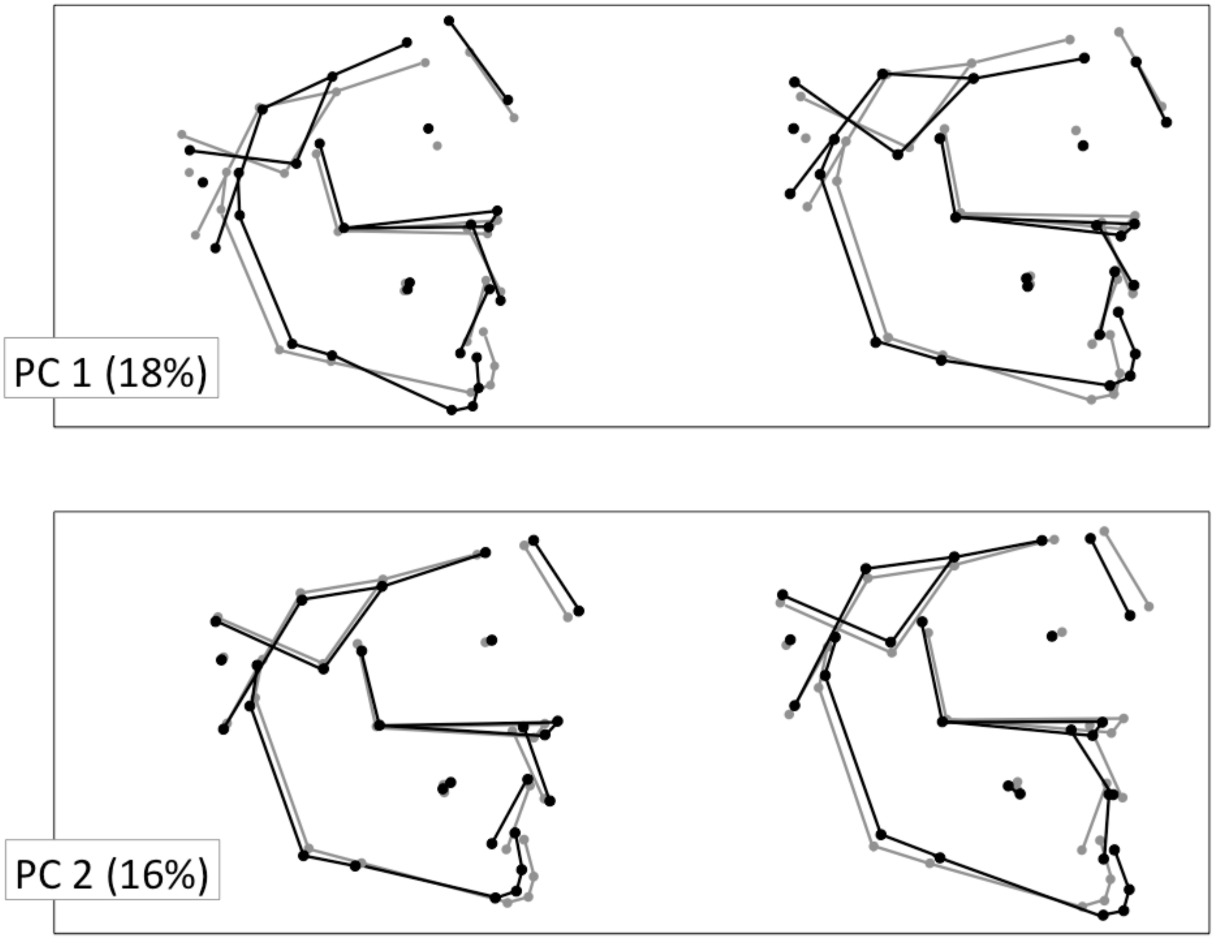

Figure 4. Shape variation along PC1 and PC2

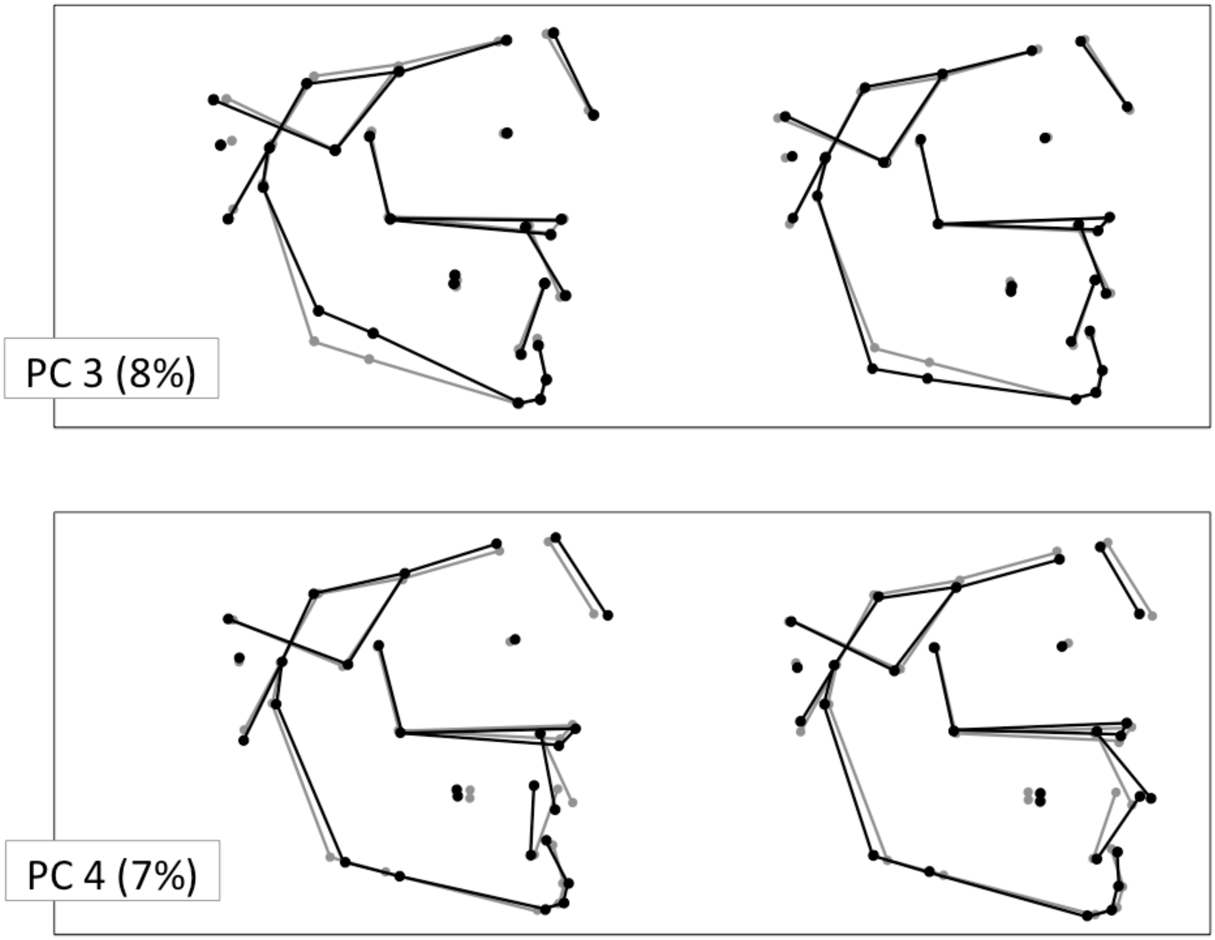

Figure 5. Shape variation along PC3 and PC4

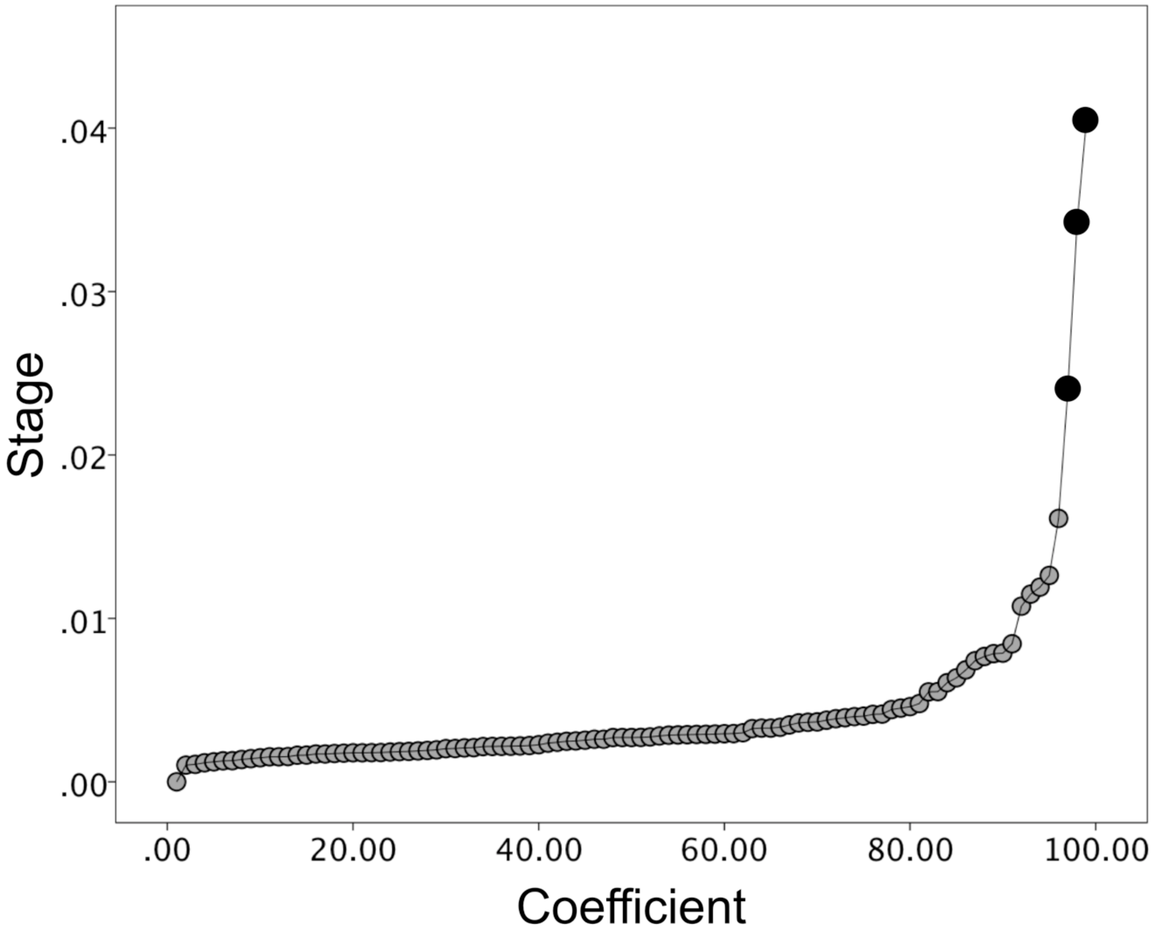

Figure 6. Scree plot of agglomeration schedule for cluster analysis

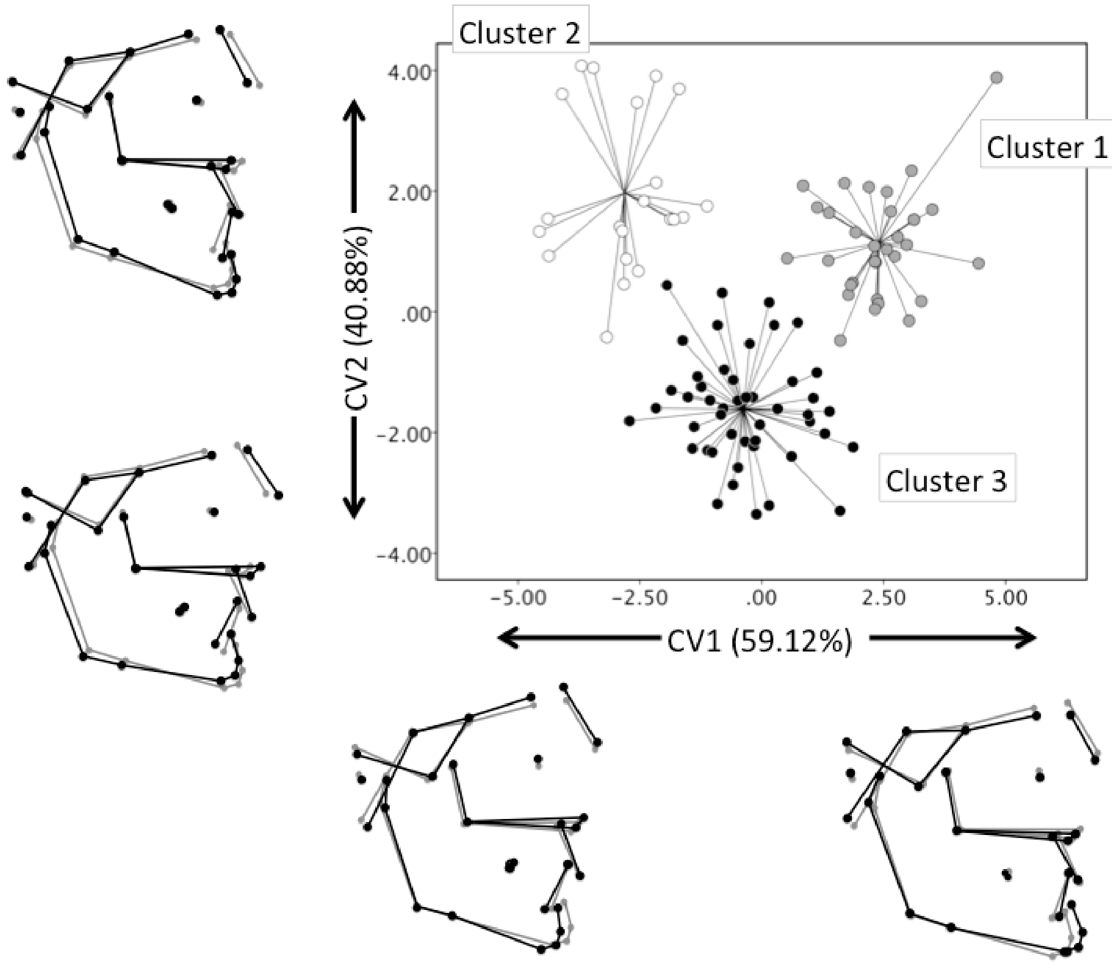

Figure 7. Scatter plot and shape variation for canonical variate analysis (CVA)

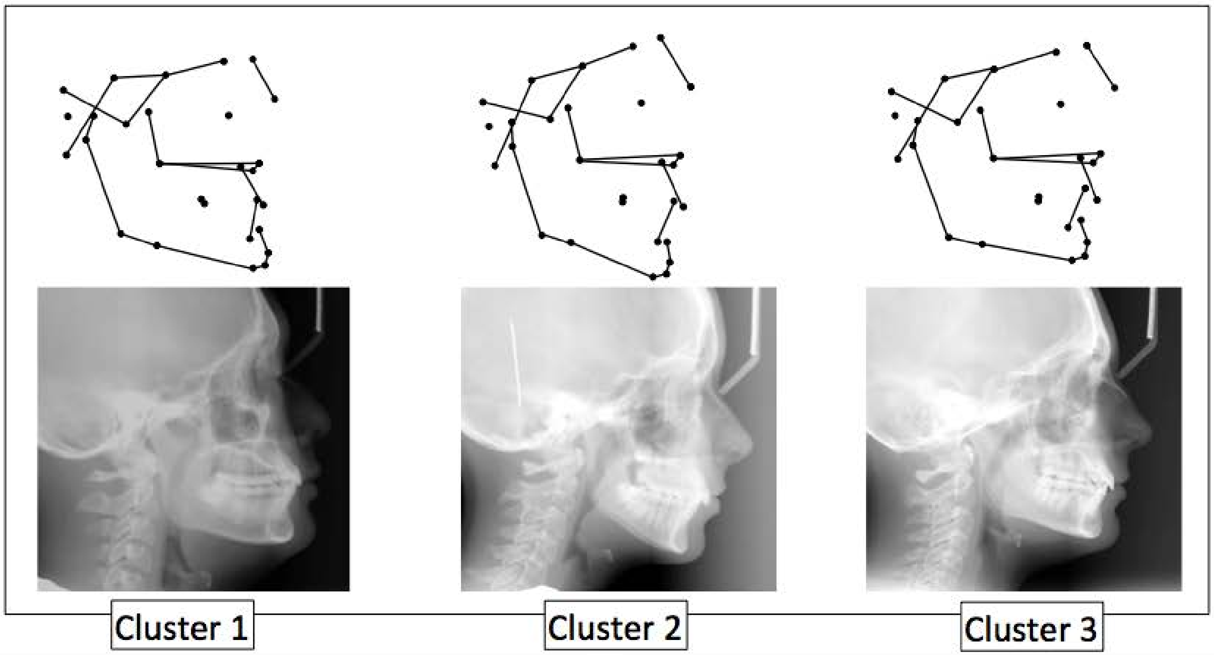

Figure 8. Mean shapes for each cluster in scatter plot

DISCUSSION

In order to effectively and accurately diagnose compounding dentoskeletal problems in the vertical dimension, the orthodontist must have an understanding of the morphologic characteristics commonly attributed to the hypodivergent patient, as well as the types and degree of variation that can be expected within the short face patient. The primary finding of this study were that great variation exists within a relatively homogenous sample of short face patients along the vertical and AP spectrums, and that overbite appears to be uncorrelated with vertical skeletal relationships.

The variation seen along PC1 is, to a great degree, related to the vertical dimension. On one extreme end of this component, we see an overall hyperdivergent facial pattern with dorsal rotation of the anterior cranial base, marked antegonial notching, and a greater degree of backward mandibular rotation. At the other end of the same component, we find a phenotype more classically descriptive of a skeletal deep bite patient. The facial planes are fairly parallel and the anterior cranial base more ventrally rotated. There is a greater degree of forward mandibular rotation with a more apparent rounded lower border of the mandible. Although the term "rocking chair mandible" exists within the literature to describe the diminished appearance of the antegonial notch attributed to the hypodivergent facial pattern; this appears to be the first time this result is documented as a result of a study of short lower anterior face patients. (Sassouni 1969) At the hypodivergent extreme of the component, a shallow cranial base is noted, corresponding with Bastir's findings with regard to cranial base flexure and overall vertical facial types. (Bastir 2006) There is also greater anterior angulation of the condyle with concurrent forward rotation of the mandible when compared to the other extreme along the same component. Björk and Björk and Skieller demonstrated through their implant studies the importance of the direction and amount of condylar growth for the development of certain patterns of growth. (Björk 1955,1969 Björk and Skieller 1972) Although the condylar head typically grows in an upward and slightly forward direction, variation in growth can contribute to vertical skeletal dysplasia. Excessive vertical or forward condylar growth may result in a greater degree of forward mandibular rotation, a characteristic classically seen in skeletal deep bite individuals. Our results support these findings, demonstrating that anterior direction of the condyle is indeed correlated with greater forward mandibular rotation. The cranial base presents with greater flexure in the hyperdivergent extreme, a finding again in accordance with that of Bastir. (Bastir 2006) The results from our canonical variate analysis, particularly CV1, support our findings from the PCA; we observe distinct groups separated along the extremes of the vertical spectrum within a sample selected for short LAFH.

The degree of overbite within the skeletal deep bite subjects was largely independent of vertical facial dimensions. That is, regardless of whether an individual exhibited relatively long or short anterior vertical facial dimensions, there was little variation in the vertical relationship between the upper and lower incisors. Indeed, Solow (1966, 1980) found that a deep bite can occur in individuals with longer faces suggesting a relative independence between skeletal vertical dimensions and overbite. However, this is in contrast to comparisons between hypodivergent and hyperdivergent subjects where the magnitude of overbite is correlated with anterior vertical facial dimensions. (Schudy 1965, Isaacson 1971, Nielsen 1991)

Our result is in general agreement with Kuitert et al. (2006) who also found that overbite was unrelated to facial height in individuals with shorter anterior vertical facial dimensions. However, unlike Kuitert at al., (2006) who argued that mandibular incisal dentoalveolar height was a key contributing factor in the degree of overbite in short face subjects, our results indicated that overbite was associated with relative skeletal anterior-posterior dimensions. In our sample, subjects with a class II skeletal and dental pattern had a greater degree of overbite while subjects with a more class III pattern had reduced overbite, and on the extreme end of the range of variation, exhibited an end-to-end incisor relationship. Additionally we found evidence that that a small percentage of variation in overbite was due to the relative proclination/retroclination of the upper and lower incisors, which was independent of shape variation in other regions of the facial skeleton. Relative proclination/retroclination of the incisors only accounted for 7% of the total shape variation and we cannot rule out the possibility that morphological variation along this axis is at least partially tied to oral habits affecting the anterior occlusion.

In PC2 and PC4 we see variation from one extreme to another in anteroposterior skeletal and dental positions and incisor angulation, respectively. CV2 demonstrates that we also see the same variation between groups of individuals. These variations were more or less unsurprising; it follows that within any sample of patients, we would expect variation in relative incisor retrusion or protrusion corresponding to differences in malocclusion. As this sample was selected by a criterion within the vertical dimension, variation along the sagittal spectrum is expected as well.

Numerous authors have reported that an obtuse gonial angle is associated with a skeletal open bite, while a more acute gonial angle is indicative of a skeletal deep bite. (Opdebeeck 1978, Sassouni 1964, Trouten 1983, Jensen 1954) In this study, PC3 demonstrates that we find great variation in gonial angle flexure within our sample of skeletal deep bite individuals. Morphology ranges from an extremely obtuse gonial angle with a shorter ramus to a highly flexed gonial angle with a longer ramus. Björk did not find the gonial angle to be a diagnostic factor between the two types of vertical extremes. (Björk 1947) The results from this study would also support the assertion that the gonial angle is not diagnostic of skeletal deep bite as we see clear evidence of both extremes within our sample of short face individuals.

Clinically, our results point to the fact that, even in seemingly homogeneous patient groups (such as short lower anterior facial height patients) orthodontists should expect to see a wide variation in cephalometric measurements. For example, in their study of mandibular changes induced by functional jaw orthopedics (FJO), Franchi and Baccetti suggested that the gonial angle could serve as a predictive parameter for mandibular changes induced by FJO, with "good responders" having a lower angular value when compared to "bad responders". (Franchi 2006) Our data suggests that, in patients with skeletal deep bite, a particular measurement of the gonial angle is not necessarily indicative of any specific type of growth or pattern of jaw relationship.

CONCLUSIONS

The primary purpose of this study was to explore the phenotypic variation within a group of skeletal deep bite individuals using principal component analysis, cluster analysis, and canonical variate analysis. The following conclusions are presented:

- A range of morphologic variation exists within a population of individuals selected for short lower anterior facial height.
- Within our sample, we see both convergent and divergent facial patterns with concomitant variation in the gonial angle and ramus height.
- Anteriorly directed condylar morphology is correlated with characteristics associated with extreme forward rotation of the mandible and less anteriorly directed condylar morphology is correlated with characteristics of backward mandibular rotation.
- Within this population of short face individuals, overbite magnitude is more greatly related to skeletal and dental AP relationship and incisal inclination that vertical skeletal relationships and/or characteristics associated with forward mandibular rotation.

REFERENCES

Sassouni V. A roentgenographic cephalometric analysis of cephalo-facial-dental relationships. Am J Orthod 1955; 41: 735-764.

Wylie WL, Johnson EL. Rapid Evaluation of facial dysplasia in the vertical plane. Angle Orthod 1952; 22: 165-182.

Schudy FF. Vertical growth versus anteroposterior growth as related to function and treatment. Angle Orthod. 1964; 34:75-93.

Sassouni V, Nanda SK. Analysis of dentofacial vertical proportions. Am J Orthod 1964; 50: 801-823.

Sassouni V. A classification of skeletal facial types. Am J Orthod 1969; 55:109-123.

Nielsen IL. Vertical Maloccusions: etiology, development, diagnosis and some aspects of treatment. Angle Ortho 1991; 61: 247-260.

Björk A. Facial growth in man, studied with the aid of metallic implants. Acta Odontol Scand 1955; 13: 9-34.

Björk A. Variations in the growth pattern of the human mandible: longitudinal cephalometric study by the implant method. J Dent Res 1963; 400-411.

Björk A. Sutural growth of the upper face studied by the implant method. Acta Odontol Scand 1966; 24:109-129.

Björk A. The use of metallic implants in the study of facial growth in children: method and application. Am J Phys Anthropol 1968; 29:243-254.

Björk A. Prediction of mandibular growth rotation. Am J Orthod 1969; 55: 585-599.

Björk A, Skieller V. Facial growth and development. An implant study at the age of puberty. Am J Orthod 1972; 48: 61-74.

Bkörk A, Skieller V. Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod 1983; 5: 1-46.

Solow B, Houston WJB. Mandibular rotations: concepts and terminology. Eur J Orthod 1988; 10: 177-179.

Isaacson RJ, Zapfel RJ, Worms FW, Erdman AG. Effects of rotational jaw growth on the occlusion and profile. Am J Orthod 1977; 72:276-286.

Baccetti T, Antonini A, Franchi L, Tonti M, Tollaro I. Glenoid fossa position in different facial types: a cephalometric study. Br J Orthod 1997; 24: 55-59.

Nanda SK. Patterns of vertical growth in the face. Am J Orthod 1988; 93: 103-116.

Fields HW, Proffit HW, Nixon WL, Phillips E, Stanek E. Facial pattern differences in long-faced children and adults. Am J Orthod 1984; 85: 217-223.

Schendel SA, Carlotti AE. Variations of total vertical maxillary excess. J Oral Maxillofac Surg 1985; 43: 590-596.

Opdebeeck H, Bell WH. The short face syndrome, Am J Orthod 1978; 73: 499-511.

Björk A. Cranial base development. Am J Orthod 1955; 41:198-225.

Enlow D. Handbook of Facial Growth. W. B. Saunders Company, Philadephia; 1982.

Bastir M, Rosas A, O'Higgins P. Craniofacial levels and the morphological maturation of the human skull. J Anat 2006; 209: 637-654.

Baumrind S, Ben-Bassat Y, Bravo LA, Curry S, Korn EL. Partitioning the components of maxillary tooth displacement by the comparison of data from three cephalometric superimpositions. Angle Orthod 1996; 66: 111-124.

Björk A, Skieller V. Postnatal growth and the development of the maxillary complex. In: McNamara JA Jr. Factors affecting the growth of the midface, monograph 6, Craniofacial growth series. Ann Arbor, MI: University of Michigan, 1976: 61-99.

Björk A, Skieller V. Facial development and tooth eruption. An implant study at the age of puberty. Am J Orthod 1972; 62: 339-383.

Buschang P, Gandini L. Mandibular skeletal growth and modeling between 10 and 15 years of age. Eur J Orthod 2002; 24: 69-79.

Isaacson JR, Isaacson RJ, Speidel TM, Worms FM. Extreme variations in vertical facial growth and associated variations in skeletal and dental relations. Angle Orthod 1971; 41: 219-229.

Janson G, Metaxas A, Woodside D. Variation in maxillary and mandibular molar and incisor vertical dimension in 12 year old subjects with excess, normal, and short lower anterior face height. Am J Orthod 1994; 106: 409-418.

Schudy FF. The control of vertical overbite in clinical orthodontics. Angle Orthod 1968; 38:19-39.

Möller E. The chewing apparatus. Acta Physiol 1966; 69:571-574.

Ingervall B. Facial morphology and activity of temporal and lip muscles during chewing and swallowing. Angle Orthod 1976; 46:372-380

Kiliaridis S, Kalebo P. Masseter muscle thickness measured by ultrasonography and its relation to facial morphology. J Dent Res 1991; 70: 1262-1265

Ingervall B, Thilander B. Relationship between facial morphology and activity of the masticatory muscles. J Oral Rehab 1974; 1:131-147

Ingervall B., Helkimo E. Masticatory muscle force and facial morphology in man. Archs Oral Biol 1978; 23:203-206

Van Spronsen PH, Weijs WA, Valk J, Prahl-Andersen B, Van Ginkel FC. Relationships between jaw muscle cross-sections and craniofacial morphology in normal adults, studied with magnetic resonance imaging. Eur J Orthod 1991; 13:351-361

Haskell B, Day M, Tesz J. Computer-aided modeling in the assessment of biomechanical determinants of diverse skeletal patterns. Am J Orthod 1986; 89: 363-382.

Van Spronsen PH, Weijs WA, Van Ginkel FC, Prahl-Andersen B. Jaw muscle orientation and moment-arms of long-face and normal adults. J Dent Res 1996; 75: 1372-1380.

Coben SE. The integration of facial skeletal variants. Am J Orthod 1955; 41:407-434.

Goldsman S. The variation in skeletal and dental pattern in excellent adult facial types. Angle Orthod 1958; 29: 63-92.

Strang RHW, Thompson WM. A Textbook of Orthodontia, 4th ed. Philadelphia: Lea and Febiger; 1958.

Weinberg H, Kronman JH. Orthodontic influence upon anterior facial height. Angle Orthod 1966; 36: 80-88.

Skieller V, Björk A, Lind-Hansen T. Prediction of mandibular growth rotation evaluated from a longitudinal implant sample. Am J Orthod 1984; 86: 359-370.

Tweed CH. The Frankfort mandibular plane angle. Am J Orthod and Oral Surg 1946; 32: 175-230

Muller G. Growth and development of the middle face. J Dent Res 1963; 42:385-399.

Baumrind S, Korn EL, West E. Prediction of mandibular growth rotation: an empirical test of clinical performance. Am J Orthod 1984; 86:371.

Jensen E, Palling M. The gonial angle. Am J Orthod 1954; 40: 120-133.

Björk A. The face in profile: an anthropological x-ray investigation on Swedish children and conscripts. Svensk Tandl Tidskr 1947:40. No. 5B, Suppl.

Mair AD, Hunter WS. Mandibular growth direction with conventional class II nonextraction treatment. Am J Orthod 1992; 101:543-549.

Engel G, Cornforth G, Damerell JM, et al. Treatment of deep-bite cases. Am J Orthod 1980; 77:1-13.

Spyropolous MN, Askarieh M. Vertical control: a multifactorial problem and its clinical indications. Am J Orthod 1976; 70:70-80.

Chua AL, Lim JYS, Lubit EC. The effects of extraction versus nonextraction orthodontic treatment on the growth of the lower anterior face height. Am J Orthod 1993; 104: 361-368.

Klien P. An evaluation of cervical traction on the maxilla and the upper first permanent molar. Angle Orthod 1957; 27: 61-68.

Melsen, B. Effects of cervical anchorage during and after treatment: An implant study. Am J Orthod 1978; 73:526-540.

Epker BN, Fish LC, Paulus PJ. The surgical-orthodontic correction of maxillary deficiency. Oral Surg Oral Med Oral Pathol 1978; 46: 171-205.

Bell WH, Jacobs JD, Legan HL. Treatment of class II deep bite by orthodontic and surgical means. Am J Orthod 1984; 85: 1-20.

Bastir M, Rosas A. Correlated variation between the lateral basicranium and the face: A geometric morphometric study in different human groups. Arch Oral Bio 2006; 51: 814-824.

Solow B. The pattern of craniofacial associations. Acta Odontol Scand 1966 Suppl; 46:45-75

Solow B. The dentoalveolar compensatory mechanism: background and clinical implications. Br J Orthod 1980; 7:145-161.

Kuitert R, Beckmann S, van Loenen M, Tuinzing B, Zetner, A. Dentoalveolar compensation in subjects with vertical skeletal dysplasia. Am J Orthod 2006; 129:649-657.

Schudy FF. The rotation of the mandible resulting from growth: Its implications in orthodontic treatment. Angle Orthod 1965; 35: 36-50.

Franchi L, Baccetti T. Prediction of individual mandibular changes induced by functional jaw orthopedics followed by fixed appliances in class II patients. Angle Orthod 2006; 76: 950-954.