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CONSTITUTIONAL DIFFERENCES OF CHIN ANATOMY AMONG GROWING AND NON GROWING PATIENTS WITH VARIOUS FACIAL DIVERGENCE PATTERNS

by

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AN ABSTRACT OF THE THESIS OF

Eliane GhariosZiade for Master of Science
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Title: Constitutional Differences of Chin Anatomy among Growing and Non Growing Patients With Various Facial Divergence Patterns

Association between bony chin, mandibular incisors, and symphyseal anatomy in different facial types has not been investigated. **Aims:** 1. evaluate components defining chin anatomy and determine constitutional differences in chin morphology, mandibular tooth size and position between hypodivergent and hyperdivergent patterns and across different types of malocclusions; 2. compare 2D and 3D imaging in determining specific morphological features of chin and teeth. **Methods:** Growing and non-growing patients were stratified into four groups based on mandibular plane inclination to cranial base angle (MP/SN). Measurements on pre-treatment lateral 2D (n=550) and 3D (n=296) cephalometric radiographs included: mandibular incisor crown (ICL) and total (IL) lengths; the following distances: between point D (center of symphysis) and both incisor apex (AD) and menton (DMe), chin width at the level of the incisor apex (CW1) and point D (CW2), between CEJ and menton (CEJ-Me), between the true vertical and points B and B1 (at intersection of the line through B parallel to MP, and posterior contour of the symphysis); and angles of anterior and posterior slopes, inter-slopes, mandibular plane and true vertical through nasion. Volume of the mandibular symphysis was measured using a special 3D imaging software. Group differences and associations between parameters were gauged using Kruskal Wallis test and non-parametric post hoc tests. **Results:** ICL, IL, AD, DMe and CEJ-Me were greaterin the hyperdivergent group ($p<0.001$). CW1 and CW2 were wider in the hypodivergent group ($p=0.003$). Analogous results were found between 2D and 3D imaging. Volume of the chin and inter-slope angles were similar in all groups ($p>0.05$), while anterior slope angle decreased with hyperdivegence ($p<0.005$) in opposite pattern to the posterior slope angle ($p<0.005$). **Conclusion:** Similarity in mandibular symphysis volume between opposite divergence patterns, along with shape differences among dental and symphyseal relations, underline the role of adaptive environmental factors during facial growth.

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Abbreviations

Abbreviations of different points used in the study	
ABBREVIATIONS	**LANDMARK**
A	A point
ANS	Anterior nasal spine
Ar	Articulare
B	B point
B1	B1 point
Ba	Basion
Co	Condylion
D	D point
I	Incisal edge
Me	Menton
Na	Nasion
OB	Overbite
OJ	Overjet
PNS	Posterior nasal spine
Pog	Pogonion
S	Sella

Abbreviations of different planes, angles and structures used in the study	
ABBREVIATIONS	**LANDMARK**
ANS-PNS	Length of the maxilla
Ant slope	Anterior symphyseal angle
AP slope	Inter-slope angle
BB1	Chin width between points B and B1
B-Pog	Length from B to pogonion
CEJ-Me	Length from CEJ to menton
Co-Go	Length of the ramus
Co-Go-Me	Jaw or gonial angle
Ar-Go-Me	Jaw or gonial angle
CWA	Chin width at the level of incisor apex
CWD	Chin width at the level of point D
Go-Me	Length of the body of the mandible
H	True horizontal
IA	Mandibular incisor length
IC	Mandibular incisor crown length
LFH/TFH	Lower to total face height ration
MP	Mandibular plane
Post slope	Posterior slope angle

PP	Palatal plane
S-Ar	Length of the posterior cranial base
SN	Length of the anterior cranial base
SN-Ar	Saddle angle
U1	Most proclined maxillary incisor
U1/L1	Inter-incisal angle
L1	Most proclined mandibular incisor

CHAPTER I

INTRODUCTION

The relationship between chin anatomy and the neighboring bony structures has been described extensively in different perspectives. Since the chin participates to a large extent in defining the facial outline, it would be interesting to assess the correlation between the mandibular incisors and the neighboring bony structures in various facial divergence patterns. Only few studies established the relationship between the mandibular symphysis and different types of malocclusions. However, the association between the bony chin, mandibular incisors, and symphyseal anatomy in different facial types namely the position of the lower jaw to the upper face in terms of vertical skeletal symphyseal morphology has not been investigated. For orthodontists, the utmost important reference of the craniofacial complex in evaluating facial esthetics of the lower third of the face is the mandibular symphysis. It plays a major role in developing a differential diagnosis while planning orthodontic treatment and orthognathic procedures. A thorough understanding and description of the symphyseal morphology is necessary to gauge individual growth changes used in weighing and planning treatment.

The aim of this study is to evaluate the components defining the chin anatomy and to determine the constitutional differences in chin morphology and tooth size between different facial patterns namely hypodivergent (flat) and hyperdivergent (steep) mandibular plane. In addition, we will be comparing the accuracy of 2D and 3D imaging in determining the chin and teeth anatomy.

Hypothesis

The presence of constitutional differences in chin anatomy and tooth size/position between hypodivergent and hyperdivergent patterns is associated with dentoalveolar adaptation to the vertical skeletal dysmorphology.

Aims and hypotheses

The aims (and corresponding hypotheses) are to:

1. Evaluate the presence of constitutional differences in chin anatomy (including symphyseal shape, size and vertical position of mandibular incisors) between hypodivergent and hyperdivergent patterns and across different types of malocclusions (Class I, II and III).

   The hypotheses corresponding to aim 1 were:

   a. *Chin volume remains the same but symphyseal components are rearranged differently across various divergence groups.*
   b. *The chin is narrower and longer in hyperdivergent individuals in comparison with hypodivergent individuals.*
   c. *Mandibular incisors are longer in hyperdivergent individuals in comparison with hypodivergent individuals.*

2. Explore constitutional components through gender differences. The corresponding hypothesis corresponding to aim 2 was:

   Males exhibit stronger and larger chin components than females.

3. Determine similarities and differences in chin components with age. The corresponding hypothesis corresponding to aim 3 was:

   Differences with ages are developmental, all components increase with age.

4. Compare 2D and 3D imaging in determining specific morphological features of chin and teeth. The corresponding hypothesis corresponding to aim 4 was:

   Chin morphology is more accurately assessed using 3D imaging compared to 2D imaging.

CHAPTER II

LITERATURE REVIEW

A. Importance of chin anatomy in orthodontics

An anatomical structure exclusive to Homo sapiens, the chin, or mentumosseum, is “a prominence at the front of the mandible” where mandibular teeth are embedded (Haskel 1979). It is formed by the dentoalveolarprocess and the basal symphysis (Nojima et al., 1998). The symphyseal feature develops early in fetal life and its architecture is maintained into adulthood (Hrdlička, 1911). According to Enlow and Moyers (1982), the infant has an incomplete shaped chin; it almost does not exist at all; he “has no chin” or “the jaw is much too small”. Nevertheless, it progressively undergoes remodeling changes along with other features of the face and becomes gradually more prominent throughout the years [Figure II.1, (Enlow, 1968)]. With age, chin prominence increases relative to the long axis of the symphysis(Bolander, 2007). Some authors defined the chin as a natural result of alveolar bone reduction and mandibular incisors’ inclination. This reduction contributed to a forward position of the basal portion and resulted in a protuberance. Hence, the chin development is related to the backward angulation of the mandibular incisors relative to the symphysis (Haskel 1979).

Symphyseal vertical growth molding is affected by the dento-alveolar development, the growth of the jaws, teeth eruption, and function of the lips and tongue

(Nielsen, 1991). The shape of the cortical bone bends and distorts as a response to forces spawned during function such as biting, chewing, and closing (Korioth et al., 1994).

Mandibular symphysis morphology influences the position of the mandibular permanent incisors during orthodontic planning and orthognathic surgery (Mahfoud et al., 2015). Theteeth attain their final position by the anterior remodeling of the mental protuberance and the posterior remodeling of the alveolar bone(Enlow et al., 1982).

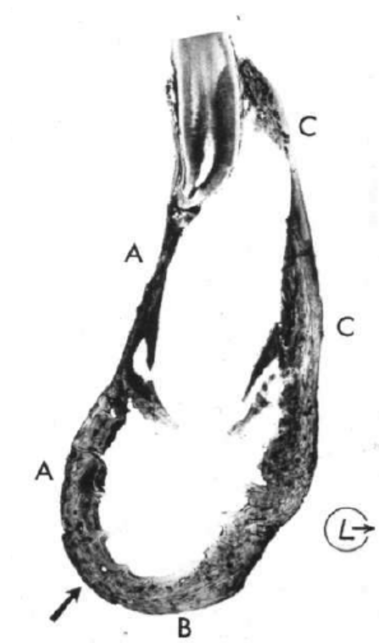

Figure II.1 Vertical section through the mandibular symphysis (adapted from Enlow 1968)

Even though the symphysis plays a major role in planning and evaluating orthodontic treatment, the literature provides very little quantitative information concerning its development and growth pattern. Symphyseal shape morphology is affected by many epigenetic and environmental factors such as the functional neuro-skeletal balance (Haskel 1979), masseter muscle thickness (Kubota et al., 1998), overbite (Haskel 1979; Kubota et al., 1998), vertical jaw relationships (Björk, 1969; Von Bremen et al., 2005), inclination of the mandibular incisors (Nojima et al., 1998; Yamada et al., 2007), inheritance (Garn et al., 1963) and more. According to Bolander (2007), symphyseal shape is affected by facial pattern starting the age of 11.

Back in 1963, Garn et al involved two generations of subjects in their study and demonstrated that the dimensions of the mandibular symphysis are predominantly gene-determined. They investigated symphyseal height and thickness starting at the age of 8, after completion of incisor eruption, and continued till 16 years of age in a total of 177 children for whom complete radiographic records were available and the parental mating was also known. 258 parents were grouped according to their mating combination High x High, High x Low, etc. Parents with greater symphyseal dimensions yielded progeny with high symphyseal heights, in contrast to parents with thicker symphyses (Garn et al., 1963)

Buschang et al. shed the light on significant symphyseal landmarks that vary between subjects depending on the direction of growth. The authors evaluated symphyseal growth of untreated subjects from childhood to puberty within an 8-year period; lateral cephalograms were taken 4 years before and after the estimated pre-pubertal growth velocity. According to their study, vertical growth changes at the level of the symphysis vary between 0.19 and 0.94 mm/year; greatest growth rates were found at the level of the most superior points of the alveolar crest (infra-dentale and lingual incisor contact point); the latter is linked to incessant supra-eruption of the dentition that fills the space created by downward and forward displacement of the mandible. Fastest growth rates are likely to occur in vertical growers, particularly those developing an anterior open bite. Intermediate and superiorly directed growth was manifested at the level of B point and the lingual symphyseal point. Menton, gnathion and pogonion showed little or no growth changes (1mm of inferior vertical growth over the 8-year period). Males exhibited considerably superior vertical growth rates than females. In terms of horizontal changes, B point presented the greatest rate for both genders (it was displacedlingually by 2mm over the 8-year period). Remarkably, infradentale and the lingual incisor contact point demonstrated lingual horizontal movement in females and no movement in males. Mandibular incisors in males preserve their horizontal position while the chin develops as a concavity increasing the mental sulcus and making the chin appear “strong” in contrast to females (P Buschang et al., 1992). Similarly, other authors described analogous interpretations and found that a decrease in MP/SN and gonial angles along with forward mandibular rotation led to bite closure in both genders. However, in terms of linear measurements, males exhibited greater values than females (Bolander, 2007; Chung et al., 2003; Karlsen, 1997). These findings corroborated with Bolander’s elliptical Fourier analysis of the chin, a clear sexual dimorphism was present in 70% of the sample (Bolander, 2007).

According to Ricketts, mandibular growth course may be anticipated by exploring the mandibular symphysis morphology. He outlined distinguished mandibular characteristics identifying the changes in the face that reflect an improved treatment planning: Mandibular plane angles, inclination of mandibular gonial angles, width of the ramus and the symphysis, thickness and inclination of the condyle head, corpus mandibular length, coronoid condyle plane or relative condyle coronoid length (suggesting that the chin habitually grows in the vertical dimension when the coronoid is higher than the condyle), and excessive notching; often indicative of condylar growth arrest and deficient posterior facial development (Ricketts, 1960).

Since 1948, orthodontists have been utilizing cephalometric landmarks in the field of comparative studies (Björk, 1963). Given that the chin is a major component of a pleasing and balanced facial appearance, Steinersearched for a stable point in the mandible to be used as a reference in studying positions of the jaws that vary with growth or orthopedic treatment. In the context of a series of cephalometric principles developed for clinical orthodontic practice, he suggested the use of point D at the center of the body of the mandibular symphysis (Figure II.2). Resembling point S (sella) in the cranium, D is not affected by teeth movement and normal growth of the underlying bone. In addition, it can be used as an accurate, reliable and easy landmark in superimpositions. Moreover, Steiner advocated the use of the angle SND as being more accurate than the angle SNB, in the assessment of the antero-posterior relationship of the jaws. He further suggested adopting the center of the symphysis to determine the correlation between the mandible and the mandibular central incisors (Steiner, 1959).

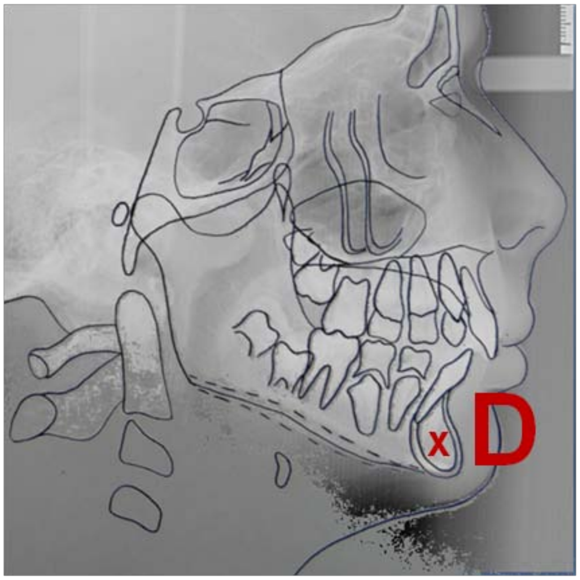

Figure II.2 Lateral cephalometric radiograph illustrating point D

B. Various facial types

Since decades, symphyseal anatomy has been a key tool for orthodontists. It dictates treatment diagnosis thus influencing treatment planning. Ricketts defined the terms “brachyfacial” and “dolicofacial” growth configurations to describe facial types according to the symphysis ratio (height/depth): it is supposed that a small symphysis ratio is concomitant with a wide chin, reduced anterior facial height and low mandibular plane to cranial base angle (MP/SN), saddle, articulare and gonial angles. Differing from large symphysis ratio, the chin is almost absent with a large anterior facial height and increased angular measurements such as mandibular plane, MP/SN, saddle, articulare and gonial angles (Ricketts, 1960). Deviations from the normal pattern are compatible with the long face syndrome or adenoid facies, representing a severe expression of the “dolichofacial” phenotype (Fields et al., 1984). These deviations, such as mouth breathing due to blocked airways, impinge on normal function resulting in a severe malocclusion (Harvold et al., 1981). Consequently, adaptive reorganization occurs recalling Moss’ functional matrix theory (Moss et al., 1969).

Schudy was the first to describe the two opposite directions of facial typology as hypodivergent and hyperdivergent patterns, based on the relation between mandibular plane (MP) and occlusal plane (Figure II.3). Moreover, he advocated the use of MP/SN angle in treatment planning to designate various facial types. Schudy asserted that the vertical dimension is “the most important dimension to the clinical orthodontist”(Schudy, 1963). Variations in the tilt of the palatal plane may contribute to hyperdivergence, the severity of the vertical skeletal discrepancy may increase when combined with a steep mandibular plane (Joseph Ghafari et al., 2013).

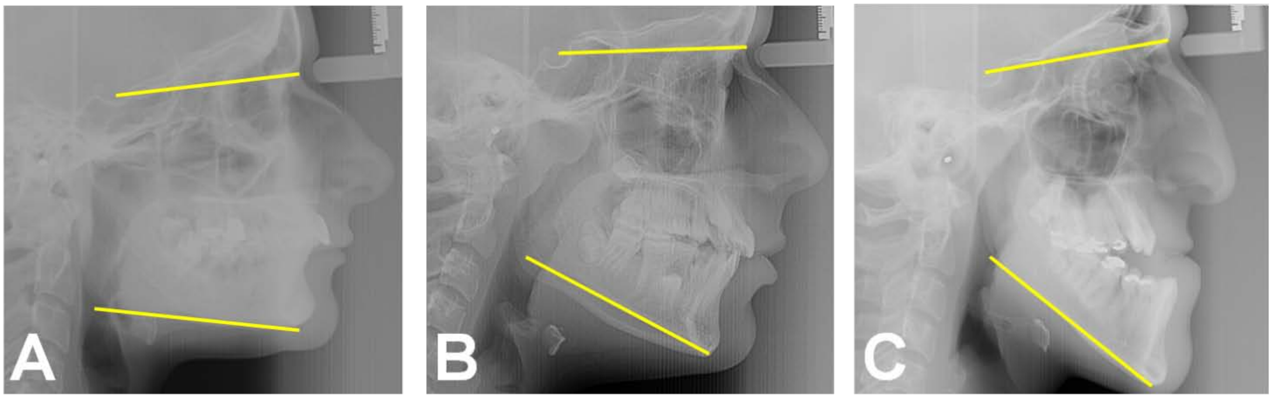

Figure II.3 Lateral cephalometric radiographs of

A. Hypodivergent individual (MP/SN ≤ 27°)

B. Normodivergentindividual (27°< MP/SN< 37°)

C. Hyperdivergent individual (MP/SN ≥ 37°)

A hypodivergent pattern is characterized by an increased posterior to anterior facial height ratio, a reduced lower facial height, an obtuse mandibular plane angle and a deep bite. Conversely, a hyperdivergent pattern displays opposed features to the hypodivergent growth pattern. These patterns were later identified as “short face syndrome” (Opdebeeck et al., 1978) and “long face syndrome” (Schendel et al., 1976). Likewise, the literature describes a multiplicity of names under one facial type with the extreme vertical growth of the maxilla: high angle type, adenoid faces, idiopathic long face, and extreme clockwise rotation, vertical maxillary excess and total maxillary alveolar hyperplasia (Schendel et al., 1976).

Some authors suggested that low MP/SN angles favour the forward rotation of the mandible. This growth pattern occurs when the sum of the vertical growth components at the facial sutures and/or alveolar processes is less than the vertical growth at the condyles leading to a decreased lower facial height and reduced ramus height. The forward rotating

MP/SN angle allows pogonion to move forward, subsequently generating a more prominent chin and a curled lower lip. The decrease in MP/SN angle affects also the dentition leading to decreased anterior dental heights, as well as shorter maxillary and mandibular molars. Even though the maxillary incisors are shorter, the patients develop a tendency toward deep overbite. Opposing morphological characteristics are expressed in backward rotating increased MP/SN angle cases. The mandible rotates backward when the vertical growth at the facial sutures exceeds the vertical growth at the condyles leading to an increased lower facial height. The latter displaces pogonion more forward and downward leading to a less prominent chin. Albeit the maxillary incisors are already distinctly longer, patients exhibit a tendency towards open bite. With continuance of the growth patterns, such overbites and open bites are expected to get worse (Isaacson et al., 1971).

Based on histological studies and metallic implants, mandibular structures were set as stable references to be used in superimposition methodology. Bjorkplaced metallic implants in the maxilla and the mandible to evaluate the absolute growth modifications of the jaws themselves. He demonstrated that the anterior border of the symphysis is particularly unchanging with no noticeable remodeling, except in rare pathologic cases. However, its lower and posterior borders are characterized by apposition leading to its increase in height and thickness accentuated during adolescence. These remodeling alterations restructure the mandible leading to considerable morphological reshaping. The inner cortical structure at the inferior border of the symphysis, the tip of the chin, the mandibular canal as well as the lower border of a developing molar germ were reported to be fairly stationary and can be used in analyzing the vertical development of the face (Björk, 1963).

The relationship between chin anatomy and the neighboring bony structures has been approached from different standpoints. However, few studies have established a relationship between the morphology of the mandibular symphysis and facial typologies. According to Haskel, the chin increases in size as the facial type varies from vertical type, to a normal type, to a horizontal type of growth pattern (Haskel 1979).

Bjork outlined clinical applications arising from studies of craniofacial growth, by means of the implant technique, in children with and without malocclusions. He termed two different types of mandibular condylar growth based on the location of the centre of rotation of the mandible (either it is as the condyle, incisors or premolars). He found the bony chin to be prominent in mandibles with anterior rotation, and inclined backwards with posterior rotation. Bjork identified 7 essential clinical signs on lateral cephalograms important in defining various types of mandibular growth According to Bjork, not all the morphologic features would be found in a particular individual, but the greater the number present the more reliable the prediction would be(Björk, 1969):

- Inclination of the condylar head
- Curvature of the mandibular canal
- Shape of the lower border of the symphysis
- Inclination of the symphysis
- Inter-incisal angle
- Inter-premolar or inter-molar angles

- Anterior lower face height

Brodie asserted in a longitudinal study of children that the morphogenetic pattern of the human head tracks a sequence from infant to adulthood that is determined by age 3 months (Brodie, 1942). In 1985, Bishara and Jakobsen examined longitudinally lateral cephalograms of 20 males and 15 female with Class I molar and canine and less than 3mm of arch circumference discrepancy. X-rays were taken biennially between the ages 4.5 and 12 years and annually from 17 to 25.5 years of age. As Bishara and Jakobsen indicated, 77% of subjects preserve the same facial type from 5 to 25.5 years of age despite the progression of facial growth even though comparable growth patterns were observed. However, the sample comprised subjects with normal occlusion; subjects with more severe and complex skeletal and dental relationships should be included to generalize the findings of the study (Bishara et al., 1985).

The data obtained from Aki et al.'s study specified that the deposition of bone at pogonion is gender linked: male subjects showed a larger symphyseal depth in comparison to females. In both genders, symphyseal changes occurred up to adulthood (mean age 20.9 years) demonstrating an increase in height and depth whereas the postero-superior angle defined between menton-B point and the mandibular plane decreased with age (Aki et al., 1994). These results are consistent with the findings of Mangla et al. (2011).Ramus height was also found to be significantly decreased in hyperdivergent individuals when compared with normodivergent and hyperdivergent groups. Additionally, sexual dimorphism was statistically significant with females having smaller ramus height than males. The mandible appeared to have reserved its infantile features with all its components undersized in high angle cases (Mangla et al., 2011; Muller, 1963; Sassouni, 1958).

Gracco (2010) and Aki (1994) demonstrated that an anterior direction of the mandibular growth is associated with small height and proportions, large thickness and angle of the symphysis. On the opposite, increased height and size, decreased thickness and angle of the symphysis are characteristics of mandibular growth with posterior direction (Aki et al., 1994; Gracco et al., 2010). Likewise, similar results were found by Handelman et al. who validated that the distance between the anterior limit of the mandibular symphysis and the root apices of the mandibular central incisors is thinner in long face than short face individuals (Handelman, 1996).

Mandibular tooth size is also affected by the vertical facial pattern. Townsend and Brown suggested that about 64% of the total variability of permanent tooth size could be due to genetic factors. Only 6% of tooth size variability were attributed to environmental factors (Townsend et al., 1978). El Bialy et al. applied pulsed ultrasound therapy to promote bone healing and to allow an increased distraction rate in mandibular osteodistraction in a rabbit model (El-Bialy et al., 2002). They proved that therapeutic ultrasound boosted mandibular incisor growth and eruption in rabbits undergoing mandibular distraction osteogenesis compared with the non-distracted rats. The ultrasound had influenced the pattern of cellular differentiation, tissue formation and growth. These finding suggest that mandibular incisor length and eruption might be influenced by environmental factors (El-Bialy et al., 2003).

Mandibular symphysis dimension and outline are essential in orthodontic planning. With a thin and long symphysis, frequently affiliated with a retrusive mandible, greater chance of extraction treatment is considered to compensate for a severe arch length discrepancy. On the contrary, more proclination and protrusion of mandibular incisors are esthetically tolerated when the symphysis is large, leading to a non-extraction technique. Treatment alternatives and the endeavor to position adequately the mandibular incisor in order to avoid any iatrogenic periodontal damages are mainly influenced by the anterior most limits of the anterior teeth. The latter is dictated by the anatomical shape of the symphysis. The amount of labiolingual bony support is critical especially when planning orthognathic surgeries; more forceful bone thickness is preferred to evade any side effects. It has been shown that, in all facial types, compared with the adjacent teeth, the symphysis is considerably larger at the level of the central incisors; providing more leeway of proclination of retroclination(Gracco et al., 2010). Some authors correlated mandibular crowding with symphysis dimensions in treated individuals. While a narrow symphysis is more commonly observed in individuals with increased facial divergence, subjects with the narrowest and taller symphysis presented significantly more incisor irregularity prior to orthodontic treatment and during the post-retention period, most probably due to reduced bony support for the mandibular incisors (Mess, 2012).

Even though both sagittal and vertical discrepancies may often be encountered separately, they are highly correlated, since a problem in the vertical pattern may camouflage or increase another problem affecting the sagittal pattern.

C. Diagnostic classification

1. Angle's classification

To achieve an ideal occlusion, the mesiobuccal cusp of the maxillary permanent first molar should is related to the buccal groove of the mandibular permanent first molar. Hence, Edward H. Angle labeled the maxillary first molar as the key to occlusion. . Consequently, arrangements falling outside this definition were considered abnormal and characterizedas a "malocclusion" (William Proffit et al., 2000).The Angle's classification of malocclusion entailed four types: (Figure II.4)

- Normal occlusion: the mesio-buccal cusp of the maxillary first permanent molar is occluding with the buccal groove of the mandibular first molar and the crowding is minimal.
- Class I: the molars occlude in normal mesio-distal relations but the amount of crowding is increased(William Proffit et al., 2000).
- Class II: mandibular molar is in a distal position relative to the maxillary molar for more than one-half the width of one cusp, however, the amount of crowding may or may not be moderate.

  In class II, there are two divisions, eachpresenting a subdivision. The foremost difference resides the position of the maxillary incisors:

  - Division 1: characterized by bilaterally distal occlusion of the teeth with proclinedmaxillary incisors. "Subdivision, Division 1" occurs when the distal occlusion is unilateral, the other being normal.

- Division 2: also characterized by bilaterally distal occlusion of the teeth with retroclinedmaxillary incisors. Also when the distal occlusion is unilateral, the other being normal, it is known as “Subdivision, Division 2”.

- Class III:mandibular molar is in a mesial position relative to upper molar more than one-half the width of one cusp, the amount of crowding may or may not be increased. When the mesiocclusion is bilateral, it is called “Division 1”; when it is unilateral, the other being normal,it is called “Subdivision, Division 1”. When the etiology is genetic, it is called a “true class III” and a “pseudo class III” when it is mostly due to habits(Angle, 1970).

One potentialmalocclusion typemight occur where one side of the mandibular arch is in distal occlusion while the other is in mesial occlusion. Such cases are very unusual that additional references to them seem pointless(Angle, 1970).

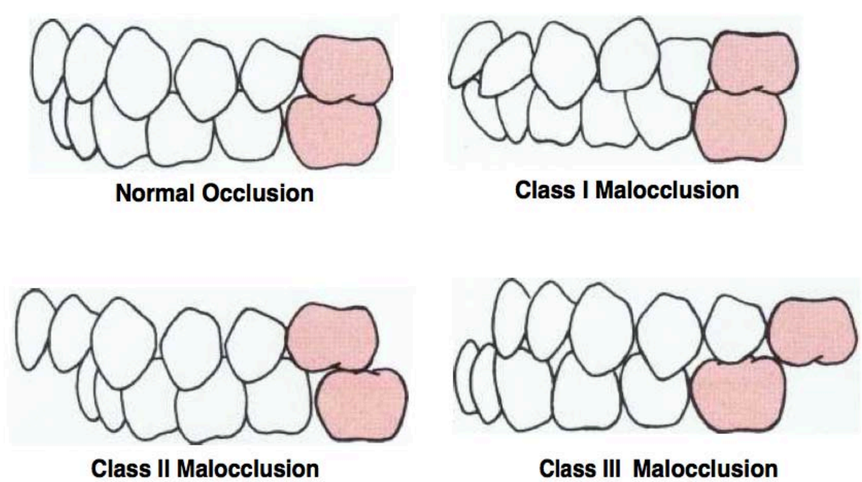

Figure II.4 Normal occlusion and malocclusion classes as indicated by Angle (adapted from Proffit and Fields 2000)

Several logical reasons reside behind this classification: the maxillary first molars offer a precise scientific basis for defining occlusal disharmony and occlusal anomalies since they are the biggest and the strongest teeth for anchorage. Moreover, they sustain the main masticatory function. These teethinfluence the vertical distance of upper and lower jaws as well as the occlusal height and esthetic proportions. Since the permanent molars are the first erupting teeth of permanent dentition, they influence the teeth erupting later behind and in front of them (Hassan et al., 2007).

Angle's classification was the first published method of recording malocclusion and is still widely used till our days due to its relative simplicity (Freer et al., 1968). Nevertheless, many authors criticized Angle's system. Most of these criticisms deal with the following problems:

- Transverse and vertical dimensions are not taken into consideration; only antero-posterior deviations are included.
- Dento-alveolar and skeletal discrepancies are not distinguished.
- It cannot be useful when the first molar is extracted.
- It is not useful in deciduous dentitions.
- The complexity of the problem is not addressed.
- It does not indicate orthodontic treatment need.
- It has poor reproducibility with no practicality in determining treatment priority (Ackerman et al., 1969).

Ackerman and Proffit proposed another index of malocclusion, founded on five characteristics, to surmount the limitations of Angle's classification. Angle's classification and the five acknowledged characteristics of malocclusion (alignment, profile, type, class and bite depth) are represented in a Venn diagram (Ackerman et al., 1969). The latterentails an assessment of facial proportions and esthetics, alignment and symmetry within the dental arches and skeletal and dental relations in the transverse, antero-posterior and vertical planes of space (Figure II.5).

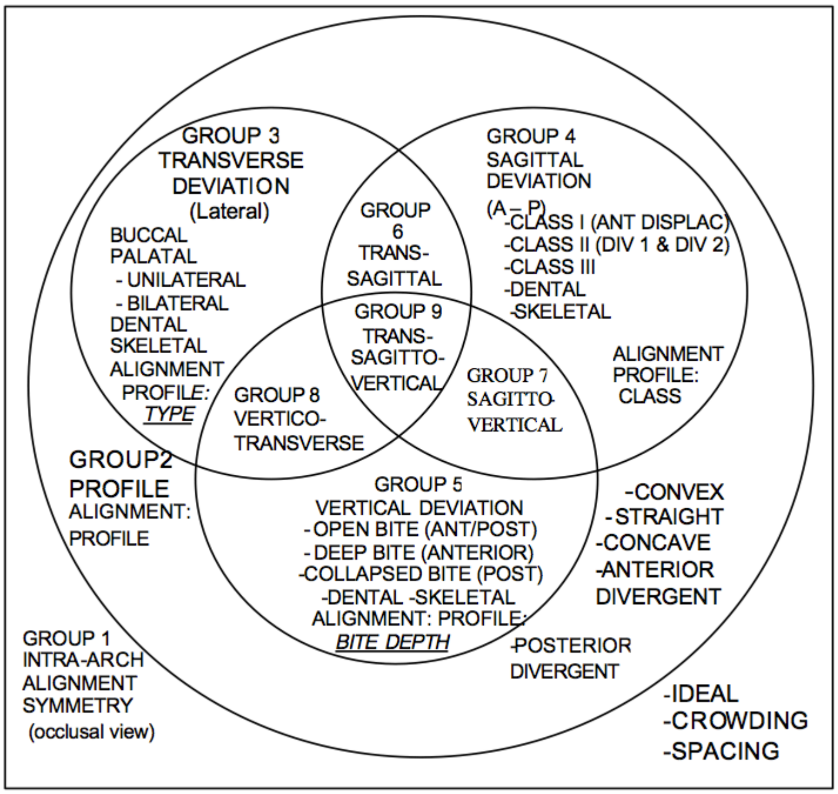

Figure II.5 Venn diagram of Ackermann and Proffit System

2. Relationship between chin anatomy and various types of malocclusion

Mandibular symphysis morphology results from the interaction of different genetic and adaptive factors (Sherwood et al., 2011). Vertical jaw relationships and mandibular incisor inclination may have an indirect effect on the antero-posterior position of the mandible and, consequently, on mandibular symphyseal shape (Von Bremen et al., 2005;

Yamada et al., 2007). Changes in the inclination of mandibular incisors to camouflage skeletal discrepancies might induce surface remodeling of the chin affecting its shape (Yu et al., 2009). It has been shown that retroclination of mandibular incisors in skeletal Class III, to compensate for the skeletal discrepancy, would result in less concavity of the anterior contour of the mandibular symphysis (Yamada et al., 2007). In the antero-posterior direction, the chin prominence was larger in Class III types compared to Class I and Class II relationships. These findings might be related to the increased linear dimensions in Class III patients in comparison to other malocclusion types (Al-Khateeb et al., 2013). Unlike the previous findings, Ulas et al. stated that the mandibular symphysis was more prominent in normodivergent Class II subjects in comparison to other classes (Ulas et al., 2013).

The alveolar bone was reported to be wider in short faced Class III patients in comparison to a narrower alveolar bone in long faced Class III patients (Molina-Berlanga et al., 2013). Esenlik et al. analyzed the symphysis region in different vertical growth patterns and showed similar findings: the hypodivergent Class II group had wider symphysis compared to other malocclusion groups, but symphysis height was comparable in all groups. The authors concluded that orthodontic movement of the mandibular incisors is more advisable in hypodivergent patients (Esenlik et al., 2012). Karlsen emphasized that the increased lower facial height was compensated by overdevelopment of the incisal heights; high angle cases exhibiting longer maxillary and mandibular incisors. Nevertheless, subjects were not stratified into Class I, II or III (Karlsen, 1997).

In the analysis of the correlation between the projection of the chin and the anatomy and cant of the symphysis, Ghafari et al. pointed out that the backward tilt of the anterior symphyseal slope was associated with a more posterior position of pogonion.

Besides, chin morphology affects the treatment of Class II, Division 1: when the anterior symphyseal angle is large, coupled with an increased Co-Gn distance and a low PP/MP angle, the response to treatment is improved (Joseph Ghafari et al., 2014).

In terms of sexual dimorphism, in their longitudinal study, Chung et al. explored longitudinally 68 skeletal Class I subjects with various facial divergences (Chung et al., 2003). In agreement with Sinclair and Little, the authors found comparable angular measurements between boys and girls from ages 9 to 18; ANB angle decreases in all groups, while SNA and SNB angles increased (Sinclair et al., 1985).

D. Imaging techniques

The association between facial patterns and the alveolar bony support have been studied through lateral cephalometry and computed tomography. By providing radiographic images in 3D volumetric images as well as in multiple slices, the latter has emerged rapidly as a program that accurately visualizes structures that conventional 2D cannot (Stratemann et al., 2010).

Unapproachable reference points in dry skulls and living beings have become easily recognizable with the introduction of standardized cephalograms by Broadbent in 1931. Clinicians tried to define a distortion-free craniofacial skeleton by analyzing two extra-oral radiographs, lateral and postero-anterior cephalograms. However, this approach is not a true 3D image of the patient (Broadbent, 1931). The limitations of 2D imaging (comprising traditional radiographs and cephalometric tracings) include geometric distortion, magnification, superimposition of structures and projective transformation and objects' displacement leading to elongation or shortening of an object's perceived proportions and dimensions (Adams et al., 2004; Tsao et al., 1983).

Research in all medical fields, including orthodontics, is imperative in order to advance knowledge of the practitioners and thus, provide high quality care for the patient. Many innovative technologies have been proposed over the time in order to improve the value of orthodontic research. One of these inventions is the Cone Beam Computed Tomography (CBCT), which was first introduced in 2000 at Loma Linda University (Al-Khateeb et al.). It acts as an evolutionary process that provides three-dimensional (3D) images of the craniofacial complex. Nowadays, CBCT is being used in many orthodontic research topics to overcome the limitations of conventional imaging, and therefore provide more precise and accurate results. However, this imaging technique should not completely replace conventional imaging and therefore be overused, in order to respect the ALARA concept which is to minimize the radiation dose transmitted to the patient(Mah et al., 2004).

The American Association of Orthodontics (AAO) and American Academy of Oral and Maxillofacial Radiology (AAOMR) Joint Task Force committee provides consensus-derived clinical guidance for specialists on the adequate application of CBCT in orthodontics. It states the explicit benchmarks for CBCT use. The latter should be based on judicious individual clinical judgment as to whether there is a clinical profit for the patient and not adequate for routinely and repetitive diagnostic use. CBCT application must be restricted to answer clinical questions for which conventional imaging cannot provide adequate information. Additionally, 2D imaging should not be taken when it is obvious that a CBCT assessment is needed for adequate diagnosis and/or treatment planning (Evans et al., 2012).

Some authors demonstrated that 2D imaging is less accurate and reliable in pinpointing some anatomical landmarks such as the inferior mandibular border, porion, orbitale, nasion, subspinale and supramentale. Investigators found no difference between 2D and 3D images in structure and cephalometric points' identification. Furthermore, CBCT enables the reestablishment of altogether conventional radiographs (such as lateral and frontal cephalograms, panoramic, periapical, occlusal and bite wings) to be reconstructed in a 3D image (Couceiro et al., 2010). The incorporation of cone-beam computed tomography (CBCT) in clinical dentistry has provided accurate and more precise study, without distortion, of the craniofacial complex in three different planes of view coronal, sagittal and transverse (Chenin et al., 2009). Several studies have reported the precision, repeatability and consistency of CBCT images. Nonetheless, patient exposure to radiation has raised a concern. In comparison to conventional multi-slice CT scans used in medicine, the effective radiation exposure with CBCT imaging has been determined by many studies to be significantly lower (Yamada et al., 2007). Several studies have determined that effective CBCT doses are much higher than those provided by conventional dental imaging; on the other hand, innovative technology has permitted CBCT exposure to be attuned (Ludlow et al., 2014; Silva et al., 2008). When compared with combined radiation exposure of a panoramic radiograph (14.2-24.3 μSv), a lateral cephalogram (10.4 μSv) and a full mouth series (13-100 μSv), CBCT radiation exposure is equal to or slightly higher than conventional orthodontic imaging ranging from 87 to 206 μSv for a full craniofacial scan (Silva et al., 2008).

For decades, the principal tool to evaluate and plan orthodontic treatment was the two-dimensional (2D) lateral cephalometric examination. However, craniofacial structures are 2D images of three-dimensional entities. Consequently, 2D imaging delivered limited information regarding the analysis and treatment planning (Scarfe et al., 2006). Deformations on panoramic images are not seen on 3D CBCT. Moreover, CBCT images were less influenced by patient position and free from the influence of the pattern of superimposition of the anatomical structures, which may have a significant influence on the measurement. Moreover, CBCT reconstruction allows greater accuracy and reliability for linear measurements (Lascala*et al.*, 2004). Since bi-dimensional radiographic images of the mandibular symphysis is masked by inherent inaccuracies (such as superimposition of anatomic structures, magnification error of the x-ray due to the divergence of the radiant beam and intricacies in recognizing single anatomical structures), precise assessment of the bony support is only attained via computed axial tomography (Yamada et al., 2007).

Numerous opinions emerged following the cumulative popularity of CBCT, some orthodontists promoted its routine application for all orthodontic patients in private practice as well as in academic institutions. While others limited its usage to some specific cases supported by scientific evidence (Turpin, 2008). 3D technologies provide 3D volumetric assessment of the individual’s anatomy to create a “virtual patient”. In spite of the increasing substantial popularity of CBCT, opinions on the use of CBCT vary from limiting its use in some specific clinical situations to its routine use for all orthodontic patients. On the basis of a benefit-to-risk evaluation, various cases would benefit from CBCT imaging modality such as: impacted and transposed teeth. CBCT can outline the optimal and most effective path of extrusion into the oral cavity with minimal collateral damage to adjacent structures. Additionally, root resorption is better detected and visualized in comparison to conventional radiographic imaging (Kapila, Conley, et al., 2014).CBCT images offer valid and precise diagnostic information of the canine's location without overlap with adjacent structures, in the sagittal, axial and coronal planes (Alqerban et al., 2011). The information derived might help the clinician in identifying which tooth is actually the normal one and which one is the supernumerary tooth. Final positioning of teeth is limited by the morphology of the alveolar bone relative to tooth root dimensions. Significant buccolingual or buccolingual inclination of teeth is influenced by the alveolar bone phenotypes (too narrow or wide). In cases of cleft lip and palate patients, facial asymmetry and history of airway difficulties the decision on obtaining a CBCT must be based on whether additional information may alter the diagnosis and treatment plan. Virtual anatomical models can be assembled from CT images. This process might provide enhanced expected changes following orthognathic surgery in comparison to less refined programs. Optimal implant placement is provided by a rigorous evaluation of the quantity and quality of bone from CBCT images. Degenerative changes in the TMJ may affect facial growth patterns and can result in adverse dental and skeletal changes (Kapila, Conley, et al., 2014)

One of the key advantages of CBCT over 2D radiography is its ability to provide 3D volumetric, surface and sectional information about the craniofacial structures. This has enabled orthodontists and researchers in the field to overcome the substantial limitations of 2D radiographs (Kapila & Nervina, 2014). Saccucci et al (2012) evaluated mandibular condylar volume in a group of young subjects, asymptomatic for TMJ pain and dysfunction, with different antero-posterior and skeletal classes using CBCT. They found that bigger condylar volume was a common characteristic of low angle cases relative to normal and high angle cases. In terms of sagittal skeletal discrepancy, subjects with severe Class II malocclusion presented larger condylar volumes compared to severe Class III malocclusion subjects (Saccucci et al., 2012).

Nevertheless, volumetric assessment of the mandibular symphysis has not been reported to date in the literature.

Various studies evaluated the relationship between the morphological features of the tooth-bearing region of the jaws and various facial types. Dento-alveolar compensation occurred mainly by adaptations in incisor alveolar and basal heights (Kuitert et al., 2006). Swasty et al. conducted the first study using CBCT to evaluate differences in the cross-sectional morphology of the mandibular body in live subjects stratified on their facial type (average, long face and short face). Swasty et al. used CBCTs of patients with various vertical facial dimensions to compare the thickness of cortical plate and mandibular cross-sectional morphology in terms of height and weight. In all areas, whether significant or not, the long-face group had the narrowest cortical bone. In addition, this group presented the most significant change in height of the mandibular cross-section from molars to symphysis. While males demonstrated wider and taller mandibles in comparison to females, no statistically significant gender differences were found in cortical bone thickness (Swasty et al., 2011). It has been shown that differences in total alveolar ridge thickness (formed by the cortical and medullary bones) between vertical facial types are mainly due to differences in cortical bone thickness. The latter is narrower in hyperdivergent than in average or hypodivergent individuals. The medullary thickness does not differ consistently between subjects (Horner et al., 2012; Scarpate, 2014). These findings are relevant when placing bicortical implants and determining the length of the miniscrew implants to use

(Beckman et al., 1998). Differences in cortical thickness are orchestrated by functional demands even though facial morphology is dominantly genetically determined (Sommerfeldt et al., 2001). Facial divergence has also been linked to functional demands (Horowitz et al., 1951; Jee, 2000).

Several animal and human studies have shown associations between the hyperdivergent growth pattern and muscular hypofunction (W Proffit et al., 1983). A naturally occurring example is found in individuals with muscular dystrophy (Joseph Ghafari et al., 1988; Ödman et al., 1996) supporting the concept that craniofacial morphology and occlusal development are influenced by a weakened and altered musculature balance (Joseph Ghafari et al., 1988). Therefore, thickness of the cortical bone can offer an insight to the forces it experiences and is expected to vary in individuals with various facial dimensions (Bresin, 2000).

Gracco et al. evaluated mandibular incisor bony support through CBCT images of 148 untreated subjects (Gracco et al., 2010). Their results confirmed those found by Siciliani et al. with bi-dimensional radiographs (Siciliani et al., 1990).At statistically significant levels, the total thickness of the symphysis was narrower in long face subjects and wider in short face subjects (Gracco et al., 2010; Siciliani et al., 1990; Tsunori et al., 1998). Long face subjects are more prone to iatrogenic problems related to orthodontic tooth movement, they can be at increased risk of moving incisors beyond alveolar bone support when exposed to noticeable antero-posterior incisor movement (Sadek et al., 2015).

The distance between the apex of the mandibular incisors and the center of the symphysis, depicting the alveolar and symphyseal interaction in various malocclusions, has not been assessed to date. The nearest indirect reference to such assessment was a study of the relationship between mandibular incisor inclination and the supporting alveolar bone shape by Yu et al. who reported that the root apex was closer to the lingual cortical bone when the tooth was buccally inclined (Yu et al., 2009). In addition, some authors evaluated soft tissue thickness at the level of the chin and found it thinner in subjects with steep hyperdivergent mandibles, namely at the level of Menton and Gnathion, in contrast with individuals with flat hypodivergent mandibles (Macari et al., 2013). Taking into consideration the limitations of the previous study that was done on cephalometric lateral films, Celikoglu et al. assessed the soft tissue thickness at the lower anterior face height in adult skeletal Class I patients with different facial patterns using cone-beam computed tomography (CBCT). They found that the soft tissue thickness measurements were the narrowest in the high angle group for both genders. However, men presented statistically significant greater values compared to women (Celikoglu et al., 2014).

CHAPTER III

MATERIALS AND METHODS

A. Materials

1. General characteristics

The sample consisted of pre-treatment lateral cephalograms of patients screened at the Division of Orthodontics and Dentofacial Orthopedics Clinics of the American University of Beirut Medical Center, and pre-treatment CBCTs recruited from a radiographic center (Lumiray- 3D Imaging Center) taken on patients seeking orthodontic treatment (a CBCT radiologic machine is not available within the premises of AUBMC). CBCT imaging entails more head stability upon image registering and less radiation than a regular dental CT scan. The images used in the present study were part of the diagnostic records collected fororthodontic treatment. None of the patients were contacted nor were CBCTs taken for the objective of the present study. IRB approval was granted before initiation of the study to evaluate the existing radiographs under specified regulations.

Based on the power analysis, whichwas calculated using an Anticipated effect size (f^2) of 0.02(Large) and a power level of 0.8 with four predictors (age, gender, MP/SN and ANB angles) and a probability level of 0.05, the ideal sample size would be 597. We were able to recruit 846 subjects stratified into 550 subjects in the lateral cephalometric 2D sample and 296 subjects in the CBCT-generated 3D sample. Each samplewas divided tofour groups based on cephalometric mandibular plane to cranial base angle(MP/SN; average = 32° ± 5°)

- Group 1: Hypodivergent pattern , MP/SN ≤ 27° (Figure III.1)
- Group 2: Tendency hypodivergent pattern, 27° < MP/SN ≤ 32° (Figure III.2)
- Group 3: Tendency hyperdivergent pattern, 32° < MP/SN ≤ 37° (Figure III.3)
- Group 4: Hyperdivergent pattern, MP/SN ≥37° (Figure III.4)

Each group was further divided into 2 age groups: growing and adult. The cutoff age between growers and adults was 16 years for females and 18 years for males. Each subgroup was evaluated according to malocclusion classes: Class I, Class II division 1, Class II division 2 and Class III malocclusions.

2. Inclusion criteria

The severity of the overjet (the cephalometric distance between maxillary and mandibular incisal edges in the sagittal plane) was a criterion common to all types of malocclusions. The ANB differentiated among all malocclusions but was not used for Class II division 2. The overbite (OB, percentage of overlap of the mandibular incisors by the maxillary incisors) was set at a minimum of 80% for Class II division 2, which is characterized by a deep overbite, and as 30% for Class I malocclusion. (TableIII.1).

TableIII.1. Sample selection / Inclusion criteria

	Class I	Class II.1	Class II.2	Class III
OJ (mm)	2-3	≥5	2-3	≤ (at least edge to edge)
OB (%)	30	-	≥80	-
ANB (°)	0<ANB<3.5	≥4.5	-	< 0

3. Exclusion criteria

We excluded subjects who had previous orthodontic treatment or any craniofacial anomalies (e.g. cleft lip/palate, hemifacialmicrosomia), or if their cephalogram or CBCT was of non-diagnostic quality.

4. Total sample characteristics

a. <u>Age distribution</u>

The 2D sample included 550 individuals stratified into the 4 defined divergence groups. (Table III.2.a)

Table III.2.a2D sample, age distribution among the divergence groups

	Hypodivergent			T. hypodivergent			T. hyperdivergent			Hyperdivergent		
	n (%)			n (%)			n (%)			n (%)		
	138(25.09)			140(25.45)			139(25.27)			133(24.18)		
Age	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
	20.13 (10.66)	16.9	5.08-54.08	18.29 (8.29)	16.83	4.75-48.75	18.58 (8.99)	16.41	7.75-55.08	17.79 (9.23)	15.08	6.83-51.92

*: T = tendency

The 3D sample comprised a total of 296 subjects (Table III.2.b).

Table III.2.b3D sample, age distribution in the divergence groups

	Hypodivergent			T. hypodivergent			T. hyperdivergent			Hyperdivergent		
	n (%)			n (%)			n (%)			n (%)		
	77(26)			86(29)			77(26)			56(19)		
Age	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
	17.71 (8.48)	15.08	7.08-42.66	20.02 (14.08)	13.66	5.33-64.25	16.21 (8.9)	13.08	8.91-59.08	19.74 (11.8)	16.08	9.08-59.83

*: T = tendency

b. Gender characteristics

The 2D sample included nearly equal male and female pre-treatment lateral cephalograms: 269 males (142 growing, 127 adults) and 281 females (138 growing, 143 adults) – Table III.3.a.

TableIII.3.a. 2D sample, gender characteristics

		Males	Females	TOTAL
N (%)		269 (49%)	281 (51%)	550
Growing	n (%)	142 (50.7%)	138 (49.3%)	280 (51%)
Adults	n (%)	127 (47%)	143 (53%)	270 (49%)
Age Mean Range (years)		18.68 ±9.22 (4.75-54.08)	18.73 ±9.47 (4.91-55.08)	18.7±9.34 (4.75-55.08)

The 3D sample comprised nearly two-third female subjects: 110 males (84 growing, 26 adults) and 186 females (111 growing, 75 adults) – Table III.3.b.

Table III.3.b 3D sample, gender characteristics

		Males	Females	TOTAL
N (%)		110 (37.2%)	186 (62.8%)	296
Growing	n (%)	84 (43%)	111 (57%)	195 (95.9%
Adults	n (%)	26 (23%)	75 (77%)	101(34.1%)
Age Mean Range (years)		16.59±9.66 (5.33-59.08)	19.63±12.23 (5.75-64.25)	18.5±11.42 (5.33-64.25)

c. Malocclusion characteristics

Each sample was divided into Class I, Class II division 1, Class II division 2 and Class III malocclusions- Tables III.4.a and III.4.b.

Table III.4.a 2D sample stratified by malocclusion

	Cl I	Cl II,1	Cl II,2	Cl III
n (%)	152 (27.6%)	162 (29.5%)	98 (17.8%)	138 (25.1%)
Age Mean Range (years)	18.8 ± 9.41 (7.75-54.08)	17.99 ± 8.35 (5.08-45.58)	20.88 ± 6.11 (12.08-55.08)	17.5 ± 8.79 (4.75-52.25)

Table III.4.b 3D sample stratified by malocclusion

	Cl I	Cl II,1	Cl II,2	Cl III
n (%)	103(34.8%)	130(43.9%)	41 (13.9%)	22(7.4%)
Age Mean Range (years)	18.34±10.6 (5.5-64.25)	16.87±11.29 (7.08-11.29)	24,2±11.36 (11.83-58.83)	22.13±12.31 (5.33-59.83)

The two samples were further evaluated according to the facial divergence groupings (hypodivergent, tendency hypodivergent, tendency hyperdivergent and hyperdivergent).

5. Group characteristics

The stratifications within each divergence group are shown separately according to malocclusion classes, age, and gender, along with representative figures of growing and adult cephalograms.

a. Hypodivergent pattern (group 1)

i. 2D sample

This group included138 patients (25%) with MP/SN $\leq 27^{o}$, it comprised gender subgroups of 73 males (36 growing, 37 adults) and 65 females (29 growing, 36 adults). The least represented malocclusion subgroup was Class III (Table III.5.a).

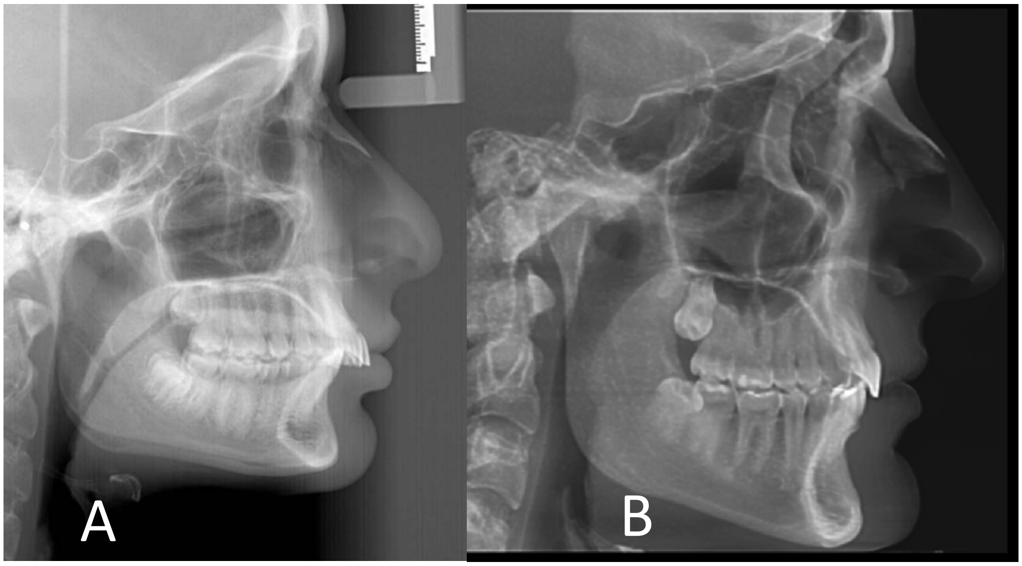

Figure III.1 Images of non-growing subjects with a hypodivergent pattern (MP/SN=20°)
A: 2D lateral cephalogram; B:CBCT lateral view

Table III.5.a 2D hypodivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N (%)	**138 (25%)**	**37 (27%)**		**41 (30%)**		**38 (27%)**		**22 (16%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		15	22	21	20	24	14	13	9
Growing	**65**	8	11	12	10	10	5	6	3
Adults	**73**	7	11	9	10	14	9	7	6
Age Mean Range (years)		20.18±10.59 (9.08-54.08)		17.61 ±8.12 (5.08-45.58)		22.86 ± 12.32 (8.25-53.5)		20.56 ± 11.36 (5.08-52.25)	

ii. 3D sample

The 3D group of hypodivergent pattern comprised 77 subjects (26%) with MP/SN < 27° divided into 31 males (20 growing, 11 adults) and 46 females (27 growing, 19 adults). All types of malocclusions were included -Table III.5.b. A representative lateral cephalogram constructed from the CBCT is displayed in Figure III.1.

Table III.5.b3D hypodivergent group characteristics

		Cl I		Cl II,1		CL II,2		Cl III	
N(%)	**77 (26%)**	**30 (39%)**		**25 (32%)**		**19 (25%)**		**3 (4%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		11	19	9	16	8	11	3	-
Growing	**47**	9	11	6	14	3	2	2	-
Adults	**30**	2	8	3	2	5	9	1	-
Age Mean Range (years)		18.21 ± 8.11 (10.66-42.41)		14.85 ± 7.63 (7.08-38.5)		23.18 ± 0.27 (11.75-2.66)		16.69 ± 8.42 (8.08-24.91)	

b. Tendency hypodivergent pattern (group 2)

i. 2D sample

In this group, 140 patients with 27° < MP/SN ≤ 32°were stratified into gender subgroups of 70 males (27 growing, 43 adults) and 70 females (31 growing, 39 adults) – Table III.6.a. An illustrative lateral cephalogram is presented in Figure III.2.

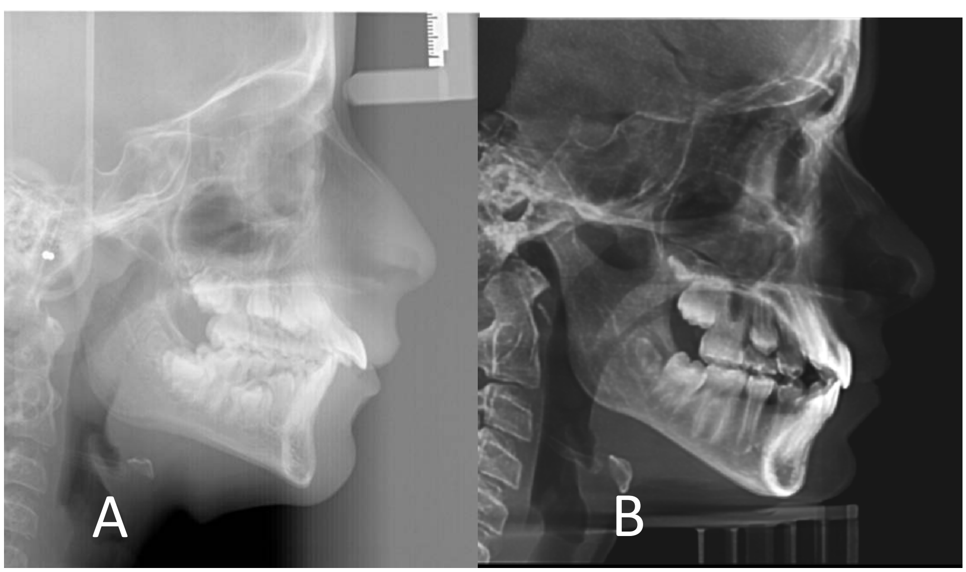

Figure III.2 Images of growing subjects with a tendency hypodivergent pattern (MP/SN=28°) A: 2D lateral cephalogram; B:CBCT lateral view

Table III.6.a 2D tendency hypodivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**140 (25.5%)**	**34 (24%)**		**37 (27%)**		**37 (26%)**		**32 (23%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		17	17	19	18	19	18	15	17
Growing	**58**	8	7	5	7	7	6	7	11
Adults	**81**	9	10	14	18	11	12	8	6
Age Mean Range (years)		18.29 ± 8.29 (8.75-48.75)		18.5 ± 8.8 (9.41-45.41)		20.69 ± 8.37 (8.83-46.08)		16.12 ± 9.16 (4.75- 48.75)	

ii. 3D sample

86 individuals were recruited in this group with 27° < MP/SN ≤ 32°and divided into 30 males (26 growing, 4 adults) and 56 females (32 growing, 24 adults) – Table III.6.b. These subjects were additionally separated into various types of malocclusion. A representative lateral cephalogram is shown in Figure III.2.

Table III.6.b3D tendency hypodivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**86 (29%)**	**27 (32%)**		**45 (52%)**		**8 (9%)**		**6 (7%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		9	18	16	29	2	6	3	3
Growing	**58**	7	10	15	20	1	-	3	2
Adults	**28**	2	8	1	9	1	6	-	1
Age Mean Range (years)		5.5 ± 64.25 (19.84-13.91)		18.92 ± 14.13 (8.5-61.58)		24.89 ± 12.33 (10.83-52.16)		18.58 ± 16.78 (5.33-47.58)	

c. Tendency hyperdivergent pattern (Group 3)

i. 2D sample

Of the 139 subjects in this group with 32° < MP/SN ≤ 37°, 67 subjects were males (33 growing, 34 adults) and 72 were females (34 growing, 38 adults) – Table III.7.a. A characteristic profile outline is presented in Figure III.3.

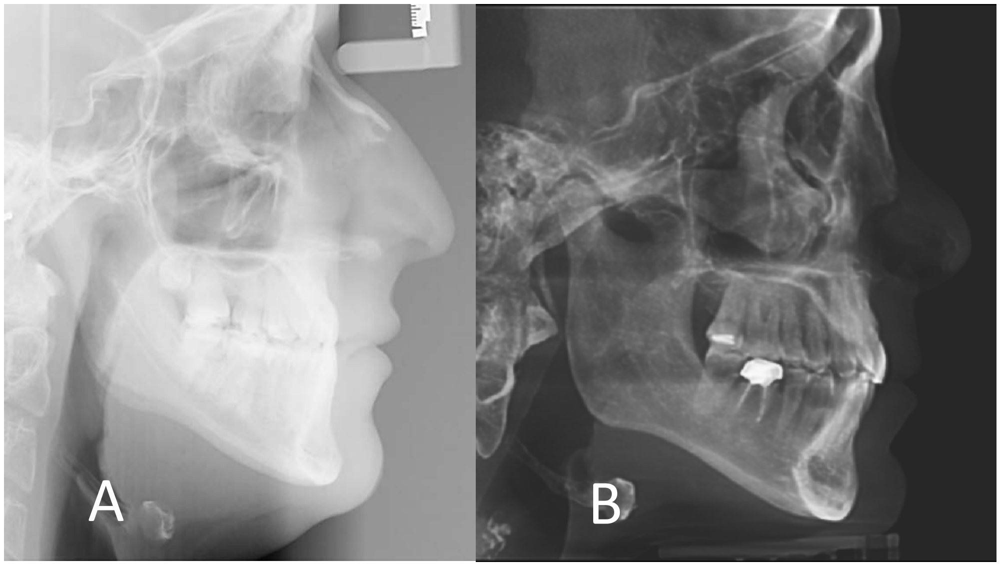

Figure III.3 Images of non-growing subjects with a tendency hyperdivergent pattern (MP/SN=34°) A: 2D lateral cephalogram; B:CBCT lateral view

Table III.7.a 2D tendency hyperdivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**139 (25.3%)**	**41 (30%)**		**39 (28%)**		**25 (18%)**		**34 (24%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		17	24	20	19	9	16	13	21
Growing	**71**	7	15	9	8	7	8	7	10
Adults	**68**	10	9	11	11	2	8	6	11
Age Mean Range (years)		18.47 ± 8.45 (7.75-41.66)		18.36 ± 8.56 (7.75-40.66)		18.65 ± 8.98 (9.25-47.33)		19.0 ± 10.9 (9.91-55.08)	

ii. 3D sample

77 subjects with a tendency hyperdivergent pattern and 32° < MP/SN ≤ 37° were included in this group with 28 males (22 growing, 6 adults) and 49 females (33 growing, 16 adults), they were also stratified into different malocclusions – Table III.7.b. Figure III.3 is a lateral cephalometric X-ray representative of this group.

Table III.7.b 3D tendency hyperdivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**77 (26%)**	**31 (40%)**		**30 (39%)**		**7 (9%)**		**9 (12%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		10	21	13	17	1	6	4	5
Growing	**55**	8	13	12	14	-	3	2	3
Adults	**22**	2	8	1	3	1	3	2	2
Age Mean Range (years)		17.42 ± 9.87 (9.33-43.91)		14.68 ± 8.66 (9.16-59.08)		19.0 ± 7.71 (11.91-35.08)		17.03 ± 11.59 (8.91-42.75)	

d. Hyperdivergent pattern (group 4)

i. 2D sample

In this group, 133 hyperdivergent patients with MP/SN ≥ 37° were divided in gender subgroups of 59 males (38 growing, 21 adults) and 74 females (37 growing, 37 adults) – Table III.8.a. Representative characteristics are displayed in Figure III.4.

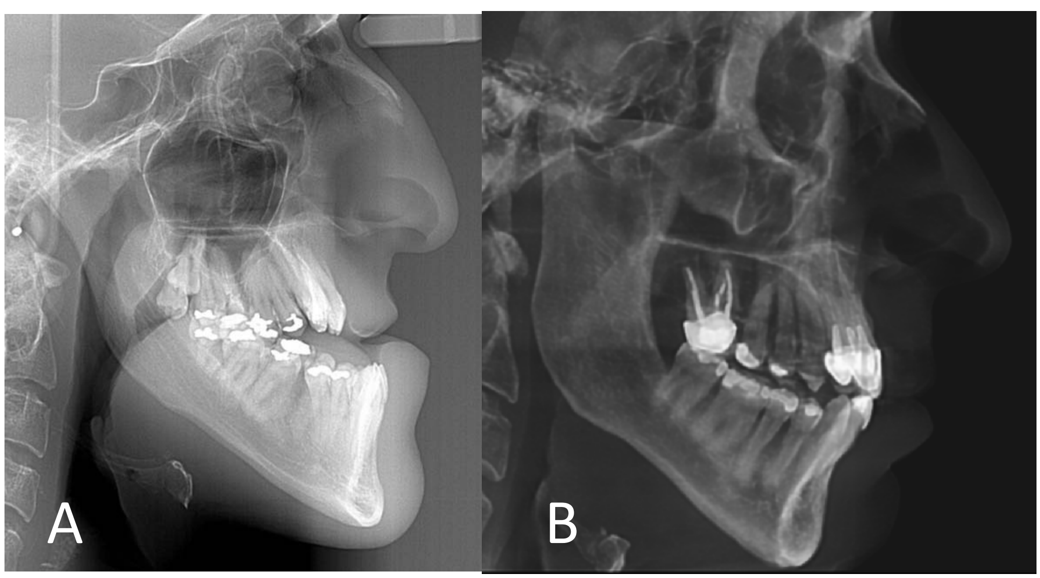

Figure III.4 Images of non-growing subjects with a hyperdivergent pattern (MP/SN=47°)
A: 2D lateral cephalogram; B:CBCT lateral view

Table III.8.a 2D hyperdivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**133 (24.2%)**	**40 (33%)**		**45 (28%)**		**13 (11%)**		**35 (28%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		18	22	19	26	5	8	17	18
Growing	75	11	13	12	13	4	3	11	8
Adults	58	7	9	7	13	1	5	6	10
Age Mean Range (years)		18.96 ± 11.45 (7.75-51.24)		17.56 ± 8.23 (8.66-39.58)		16.25 ± 6.0 (6.83-29.75)		19.1 ± 12.13 (8.0-51.92)	

ii. 3D sample

This group comprised 56 hyperdivergent individuals with MP/SN $\geq 37^{o}$: 21 males (16 growing, 5 adults) and 35 females (19 growing, 16 adults) – Table III.8.b. Figure III.4.bis a representative lateral cephalogram of this group.

Table III.8.b 3D hyperdivergent group characteristics

		Cl I		Cl II,1		Cl II,2		Cl III	
N(%)	**56 (19%)**	**15 (27%)**		**30 (53%)**		**6 (11%)**		**5 (9%)**	
Gender		**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
n		6	9	10	20	2	4	3	2
Growing	**35**	5	5	8	13	1	1	2	-
Adults	**21**	1	4	2	7	1	3	1	2
Age Mean Range (years)		16.42 ± 4.27 (9.91-23.08)		17.31 ± 10.33 (9.08-50.16)		20.75± 6.37 (12.91-59.83)		22.08 ± 5.27 (16.08-22.06)	

B. Methods

Pre-treatment lateral cephalograms were taken at the Division of Orthodontics and Dentofacial Orthopedics Clinics of the American University of Beirut Medical Center using the same digital machine (GE, Instrumentarium, Tuusula, Finland).

The pre-treatment CBCTs recruited from a radiographic center (Lumiray- 3D Imaging Center) were taken on patients seeking orthodontic treatment using Pax-Zenith 3D, Vatech, E-WOO technology for 3D imaging following standardized procedures as instructed by the manufacturer.

1. Cephalometric assessment

All lateral cephalometric radiographs and CBCTs were taken in natural head position (Moorrees et al 1995) with posterior teeth in maximum intercuspation and the lips touching gently. The patient's body was covered with lead apron. 2D images were automatically saved and stored in the dedicated computer within the available software (Cliniview 9.3). Similarly, CBCTs were spontaneously saved and deposited in a corresponding radiologic software (EZ3D).

In both 2D and 3D software programs, the identity of the patient is not part of the image. Accordingly, the radiographs were located and exported from both softwares to a digital folder named X-Rays. The radiographs were assigned a serial number by the administrators (Dr. Anthony Macari for 2D images and Ms Rima Kawch. for 3D images) starting from Patient 001, Patient 002, Patient 003, Patient 004, etc. The exported image cannot be linked back to the subject. This way the "coding" of all radiographs was assured.

Upon this process, the administrators provided the investigator (EZ) with the following **coded** records for data collection:

- The digital folders containing the radiographs.
- A list that contains the serial number, gender, and chronological age of the subjects when the records were taken. This information was critical for organizing and recordingoutcome measures. This list did NOT contain the patients' names.

The investigator (EZ) exported lateral cephalometric images generated from the CBCTs and those provided from Cliniview and imported them in an Imaging program (Dolphin Imaging and Management Solutions, version 11,5, La Jolla, California). 2D and 3D images were digitized by one investigator (EZ). Figure III.5 represents the screen view during digitizationinthe Dolphin Imaging program.

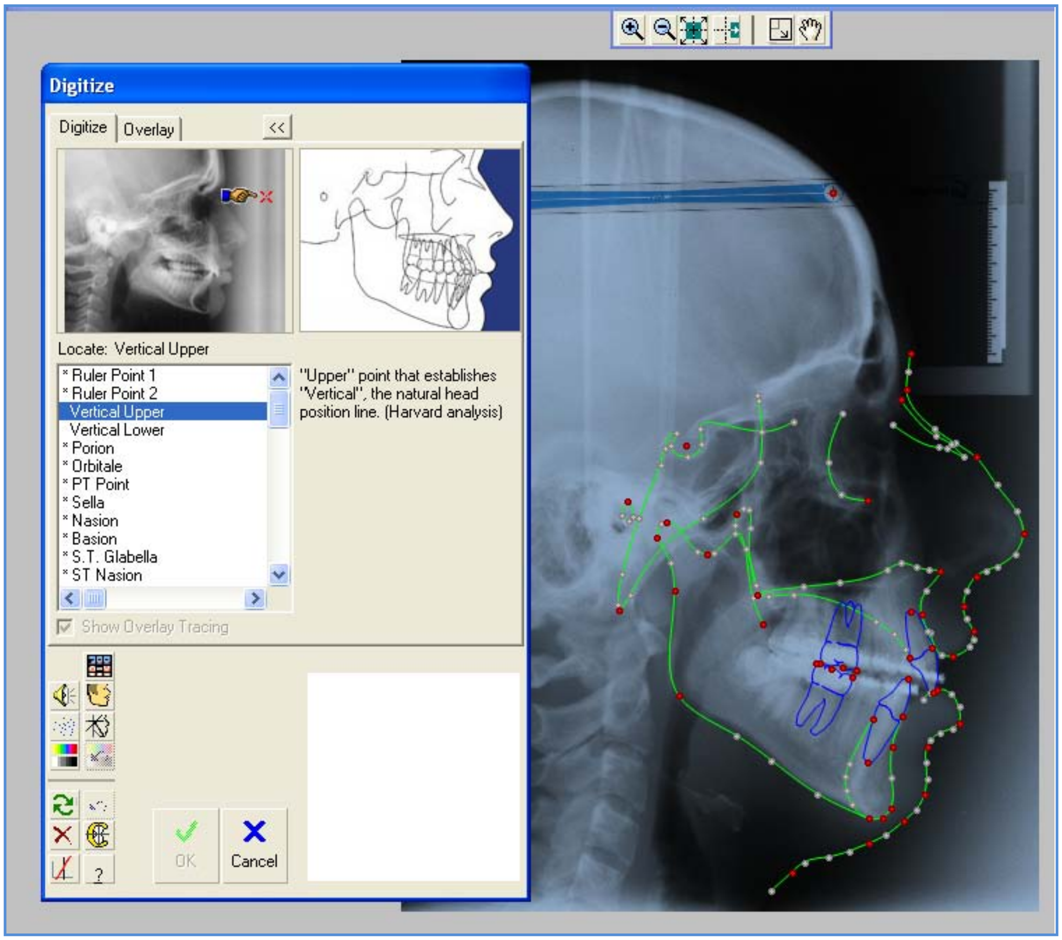

Figure III.5 Representativeillustration of the computer view while digitizing a lateral cephalometric radiograph using Dolphin Imaging program

2. Cephalometric landmarks

Soft and hard tissue landmark definition was adopted from the glossary of the American Association of Orthodontists (Tables III.9.a and III.9.b); their corresponding locations are identified in Figure III.6.

Table III.9.a Soft tissue landmarks definition

Number	Landmark	Definition
1	Glabella	Most prominent or anterior point in the mid-sagittal plane of the forehead at the level of the superior orbital ridges
2	Soft tissue Nasion	Point of intersection of the soft-tissue profile with a line drawn from the center of Sella turcica through Nasion
3	Bridge of nose	Mid-way between the soft tissue N and tip of nose
4	Tip of nose	Most prominent or anterior point of the nose tip
5	Subnasale	Midpoint of the columella base at the apex of the angle where the lower border of the nasal septum and the surface of the upper lip meet
6	Soft tissue A point	Deepest point on the upper lip determined by an imaginary line joining subnasale with the laberalesuperius
7	Superior lip	Midpoint of the upper vermilion line
8	Stomion superior	Most inferior point located on the upper lip
9	Stomion inferior	Most inferior point located on the lower lip
10	Lower lip	Midpoint of the lower vermilion line
11	Soft tissue B	Point at the deepest concavity between laberaleinferius and soft-tissue pogonion
12	Soft tissue pogonion	Most prominent or anterior point on the soft-tissue chin in the mid-sagittal plane
13	Soft tissue gnathion	Midpoint between soft-tissue pogonion and soft-tissue menton
14	Soft tissue menton	Most inferior point on the soft-tissue chin
15	Throat point	Intersection of lines tangent to the neck and throat

Table III.9.b Hard tissue landmarks definition

Number	Landmark	Definition
16	Nasion (N)	The junction of the frontal and nasal bones
17	Sella (S)	The pituitary fossa. The center is used as a cephalometric landmark
18	Porion (Po)	Highest point on the roof of the external auditory meatus
19	Basion (Ba)	Most inferior point on the anterior margin of the foramen magnum in the midsagittal plane
20	Pterygoid point	Most posterior point on the outline of the pterygopalatine fossa
21	Orbitale (Or)	Lowest point on the lower margin of the orbit
22	Condylion (Co)	The highest point on the superior outline of the mandibular condyle
23	Articulare (Ar)	A (Bjork) constructed point representing the intersection of three radiographic images: the inferior surface of the cranial base and the posterior outlines of the ascending rami or dorsal contour of the mandibular condyles bilaterally
24	Sigmoid notch	Deepest point on the sigmoid notch of the mandible
25	Ramus point	Most posterior point up the border of the ramus
26	Mid ramus	Most concave point of the inferior of the ramus
27	Gonion(Adams et al.)	The most posterior inferior point on the outline of the angle of the mandible. It is identified by bisecting the angle formed by the tangents to the mandibular corpus (mandibular plane) and posterior border of the mandible (dorsal ramal plane)
28	Menton (Me)	The most inferior point on the chin in the lateral view
29	Gnathion(Kuitert et al.)	The lowest point of the mandibular symphysis
30	Pogonion (Pog)	The most anterior point on the contour of the bony chin in the midsagittal plane
31	B point	The deepest (most posterior) midline point on the bony curvature of the anterior mandible, between infradentale and pogonion. Also called supramentale. (Downs)
32	Posterior nasal spine (PNS)	The most posterior point on the bony hard palate in the midsagittal plane; the meeting point between the inferior and the superior surfaces of the bony hard palate (nasal floor) at its posterior aspect
33	Anterior nasal spine (ANS)	The tip of the bony anterior nasal spine at the inferior margin of the piriform aperture, in the midsagittal plane
34	A point	Subspinale, the deepest (most posterior) midline point on the curvature between the ANS and prosthion (dental alveolus) (Downs)

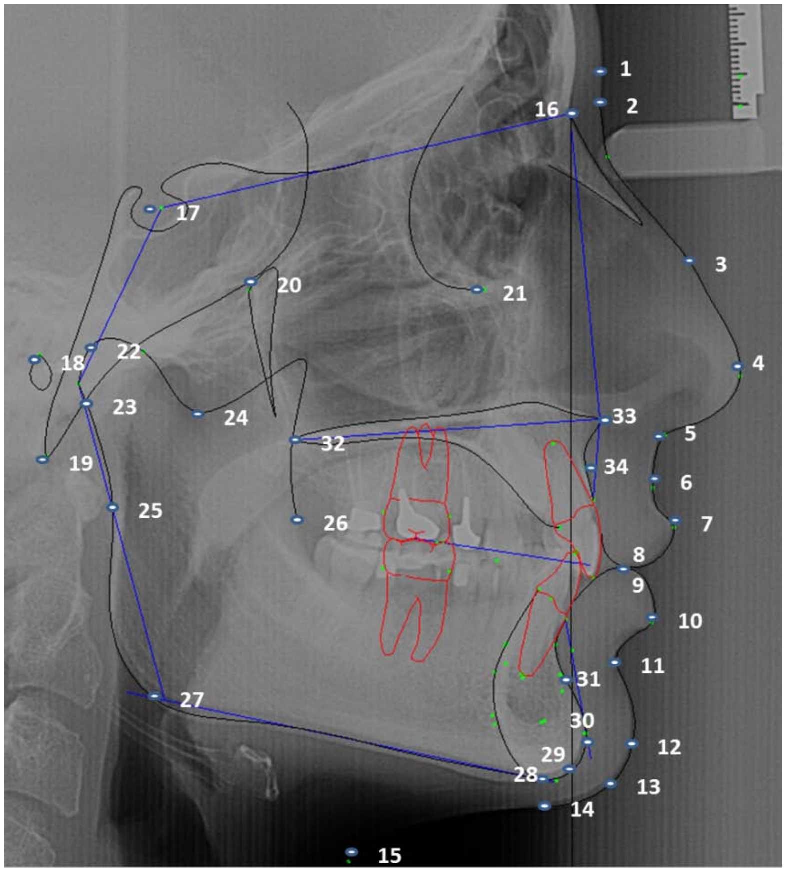

Figure III.6 Lateral cephalogram digitized with soft and hard tissue landmarks

3. Cephalometric measurements

Linear and angular measurements were performed to gauge the characteristics of the cranial base and each jaw, as well as the relationships of the jaws to the cranial base and to each other. A lateral cephalometric radiograph with landmarks and angles used to describethe relationship among cranial base, jaws, and teeth is presented in Figure III.6. Definitions of cephalometric measurements adopted are listed in Table III.10

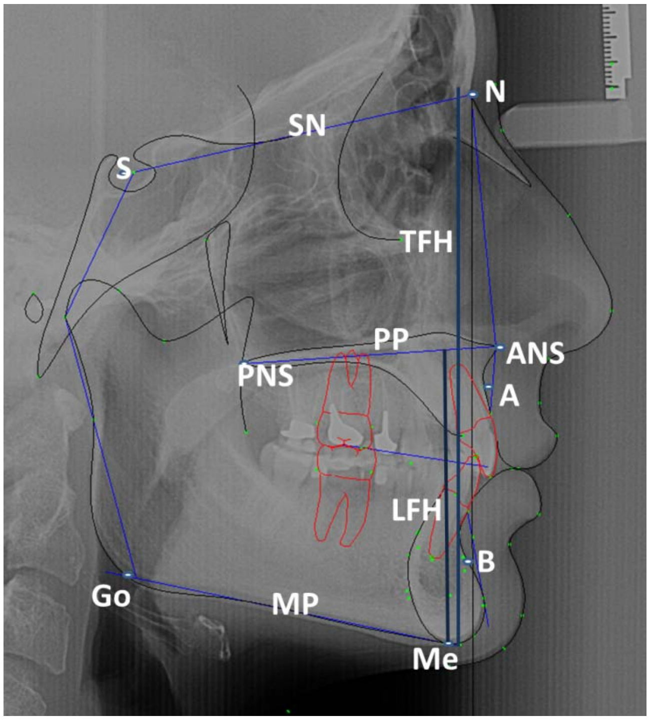

Figure III.7 Lateral cephalometric tracing with landmarks and angles used in this study to describe the relationship between jaws, cranial base, and horizontal

Table III.10 Definitions of cephalometric measurements

Cranial base measurements	
SN	Anterior cranial base: reference line connecting the center of the sellaturcica with nasion
SN/H	Inclination of anterior cranial base in reference to natural head position
SN-Ar	Saddle angle: Evaluates cant of the anterior cranial base
S-Ar	Posterior cranial base
Relationship between jaws, cranial base and horizontal	
SNA (maxilla)	Angle between anterior cranial base cant (SN) and point A (most posterior point on anterior contour of the maxilla)
SNB (mandible)	Angle between anterior cranial base cant (SN) and point B (most posterior point on anterior contour of the mandible)
ANB	Angle between points A and B
PP/MP	Palatal plane to mandibular plane: represents the vertical relationship between the jaws through the angle between palatal plane and mandibular plane
MP/SN	Represents the vertical inclination of the mandible relative to SN

LFH/TFH	Lower to total facial height: depicts the relationship between anterior facial height (Subnasale-Menton) and total facial height (Nasion-Menton)
PP/H	Represents vertical inclination of PP to Horizontal (in natural head position)
MP/H	Represents the vertical inclination of the mandible relative to the true horizontal (in natural head position)
MP/V	Represents the horizontal inclination of the mandible relative to the true horizontal (in natural head position)
Jaw specific measurements	
Co-Go, Co-Gn,Ar-Gn	Length of mandible
Go-Me, GoPog, Ar-Go	Length of mandibular components (body and ramus)
Ar-Go-Me	Mandibular angle between ramus (Articulare-Gonion) and body
Co-Go-Me	Mandibular angle between ramus (Condylion-Gonion) and body
ANS-PNS	Length of maxilla
Relationship between teeth and jaws	
U1-NA mm, U1/NA °	Inclination of maxillary incisors to NA
U1/SN	Inclination of maxillary incisors to SN
U1/PP	Inclination of maxillary incisors to PP
L1-NB mm, L1/NB °	Inclination of maxillary incisors to NB
L1/MP	Inclination of maxillary incisors to MP
Relationship between teeth	
U1/L1	Inter-incisal angle
OB	Percent of overlap of mandibular incisors by maxillary incisors
OJ	Horizontal projection of maxillary incisors relative to mandibular incisors

4. Symphyseal components

These components consisted of measurements within the symphysis (height and depth, and slope inclinations) and among the mandibular central incisor and symphysis (to this end, a critical point D at the symphyseal center (Steiner, 1959)was used (Figure III.7, Table III.11).

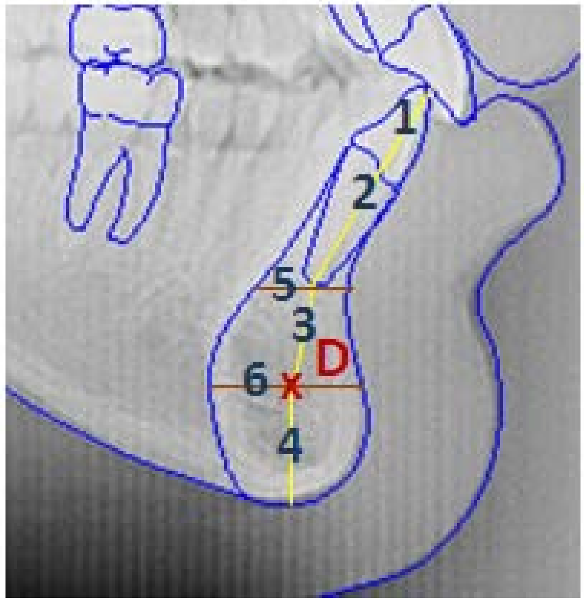

Figure III.8 Cephalometric tracing indicating the relationship among components of the symphysis (centered at point D) and the mandibular incisors.

Table III.11 Definitions of cephalometric measurements

	Measurement	**Landmarks**
1	Mandibular incisor length	I edge (I) to apex (A)
2	Mandibular incisor crown length	I edge (I) to cervical point (C)
3	Distance between point D and incisor apex	D to A
4	Distance between point D and menton	D to Me
5	Chin width at the level of the incisor apex	Line through A parallel to the horizontal, intersecting anterior and posterior contours of symphysis
6	Chin width at the level of point D	Line through D parallel to the horizontal, intersecting anterior and posterior contours of symphysis

Chin anatomy was further delineated through the methods adapted from Ghafari and Macari (2014) (Figure III.8) along with cephalometric measurements in Table III.12. The anterior and posterior slopes of the symphysis are defined to help determine the inclination of the symphysis.

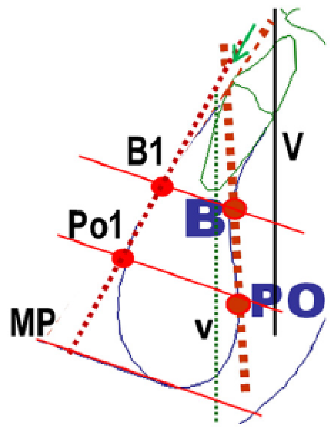

Figure III.9 Chin drawing from cephalometric radiograph indicating the component analysis of the symphysis (Ghafari and Macari, 2014)

Table III.12 Definitions of symphyseal cephalometric measurements

	Measurement	Landmarks
1	Anterior slope plane	Through Pogonion (Po: most anterior point on the mid-sagittal symphysis) and B points
2	Posterior slope plane	Through Pogonion 1 (Po1: most convex point on the posterior symphyseal cortical) and point B1(intersection of the parallel to Po–Po1 through B and the posterior cortical of the symphysis)
3	MP and V angle	Angle between mandibular plane (MP) and V (true vertical through nasion)
4	Angle formed by the anterior and posterior slopes	Angle between anterior slope plane and posterior slope plane
5	Distance measured from B point perpendicular to the true vertical	Point B (most posterior point on anterior contour of the mandible)
6	Distance measured from B1 to the true vertical	Point B1 (point of intersection between the line through B parallel to MP, intersecting posterior contour of the symphysis)

5. Volume assessment

All volume measurements were done by one orthodontist (AK) who developed the specific software, SolidPlanner Pro®, developed by Solid Models Co, and who is affiliated to the Division of Orthodontics and Dentofacial Orthopedics on its associated faculty, and all measurements were performed on the 3D models in a 15-inch, high resolution LED Laptop screen (HP, Pavillion dv6). Bone surface of the chin volumes was generated from the CBCT images by extracting iso surfaces of Hounsfield values (HV) of 1500. The rendered volumes were cropped to the boundaries of the anatomic chin as defined by Bähr et al. (1996), which extendbetween distal surfaces of the mandibular canines (Figure III.9).Chin volume then was recorded in (mm^3), and a reference "print screen" image was saved for each model.

For each original image, an outline of the region of interest was delineated (in the transverse dimension from the distal surface the mandibular canine to the distal surface of the contralateral one), then the region was further cropped, cleaned and refined. The crowns of teeth were cropped and the remaining volume included the bony symphysis and the structures held within the labial and the lingual boundaries of the chin (bone trabeculae, roots of teeth, and associated structures) (Figure III.10).

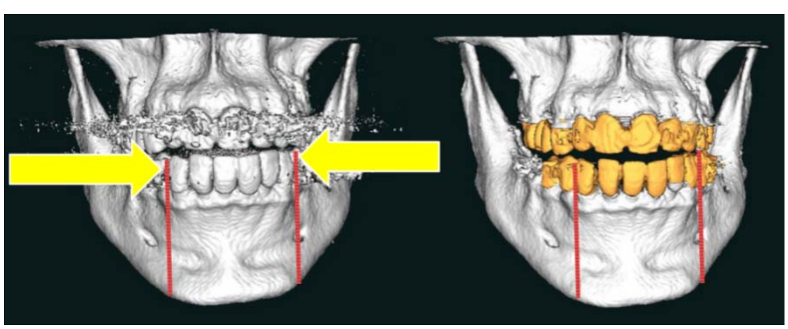

Figure III.10 Cleaning and segmentation

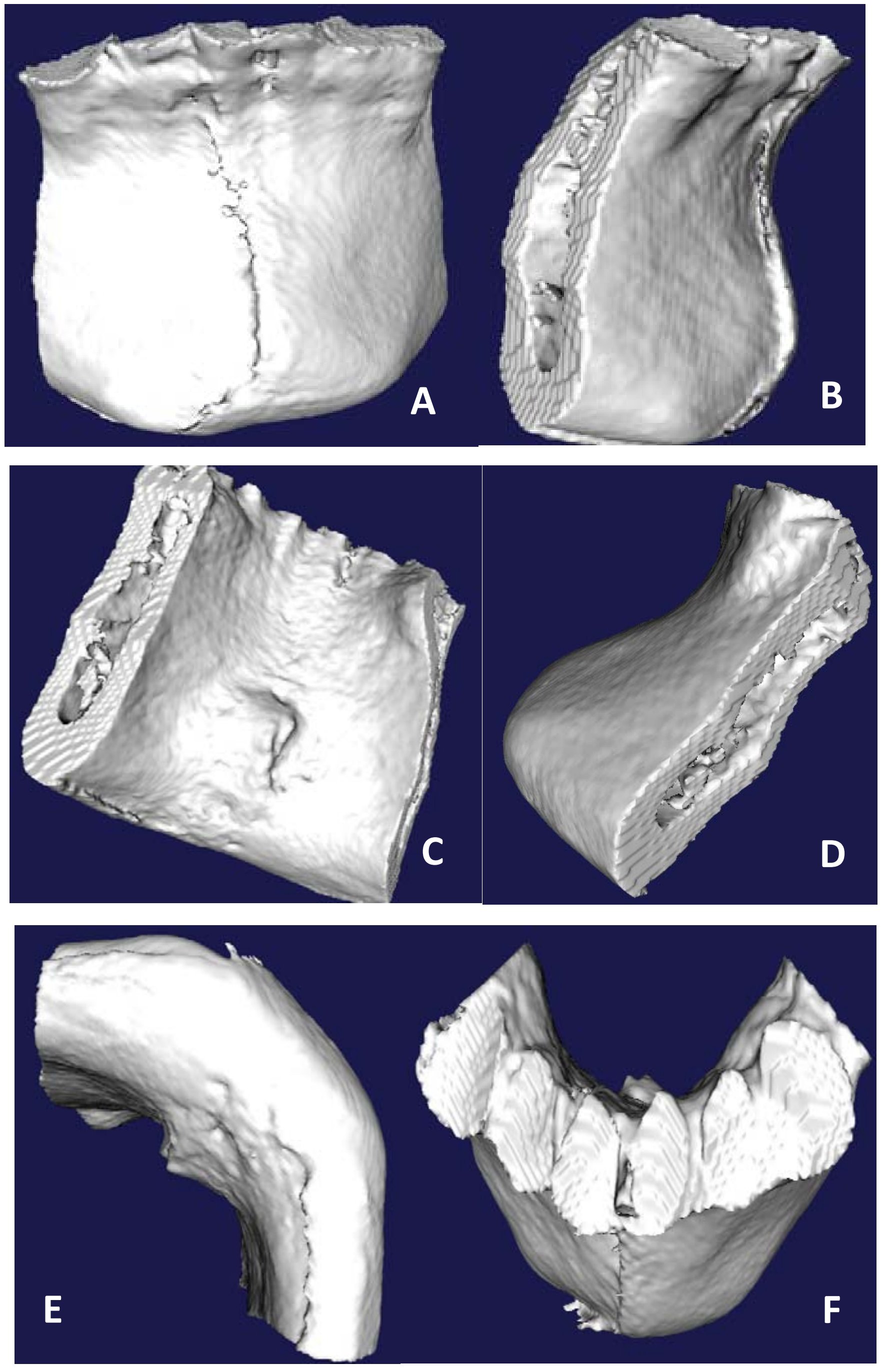

Figure III. 11 Reconstructed high-quality 3D images indicating the boundaries of the chin A: frontal view, B: lateral view of the right side, C: lingual view, D: lateral view of the left side, E: basal view F: occlusal view

6. *Repeated measurements*

To gauge intra-examiner reliability, the entire research procedures were repeated by the same investigator on randomly selected 55 2D lateral cephalograms and 30 3D lateral cephalograms that constituted 10% of the total sample population. The intra-class coefficient of correlation was applied to test examiner reliability.

7. Statistical analysis

The test of normality revealed that the variables did not follow a normal distribution and therefore, non-parametric tests were performed throughout this thesis.Numerous statistical analyses were performed in both 2D and 3D samples:

a. Spearman intra-class coefficient of correlation was applied to gauge examiner reliability.
b. Descriptive statistics for the total sample and for each group of malocclusion divided further into 4 facial types (hypodivergent, tendency hypodivergent, tendency hyperdivergent and hypodivergent). Frequency distribution was performed for the categorical variables (divergence, malocclusion, growing/adult patients and gender). For quantitative variables, means, medians, standard deviations, minimums and maximums were presented. For further analysis, each sample was stratified by gender and age.
c. Kruskal Wallis test was employed to assess the differences between and among groups, by malocclusion across all facial types. Post hoc for non-parametric tests

was employed after Kruskal Wallis test to evaluate differences between malocclusions across gender.

d. Spearman product-moment correlation coefficient was computed to gauge:
   - the relationship with age in total 2D and 3D samples
   - with age in growing and adults in 2D and 3D samples
   - with MP/SN angle in total 2D and 3D samples
   - with MP/SN in growing and adults in 2D and 3D samples
   - with age across different facial divergence
e. For gender differences in each sample apart and between 2D and 3D samples, Mann Whitney test was applied.
f. Mann-Whitney was also used to measure differences between 2D versus 3D total samples and taking into account genders as well as growing and non-growing subjects.
g. Logistic regressions with the clinically significant variables were performed:
   - in 2D and 3D samples with variables related to chin only to predict the divergence pattern
   - to assess gender differences across all malocclusion types in growing and adults.

SPSS and STATA statistical packages were used to perform all tests, at a level of significance of $p \leq 0.05$.

CHAPTER IV

RESULTS

This chapter includes first the intra-examiner reliability results, then the differences among vertical facial patterns in the entire samples followed by correlations of dentofacial parameters with facial divergence (MP/SN) and multivariate regressions to assess the divergence pattern and to predict chin components. The remaining analyses were carried out to evaluate gender differences in the entire samples and across malocclusions types. We further assessed similarities and differences with age. The latter included subgrouping by growing / non-growing and malocclusions across different facial patterns followed by correlations with age in the entire samples, in growing and adult groups and across different facial patterns. Finally, a comparison between 2D and 3D wasgaugedin males and females, and in growing and adult groups.

A. Intra-examiner reliability

The intra-examiner correlation coefficient ranged from 0.9 to 0.982 for the various measurements (Appendix 1).

B. Differences among vertical facial patterns

1. Total sample

2D sample consisted of 550 individuals distributed as 138 hypodivergent (group 1),140 tendency hypodivergent (group 2), 139 tendency hyperdivergent (group 3) and 133 hyperdivergent (group 4) individuals; while the 3D sample comprised 296 individuals divided into 77 hypodivergent (group1), 86 tendency hypodivergent (group 2), 77 tendency hyperdivergent (group 3) and 56 hyperdivergent (group 4) individuals.

No age difference was found among the 4 groups in both 2D and 3D samples (p=0.150 and p=0.098 respectively) – Tables II. a and II .b.

a. Cranial base measurements

i. 2D sample

Statistically significant differences were observed in the following sets of variables:

- The anterior cranial base SN (p=0.0001) was the longest in group 1 (66.67mm ± 4.34mm) compared to groups 2 (65. 88mm ± 5.08mm) and 4 (64.2mm ± 4.79mm).
- The posterior cranial base S-Ar (p=0.0001) was also the longest in group 1 (33.37mm ± 3.67mm) and the shortest in group 4 (29.6mm ± 3.44mm). S-Ar was statistically significant different in all groups compared to each other except for groups 2 and 3.
- The inclination of the anterior cranial base SN to the true horizontal SN/H (p=0.0001) increased with the divergence pattern ranging from $8.03^o \pm 3.6^o$ in group 1 to $13.41^o \pm 4.01^o$ in group 4.
- Similarly, the saddle angle SN/Ar (p=0.0001) increased with the divergence. It was statistically significant between group 1 ($121.93^o \pm 5.28^o$) and both groups 2 ($124.35^o \pm 5.23^o$) and 3($125.0^o \pm 5.38^o$). It was also different between groups 2 and 4 whereby it was more obtuse in hyperdivergent individuals.The difference between

groups 2 and 3 as well as 3 and 4were not statistically significant. (Tables IV. 1.a and IV.1.b)

ii. 3D sample

Unlike the previous sample, SN and SN/Ar were similar in all groups. However, similarities with the 2D sample were found at the level of S-Ar and SN/H:

- S-Ar (p=<0.001) decreased with the divergence. It was statistically significant between groups 1 (33.07mm ± 3.13mm), 2 (32.02mm ± 3.77mm), and 4 (30.48mm ± 3.71mm). It was also different between groups 2 and 3.
- SN/H (p=<0.001) increased significantly with the increase in divergence: group 1 (10.46 ± 4.75), group 2 (12.21° ± 4.13°), group 3 (12.06° ± 3.81°), and group 4 (15.92° ± 4.28°). Statistically significant differences were found between all groups except between groups 1 and 3, 2 and 3. (Tables IV.1.c and IV.1.d)

b. Relationship between jaws

The ANB angle was similar in all groups in both 2D and 3D samples. Moreover, the mandibular plane MP/H was flatter in group 1 compared to all groups in both samples (17.92° ± 3.74° and 19.49° ± 3.15° correspondingly) [p=0.0001].

i. 2D sample

- SNA and SNB angles were different among all groups (p=0.0001), being the most increased in group 1 (84.66° ± 3.67° and 81.5° ± 4.1° respectively) and decreasing towards group 4.

- The opposite applies to the lower facial height ($p=0.015$) and the divergence angle between the two jaws PP/MP that were increased in group 4 (55.76% ± 2.13% and $29.98^{o} \pm 4.66^{o}$ respectively) compared to group 1 (54.74% ± 2.69% and $18.74^{o} \pm 4.44^{o}$ respectively).
- The inclination of the palatal plane PP/H was similar in all groups. (Tables IV.2.a and IV.2.b)

ii. 3D sample

- SNA angle was statistically significant different among all groups except for group 2 ($83.08^{o} \pm 3.5^{o}$). The latter was close to groups 1 ($84.41^{o} \pm 3.29^{o}$) and 3 (82.16 ± 3.07).
- SNB angle was statistically different among all groups ($p=<0.001$) except between groups 2 and 3. Moreover, similarly to the 2D sample, SNB angle decreased with the increase in divergence.
- The inclination of the palatal plane to the horizontal (PP/H) was different between groups 3 ($-2.02^{o} \pm 3.7^{o}$) and 4 ($-3.12^{o} \pm 4.22^{o}$) [$p=0.012$]. The counter-clockwise rotation of the palatal plane increased from group 1 ($1.67^{o} \pm 3.57^{o}$) to group 4.
- The divergence angle between the two jaws PP/MP ($p<0.001$) was statistically different among all groups, increasing from group 1 ($19.37^{o} \pm 4.42^{o}$) to group 4($29.93^{o} \pm 4.02^{o}$). (Tables IV.2.c and IV.2.d)

c. Jaw specific measurements

Mandibular length Co-Gn and Ar-Gn were similar among all groups in 2D and 3D samples.

i. 2D sample

- The length of the maxilla (ANS-PNS) was different among all groups except between groups 1 and 2. It was increased in the group 1 (51.68mm ± 4.24mm), compared to groups 2 (50.66mm ± 5.78mm) and 3 (49.18mm ± 5.41mm) and the shortest in group 4 (47.21mm ± 4.72m).
- Mandibular body lengths (Go-Pog and Go-Me) were statistically different between groups 1 and 4 ($p<0.001$), 2 and 4 (Go-Pog: $p=0.008$, Go-Me: $p=0.004$), and 3 and 4 (Go-Pog: $p=0.024$, Go-Me: $p=0.02$). Go-Pog and Go-Me were the shortest in the group 4 (65.75mm ± 7.26mm and 62.13mm ± 7.12mm respectively) and the longest in the group 1 (70.13mm ± 7.11mm and 65.54 mm± 5.97mm respectively).
- The vertical ramus heights (Ar-Go and Co-Go) were statistically significant different among groups, group 1 presented the biggest length (Ar-Go: 46.85mm ± 6.68mm, Co-Go: 55.42mm ± 7.7mm) in comparison to other groups.
- The gonial angle was reduced in group 4 (Ar-Go-Me: $132.41^{o} \pm 5.78^{o}$, Co-Go-Me: $126.23^{o} \pm 5.78^{o}$) compared to group 3 (Ar-Go-Me: $127.34^{o} \pm 5.08^{o}$, Co-Go-Me:$121.1^{o} \pm 4.89^{o}$), group 2 (Ar-Go-Me: $124.79^{o} \pm 5.05^{o}$, Co-Go-Me: $118.3^{o} \pm 4.92^{o}$) and group 1 (Ar-Go-Me:$122.18^{o} \pm 5.11^{o}$, Co-Go-Me: $115.23^{o} \pm 5.33^{o}$). (Tables IV.3.a and IV.3.b)

ii. 3D sample

- Similarly to the 2D sample, ANS-PNS decreased from group 1 to group 4. However, it was statistically significant only between groups 1 and 3($p=0.012$), 1 and 4 ($p=0.024$).

- Unlike the 2D sample, Go-Pog and Go-Me were similar among different facial types.
- Additionally, the vertical ramus heights (Ar-Go and Co-Go) were statistically different among groups, group 1 presented, similar to the 2D sample, the smallest length (Ar-Go: 45.29mm ± 4.91mm, Co-Go: 50.97mm ± 5.17mm) in comparison to other groups.
- Moreover, the gonial angle was reduced in group 4 (Ar-Go-Me: 131.33° ± 5.6°, Co-Go-Me:126.06° ± 5.48°) compared to group 3 (Ar-Go-Me: 128.87° ± 4.8°, Co-Go-Me: 123.81° ± 4.63°), group 2 (Ar-Go-Me:119.98° ± 4.76°, Co-Go-Me: 119.98° ± 4.76°) and group 1 (Ar-Go-Me: 123.87° ± 4.52°, Co-Go-Me: 117.06° ± 4.23°). (Tables IV.3.c and IV.3.d)

d. Relationship between teeth and jaws

- The inclinations of the maxillary incisors to the palatal plane (U1/PP) and to SN (U1/SN) as well as the inclination of the mandibular incisors to NB (L1/NB) were not statistically significant different across various facial patterns.
- The proclination and protrusion of maxillary incisors (U1/Na and U1-Na) increased with the divergence in both samples (2D: from 21.78° ± 9.6° to 23.67° ± 7.72°, and 3.32 mm ± 2.97mm to 4.75mm ± 3.16mm; 3D: from 19.16° ± 8.78° to 20.41° ± 8.95°, and 2.95mm ± 1.58mm to 3.56mm ± 2.45mm); however, U1/Na was only statistically significant in the 2D sample.

- On the opposite, the inclination of the mandibular incisors to MP (L1/MP) decreased with the divergence (2D: from 98.2° ± 8.96° to 88.95° ± 9.07°, 3D: 99.44° ± 8.33° to 92.41° ± 7.84°). (Tables IV.4 a to IV.4.d)

e. Inter-dental relationship

The inter-incisal angle (U1/L1) and the overjet were not statistically significant in both 2D and 3D samples.

i. 2D sample

- The overbite (OB) was statistically significantly different among all groups except between groups 1 and 2. Group 1 presented the largest OB (3.65% ± 2.33%) followed by the other groups: 1 (3.12% ± 2.46%), 2 (2.15% ± 2.46%) and 4(1.27% ± 2.58%). (Tables IV.5.a and IV.5.b)

ii. 3D sample

- Likewise, OB decreased from group 1 (3.81 % ± 2.32%) to 4 (2.53 % ± 2.58%), however it was only statistically significant different between groups 1 and 4 (p=0.008), 3 and 4 (p=0.012). (Tables IV.5.c and IV.5.d)

f. Symphyseal components

In both 2D and 3D samples, inter-slopes angles (AntPost Slopes) were similar in all groups (p>0.05), while anterior slope angle (Ant Slope) decreased with hyperdivergence (p<0.005) in opposite pattern to the posterior slope angle (p<0.005). Moreover, the distance between point D and incisor apex (D-A) as well as the distance between point D and

Menton (D-Me), from CEJ to Menton (CEJ-Me) and between points B and B1 (BB1) were statistically longer in group 4 in comparison to other groups. In opposite to chin width at the level of the apex and point D, the latter were wider in hypodivergent patients.

i. 2D sample

- I-A was statistically significant different between groups 1 and 4 ($p<0.001$), 2 and 4 ($p<0.001$). Likewise, I-C was significant between groups 1 and 3($p=0.02$), 1 and 4 ($p<0.001$) and 2 and 4 ($p<0.001$). I-A and I-C decreased with the divergence, being the longest in group 4 (I-A: 20.77mm ± 1.8mm, I-C: 8.24mm ± 0.91mm) and the shortest in group 1 (I-A: 21.82mm ± 2.24mm, I-C: 8.7mm ± 1.07mm).
- Chin width at the level of the apex was statistically significant among all groups, decreasing from group 1 (10.57mm ± 1.92mm) to 4 (7.56mm ± 1.96mm). Similarly, chin width at the level of point D was statistically significant different in all groups except between groups 2 and 3. It also decreased from group 1 (13.67mm ± 1.82mm) to 4 (11.92mm ± 1.67mm).
- D-A was not statistically significant different between groups 3 and 4, but it was significant in all other groups increasing from group 1(7.63mm ± 2.16mm) to 4 (9.7mm ± 2.65mm).
- D-Me was statistically significant between groups 1 and 4 ($p=0.004$) and between groups 2 and 4 ($p=0.02$); it also increased from group 1 (9.03mm ± 1.29mm) to 4 (9.54mm ± 1.34mm).

- CEJ-Me was statistically significant different between groups 1 and 3($p<0.001$) and 1 and 4($p<0.001$). It increased with the divergence from group 1 (29.78 mm ± 3.54mm) to 4 (31.78 mm ± 3.61mm).
- BB1 was different among all groups decreasing from group 1 (9.48mm ± 3.2mm) to 4 (6.45mm ± 1.95mm).
- In terms of chin prominence, AntPost Slope angle remained the same however the components of this angle were expressed differently: Ant Slope angle was statistically significant among all groups except between groups 1 and 2, and 2 and 3. It decreased from group 1 (12.89^o ± 7.58^o) to 4 (5.86^o ± 7.49^o). In opposite to Post Slope angle that increased from group 1 (16.02^o ± 8.48^o) to 4 (23.17^o ± 8.45^o). This angle was statistically significant among all groups except between groups 1 and 2, 3 and 4. (Tables IV.6.a and IV.6.b)

ii. 3D sample

- Chin width at the level of apex, D-A, D-Me and BB1 were similar in all groups.
- In terms of I-A and I-C, the results were at odds with the 2D measurements. They statistically significantly increased with greater divergence, from group 1 (I-A: 22, 36 mm ± 1.88mm, I-C: 8.91mm ± 0.87mm) to 4 (I-A: 26.73 mm ± 1.67mm. I-C: 10.09 mm ± 1.07mm).
- CEJ-Me increased from group 1 (CEJ-Me: 2893 mm ± 3.19mm) to 4 (CEJ-Me: 33.21 mm ± 3.78mm).
- In opposite direction to the previous variables, chin width at the level of point D decreased from group 1 (13.93 mm ± 1.52 mm) to 4 (12.95 mm ± 1.46 mm).

The difference between groups 1 and 3 (p=0.012) and between 1 and 4 (p=0.004) were statistically different.

- Chin volume was similar in all groups (p>0.05) however, symphyseal components were conveyed inversely in different facial patterns (Tables IV.6.c and IV.6.d).

Additionally,chin volume was neither affected by the position of the mandibular incisor L1/MP (p=0.143) nor by the malocclusion type (p=0.0678) (Table IV.6.e), chin volume remains the same regardless of the sagittal and vertical dimensions.

2. Correlations of dentofacial parameters with facial divergence (MP/SN)

Spearman correlation test was conducted to check the presence of possible associations between the variables with MP/SN in the total sample and within growing and non-growing subjects.

a. Correlations with MP/SN in the entire samples

i. 2D sample

- PP/MP, MP/H and SN/H, other identifiers of divergence, as well as Ar-Go-Me and Co-Go-Me, presented a statistically significant very high correlations with MP/SN (r=0.730, r=0.611, r=0.508, r=0.637 and r=0.936 respectively), all the variables increased when MP/SN increased.
- SNA angle presented asignificant negative correlation with MP/SN (r=-0.509).

- A high negative correlation was noted between chin width at the level of apex and MP/SN (r=-0.519). Additionally, D-A, D-Me and CEJ-Me significantly positively correlated with MP/SN (r=0.268, r=0.128 and r=0.179 respectively) in opposite direction to BB1 (r=-0.329). (Table IV.7.a)

ii. 3D sample

- The correlation between chin volume and MP/SN was not statistically significant.
- Similar to the 2D sample, statistically significant high correlations were found at the level of PP/MP (r=0.684), Ar-Go-Me (r=0.476), Co-Go-Me (r=0.586), I-A (r=550) and MP/H (r=0.909).
- Chin width at the level of the apex was not statistically significant however chin width at the level of point D significantly correlated negatively with MP/SN (r=-0.238).
- I-C and CEJ-Me were found to be significantly positively correlated with MP/SN (r=0.375 and 0.298 respectively).
- Slope angles behaved differently with lowcorrelations relative to MP/SN: Ant slope decreased with MP/SN (r=-0.211) while Post slope increased with MP/SN (r=0.188). (Table IV.7.a)

b. Correlations with MP/SN in growing and adult groups

i. 2D sample

- Statistically significant correlations with MP/SN were high in the growing group and low in the corresponding adult group: PP/MP (growing: r=0.722, adult r=-0.078), SNA (growing r=-0.573, adult r=0.027), SNB (growing: r=-0.512, adult r=-0.135), Ar-Go-Me (growing r= 0.608, adult r=-0.203), Co-Go-Me (growing r=0.608, adult r=-0.192), chin width at the level of apex (growing r=0.615, adult r=-0.061). (Table IV.7.b)

ii. 3D sample

- After stratifying the individuals into growing and adult, the correlation between chin volume and MP/SN remained not statistically significant.

  The correlation between Co-Go-Me and MP/SN remained positively high in both growing and adult groups (r=0.583 and r=0.592 respectively). MP/H and PP/MP presented positive high correlations with MP/SN in both groups (MP/H: growing r=0.902, adult r=0.917; PP/MP: growing r=0.684, adult r=0.675). (Table IV.7.b)

3. Multivariate logistic regressions to assess the divergence pattern

Taking into account the need to predict the divergence pattern, logistic regression was performed for symphyseal components considering as reference the hypodivergent pattern.

The results of the logistic regression analysis for the tendency hypodivergent, tendency hyperdivergent and hyperdivergent with the hypodivergent pattern as a reference were displayed in Table IV.8.a and IV.8.b. 95% confidence intervals and the p-values were reported. All covariates that had a p<0.2 at a bivariate level were included in the analysis.

a. 2D sample

- Compared to the group 1, no variable was statistically significant in group 2.

- The remaining significant variables when comparing group 3 to 1 were: chin width at the level of point D (RRR=0.689, p=0.007) and posterior slope angle (RRR=1.07, p=0.003). When modeling the group 4 with 1, we noted a narrower chin width at the level of point D and an increased posterior slope angle among subjects with a tendency hyperdivergent pattern compared to those with a hypodivergent pattern.
- When comparing groups 1 and 4, more variables became statistically significant: chin width at the level of point D (RRR=0.586, p=0.001), chin width at the level of the apex (RRR=0.734, p=0.032), anterior slope angle (RRR=0.899, p<0.001), posterior slope angle (RRR=1.067, p=0.017) and BB1 (RRR=1.458, p=0.001). We found out that group 4 presented narrower chin widths at the level of point D and the apex, a more acute anterior slope angle but an increased posterior slope angle relative to the group 1.
- The following models explain the difference in odds between group 1 and the other groups:

$$\log(\Pi_{T.HYPO}/\pi_{HYPO})=0.11CEJME-0.15ChinWidth(APEX)-$$

$$0.12Chin0.02Width(pt\ D)-0.01DA-0.11DME-$$

$$0.02AntSLOPE+0+0.01PostSLOPE+0.11BB1+1.93$$

- All the regression equations are interpreted in the same way, for example: the odds of having a tendency hypodivergent pattern rather than a hypodivergent patternare multiplied by 0.11 with every 1 mm of increase in CEJ-Me holding all the other variables constant.

$$\log(\pi_{T.HYPER}/\pi_{HYPO})=0.21CEJMe-0.37ChinWidth(APEX)-0.18ChinWidth(pt\ D)-0.01DA-0.27DMe-0.04AntSLOPE+0.07PostSLOPE+0.16BB1+2.41$$

$$\log(\pi_{HYPER}/\pi_{HYPO})=0.02CEJMe-0.53ChinWidth(APEX)-0.3ChinWidth(pt\ D)+0.11DA+0.2DMe-0.1AntSLOPE+0.06PostSLOPE+0.37BB1+7.77$$

b. <u>3D sample</u>

- In comparison to the 2D samples, more variables became significant relative to group 1that was taken as a reference.
- When group 2 was compared to group 1, only one variable was significant: chin width at the level of point D (RRR=0.719, p=0.008). When modeling group 2 with 1, a narrower chin width at the level of point D was noted in group 2 relative to group 1.
- After modeling group 3 with 1, the remaining significant variables were: I-A (RRR=3.679, p<0.001), chin width at the level of point D (RRR=0.588, p<0.001), D-A (RRR=2.5, p=0.001), posterior slope angle (RRR=<0.001) and CEJ-Me (RRR=0.535, p=0.002).This model showed that group 3 exhibited longer mandibular incisor length, narrower chin width at the level of point D, decreased posterior slope angle and distance from CEJ-Me relative to group 1.
- The results of the logistic regression for group 4taking group1 as a reference were the following: I-A (RRR=17.23, p<0.001), I-C (RRR=0.214, p=0.004), chin width at the level of point D (RRR=0.467, p=0.002), D-A (RRR=2.609, p=0.014), posterior slope angle (RRR=1.067, p=0.043) and CEJ-Me (RRR=0.491, p=0.008). This model showed that, in comparison to group

1,group 4 presented longer mandibular incisor length but shorter mandibular incisor crown length, the narrowest chin width at the level of point D, an increased posterior slope angle and a decreased CEJ-Me distance.

- The following models explain the difference in odds between group 1and the other groups:

$$\log(\pi_{T.HYPO}/\pi_{HYPO})=0.27IA+0.27IC-0.32ChinWidth(ptD)+0.11DA-0.01AntSLOPE+0.02PostSLOPE-0.06CEJMe-2.92$$

$$\log(\pi_{T.HYPER}/\pi_{HYPO})=1.3IA-0.66IC-0.53ChinWidth(pt\ D)+0.91DA-0.01AntSLOPE+0.11PostSLOPE-0.62CEJMe-6.26$$

$$\log(\pi_{HYPER}/\pi_{HYPO})=2.84I-1.53IC-0.76ChinWidth(pt\ D)+0.95DA-0.004AntSLOPE+0.07PostSLOPE-0.71CEJMe-31.63$$

All the regression equations are interpreted in the same way, for example, the odds of having a tendency hypodivergent pattern rather than a hypodivergent pattern are multiplied by 0.27 with every 1mm of increase in IA holing all other variables constant.

4.Multivariate linear regression to predict chin components

A multivariate linear regression was conducted combining 2D and 3D samples to predict chin components only in groups 1 and 4.

a. Prediction of chin width

The highest r^2 was noted when chin width at the level of incisor apex CWA was predicted ($r^2 = 0.315$) relative to ANB and MP/SN reflecting the sagittal and vertical dimensions. The following equation explained this model: CWA=0.05ANB-0.144MP/SN+14.1(Table IV.9.a).Hence, all the equations are interpreted in the same way: for each 1 degree of increase in ANB, corresponds 0.05mm of increase in CWA; and for each 1degree of increase in MP/SN corresponds 0.144mm of decrease in CWA.

When other variables were included, the model presented a higher significance with $r^2= 0.622$. Therefore, for each 1 mm of increase in IA corresponds 0.27mm of increase in CWA; and for each 1mm of increase in DA corresponds 0.48mm of decrease in CWA; and for each 1mm of increase in DMe corresponds 0.2mm of increase in CWA; and for each 1 degree of increase in ANB matches 0.03mm of increase in CWA; and finally for each 1 degree of increase in MP/SN equals 0.1mm of decrease in CWA. In conclusion, the prediction of CWA is explained by the following model:

CWA=0.27IA-0.48DA+0.2DMe+0.03ANB-0.1MP/SN+8.8 (Table IV.9.b)

Chin width at the level of point D, CWD, presented a lower $r^2$of 0.24. Both ANB and MP/SN were statistically significant: for each 1 degree of increase in ANB matches 0.043mm of increase in CWD and for each 1 degree of increase in MP/SN equals 0.09mm of decrease in CWD. The following equation illustrates this model:

CWD=0.043ANB-0.095MP/SN+15.96 (Table.9.c)

b. Prediction of chin volume

While attempting to predict chin volume, ANB and MP/SN were not statistically significant and r^2 was low (r^2=0.018). The following equation explains this model:

Volume=-94.67ANB-3.38MP/SN+7753 (Table IV.9.d)

c. Prediction of IA and IC

A low $r^2$was shown while predicting mandibular incisor length IA and crown length IC. Only ANB was statistically significant different indicating that IA and IC increased with ANB:

IA=0.06ANB+0.001MP/SN+21.81 (Table IV.9.e)

IC=0.03ANB-0.005MP/SN+8.81 (Table IV.9.f)

d. Prediction of the distances from point D to both incisor apex and menton

Statistically significant differences were found at the level of MP/SN for the prediction of distances from point D to both incisor apex (DA) and menton (DMe). The latter increased with divergence. The linear regression is represented by these equations:

DA=0.008ANB+0.096MP/SN+5.14 (Table IV.9.g)

DMe=0.011ANB+0.02MP/SN+8.34(Table IV.9.h)

e. Prediction of slope angles

Inter-slope angle (AP slope) were similar across divergence ($p=0.806$), while anterior slope angle decreased with hyperdivergence (coefficient=-0.419, $p<0.001$) in opposite pattern to the posterior slope angle (coefficient=0.407, $p<0.001$). These findings were explained in the following equations (Tables IV.9.i to IV.9.k):

Ant slope=-0.157ANB-0.419MP/SN+24.65

Post slope=0.122ANB+0.407MP/SN+4.49

AP slope=-0.035ANB-0.011MP/SN+29.15

C. Gender differences

1. Total sample

Only the variables found to have statistically significant differences between males and females are displayed in Tables IV.10.a and IV.10.b.

a. 2D sample

- LFH/TFH was only statistically significant in the 2D sample ($p<0.001$), it was greater in males (55.6 % ± 2.5%) compared to females (54.77% ± 2.33%). SNB was also greater ($p=0.025$) in males (79.14% ± 6.63%) than females (78.62% ± 4.28%) in the 2D sample.

b. 3D sample

- Chin volume was statistically significant ($p<0.001$) larger in males ($7.66cm^3$ ± $1.42\ cm^3$) than females ($6.85\ cm^3$ ± $1.27\ cm^3$). Additionally, saddle angles were statistically significantly larger in males and females: Ar-Go-Me (127.94° ± 5.62° and 126.41° ± 5.52°) and Co-Go-Me (122.04° ± 5.73° and 120.72° ± 5.52°).

- In comparison to the 2D sample, S-Ar and chin width at the level of apex were statistically significant larger in males (32.5mm ± 4.05mm and 11.53mm ± 1.63mm respectively) than females (31.16mm ± 3.23mm and 10.73mm ± 1.71mm).

c. Common findings

The following linear measurements were all statistically significantly larger in males than females in both samples:

- Go-Pog (**2D**: 69.47mm ± 8.19mm and 67.08mm± 6.72mm , **3D**: 68.62mm ± 6.1mm and 66.91mm± 5.69mm)
- Co-Gn (**2D**: 112.41mm ± 12.76mm and 107.3mm ± 9.69mm , **3D:** 109.15mm ± 9.48mm and 105.75mm ± 6.79mm)
- Ar-Gn (**2D**: 108.21mm ± 12.15mm and 103.21mm ± 9.09mm, **3D:** 104.83mm ± 9.25 mm and 101.42mm ± 6.17mm)
- Go-Me (**2D**: 65.32 mm ± 7.83mm and 63. 25mm ± 5.93mm, **3D:** 65.46 mm ± 5.98mm and 63.63mm ± 4.8mm)
- Co-Go (**2D**: 55.23mm ± 8.32mm and 51.44mm ± 5.78mm, **3D:** 52.49 mm ± 6.17mm and 51.33mm ± 4.75mm)
- SN (**2D**: 67.44mm ± 4.72mm and 63.98mm ± 4.23mm, **3D:** 65.99mm ± 4.33mm and 63.94mm ± 3.25mm)

- SN-Ar (**2D**: 123.45^o ± 5.55^o and 125.11^o ± 5.71^o, **3D:** 126.61^o ± 5.71^{o}and 125.91^o ± 5.37^o)
- ANS-PNS (**2D**: 50.9mm5 ± 5.3mm and 48.52mm ± 5.1mm, **3D:** 51.98mm ± 4.14mm and 50.25 mm ± 3.73mm)
- I-A (**2D**: 21.97mm ± 2.38mm, **3D:** 24.27mm ± 2.26mm and 23.33mm ± 2.15mm)
- I-C (**2D**: 8.71 mm ± 1.15mm, **3D:** 9.7 mm ± 1.05 mm and 9.17mm ± 0.86mm)
- chin width at point D (**2D**: 13.12mm ± 1.88mm and 12.63 mm ± 1.83mm, **3D:** 13.83mm ± 1.55 mm and 13.21mm ± 1.49mm)
- and D-Me (**2D**: 9.7mm ± 1.49mm and 8.77mm± 1.2mm, **3D:** 8.74mm ± 1.39mm and 8.3mm ± 1.17mm).

2. *Multivariate logistic regressions to evaluate gender differences*

Taking into consideration the need to estimate gender differences, logistic regressions were performed in each sample, taking females as a reference. 95% confidence intervals and the p-values were reported in the following tables. All covariates that had a p<0.2 at a bivariate level were included in the analysis.

a. <u>2D sample</u>

When modeling males with females, the following variables were statistically significant: L1/NB (OR=0.962, p=0.015), LFH/TFH (OR=1.172, p=0.012), age (OR=0.936, p<0.001), Ar-Go (OR=0.954, p=0.004), SN (OR=1.188, p<0.001), S-Ar (OR=1.146, p<0.001), CEJ-Me (OR=1.111, p=0.024) and CWA (OR=1.168, p=0.043). We noted that, in comparison to females, males presented less proclined mandibular incisors, increased LFH/TFH, younger age, decreased Ar-Go, increase anterior and posterior cranial base, longer chin height and wider chin width(Table IV.11). The following equation explains the difference in odds between males and females:

$\mathrm{Log}(\pi_{male}/\pi_{female})$=0.26Class II,1 + 0.49 Class III + 0.24 Class II, 2 + 0.05MP/SN + 0.05PP/H – 0.03L1/NB + 0.01SNB + 0.15LFH/TFH – 0.06AGE – 0.01Go-Pog + 0.09Ar-Go + 0.17SN + 0.02SN/H -0.03SN-Ar + 0.13S-Ar – 0.04ANSPNS +0.03IA + 0.1CEJ-Me – 0.01BB1 + 0.15CWA - 22.38

The equations in this section are interpreted in the same way, for example, in subjects who have a Class II division 1 instead of a class 1, the odds of being a male rather than a female is multiplied by 0.26, and the odds of being a male rather than a female isis multiplied by 0.05 with every 1 degree of increase in MP/SN angle, holding all other variables constant.

b. 3D sample

In this model, the following variables were statistically significant: Class III (OR=1.002, p=0.048), SN (OR=1.128, p=0.026), S-Ar (OR=1.128, p=0.011), IA (OR=1.46, p=0.002), and CEJ-Me (OR=0.762, p=0.014); indicating that Class III males exhibited larger measurements relative to Class III females. In addition, relative to females, males had longer anterior and posterior cranial base, longer mandibular incisors and shorter chin height (Table IV.11). The following equation explains the relationship between males and females:

$\text{Log}(\pi_{male}/\pi_{female})$= -0.17Clas II,1 + 1.14Class III + 0.002Class II,2 + 0.02U1/PP - 0.001L1/NB -0.03AGE + 0.008Go-Pog + 0.03Ar-Go -0.01Ar-Gn + 0.03Ar-Go-Me + 0.12S-Ar + 0.05ANSPNS + 0.37IA + 0.31DMe + 0.15CWD -0.02BB1 -0.06CWA – 0.03Aslope -0.27CEJ-Me -26.24

D. Similarities and differences with age

1. *Subgrouping by growing/non-growing and malocclusion across different facial patterns*

Results in this section pertain to the 4 subgroups stratified by malocclusion. Each subgroup was further divided by growing status, yielding a total of 8 subgroups.p-values related to the divergence difference among these subgroups are displayed in Tables IV.12.

We gathered the data in this table by comparing, for each parameter, the significance between growing and non-growing groups. We pointed out 3 different categories:

- In yellow, we highlighted unchanged patterns, variables that were statistically significant between different between facial types in the growing subgroup and remained significant in the non-growing subgroup or that were not statistically significant and remained the same in both growing and non-growing subgroups.
- In red, we stressed on variables that were significant between different facial types in the growing subgroup and were not significant in the non-growing section.
- In green, we presented variables that were not significant in the growing subgroup and were significant in the non-growing section.

a. <u>Cranial base measurements</u>

- The anterior cranial base SN went being from not statistically significant in the growing subgroups to statistically significant only in adults Classes II,1 and III in the 2D sample. In both classes, SN was the longest in group 2 and the shortest in the group 4 (Class II,1: 68.5mm ± 3.28mm and 64.49mm ± 4.31mm respectively, Class III: 68.58mm ± 5.07mm and 64.14mm ± 4.2mm). While in the 3D Class III subgroup, SN was statistically significant different only in the growing subgroup; it was the longest in group 2 (65.82mm ± 1.12mm).
- SN/H was statistically significant in all subgroups except in the 3D sample in terms of growing Class I and adults Class II,2. In both samples, SN/H increased with divergence.
- The saddle angle, SN-Ar, was statistically significant different only in the 2D sample. Similar to SN/H, it increased with divergence.
- Posterior cranial base, SN, went from being statistically significant in growing subgroups to not statistically significant in adults in both samples at the level of Class I subgroup. SN decreased with divergence in all subgroups.

b. <u>Relationship between the jaws</u>

- SNA, SNB, PP/MP and MP/H were statistically significant in the 2D sample. The sagittal variables were affected by the vertical pattern since SNA and SNB decreased with divergence in opposite pattern to PP/MP and MP/H in both 2D and 3D samples.

- LFH/TFH was only statistically significant different at the level of the growing Class I in the 3D sample where group 1 presented the highest ratio.
- PP/H was similar in all subgroups.

c. <u>Jaw specific measurements</u>

- The size of the mandible, Go-Pog, was only statistically significant in the 2D sample in terms of non-growing Class I, Class II,1 and Class III. Go-Pog decreased significantly with the divergence in adults.
- The pattern of Ar-Go, position of the mandible relative to the cranial base, was statistically significant different in the entire 2D sample except in the Class III. Moreover, it was statistically significant only in the growing Class III in the 3D sample. Similar to Go-Pog, Ar-Go decreased with the divergence.
- Co-Gn, Ar-Gn and Co-Go were statistically significant different only in growing 2D Class I and were similar in adults across all facial types. Both increased with the divergence.
- In terms of angular measurements, Ar-Go-Me and Co-Go-Me had unchanged patterns in the 2D sample; however, in the 3D sample, Class II div 1, both variables went from being statistically significant different between facial types in growing patients to not significant in adults. The opposite pattern occurred in Class II div 2. Both angles increased significantly with the divergence in all groups.
- The palate exhibited different patterns between growing and non-growing groups. ANS-PNS went from being not significant to significant in Class I, 2D sample. The

opposite pattern was found in Class I, 3D sample. Class II div 2 and Class III in the 2D sample behaved similar to the previously mentioned subgroup.

d. Relationship between teeth and jaws

Most of the changes were noted in the 2D sample in comparison to the 3D sample. The following variables went from being significant in the growing subgroups to not significant in the corresponding adult subgroups: U1-Na (Class I and Class III), L1-NB (Class I and Class II div 2) and L1/MP (in Class II div 2). U1-Na and U1/SN in Class II,1 were not significant in growing subgroups and became significant in the corresponding adult subgroups.The inclination of maxillary and mandibular incisors decreased with the divergence.

e. Relationship between teeth

- Changed patterns only occurred at the level of U1/L1 and OJin Class II div 1 in the 2D sample.

f. Symphyseal components

- The volume of the chin was similar in all subgroups across all facial patterns
- Most of the statistically significant differences were observed in the 2D sample relative to the 3D sample.
- In the 2D sample, mandibular incisor length I-A was statistically significant in growing Class I and Class II,1 and in the non-growing Class II,1. I-A was the longest in group 2 in comparison to other groups. However, in the 3D sample, I-A increased significantly from group 1 to 4 across all malocclusion types. It was

statistically significant at the level of Class I and Class II,1 subgroups and in non-growing Class II,2.

- Analogous to I-A, the incisor crown length I-C was the longest in group 2 in the 2D sample and it increased with divergence in the 3D sample with being statistically different among divergence groups in growing Class I and Class II,1 and in non-growing Class II,2. In both samples, no changes were statistically significant in terms of Class III subgroup.
- Chin width at the level of apex and point D differed, distances between point D and incisor apex and between BB1 were statistically significant different among facial types only in the 2D sample. Chin width at the level of point D, incisor apex and BB1 was the widest in group 1, while the distances between point and both incisor apex and menton were greater in group 4.
- Anterior slope angle decreased with the increase in divergence in opposite pattern to the posterior slope angle. Most of the statistically significant differences were at the level of the 2D sample Class I and Class II,1.
- The distance between CEJ-Me were statistically significant different in the 2D sample in growing and adults Class I and in adults Class II,1 and Class III, and in the 3D sample only in adults Class II,1. Analogous to the distances between point D and both incisor apex and menton, CEJ-Me increased with divergence.

Most of the pattern changes occurred in Class I and Class II,1 especially in the 2D sample. This table summarizes the fact that unchanged and redundant patterns were more dominant when comparing growing subgroups and their corresponding adult subgroups across different types of malocclusion stratified among various facial patterns.

2. *Correlations with age*

The Spearman correlation test was conducted to check the presence of possible associations between the variables with age in the total sample, within growing and non-growing subjects.The main findings were the following:

a. Correlations with age in the total sample

i. 2D sample

- All the correlations were low (less than 0.3) however the most interesting ones were found between age and the following variables MP/SN (r=-0.124), PP/MP (r=-0.177), LFH/TFH (r=-0.114), Ar-Go-Me (r=-0.113) and Co-Go-Me (r=-0.137), all these variables decreased with age.
- Inter-slope angle was not statistically correlated with age, nevertheless its components behaved differently: a positive correlation was found between the anterior slope with age (r=0.206), in opposite direction to the posterior slope (r=-0.143). (Table IV.13.a)

ii. 3D sample

- A moderatepositive correlation was noted between chin volume and age (r=0.424) and at the level of CEJ-Me (r=0.496), DA (r=0.495) and DMe (r=0.405).
- Higher correlations, in comparison to the 2D sample, were found at the level of Go-Pog (r=0.465), Ar-Go (r=0.433), Co-Gn (r=0.542), Ar-Gn (r=0.507), Go-Me (r=0.501), Co-Go (r=0.557). All these variables increased with age.
- Ar-Go-Me and Co-Go-Me were significantly correlated (r=-0.293 and r=-0.248 respectively), both decreased with age. (Table IV.13.a)

b. Correlations with age in growing and adult groups

i. 2D sample

- Ar-Go (r=0.469), Ar-Gn (r=0.433), Go-Me (r=0.408), SN (r=0.437), ANS-PNS (r=0.489), MP/H (r=-0.218), chin width at the level of point D (r=0.244), I-A (r=0.141), I-C (0.276) correlated positively with age in the growing subjects, yet in the adults group the correlation was not statistically significant.
- Co-Gn correlated positively in the growing group but negatively in the adults group, even though in the latter the correlation was not high (r=0.419 and r=-0.017 respectively).
- Anterior and posterior slopes correlated in opposite directions (r=0.186 and r=-0.201 respectively) in the growing group. In adult patients, these correlations

were not statistically significant. Additionally, the correlation with the inter-slope angle remained not statistically significant.(Table IV.13.b)

ii. 3D sample

- The volume of the chin was found to be statistically positively correlated with age in the growing group (r=0.409) however it was not significant in the adult group.
- The same applies to the following measurements: Go-Pog, Ar-Go, Co-Gn, Ar-Gn, Go-Me, Co-Go, ANS-PNS, I-A, chin width at the level of point D, D-A, D-Me and CEJ-Me.
- Slope angles were expressed in opposite direction nevertheless both significantly correlated in the growing group (Ant Slope r=0.199, Post Slope r=-0.249) and the correlation was not significant in the adult group. (Table IV.13.b)

c. Correlations with age across different facial patterns

i. 2D sample

- The highest positive correlations found across all facial patterns were at the level of Go-Pog, Ar-Go, Co-Gn, Ar-Gn, Go-Me, Co-Go, D-Me and CEJ-Me.
- ANS-PNS correlated positively among all groups except in the hypodivergent one. (Table IV.14.a)

ii. 3D sample

- The correlation between age and the following variables chin volume, anterior slope angle, inter-slope angle, chin width at the level of point D and MP/H separately with age were not statistically significant among the 4 groups.
- The highest correlations across all groups were found at the level of Go-Pog, Co-Gn, and Go-Me, D-A, D-Me and CEJ-Me.

BB1 correlated statistically positively with age only in the hyperdivergent group (r=0.349). (Table IV.15.b)

E. Comparison between 2D and 3D samples

In this section, differences between 2D and 3D imaging are presented: in the total sample, in males, in females, in the total growing sample and the total non-growing sample. Only statistically significant measurements between 2D and 3D are mentioned below.

1. Total 2D and 3D samples

The age was not statistically significant between the two samples. Below are listed the statistically significant variables when comparing 2D and 3D samples (Table IV.1.a):

a. Cranial base measurements

- SN (2D: 65.66 ± 4.79, 3D: 64.71 ± 3.81), SN/H (2D: 10.4 ± 4.21, 3D: 12.28 ± 4.49), SN-Ar (2D: 124.3 ± 5.69, 3D: 126.17 ± 5.5).

b. Relationship between the jaws

- SNA (2D: 81.84 ± 4.15, 3D: 82.69 ± 3.49), ANB (2D: 2.95 ± 5.27, 3D: 4.17 ± 2.75), MP/SN (32.43 ± 6.84, 3D: 31.19 ± 5.55), PP/H (2D: -2.03 ± 3.83, 3D: -2.78 ± 4.21).

c. Jaw specific measurements

- Most of the variables (except Co-Go-Me) were bigger in the 2D relative to the 3D sample, Ar-Go (2D: 44.85 ± 6.62, 3D: 43.27 ± 5.13), Co-Gn (2D: 109.8 ± 11.58, 3D: 107.01 ± 8.05), Ar-Gn (2D: 105.66 ± 10.97, 3D: 102.69 ± 7.63), Co-Go (2D: 53.5 ± 7.38, 3D: 51.76 ± 5.34), Co-Go-Me (2D: 120.17 ± 6.59, 3D: 121.21 ± 5.63).

d. Relationship between teeth and jaws

- 3 measurements were the biggest in the 2D sample: U1-Na (2D: 4.02 ± 3.07, 3D: 3.0 ± 1.96), U1/Na (2D: 22.51 ± 8.79, 3D: 20.23 ± 8.29), U1/SN (2D: 104.19 ± 9.44, 3D: 102.6 ± 8.78).
- The remaining two significant variables were the smallest in the 2D sample in comparison with the 3D sample: L1/NB (2D: 25.3 ± 7.59, 3D: 27.43 ± 7.76) and L1/MP (2D: 93.72 ± 9.41, 3D: 96.69 ± 8.56).

e. Relationship between teeth

- U1/L1 was larger in the 2D sample (2D: 129.59 ± 13.25, 3D: 128.27 ± 13.11) conversely, OB and OJ were larger in the 3D sample (2D: 2.56 ± 2.62, 3D: 3.29 ± 2.32 and 2D: 2.89 ± 3.34, 3D: 3.85 ± 2.84 respectively).

f. Symphyseal components

- Mandibular teeth and distance between BB1were longer and the symphysis wider in the 3D relative to the 2D sample: I-A (2D: 21.42 ± 2.22, 3D: 23.68 ± 2.23), I-C (2D: 8.46 ± 1.09, 3D: 9.37 ± 0.97), BB1 (2D: 7.99mm ± 5.5mm, 3D: 7.67mm ± 5.67), chin width at the level of the apex (2D: 9.03 ± 2.17, 3D: 11.02 ± 1.72), chin width at the level of point D (2D: 12.87 ± 1.87, 3D: 13.44 ± 1.54).
- Even though anterior slope angle was bigger in the 3D relative to the 2D (2D: 9.81 ± 8.07, 3D: 12.31 ± 8.97), posterior slope angle, inter-slope angle and CEJ-Me were the largest in the 2D sample (2D: 19.32 ± 8.75, 3D: 15.02 ± 8.75 and 2D: 29.14 ± 8.11, 3D: 27.34 ± 10.7, 30.94 ± 3.9, 3D: 30.01 ± 3.47 respectively).

2. Gender differences between 2D and 3D samples

Only statistically significant differences between genderswere represented in Table IV.15.b and IV.15.c.

a. Differences in males between 2D and 3D

i. Cranial base measurements

- SN, SN/H, SN-Ar and S-Ar showed statistically significant differences between 2D and 3D samples. All the variables were bigger in the 2D sample relative to the 3D sample: SN (2D: 67.44 ± 4.72, 3D: 52.04 ± 5.73), SN/H (2D: 9.7 ± 4.17, 3D: 5.99 ± 4.33), SN-Ar (2D: 122.9 ± 4.27, 3D: 120.07 ± 4.38) and S-Ar (2D: (2D: 32.9 ± 4.27, 3D: 26.61 ± 5.71).

ii. Relationship between jaws

- SNA, SNB and ANB were bigger in the 2D sample (2D: 82.05 ± 4.13, 3D: 83.06 ± 5.31, 2D: 79.14 ± 6.63, 3D: 82.75 ± 3.51 and 2D: 2.9 ± 6.76, 3D: 8.71 ± 3.76).
- The highest identifiers of divergence were noted in the 2D sample: MP/SN (2D: 31.95 ± 6.69, 3D: 31.04 ± 5.75), PP/MP (2D: 23.9 ± 5.8, 3D: 16.59 ± 9.66) and LFH/TFH (2D: 55.6 ± 2.5, 3D: 53.96 ± 3.04).

iii. Jaw specific measurements

- Out of the 5 statistically significant variables between 2D and 3D, 4 were linear measurements: Ar-Go (2D: 46.21 ± 7.42, 3D: 68.62 ± 6.1), Co-Gn (2D: 112.41 ± 12.76, 3D: 143.94 ± 6.24), Ar-Gn (2D: 108.21 ± 12.15, 3D: 109.15 ± 9.48) and Co-Go (2D: 55.23 ± 8.32, 3D: 65.46 ± 5.98).
- Only one angular measurement, Co-Go-Me, was statistically different between the two samples (2D: 120.29 ± 6.66, 3D: 127.64 ± 5.62).
- All of the statistically significant variables were larger in the 3D relative to the 2D sample.

iv. Relationship between teeth and jaws

- Maxillary incisors were statistically more protruded in the 2D relative to the 3D sample: U1-Na (2D: 4.11 ± 3.1, 3D: -2.47 ± 4.43). Moreover, mandibular incisors were more proclined in the 2D sample: L1/NB (2D: 24.9 ± 7.32, 3D: 24.69 ± 2.13). However, mandibular incisors were more proclined in the 3D sample relative to the mandibular plane: L1/MP (2D: 93.57 ± 9.59, 3D: 98.03 ± 7.28).

v. Relationship between teeth

- The deepest overbite and the largest overjet were found in the 3D sample relative to the 2D sample: OB (2D: 2.63 ± 2.79, 3D: 7.66 ± 1.42), OJ (2D: 2.6 ± 3.61, 3D: 3.28 ± 2.51). Conversely, U1/L1 was more obtuse in the 2D relative to the 3D sample (2D: 129.82 ± 12.91, 3D: 97.12 ± 8.19).

vi. Symphyseal components

- Relative to the symphysis, angular measurements were more obtuse in the 2D sample: anterior slope angle (2D: 9.63 ± 7.9, 3D: 8.74 ± 1.39), posterior slope angle (2D: 19.34 ± 9.38, 3D: 10.89 ± 7.46) and inter-slope angle (2D: 28.98 ± 8.49, 3D: 15.32 ± 9.85).
- On one hand 7 linear measurements were statistically significant between 2D and 3D samples. 5 out 7 were longer in the 3D sample: I-A (2D: 21.97 ± 2.38, 3D: 26.95 ± 2.52), I-C (2D: 8.71 ± 1.15, 3D: 9.27 ± 2.26), chin width at the level of the apex (2D: 9.23 ± 2.23, 3D: 9.7 ± 1.05), D-A (2:D 9.11 ± 2.84, 3D: 13.83 ± 1.55) and CEJ-Me (2D: 28.28 ± 3.04, 3D: 29.15 ± 6.01).

- On the other hand, the remaining 2 variables were the smallest in the 3D sample: D-Me (2D: 9.7 ± 1.49, 3D: 7.09 ± 1.81) and BB1 (2D: 32.08 ± 4.01, 3D: 30.4 ± 3.51).

b. Differences in females between 2D and 3D

i. Cranial base measurements

- SN/H and S-Ar were statistically significant between the two samples (SN/H 2D: 11.08 ± 4.15, 3D: 13.94 ± 3.25 and S-Ar 2D: 30.45 ± 3.24, 3D: 25.91 ± 5.37), displaying a higher Sella and a longer posterior cranial base in the 2D sample.

ii. Relationship between jaws

- Unlike the findings in the female section, SNA and ANB were statistically significant different between 2D and 3D samples (SNA 2D: 81.65 ±4.18, 3D: 83.45 ± 5.21 and ANB 2D: 3.02 ± 3.27, 3D: 2.3 ± 3.73), showing that the maxilla was more protrusive in the 2D sample compared to the 3D sample.
- PP/MP, LFH/TFH and MP/H were similar between the two samples.

iii. Jaw specific measurements

- Only two variables were statistically significant in this section; Ar-Gn was the shortest in the 2D sample (2D: 103.21 ± 9.09, 3D: 105.75 ± 6.79), while the palate ANS-PNS was the shortest in the 3D sample (2D: 48.52 ± 5.1, 3D: 31.16 3.23).

iv. Relationship between teeth and jaws

- Maxillary and mandibular incisors were statistically more proclined and protruded in the 2D sample: U1-Na (2D: 3.93 ± 3.06, 3D: 2.97 ± 4.07), U1/Na (2D: 22.27 ± 8.83, 3D: 21.87 ± 1.87), U1/SN (2D: 103.64 ± 9.75, 3D: 102.75 ± 8.22), L1/NB (2D: 25.69 ± 7.82, 3D: 21.41 ± 2.45).

v. Relationship between teeth

- OJ was statistically significant larger in the 2D sample (2D: 3.17 ± 3.06, 3D: 3.3 ± 2.21).

vi. Symphyseal components

- Similar results were found in comparison to the female group. All the angular measurements were more obtuse in the 2D sample in comparison to the 3D sample: anterior slope angle (2D: 9.99 ± 8.24, 3D: 8.3 ± 1.17), posterior slope angle (2D: 19.3 ± 8.12, 3D: 13.16 ± 9.67) and inter-slopes angle (2D: 29.29 ± 6.8, 3D: 14.85 ± 8.06).
- In terms of linear measurements, 4 out of 6 were shortest in the 2D sample: I-A (2D: 20.88 ± 1.91, 3D: 19.05 ± 1.42), I-C (2D: 8.22 ± 0.97, 3D: 7.33 ± 2.15), chin width at the level of apex (2D: 8.84 ± 2.09, 3D: 9.17 ± 0.86), D-Me (2D: 8.77 ± 1.2, 3D: 7.32 ± 1.97).
- Only chin width at the level of point D and D-Me were statistically longer in the 2D sample (2D: 12.63 ± 1.83, 3D: 10.73 ± 1.71 and 2D: 8.77 ± 1.2, 3D: 7.32 ± 1.97).

Further evaluation of the changes between 2D and 3D were performed in growing and non-growing individuals.

c. <u>Total growing sample: 2D vs 3D</u>

- Results showed that 72% of the statistically significant variables indicated that the 3D growing individuals exhibited bigger variables relative to the 2D sample. Out of these 72%, the majority was related to linear measurements such as Go-Me, S-Ar, ANS-PNS, I-A, I-C, CEJ-Me, chin width at the level of the apex and point D.
- Moreover, most of the measurements showing bigger results in the sample were angular measurements such as MP/SN, PP/MP, U1/Na, posterior slope angle and inter-slope angle. (Table IV.15.d)

d. <u>Total non-growing sample: 2D vs 3D</u>

- Most of the statistically significant differences between 2D and 3D occurred among growing individuals in comparison to adults. In the latter, most of the results pointed out that 2D samples presented bigger and larger linear and angular variables in comparison to the 3D sample. All of the variables related to the jaws were longer in the 2D sample such as Ar-Go, Co-Gn, Co-Gn, Ar-Gn and Co-Go. The 2D adult individuals had more proclined and protruded incisors (in terms of U1-Na, U1/Na, U1/SN, U1/PP) but shorter mandibular teeth and crowns relative to the 3D sample. Even though chin width at the level of the apex and point D and BB1 were wider in the 3D sample, D-A, D-Me and CEJ-Me were longer in the 2D in comparison to the 3D sample.

- Moreover, while anterior slope angle was more obtuse in the 3D, posterior slope angle was more acute in the 3D relative to the 2D non-growing individuals. (Table IV.15.e).

CHAPTER V

DISCUSSION

The present study sheds light on chin morphology with new concepts heretofore not reported. The hypotheses and research questions permitted the formulation of further tenets or interpretation of existing ones. The derivative insights into chin anatomy may aid in the understanding of the craniofacial complex when comparing the research parameters between younger and adult individuals among various vertical and sagittal facial types.

A. Chin volume: Moss's theory revisited

The association between bony chin and symphyseal volume has not been investigated. We found that the volume of the chin was similar in all groups ($p>0.05$) regardless of the facial pattern and the underlying malocclusion type. The correlation between chin volume and MP/SN was not statistically significant in the entire sample. However, a moderate positive correlation was noted between the chin volume and age ($r=0.424$), it was statistically positively correlated with in the growing subgroup ($r=0.409$) and not significant in the adult subgroup. These findings reinforce Moss's theory of "functional matrix", which stipulates that facial growth is affected by the function of various body parts in the head and neck region. Changes in form often point out modifications in function (Moss, 1964). Growth in size, shape and spatial position of all skeletal units are secondary to main alterations in their specific functional matrices and relevant cranial components. The functional matrix is composed of capsular and periosteal matrices, sequentially contributing to shaping the associated skeletal units, which in turn protect the associated matrix. Teeth are considered a part of the periosteal matrix. Actually, most orthodontic treatment is based on the fact that when teeth are moved, the related skeletal unit, such as the alveolar bone, reacts properly to its “morphogenetically primary demand”(Moss et al., 1969). Supporting Moss’ findings, our data suggest that adaptive modeling of the skeletal units is affected by changes in the oropharyngeal region. The adaptation may range from a simple tilt of the mandibular symphysis to vertical skeletal changes with or without an underlying malocclusion. Not surprisingly, our study has reached similar conclusions regarding the early adaptation of the mandibular symphysis as a response to vertical and sagittal changes among individuals.

The chin, similar to a “balloon” filled with air, whether shortened or elongated, extended or flattened, its volume remaining the same. Another excellent example is the relationship between measurements relating vertical relations and mandibular shape.

B. Constitutional differences within the chin

1. Symphyseal shape

Even though the chin volume was similar among individuals, its shape components were expressed differently in the various vertical facial patterns. This finding suggests that long standing environmental stimuli help determine the final shape of the chin.

In terms of linear measurements, this outcome was supported by the variations, presumably adaptations, in chin width and height. We used point D, a landmark advocated by Steiner as reliable and accurate in representing the center of the symphysis (Steiner, 1959) to determine chin height from incisor apex to menton. A statistically significant relationship was found between facial type and both alveolar height and thickness. Distances from point D to both mandibular incisor apex and menton were statistically significantly longer in the hyperdivergent group (2D: 9.7mm ± 2.65mm and 9.54mm ± 1.34mm respectively; 3D: 8.07mm ± 1.98mm and 8.49mm ± 1.47mm respectively) and shorter in the hypodivergent group (2D:7.63mm ± 2.16mm and 9.03mm ± 1.29mm; 3D: 6.69mm ± 1.87mm and 8.52mm ± 1.44mm respectively) . Accordingly, the distance between CEJ and Me increased with the divergence (2D:from 29.78mm ± 3.54mm to 31.78mm ± 3.61mm; 3D: 28.93mm ± 3.19mm and 33.21mm ± 3.78mm).

Significantly moderate positive correlations were noted between the above mentioned variables and MP/SN. Furthermore, compared to other groups, high angle group presented thinner chin width at the point D level (p=0.004). Even though chin width at the level of the incisor apex was similar in all groups in the 3D sample, it decreased from hypodivergent (13.67mm ± 1.82mm) to hyperdivergent group (11.92mm ± 1.67mm) in the 2D sample. These results are consistent with the findings of other studies (Aki et al., 1994; Björk, 1969; Gracco et al., 2010; Mangla et al., 2011; Ricketts, 1960).

Chin prominence contributes significantly to the outline of the profile, thus the inclination of the anterior and posterior chin slopes were evaluated as determinants of the prominence. While the inter-slope angle remained the same across all facial patterns except in growing Class II,1 in the 2D sample (p=0.013) and in non-growing Class I in the 3D sample (p=0.029), in both subgroups, the inter-slope angle was more obtuse in the hypodivergent group ($29.8^{o}\pm6.63^{o}$ and $32.68^{o}\pm10.39^{o}$ respectively). Furthermore, this angle was not correlated with age. Nevertheless, the components of this angle were expressed differently: anterior slope angle decreased with hyperdivergence (p<0.005). These angles were statistically significantly different only in the growing subgroups, confirming data from studies indicating that growth changes of the facial tissues, though not completed, occurred mainly before the age of 18 years (Formby et al., 1994).

The multivariate analyses suggest associations among chin components, including interaction between boney distances (1mm increase in the height from point D to incisor apex corresponds a decrease of 0.47mm in chin width at the level of incisor apex; each 1mm increase in height from point D to menton corresponds 0.19 of increase in chin width at the level of incisor apex), and between dental and skeletal distances (each 1 mm of increase in incisor crown length corresponds to 0.16mm of increase in chin width at the level of the incisor apex; each 1mm of increase in mandibular incisor length corresponds 0.22mm of increase in chin width at the level of incisor apex).

Not surprisingly, chin width at the level of BB1 was statistically significantly thinner in the hyperdivergent group relative to the hypodivergent group (RRR=1.458, p=0.001). Interestingly, statistically significant negative correlations were noted between chin width and MP/SN in growing and non-growing subgroups, indicating perhaps that remaining growth occurred in the non-growing subgroups after the age of 16 in females and 18 in males.

2. Tooth length

The length of the mandibular incisor was revealed as an important component in defining various types of mandibular growth, possibly becoming an 8th essential clinical sign if one expands on the work of Bjork (Björk, 1963). We had stipulated that the longest mandibular incisor length would likely be found in hyperdivergent individuals, in addition to hyperplasia of the alveolar bone. This hypothesis stemmed from observations of increased incisor length in high angle subjects. Tooth size variability appears to have a strong genetic component, but our findings support the notion that environmental factors may also be at play.

In the 2D sample, mandibular incisor length I-A was statistically significantly different in growing Class I and Class II,1 and in the non-growing Class II,1. I-A was the longest in the tendency-hypodivergent group in comparison to other facial types. Yet, overall, the average differences across groups were within nearly 1mm and potentially not of clinical significant. However, in the 3D sample, I-A increased significantly from hypodivergent group to hyperdivergent group across all malocclusion types. It was statistically significant at the level of Class I and Class II,1 subgroups and in non-growing Class II,2. While The difference between hypodivergent and hyperdivergent groups in the 2D sample was equal to 1.05mm, in the 3D sample it was equivalent to 4.7mm. The 3D results, if confirmed by warranted further investigations, would underline the role of dental growth in compensation for deviating growing skeletal structures. This inference of environmental influence finds tangential support in a study of distraction osteogenesis whereby distraction “dentogenesis” occurred accidentally ((El-Bialy et al., 2003) , suggesting the potential for dental environmental adaptability. The difference between the 2D and 3D samples might be biased in the non-growing group since the root formation of mandibular incisors might not be complete before the age of 9.

C. Varied adaptations among facial patterns

The anterior and posterior cranial base lengths (SN and S-Ar) were the longest in the hypodivergent group in comparison to the other groups. A significant opposite trend was found at the level of the cranial base flexure (SN-Ar) that increased significantly with the increase in divergence in the 2D sample (from $121.93^{o} \pm 5.28^{o}$ to $125.0^{o} \pm 5.38^{o}$). The findings that SN-Ar was more obtuse and the inferior cant of SN was more pronounced in high angle cases relative to normal or low angle cases validate prior results (Schendel et al., 1976). High correlations were identified between SN/H and MP/SN (2D: r=0.508, 3D: r=0.251).

Ramus heights (Ar-Go and Co-Go) were also found to be significantly increased in hypodivergent and normodivergent groups when compared with hyperdivergent group. Both measurements correlated negatively with MP/SN. The findings were in agreement with Sassouni (1958), Muller (1963), Schudy (1963), Mangla et al (2011), all of whom reported a considerable deficiency in dimension in the hyperdivergent group.

The overall mandibular lengths (Co-Gn and Ar-Gn) were similar among different facial types in both 2D and 3D samples. However, Ar-Gn correlated negatively with MP/SN suggesting that mandibular length decreased with divergence. Pollard et al pointed out that the increase in Co-Gn highly correlated with ramal height and body length changes.

They also found mandibular length measurements from condylion and articulare highly correlative, suggesting that articulare may be substituted for condylion(Pollard et al., 1995). Nevertheless, while such substitution may be valid on average, it may not be in the individual patient, as Ar-Gn reflects more mandibular position than mandibular length (Efstratiadis et al., 2005).

The gonial angle (through both Ar-Go-Me and Co-Go-Me) was found to be significantly increased in the hyperdivergent group when compared with the other groups. Various investigators have also specified that an obtuse gonial angle was related to a downward and backward rotation of the mandible increasing the severity of the divergence type (Mangla et al., 2011; Ricketts, 1960; Sassouni, 1958; Schendel et al., 1976).

Vertical growth direction may have an indirect effect on the antero-posterior position of the mandible and, consequently, on mandibular symphyseal morphology (Al-Khateeb et al., 2013). Within the context of inter-jaw relations, the SNA and SNB angles were statistically different among all facial patterns ($p<0.001$), being the most increased in the tendency-hypodivergent and hypodivergent groups and decreased in the tendency-hyperdivergent and hyperdivergent groups. These differences between the variables relating the jaws together among different facial patterns highlight the fact that a vertical problem may camouflage or worsen a discrepancy in the sagittal plane (Joseph Ghafari et al., 2013).

Most of the unchanged growth patterns occurred in Class I and Class II,1 emphasizing the fact that the severity of Class II,2 and Class III increased in time. However, unchanged and redundant patterns were more dominant when growing subgroups were compared to their corresponding adult subgroups across different types of malocclusion, stratified into the various vertical facial types.

The correlations between MP/SN and other mandibular and maxillary vertical measurements such as PP/MP expectedly presented positively high correlations (2D: r=0.730, 3D: r=0.519). The tip of the palatal plane, especially if inclined postero-inferiorly, may exacerbate the severity of an underlying skeletal hyperdivergent problem.

A well-established relationship between the amount of overbite (OB) in different facial types was underlined. The OB decreased with divergence and remained positive in the hyperdivergent groups, emphasizing Betzenberger et al's findings who reported that 80% of hyperdivergent children presented a positive OB, underlining the compensatory mechanisms by environmental factors (Betzenberger et al., 1999).

The inclination of mandibular incisors may indirectly affect chin morphology (Al-Khateeb et al., 2013). Our findings suggest that L1/MP decreased significantly with divergence as a result of dento-alveolar compensation occurring during the growth period, albeit the correlations were relatively low (r ranging from -0.353in the 2D sample to -0.284 in the 3D sample).

D. Gender differences

Our data showed the presence of sexual dichotomy, a well-established finding on craniofacial components in various investigations (Bishara et al., 1985; Nanda, 1988;

Schudy, 1963). The smaller female measurements compared to their male counterparts may be associated with the earlier growth spurt in females, who also grow over shorter periods of time than males (Peter Buschang et al., 1982).

E. 2D versus 3D imaging

Orthodontists have for long focused on the difference in diagnosis, treatment and responses between hypodivergent and hyperdivergent facial types. With the introduction of radiographic imaging techniques, facial types could be studied with emphasis on their relationship with sagittal skeletal discrepancies. Although 3D imaging was broadly recognized for limiting errors of structure identification and concomitant misinterpretations, there is no evidence that it has advanced the diagnosis of malocclusions, particularly the vertical dimension, or enhance treatment decision. Technological innovations to reduce radiation are needed to use the CBCT as a routine orthodontic diagnostic tool, because of the increased exposure that still limit its use as a routine record (Evans et al., 2012).

While the greater majority of linear and angular measurements between 2D and 3D samples corresponded, many exhibited differences. Since it is not ethically possible to expose the same patients to both imaging techniques, the two samples consisted of different individuals. Thus, the benefits of comparisons of matched subjects conflicting results in terms of facial growth. Differences related to the main aim of this thesis, chin morphology and dimensions, were relatively small for skeletal components, but differed on the length of the mandibular central inciros. While further investigation is warranted, the results underscore the importance of carrying out a thorough analysis for each patient as a separate entity.

As observed by Adams et al (2004), who were among the first to conduct on human dry skulls a comparison between conventional lateral 2D cephalometric radiographs and constructed 3D lateral images, 3D imaging techniques are 4 to 5 times more accurate and precise than traditional 2D views. They reported that 7-12% magnification of 2D cephalometric images explains the inherent problems of representing an object occupying a 3D space with a 2D image; They pointed out that measurements acquired from the 2D approach ranged from underestimating (up to -17.68mm) to grossly overestimating (up to +15.52mm) the true values when compared to actual measurements on each dry skull; the 3D technique presented a much smaller range (-3.99mm to +2.96mm). While Adams et al concluded that the cephalometric 2D measures provide a distorted view of craniofacial growth, (Adams et al., 2004).

F. Research considerations

Our findings improve knowledge of the various dento-skeletal components of the vertical dimension; methodological limitations are noted in view of the cross-sectional nature of our samples. However, recruitment of untreated subjects in a longitudinal sample would imply more demanding IRB thresholds.

Additional investigations are suggested regarding facial musculature, since subjects with short facial type have significantly heavier muscles compared to long face subjects.

Further research should focus on comparing the palatal vault and soft tissue structures in various mandibular divergence patterns. Similarity in the palatal vault volume and soft tissue thickness may imply functional adaptation of the naso-pharyngeal matrix, suggesting both an adaptive nature of and environmental influence on the morphology of the craniofacial complex.

Given that chin volume is not different across the vertical and sagittal dimensions, the symphyseal components remodel around it to yield various shapes. The effect of the environmental elements on chin anatomy triggers the following questions:

1. Would the orthodontic treatment, if initiated at an early age, improve dentofacial relationships leading to a less severe expression of the phenotype?

2. Why would not the facial phenotype of individuals with a tendency hypodivergent or hyperdivergent develop all the way to severe hypo or hyper-divergence? Is there a stronger genetic determinant in those who end up having a severe hypodivergent or a hyperdivergent facial type, thus the concert of environmental factors further enhancing severity in a genetically prevalent pattern? Inversely, in the less severe facial patterns, the environment would be the main factor affecting the phenotype in the direction or tendency towards hypo or hyper-divergence.

Existing human (Joseph Ghafari et al., 2014) and animal (Harvold et al., 1981) research would reinforce the tenets of these questions, in that the response to similar insults of airway blockage nevertheless resulted in different adaptations thus various expressions of malocclusion, albeit the most severe was a full expression of the long face syndrome or adenoid facies (with prevalent hyperdivergence). Ghafari et al (2014) suggested on the basis of various research studies that genetic factors may be more at play in hypodivergence, whereas environmental insults had greater associations with hypedivergence.

Much research remains to be invested to answer these emerging questions, underscoring one research advantage of the present study: the categorization of malocclusion on vertical and sagittal components across the severity poles (hypo to hyper-divergence; Class I to Class III), proved to be a helpful tool to discern these various possibilities or future hypotheses.

G. Clinical implications

The immediate implications from the above research considerations might be the importance of early intervention to remove the obstacles to normal development, such as obstacles to nasal breathing that might lead to hyperdivergence, or bite opening in a developing Class II, division 2 with signs of hypodivergence (Ghafari et al 2014).

It is important to associate the present findings with diagnosis and treatment planning of patients seeking orthodontic treatment since the latter is completed through bone remodeling of the alveolar process. To achieve an ideal position of the mandibular incisors, that is esthetically pleasing and long lasting, it is necessary to identify possible hard and soft tissue limitations to orthodontic tooth movement, minimizing the risk of potential damage to the roots and surrounding alveolar bone (Beckman et al.). Much attention is first given to the diagnosis and treatment of sagittal problems. However, dysmorphologies associated with vertical problems are often difficult to tackle, since relapse in the vertical dimension is the first sign to be noted and depends on the corresponding severity (Mangla et al., 2011).

The main contribution of this study would be the determination of potential environmental concert to chin morphology, as chin anatomy and its relation to the anterior dentition adapt to changes in skeletal vertical relations between the jaws- while the volume of the chin remains equal in all individuals regardless of the sagittal and vertical problems. In addition, the observed relationship between mandibular incisor length and symphyseal height among patients with different facial patterns seemingly explain anatomical related to camouflaging or worsening the severity of an existing vertical skeletal discrepancy.

The strong association found between high-angle patterns and mandibular incisor length may be correlated to the dento-alveolar compensation in the vertical dimension. As the divergence increases, mandibular teeth may continue their eruption and might increase in length (as per 3D data) as an attempt to maintain a positive overbite, bringing their alveolar bony support with them, resulting in an increased symphyseal height. A skeletal open-bite associated with (compensatory) elongated mandibular teeth would decrease the skeletal discrepancy and enhance treatment results.

The size and shape of the mandibular symphysis should be taken into consideration during treatment planning. With a large and wide symphysis, more leeway of movement may be affordable in an environment with seemingly more bone support around the tooth. In the opposite morphology, the mandibular incisors have “over-erupted” to a point where the apex nearly “sits” on the symphyseal bone, with reduced bony housing buccally and even lingually. Accordingly, subjects with high angle can be at increased risk of moving the incisors beyond alveolar bone support when subjected to marked antero-posterior incisor movements. In other words, the sagittal position of the mandibular incisors is defined in a narrower margin of bucco-lingual movement.In more severe dysplasias (e.g. severe high angle) when the mandible has grown more vertically at the expense of the sagittal dimension; more advancement genioplastymight be needed to improve chin projection (Macari et al 2014).

CHAPTER VI

CONCLUSION

Mandibular symphyseal morphology is a complex phenotype subsequent to the interplay of various genetic, environmental and adaptive factors. The evidence in this study supports the theory that mandibular shape and size are the product of actions related to compensative adaptation in the corresponding developing structures (Moss et al., 1969). Our findings disclosed for the first time that shape differences in mandibular symphysis are nevertheless associated with similar chin volumes between opposite divergence patterns, while shape differences among dental and symphyseal relations remain. This result highlights the role of adaptive environmental factors during facial growth.

The variability of bony chin form among various facial types may be affected by compensatory mechanisms related to contiguous soft and hard tissue environment and the intrinsic genotype of the mandible. The decisive morphology of the bony chin apparently results from mandibular adaptation to the functional musculoskeletal balance in the craniofacial complex.

With the introduction of radiographic imaging techniques, the interest in the variability of facial patterns was expanded. Even though the vertical disparity is predominant, the vertical problem may mask or worsen an existing sagittal or transverse discrepancy, as a change in one dimension unavoidably disturbs the other dimensions. Vertical growth direction indirectly affects the antero-position of the jaws and, consequently chins morphology.

TABLES

Table IV.1.a Cranial base measurements in the 2D sample

	Hypodivergent (Beckman et al.) n=138		Tendency Hypodivergent(2) n=140		TendencyHyperdivergent (3) n=139		Hyperdivergent(4) n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
SN	66.67 (4.34)	56.7-77.9	65.88 (5.08)	52.3-77.7	65.77 (4.65)	48.5-77.6	64.2 (4.79)	46.7-77.7	0.0001
S-Ar	33.37 (3.67)	24.9-44.4	31.86 (3.97)	21.9-43.5	31.69 (3.87)	20.8-44.2	29.6 (3.44)	20.1-40.2	0.0001
SN/H	8.03 (3.6)	0.4-17	9.17 (3.39)	0.9-17.4	11.11 (3.79)	0.6-21.6	13.41 (4.01)	0.4-29	0.0001
SN/Ar	121.93(5.28)	106.9-138.6	124.35(5.23)	111.5-136.2	125.0 (5.38)	111.2-142.2	125.97 (6.11)	104.8-43.2	0.0001

Table IV.1.b p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variables	**1 vs 2**	**1 vs 3**	**1 vs 4**	**2 vs 3**	**2 vs 4**	**3 vs 4**
SN	NS	NS	<0.001	NS	0.004	0.024
S-Ar	0.004	<0.001	<0.001	NS	<0.001	<0.001
SN/H	0.016	<0.001	<0.001	<0.001	<0.001	<0.001
SN/Ar	<0.001	<0.001	<0.001	NS	0.024	NS

Table IV.1.c. Cranial base measurements in the 3D sample

	Hypodivergent (Beckman et al.) n=77		Tendency Hypodivergent(2) n=86		TendencyHyperdivergent (3) n=77		Hyperdivergent(4) n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
SN	65.08 (3.84)	56.1-75.3	64.5 (4.18)	53.7-74.1	64.46 (3.29)	57.5-74.2	64.77 (3.78)	58.3-74.8	0.604
S-Ar	33.07 (3.13)	26.0-40.4	32.02 (3.77)	25.5-43.0	30.51 (3.35)	21.4-40.3	30.48 (3.71)	24.6-39.5	<0.001
SN/H	10.46 (4.75)	2.0-20.1	12.21 (4.13)	3.0-19.5	12.06 (3.81)	2.6-20.8	15.92 (4.28)	9.3-24.7	<0.001
SN/Ar	125.09(5.68)	112.8-139.4	126.51(5.27)	113.1-140.7	126.02 (5.56)	111.3-138.8	127.13(12.21)	116.2-40.9	0.156

Table IV.1.d p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
S-Ar	0.032	<0.001	<0.001	0.04	NS	NS
SN/H	0.028	NS	<0.001	NS	<0.001	<0.001

Table IV.2.a. Measurements of the relationship between jaws in the 2D sample

	Hypodivergent (Beckman et al.) n=138		**Tendency Hypodivergent(2)** n=140		**TendencyHyperdivergent (3)** n=139		**Hyperdivergent(4)** n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
SNA	84.66 (3.67)	76.2-94.7	82.61 (3.31)	73-91.6	81.07 (3.63)	71.4-88.7	81.07 (3.63)	71.4-88.7	0.0001
SNB	81.53 (4.1)	72.9-95	79.91 (3.36)	72.3-88.6	78.55 (3.94)	70.0-91.7	78.55 (3.94)	70-91.7	0.0001
ANB	3.15 (3.63)	-12.4-11.3	2.69 (3.35)	-7.5-10.6	2.52 (3.44)	-6.5-11.4	2.52 (3.44)	-6.59-1.4	0.450
PP/MP	18.74 (4.44)	1.5-33.4	22.53 (3.78)	12.2-33.4	25.15 (3.68)	16.1-34.7	29.98 (4.66)	18.9-47.2	0.001
LFH/TFH	54.74 (2.69)	48.4-61.7	55.01 (2.41)	48.3-60.1	55.22 (2.44)	49.6-62.2	55.76 (2.13)	50-61	0.015
MP/H	17.92 (3.74)	4.1-26.4	23.06 (2.78)	9.2-34.1	27.09 (2.5)	17.5-36.0	34.1 (4.31)	25.2-49	0.001
PP/H	1.67 (3.57)	-10.2-6.4	1.3 (3.63)	-13.4-6.9	-2.02 (3.7)	-12.5-64.6	-3.12 (4.22)	-15.3-8.8	0.370

Table IV.2.b p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
SNA	<0.001	<0.001	<0.001	0.004	<0.001	<0.001
SNB	0.012	<0.001	<0.001	0.008	<0.001	<0.001
PP/MP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LFH/TFH	NS	NS	0.008	NS	NS	NS
MP/H	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table IV.2.c Measurements of the relationship between jaws in the 3D sample

	Hypodivergent (Beckman et al.) n=77		**Tendency Hypodivergent(2)** n=86		**TendencyHyperdivergent (3)** n=77		**Hyperdivergent(4)** n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
SNA	84.41 (3.29)	77.4-91.8	83.08 (3.5)	73.7-91.0	82.16 (3.07)	74.6-89.9	80.09 (2.94)	75.0-88.6	<0.001
SNB	80.31 (3.04)	73.0-86.0	78.85 (3.62)	70.0-89.4	78.12 (3.23)	72.0-87.6	75.31 (3.89)	69.8-85.4	<0.001
ANB	4.05 (2.49)	-2.6-8.6	4.22 (2.72)	-3.8-11.4	3.93 (2.77)	-2.6-9.8	4.72 (3.32)	-2.9-10.1	0.212
PP/MP	19.37 (4.42)	9.2-31.1	22.28 (3.87)	13.7-32.7	24.92 (3.6)	16.5-34.0	29.93 (4.03)	22.5-39.7	<0.001
LFH/TFH	54.36 (2.52)	48.8-59.8	55.08 (1.96)	51.1-59.3	55.92 (2.2)	50.6-61.2	56.22 (2.37)	51.0-61.3	<0.001
MP/H	19.49 (3.15)	10.6-25.7	24.22 (2.1)	18.6-29.7	27.86 (2.34)	21.9-32.7	33.28 (2.76)	27.0-39.7	<0.001
PP/H	-2.63 (4.85)	-11.4-9.8	-2.71 (3.59)	-13.3-8.7	-2.09 (3.71)	-10.6-7.2	-4.91 (4.78)	-16.2-4.3	0.036

Table IV.2.d p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
SNA	NS	<0.001	<0.001	NS	<0.001	0.004
SNB	0.008	<0.001	<0.001	NS	<0.001	<0.001
PP/MP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LFH/TFH	NS	<0.001	<0.001	NS	0.036	NS
MP/H	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table IV.3.a Jaw specific measurements in the 2D sample

	Hypodivergent (Beckman et al.) n=138		**Tendency Hypodivergent(2)** n=140		**TendencyHyperdivergent (3)** n=139		**Hyperdivergent(4)** n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
ANS-PNS	51.68 (4.24)	43.6-64.2	50.66 (5.78)	26.3-64.8	49.18 (5.41)	34.7-64.6	47.21 (4.72)	31-63.2	0.0001
Go-Pog	70.13 (7.11)	53-89.9	68.75 (7.69)	48.9-87	68.26 (7.61)	47.2-95.6	65.75 (7.26)	42-87.2	0.0001
Ar-Go	46.85 (6.68)	34.7-66.1	45.24 (5.81)	29.4-62.6	43.99 (6.71)	27.9-70.1	41.74 (6.25)	30.5-64.6	0.001
Co-Gn	108.16(9.95)	87.7-40.2	108.96(10.94)	77.9-38.1	111.37(12.22)	73.2-71.1	110.73(12.86)	82.3-53.5	0.09
Ar-Gn	104.97(9.31)	87.2-32.6	105.4(10.34)	73.9-32.4	106.6(11.83)	69.4-63.7	105.6 (12.26)	79.8-148.6	0.62
Go-Me	65.54(5.97)	46.4-81.9	64.96 (7.03)	45.4-84.4	64.34 (7.38)	42.2-98.6	62.13 (7.12)	42.5-85.3	0.0001
Co-Go	55.42(7.7)	42.4-77.4	53.55(6.82)	36.2-71.4	53.46(7.33)	35.2-83.7	50.66 (6.92)	37.2-70.6	0.001
Ar-Go-Me	122.18(5.11)	103.2-133.1	124.79(5.05)	108.3-136.1	127.34 (5.08)	104.9-139.1	132.41 (5.78)	116.2-148.9	0.0001
Co-Go-Me	115.23(5.33)	98.6-127.7	118.3(4.92)	103.8-132.8	121.1 (4.89)	103.3-133.9	126.23 (5.78)	108.5-142.4	0.0001

Table IV.3.b p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
ANS-PNS	NS	<0.001	<0.001	0.032	<0.001	0.008
Go-Pog	NS	NS	<0.001	NS	0.008	0.024
Ar-Go	NS	0.004	<0.001	NS	<0.001	0.008
Go-Me	NS	NS	<0.001	NS	0.004	0.02
Co-Go	NS	NS	<0.001	NS	0.004	0.008
Ar-Go-Me	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co-Go-Me	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table.3.c Jaw specific measurements in the 3D sample

	Hypodivergent (Beckman et al.) n=77		Tendency Hypodivergent(2) n=86		Tendency Hyperdivergent (3) n=77		Hyperdivergent(4) n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
ANS-PNS	51.94 (3.45)	45.0-66.7	51.03 (3.87)	40.5-8.0	50.25 (4.3)	40.562.3	49.96 (4.15)	42.0-60.6	0.008
Go-Pog	67.74 (5.49)	55.5-80.0	67.64 (6.0)	51.3-3.7	67.36 (5.93)	53.0-1.6	67.3 (6.46)	53.5-81.6	0.970
Ar-Go	45.29 (4.91)	37.0-59.0	43.16 (5.09)	32.9-58.6	42.32 (4.07)	33.1-2.3	41.81 (5.51)	32.2-57.1	<0.001
Co-Gn	105.59(7.26)	89.9-22.5	106.5 (8.45)	88.6-124.5	107.6 (7.02)	93.9-29.9	109.45(9.53)	93.6-134.0	0.304
Ar-Gn	102.81(6.73)	90.2-117.1	102.09(7.91)	87.5-123.9	102.67(7.03)	90.1-123.8	103.91(9.07)	89.8-127.1	0.780
Go-Me	64.58 (5.23)	53.5-77.9	64.22 (5.34)	50.8-77.7	64.38 (5.3)	54.5-76.0	64.09 (6.06)	53.4-80.1	0.858
Co-Go	52.76 (5.48)	42.9-66.5	51.99 (5.63)	39.9-65.9	50.84 (4.26)	42.8-61.7	50.97 (5.17)	42.2-64.9	0.043
Ar-Go-Me	123.87(4.52)	112.2-134.8	125.93(5.26)	114.3-139.8	128.87 (4.8)	119.3-139.3	131.33 (5.6)	118.1-141.0	<0.001
Co-Go-Me	117.06(4.23)	102.6-125.8	119.98(4.76)	107.6-130.1	123.81(4.63)	113.9-133.6	126.06(5.48)	113.9-136.3	<0.001

Table IV.3.d.p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
ANS-PNS	NS	0.012	0.024	NS	NS	NS
Ar-Go	0.024	<0.001	<0.001	NS	NS	NS
Ar-Go-Me	0.044	<0.001	<0.001	<0.001	<0.001	0.036
Co-Go-Me	<0.001	<0.001	<0.001	<0.001	<0.001	NS

Table IV.4.a Relationship between teeth and jaws in the 2D sample

	Hypodivergent (Beckman et al.) n=138		Tendency Hypodivergent(2) n=140		TendencyHyperdivergent (3) n=139		Hyperdivergent(4) n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
U1-Na	3.32 (2.97)	-2.8-14.9	3.56 (2.45)	-3-10	4.47 (3.44)	-1.4-33.6	4.75 (3.16)	0-28.2	0.0001
U1/Na	21.78 (9.6)	0-42.6	21.17 (8.88)	0.6-39.9	24.46 (8.62)	1.8-41	23.67 (7.72)	0.7-39.9	0.04
U1/SN	106.43(9.71)	82.8-27.9	103.39(9.7)	70.9-121.9	104.47(9.52)	75.6-121.4	102.43(8.35)	69.4-123.8	0.090
U1/PP	112.68(9.01)	94-131.8	111.21(9.27)	82.8-129.9	113.6(9.19)	87.6-131	112.7 (8.01)	83.1-133.1	0.144
L1-NB	3.62 (2.63)	-4.4-11.2	3.99 (2.47)	-1.7-10.7	4.7 (2.52)	0-11.8	5.48 (2.32)	0.1-11.4	0.0001
L1/NB	24.93 (8.13)	0.6-47.2	24.71 (8.01)	0.2-46.9	25.5 (7.39)	6.1-40.6	26.12 (6.69)	6.6-40.8	0.327
L1/MP	98.2 (8.96)	75.4-12-.2	94.87 (8.39)	71.5-117.8	25.5 (7.39)	6.1-40.6	88.95 (9.07)	59.6-110.1	0.0001

Table IV.4.b.p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
U1-Na	NS	0.004	<0.001	0.036	0.004	NS
L1-NB	NS	0.004	<0.001	0.036	0.004	NS
L1/MP	0.004	<0.001	<0.001	NS	<0.001	<0.001

Table IV.4.c Relationship between teeth and jaws in the 3D sample

	Hypodivergent (Beckman et al.) n=77		Tendency Hypodivergent(2) n=86		TendencyHyperdivergent (3) n=77		Hyperdivergent(4) n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
U1-Na	2.95 (1.58)	0.2-6.7	2.52 (1.93)	0-7.5	3.27 (1.96)	0-9.0	3.56 (2.45)	0.1-9.7	0.010
U1/Na	19.16 8.78)	2.0-36.1	19.22 (7.69)	1.4-38.6	21.9 (8.34)	0.1-44.2	20.41 (8.95)	2.9-36.6	0.233
U1/SN	103.1(9.53)	81.7-120.2	101.95(8.36)	80.4-118.0	103.98(8.33)	78.4-127.0	99.99 (9.81)	72.6-119.1	0.200
U1/PP	110.85(8.72)	92.1-129.4	111.45(7.69)	88.1-128.5	113.95(7.93)	94.9-136.0	111.01(8.38)	86.0-123.3	0.426
L1-NB	3.69 (2.2)	0.2-8.9	4.34 (2.42)	0-10.3	4.78 (2.03)	0.2-9.5	5.79 (2.51)	0.7-11.7	<0.001
L1/NB	26.41 7.86)	11.1-42.8	27.19 (8.88)	2.9-42.7	28.17 (6.34)	8.9-41.7	28.05 (7.42)	4.7-40.4	0.366
L1/MP	99.44 8.33)	81.7-115.9	97.41 (9.11)	69.4-115.9	95.22 (7.52)	74.5-109.1	92.41 (7.84)	68.6-105.9	<0.001

Table IV.4.d.p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
U1-Na	NS	NS	NS	0.024	NS	NS
U1/Na	NS	NS	NS	NS	0.048	NS
L1-NB	NS	0.012	<0.001	NS	NS	NS
L1/MP	NS	0.016	<0.001	NS	0.004	NS

Table IV.5.a Inter-dental relationship in the 2D sample

	Hypodivergent (Beckman et al.) n=138		Tendency Hypodivergent(2) n=140		TendencyHyperdivergent (3) n=139		Hyperdivergent(4) n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
U1/L1	130.26(14.01)	97.6-169.5	131.69(13.5)	98.2-162.2	128.79(12.98)	97.5-160.4	127.52(12.18)	100.9-156.7	0.098
OB	3.65 (2.33)	-1.8-11	3.12 (2.46)	-1.8-10.2	2.15 (2.46)	-5.6-8.4	1.27 (2.58)	-7.7-8.7	0.0001
OJ	3.32 (2.91)	-9.9-11.6	2.85 (2.73)	-2.9-12.4	2.84 (3.47)	-8.8-11.6	2.53 (4.12)	-13.8-12.6	0.46

Table IV.5.b p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variable	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
OB	NS	<0.001	<0.001	0.008	<0.001	0.036

Table IV.5.c Inter-dental relationship in the 3D sample

	Hypodivergent (Beckman et al.) n=77		Tendency Hypodivergent(2) n=86		TendencyHyperdivergent (3) n=77		Hyperdivergent(4) n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
U1/L1	130.85(13.48)	107.6-164.2	129.37(14.42)	103.3-172.0	125.9(10.92)	99.4-167.5	126.98(12.84)	107.1-163.5	0.141
OB	3.81 (2.32)	-2.2-8	3.58 (2.26)	-4.0-7.9	3.02 (2.1)	-6.0-8.5	2.53 (2.58)	-1.8-8.1	0.003
OJ	3.72 (2.7)	-3.3-12.5	3.89 (2.8)	-3.5-11.5	3.56 (2.89)	-3.0-11.3	4.42 (3.17)	-2.3-11.9	0.176

Table IV.5.d p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variable	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
OB	NS	NS	0.008	NS	0.012	NS

Table IV.6.a Symphyseal components in the 2D sample

	Hypodivergent (Beckman et al.) n=138		Tendency Hypodivergent(2) n=140		TendencyHyperdivergent (3) n=139		Hyperdivergent(4) n=133		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
I-A	21.82 (2.24)	18.2-28.1	21.68 (2.32)	13.4-28	21.37 (2.33)	18.1-29.9	20.77 (1.8)	18.1-26.3	0.0002
I-C	8.7 (1.07)	5.2-11	8.53 (1.17)	5.1-10.9	8.35 (1.12)	5.4-10.9	8.24 (0.91)	6.1-10.4	0.0001
CWA	10.57 (1.92)	6.2-18.1	9.46 (1.96)	3.6-18.2	8.48 (1.61)	5.0-13.1	7.56 (1.96)	4.1-18.6	0.0001
CWD	13.67 (1.82)	7.3-17.7	13.08 (1.8)	4.6-17	12.77 (1.76)	3.3-16.5	11.92 (1.67)	5.5-17.1	0.0001
D-A	7.63 (2.16)	3.5-14.5	8.45 (2.57)	3.7-16.1	9.28 (2.74)	4.4-18.1	9.7 (2.65)	4.6-16.8	0.0001
D-Me	9.03 (1.29)	6.5-12.6	9.11 (1.48)	6.3-13.8	9.23 (1.54)	5.6-14.1	9.54 (1.34)	6.7-14.3	0.0009
Ant slope	12.98 (7.58)	1-33.8	11.38 (7.85)	-9.5-32.3	8.89 (7.62)	-6.9-31.2	5.86 (7.49)	-22-30.5	0.0001
Post slope	16.02 (8.48)	0.1-38.5	17.0 (7.43)	0.2-33	21.23 (8.67)	1.2-44.3	23.17 (8.45)	1.4-49.2	0.0001
AP slope	29.01 (8.33)	5.4-49.8	28.38 (8.26)	4.74-56.1	30.12 (8.63)	4.0-50.6	29.03 (7.1)	6-50.2	0.294
BB1	9.48 (3.2)	6.0-4.10	8.36 (2.33)	1.6-26.18	7.61 (1.97)	0.2-17.0	6.45 (1.95)	1.9-16.8	<0.001
CEJ-Me	29.78 (3.54)	23.3-38.9	30.72 (4.01)	20.3-41.4	31.53 (4.12)	24.1-43.8	31.78 (3.61)	23.4-41	0.0001

Table IV.6.b.p-values of corresponding post hoc for non-parametric tests in the 2D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
I-A	NS	NS	<0.001	NS	<0.001	NS
I-C	NS	0.02	<0.001	NS	0.04	NS
CWA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CWD	0.028	<0.001	<0.001	NS	<0.001	<0.001
D-A	0.036	<0.001	<0.001	0.036	<0.001	NS
Ant slope	NS	<0.001	<0.001	NS	<0.001	0.012
Post slope	NS	<0.001	<0.001	<0.001	<0.001	NS
BB1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CEJ-Me	NS	<0.001	<0.001	NS	NS	NS

Table IV.6.c Symphyseal components in the 3D sample

	Hypodivergent (Beckman et al.) n=77		**Tendency Hypodivergent(2)** n=86		**TendencyHyperdivergent (3)** n=77		**Hyperdivergent(4)** n=56		p-Value Kruskal Wallis
Variables	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	Mean (Kapila & Nervina)	Range	
Volume	7.24 (1.33)	4.02-10.95	7.12 (1.4)	3.86-10.82	7.06 (1.29)	4.72-10.71	7.23 (1.61)	4.22-6.78	0.880
I-A	22.36 (1.88)	18.2-26.6	23.19 (1.79)	18.7-28.0	23.9 (1.73)	19.3-27.4	26.73 (1.67)	19.9-30.5	<0.001
I-C	8.91 (0.87)	6.5-10.7	9.3 (0.58)	7.4-11.7	9.5 (0.93)	6.9-11.8	10.09 (1.07)	7.8-13.5	<0.001
CWA	11.25 (1.72)	7.9-16.2	11.14 (1.55)	6.8-15.6	11.0 (1.85)	6.4-16.0	10.33 (1.86)	4.9-13.7	0.221
CWD	13.93 (1.52)	10.5-17.5	13.48 (1.45)	9.9-16.6	13.19 (1.6)	9.1-17.4	12.95 (1.46)	10.3-15.6	0.003
D-A	6.96 (1.87)	4.0-11.3	7.1 (2.06)	3.0-13.4	7.22 (1.64)	4.1-12.0	8.07 (1.98)	5.0-13.9	0.068
D-Me	8.52 (1.44)	5.4-13.8	8.58 (1.18)	6.0-13.4	8.27 (1.07)	5.6-11.6	8.49 (1.47)	5.3-12.2	0.285
Ant slope	15.27 (9.6)	0-39.3	12.49 (9.65)	0-57.2	10.72 (7.6)	0-36.9	10.35 (7.55)	0-34.9	0.003
Post slope	13.05 (7.55)	0.7-39.0	13.86 (8.17)	0-32.4	17.59 (10.16)	1.5-74.5	16.19 (8.35)	0-36.6	0.013
AP slope	28.33 (9.65)	8.0-57.7	26.35 (10.64)	5.9-79.8	28.32 (12.74)	7.2-98.5	26.54 (8.79)	10.3-53.8	0.198
BB1	9.59 (4.2)	7.1-31.6	9.06 (4.11)	20.8-28.2	9.57 (2.41)	5.9-21.7	9.05 (4.49)	5.4-31.8	0.340
CEJ-Me	28.93 (3.19)	23.3-36.5	29.57 (3.42)	22.5-37.9	29.89 (2.67)	24.3-36.2	33.21 (3.78)	25.9-43.5	<0.001

Table IV.6.d p-values of corresponding post hoc for non-parametric tests in the 3D sample

Variables	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
Volume	NS	NS	NS	NS	NS	NS
I-A	0.032	<0.001	<0.001	0.02	<0.001	<0.001
I-C	NS	<0.001	<0.001	NS	<0.001	0.008
CWD	NS	0.012	0.004	NS	NS	NS
D-A	NS	NS	0.04	NS	NS	NS
Ant slope	NS	0.004	0.008	NS	NS	NS
Post slope	NS	0.02	NS	0.04	NS	NS
CEJ-Me	NS	NS	<0.001	NS	<0.001	<0.001

Table IV.6.e Chin volume across malocclusions types in the 3D sample

Variable	Class I	Class II,1	Class II,2	Class III	p-Value Kruskal Wallis
Volume cm^3	7.19 (1.38)	6.93 (1.25)	7.41 (1.54)	7.7 (1.61)	0.0678

Table IV.7.a Correlations with MP/SN

	2D	3D
Variables	**MP/SN**	**MP/SN**
MP/SN		
Symphyseal components		
Volume	-	NS
I-A	-0.174	0.550
I-C	-0.163	0.375
CWA	-0.519	NS
CWD	-0.343	-0.238
D-A	0.268	0.141
D-Me	0.128	NS
Ant slope	-0.333	-0.211
Post slope	0.348	0.188
AP slope	NS	NS
MP/H	0.936	0.909
BB1	-0.329	NS
CEJ-Me	0.179	0.298
Cranial base measurements		
SN	-0.230	NS
SN/H	0.508	0.251
SN-Ar	0.261	0.112
S-Ar	-0.342	-0.284
Relationship between jaws		
SNA	-0.509	-0.380
SNB	-0.051	-0.402
ANB	NS	NS
PP/MP	0.730	0.684
PP/H	-0.141	NS
LFH/TFH	0.146	0.303
Jaw specific measurements		
Go-Pog	-0.241	NS
Ar-Go	-0.321	-0.236
Co-Gn	NS	NS
Ar-Gn	NS	NS
Go-Me	-0.206	NS
Co-Go	-0.238	-0.148
Ar-Go-Me	0.611	0.476
Co-Go-Me	0.637	0.586
ANS-PNS	-0.345	-0.187
Relationship between teeth and jaws		
U1-Na	0.186	NS
U1/Na	0.086	NS
U1/SN	-0.140	NS
U1/PP	NS	NS
L1-NB	0.287	0.260
L1/NB	NS	NS
L1/MP	-0.353	-0.284
Relationship between teeth		
OB	-0.352	-0.220
OJ	NS	NS
U1/L1	-0.065	-0.109

Table IV.7.b Correlations with MP/SN among growing and adults

	2D			3D	
Variables	**G**	**NG**		**G**	**NG**
MP/SN					
Symphyseal components					
Volume	-	-		NS	NS
I-A	0.141	0.001		0.493	0.088
I-C	0.276	0.036		0.399	0.338
CWA	0.615	-0.061		NS	-0.176
CWD	0.244	0.037		-0.206	-0.294
D-A	0.325	0.131		NS	0.241
D-Me	0.303	0.160		NS	NS
Ant slope	0.186	0.057		-0.184	-0.292
Post slope	-0.201	-0.023		0.153	0.244
AP slope	NS	NS		NS	NS
MP/H	-0.218	-0.054		0.902	0.917
BB1	-0.169	0.043		NS	NS
CEJ-Me	0.347	0.162		0.242	0.475
Cranial base measurements					
SN	-0.195	0.022		NS	NS
SN/H	0.483	0.121		0.229	0.306
SN-Ar	0.305	-0.047		NS	NS
S-Ar	-0.331	0.135		-0.305	0.087
Relationship between jaws					
SNA	-0.573	0.027		-0.425	-0.308
SNB	-0.512	-0.135		-0.465	-0.304
ANB	NS	NS		NS	NS
PP/MP	0.722	-0.078		0.684	0.675
LFH/TFH	NS	0.153		0.345	0.241
PP/H	NS	-0.214		NS	NS
Jaw specific measurements					
Go-Pog	-0.123	-0.003		NS	NS
Ar-Go	-0.252	0.100		-0.208	-0.277
Co-Gn	0.128	NS		NS	NS
Ar-Gn	NS	NS		NS	NS
Go-Me	-0.167	-0.016		NS	NS
Co-Go	-0.168	0.139		-0.155	NS
Ar-Go-Me	0.608	-0.203		0.452	0.507
Co-Go-Me	0.608	-0.192		0.583	0.592
ANS-PNS	-0.396	0.046		-0.191	-0.177
Relationship between teeth and jaws					
U1-Na	0.257	-0.116		NS	NS
U1/Na	0.120	NS		NS	NS
U1/SN	-0.152	-0.103		-0.167	NS
U1/PP	NS	NS		NS	NS
L1-NB	0.261	0.110		0.172	0.421
L1/NB	NS	NS		NS	NS
L1/MP	-0.397	0.141		-0.339	-0.221
Relationship between teeth					
OB	-0.303	0.053		-0.179	NS
OJ	NS	NS		NS	NS
U1/L1	NS	NS		NS	-0.226

Table IV.8.a Logistic regression by divergence with hypodivergent group as a reference in the 2D sample

Divergence	Variable	RRR	95% CI	p- value
Hypodivergent (BASE OUTCOME)				
Tendency hypodivergent	CEJ-ME	1.127	0.94-1.35	0.194
	CWA	0.856	0.69-1.05	0.150
	CWD	0.884	0.69-1.11	0.302
	DA	0.981	0.76-1.25	0.883
	DMe	0.975	0.65-1.20	0.448
	Ant slope	1.013	0.93-1.01	0.276
	Post slope	1.126	0.96-1.05	0.558
	BB1	6.889	0.96-1.31	0.121
Tendency hyperdivergent	CEJ-ME	1.240	1.01-1.51	0.032
	CWA	0.689	0.52-0.90	0.007
	CWD	0.834	0.64-1.08	0.177
	DA	0.982	0.74-1.28	0.897
	DMe	0.763	0.54-1.06	0.110
	Ant slope	0.954	0.90-1.00	0.062
	Post slope	1.07	1.02-1.13	0.003
	BB1	1.176	0.98-1.41	0.080
Hyperdivergent	CEJ-ME	1.023	0.81-1.29	0.845
	CWA	0.586	0.42-0.80	0.001
	CWD	0.734	0.55-0.97	0.032
	DA	1.125	0.82-1.53	0.451
	DMe	1.225	0.84-1.78	0.288
	Ant slope	0.899	0.85-0.95	<0.001
	Post slope	1.067	1.01-1.12	0.017
	BB1	1.458	1.16-1.83	0.001

Table IV.8.b Logistic regression by divergence with hypodivergent group as a reference in the 3D sample

Divergence	Variable	RRR	95% CI	p- value
Hypodivergent (Beckman et al.) (BASE OUTCOME)				
Tendency hypodivergent (2)	IA	1.316	0.81-2.13	0.267
	IC	1.315	0.63-2.17	0.458
	CWD	0.719	0.56-0.91	0.008
	DA	1.124	0.72-1.75	0.603
	Ant slope	0.989	0.95-1.02	0.594
	Post slope	1.021	0.97-1.07	0.390
	CEJ-ME	0.937	0.68-1.29	0.692
Tendency hyperdivergent (3)	IA	3.679	2.04-6.62	<0.001
	IC	0.514	0.22-1.18	0.118
	CWD	0.588	0.43-0.78	<0.001
	DA	2.504	1.45-4.30	0.001
	Ant slope	0.983	0.94-1.02	0.452
	Post slope	1.118	1.05-1.18	<0.001
	CEJ-ME	0.535	0.36-0.79	0.002
Hyperdivergent (4)	IA	17.236	7.25-40.96	<0.001
	IC	0.214	0.075-0.61	0.004
	CWD)	0.467	0.29-0.75	0.002
	DA	2.609	1.21-5.59	0.014
	Ant slope	0.995	0.92-1.06	0.887
	Post slope	1.076	1.00-1.15	0.043
	CEJ-ME	0.491	0.29-0.82	0.008

Table IV.9.a Linear regression for the outcome CWA model 1

Variable	Coefficient	95% CI	p-value
ANB	0.05	0.015-0.085	0.005
MP/SN	-0.144	-0.166- - 0.122	<0.001

Table IV.9.b Linear regression for the outcome CWA model 2

Variable	Coefficient	95% CI	p-value
IA	0.278	0.22-0.336	<0.001
DA	-0.483	-0.552- -0.414	<0.001
DMe	0.205	0.089-0.320	<0.001
ANB	0.034	0.008-0.06	<0.001
MP/SN	-0.102	-0.12- -0.66	<0.001

Table IV.9.c Linear regression for the outcome CWD

Variable	Coefficient	95% CI	p-value
ANB	0.043	0.014-0.071	0.003
MP/SN	-0.095	-0.114- -0.077	<0.001

Table IV.9.d Linear regression for the outcome volume

Variable	Coefficient	95% CI	p-value
ANB	-94.67	-191.67-2.32	0.056
MP/SN	-3.38	-37.57-30.8	0.830

Table IV.9.e Linear regression for the outcome IA

Variable	Coefficient	95% CI	p-value
ANB	0.063	0.018-0.108	0.006
MP/SN	0.001	-0.026-0.03	0.903

Table IV.9.f Linear regression for the outcome IC

Variable	Coefficient	95% CI	p-value
ANB	0.03	0.011-0.049	0.002
MP/SN	-0.005	-0.017-0.006	0.346

Table IV.9.g Linear regression for the outcome DA

Variable	Coefficient	95% CI	p-value
ANB	0.008	-0.032-0.049	0.690
MP/SN	0.096	0.07-0.122	<0.001

Table IV.9.h Linear regression for the outcome DMe

Variable	Coefficient	95% CI	p-value
ANB	0.011	-0.013-0.035	0.369
MP/SN	0.020	0.005-0.036	0.009

Table IV.9.i Linear regression for the outcome Anterior slope angle

Variable	Coefficient	95% CI	p-value
ANB	-0.157	-0.293- - 0.216	0.023
MP/SN	-0.419	-0.505- -0.333	<0.001

Table IV.9.j Linear regression for the outcome Posterior slope angle

Variable	Coefficient	95% CI	p-value
ANB	0.122	-0.022-0.266	0.097
MP/SN	0.407	0.316-0.499	<0.001

Table IV.9.k Linear regression for the outcome inter-slope angle

Variable	Coefficient	95% CI	p-value
ANB	-0.035	-0.178-0.108	0.630
MP/SN	-0.011	-0.102-0.079	0.806

Table IV.10.a Gender differences in the 2D sample

	MALES			FEMALES			p-Value Mann-Whitney test
	269 (48.9)			281 (51.1)			
Variables	Mean (Kapila & Nervina)	Median	Range	Mean (Kapila & Nervina)	Median	Range	
Symphyseal components							
I-A	21.97 (2.38)	21.5	18.1-29.9	20.88 (1.91)	20.6	13.4-28.0	<0.001
I-C	8.71 (1.15)	8.7	5.2- 11.0	8.22 (0.97)	8.1	5.1- 10.9	<0.001
CWD	13.12 (1.88)	13.1	3.3-17.7	12.63 (1.83)	12.6	4.6- 17.1	0.001
D-A	9.11 (2.84)	8.8	3.6-17.1	8.42 (2.42)	8.1	3.5-18.1	0.004
D-Me	9.7 (1.49)	9.7	6.3-14.3	8.77 (1.2)	8.6	5.6-12.4	<0.001
MP/H	24.71 (6.69)	24.6	4.1- 47.6	26.17 (6.8)	25.5	6.2-49.0	0.016
BB1	8.28 (3.04)	8.0	0.2-41.0	7.72 (2.19)	7.7	1.9-26.18	<0.001
CEJ-Me	32.08 (4.01)	31.8	23.3-43.0	29.86 (3.46)	29.4	20.3-43.8	<0.001
Cranial base measurements							
SN	67.44 (4.72)	67.4	52.3-77.9	63.98 (4.23)	64.0	46.7-77.7	<0.001
SN/H	9.7 (4.17)	9.7	0.4-23.9	11.08 (4.15)	11.0	0.4- 29.0	<0.001
SN-Ar	123.45(5.55)	123.3	104.8-141.6	125.11 (5.71)	125.4	111.2-143.2	<0.001
S-Ar	32.9 (4.27)	32.8	20.1-44.4	30.45 (3.24)	30.6	20.8- 40.2	<0.001
ANS-PNS	50.95 (5.3)	51.2	35.3-64.2	48.52 (5.1)	48.6	26.3-64.8	<0.001
Relationship between jaws							
SNB	79.14 (6.63)	79.4	92.5-95.0	78.62 (4.28)	78.6	67.3-94.6	0.025
LFH/TFH	55.6 (2.5)	55.7	48.3-62.2	54.77 (2.33)	54.8	48.4-61.2	<0.001
Jaw specific measurements							
Go-Pog	69.47 (8.19)	69.2	45.8-95.6	67.08 (6.72)	67.1	42.0-87.2	0.001
Ar-Go	46.21 (7.42)	45.9	31.5-70.1	42.82 (5.25)	43.0	27.9-56.3	<0.001
Co-Gn	112.41(12.76)	111.8	82.3-171.1	107.3 (9.69)	107.0	73.2-145.0	<0.001
Ar-Gn	108.21(12.15)	107.1	78.8-163.7	103.21 (9.09)	102.8	69.4-138.1	<0.001
Go-Me	65.32 (7.83)	65.2	42.5-98.6	63.25 (5.93)	63.1	42.2-85.3	0.002
Co-Go	55.23 (8.32)	55.3	38.5-83.7	51.44 (5.78)	51.2	35.2-67.9	<0.001

Table IV.10.b Gender differences in the 3D sample

	MALES			FEMALES			p-Value Mann-Whitney test
	110 (37.2)			186 (62.8)			
Variables	Mean (Kapila & Nervina)	Median	Range	Mean (Kapila & Nervina)	Median	Range	
Age	16.59 (9.66)	13.49	5.33- 59.08	19.63 (12.23)	14.33	5.75-64.25	0.038
Symphyseal components							
Volume	7.66 (1.42)	7.57	4.78-11.0	6.85 (1.27)	6.82	3.86-10.82	<0.001
I-A	24.27 (2.26)	24.5	18.7-30.5	23.33 (2.15)	23.05	18.2- 29.4	<0.001
I-C	9.7 (1.05)	9.7	7.0-13.5	9.17 (0.86)	9.2	6.5- 11.3	<0.001
CWA	11.53 (1.63)	11.5	6.9-16.2	10.73 (1.71)	10.7	4.9 16.0	<0.001
CWD	13.83 (1.55)	13.7	10.4- 17.8	13.21 (1.49)	13.2	9.1- 17.5	0.002
D-Me	8.74 (1.39)	8.5	6.2 13.4	8.3 (1.17)	8.30	5.3- 13.8	0.021
BB1	9.79 (2.36)	9.7	2.2-21.7	9.05 (4.43)	8.95	20.8-31.8	<0.001
Cranial base measurements							
SN	65.99 (4.33)	65.35	53.7-75.3	63.94 (3.25)	64.05	56.1- 74.2	<0.001
S-Ar	32.5 (4.05)	32.3	21.4-43.0	31.16 (3.23)	31.2	23.7- 40.1	0.005
Jaw specific measurements							
ANS-PNS	51.98 (4.14)	52.25	41.9-66.7	50.25 (3.73)	50.2	40.5- 59.6	<0.001
Go-Pog	68.62 (6.1)	68.45	55.5- 81.6	66.91 (5.69)	66.9	51.3- 83.7	0.033
Co-Gn	109.15 (9.48)	107.85	89.2-134.0	105.75 (6.79)	105.65	88.6-123.6	0.004
Ar-Gn	104.83 (9.25)	104.0	87.5-127.1	101.42 (6.17)	101.05	87.9- 117.8	0.002
Go-Me	65.46 (5.98)	64.7	52.9-80.1	63.63 (4.8)	63.65	87.9- 117.8	0.023
Ar-Go-Me	127.94 (5.62)	127.85	112.2-140.9	126.41 (5.52)	126.0	114.3- 141.0	0.011
Co-Go-Me	122.04 (5.73)	122.05	102.6-136.3	120.72 (5.52)	120.05	107.6- 134.1	0.033

Table IV.11 Multivariate logistic regression for gender differences with females as a reference

2D			
Variable	**OR**	**95% CI**	**p-value**
Class II,1	1.302	0.731-2.318	0.370
Class II,2	1.273	0.890-3.036	0.112
Class III	1.644	0.679-2.384	0.451
MP/SN	1.057	0.997-1.121	0.060
PP/H	1.059	0.973-1.152	0.183
L1/NB	0.962	0.932-0.992	0.015
SNB	1.013	0.957-1.073	0.645
LFH/TFH	1.172	1.035-1.326	0.012
Age	0.936	0.91-1.031	<0.001
Go-Pog	0.954	1.031-1.179	0.496
Ar-Go	1.102	0.906-1.005	0.004
Ar-Gn	0.954	1.106-1.277	0.061
SN	1.188	0.931-1.128	<0.001
SN/H	1.025	0.919-1.005	0.606
SN-Ar	0.961	1.065-1.232	0.083
S-Ar	1.146	0.9-1.023	<0.001
ANS-PNS	0.958	0.916-1.166	0.210
IA	1.033	1.013-1.218	0.592
CEJ-Me	1.111	0.894-1.065	0.024
BB1	0.985	1.004-1.358	0.761
CWA	1.168	1.0-1.358	0.043

3D			
Variable	**OR**	**95% CI**	**p-value**
Class II,1	0.837	0.407-1.718	0.628
Class II,2	3.146	1.01-9.8	0.996
Class III	1.002	0.339-2.96	0.048
U1/PP	1.023	0.979-1.068	0.302
L1/NB	0.998	0.949-1.049	0.951
Age	0.962	0.93-0.996	0.030
Go-Pog	1.008	0.917-1.107	0.860
Ar-Go	1.038	0.932-1.156	0.492
Ar-Gn	0.982	0.873-1.105	0.770
Ar-Go-Me	1.036	0.954-1.123	0.394
SN	1.128	1.014-1.255	0.026
S-Ar	1.128	1.027-1.238	0.011
ANS-PNS	1.051	0.947-1.167	0.345
IA	1.46	1.147-1.859	0.002
DMe	1.364	0.943-1.975	0.099
CWD	1.165	0.883-1.538	0.278
BB1	0.979	0.907-1.057	0.591
CWA	0.94	0.72-1.226	0.649
A slope	0.965	0.929-1.002	0.069
CEJ-Me	0.762	0.613-0.947	0.014

Table IV.12 Subgrouping by growing/non-growing and malocclusion across different facial patterns

Variables	2D sample								3D sample							
	Class I		Class II,1		Class II,2		Class III		Class I		Class II,1		Class II,2		Class III	
	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG
Cranial base measurements																
SN	0.289	0.704	0.337	0.017	0.437	0.253	0.170	0.018	0.638	0.340	0.878	0.133	0.075	0.943	0.013	0.278
SN/H	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.013	<0.001	0.181	0.037	0.002	0.047	0.452	0.139	0.493	0.279
SN-Ar	0.003	0.235	0.004	0.180	0.006	0.001	0.358	0.011	0.759	0.934	0.060	0.581	0.683	0.910	0.970	0.849
S-Ar	0.007	0.073	0.017	0.069	0.039	0.006	0.056	<0.001	0.029	0.693	0.035	0.039	0.179	0.937	0.291	0.233
Relationship between jaws																
SNA	<0.001	0.003	<0.001	0.013	<0.001	<0.001	0.002	<0.001	0.015	0.019	<0.001	0.485	0.340	0.394	0.258	0.399
SNB	<0.001	0.001	<0.001	<0.001	0.001	<0.001	0.006	0.005	0.028	0.041	<0.001	0.206	0.143	0.097	0.375	0.457
ANB	0.735	0.512	0.729	0.005	0.019	0.154	0.585	0.199	0.981	0.005	0.745	0.308	0.368	0.103	0.977	0.591
PP/MP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.075	<0.001	0.001	0.037	0.012	0.079	0.109
LFH/TFH	0.461	0.955	0.781	0.071	0.338	0.341	0.623	0.301	0.003	0.344	0.165	0.253	0.163	0.262	0.198	0.399
PP/H	0.506	0.611	0.215	0.633	0.266	0.282	0.972	0.033	0.712	0.612	0.623	0.135	0.242	0.688	0.289	0.322
MP/H	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	0.024	<0.001	<0.001	<0.001	<0.001	<0.001	0.020	0.001	0.016	0.089
Jaw specific measurements																
Go-Pog	0.185	0.026	0.203	0.022	0.177	0.961	0.137	0.015	0.390	0.202	0.394	0.017	0.350	0.264	0.405	0.362
Ar-Go	<0.001	0.032	0.019	0.001	0.017	0.028	0.269	0.134	0.117	0.024	0.113	0.135	0.164	0.143	0.039	0.634
Co-Gn	0.003	0.111	0.158	0.406	0.562	0.266	0.531	0.797	0.420	0.983	0.262	0.087	0.129	0.364	0.173	0.461
Ar-Gn	0.015	0.318	0.270	0.291	0.633	0.388	0.513	0.758	0.323	0.438	0.813	0.119	0.086	0.260	0.130	0.962
Go-Me	0.615	0.083	0.148	0.018	0.016	0.773	0.297	0.068	0.446	0.564	0.346	0.018	0.401	0.498	0.614	0.541
Co-Go	<0.001	0.063	0.328	0.032	0.075	0.008	0.534	0.112	0.265	0.143	0.111	0.399	0.269	0.563	0.064	0.949
Ar-Go-Me	0.004	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	0.021	0.038	<0.001	0.137	0.383	0.023	0.146	0.165
Co-Go-Me	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.009	<0.001	0.280	0.304	0.012	0.028	0.209
ANS-PNS	0.152	0.015	<0.001	0.004	0.010	0.083	0.008	0.053	0.039	0.081	0.067	0.261	0.210	0.630	0.429	0.801
Relationship between teeth and jaws																
U1-Na	0.020	0.584	0.059	0.038	0.677	0.647	0.035	0.375	0.114	0.269	0.676	0.347	0.167	0.206	0.051	0.631
U1/Na	0.667	0.656	0.220	0.109	0.946	0.395	0.207	0.153	0.692	0.152	0.674	0.252	0.915	0.538	0.232	0.631
U1/SN	0.060	0.060	0.271	0.022	0.016	0.003	0.044	<0.001	0.233	0.136	0.274	0.263	0.839	0.126	0.451	0.490
U1/PP	0.828	0.566	0.790	0.100	0.584	0.134	0.255	0.053	0.493	0.633	0.966	0.098	0.759	0.630	0.306	0.602
L1-NB	0.001	0.064	0.032	0.001	0.010	0.216	0.329	0.678	0.104	0.075	0.902	0.070	0.314	0.104	0.096	0.122
L1/NB	0.843	0.344	0.735	0.144	0.109	0.457	0.933	0.830	0.925	0.042	0.573	0.318	0.489	0.086	0.432	0.143
L1/MP	<0.001	0.002	0.001	0.001	0.003	0.597	0.003	0.001	0.016	0.003	<0.001	0.072	0.561	0.203	0.410	0.596
Relationship between teeth																
U1/L1	0.471	0.354	0.470	0.033	0.285	0.593	0.444	0.741	0.766	0.120	0.737	0.173	0.504	0.186	0.183	0.191
OB	0.012	0.008	0.043	<0.001	0.114	0.460	0.512	0.338	0.531	0.403	0.007	0.271	0.254	0.378	0.111	0.251
OJ	0.845	0.821	0.120	0.008	0.789	0.620	0.622	0.154	0.352	0.281	0.900	0.166	0.778	0.822	0.409	0.929
Symphyseal components																
Volume									0.578	0.342	0.390	0.356	0.355	0.275	0.116	0.659
I-A	0.007	0.766	0.017	0.002	0.630	0.058	0.289	0.274	<0.001	0.020	<0.001	0.001	0.052	0.003	0.144	0.119
I-C	0.042	0.012	0.022	0.017	0.705	0.009	0.425	0.109	0.002	0.696	0.005	0.096	0.686	0.017	0.130	0.364
CWA	<0.001	<0.001	<0.001	<0.001	0.001	0.013	<0.001	<0.001	0.666	0.103	0.831	0.740	0.690	0.182	0.241	0.142
CWD	0.005	0.179	0.137	0.018	0.063	0.136	0.004	0.002	0.557	0.070	0.071	0.923	0.544	0.279	0.856	0.349

D-A	0.001	<0.001	0.002	0.002	0.208	0.880	0.065	0.013		0.381	0.592	0.788	0.831	0.694	0.290	0.180	0.634
D-Me	0.040	0.165	0.040	0.046	0.787	0.922	0.147	0.016		0.619	0.466	0.396	0.002	0.713	0.972	0.116	0.240
Ant slope	0.005	0.016	0.008	0.005	0.340	0.074	0.218	0.849		0.180	0.012	0.193	0.973	0.109	0.391	0.900	0.322
Post slope	<0.001	0.007	0.002	<0.001	0.446	0.020	0.935	0.233		0.457	0.414	0.340	0.737	0.726	0.443	0.954	0.490
AP slope	0.071	0.706	0.013	0.159	0.564	0.319	0.469	0.824		0.717	0.029	0.191	0.829	0.900	0.964	0.801	0.089
BB1	<0.001	<0.001	<0.001	<0.001	0.032	0.016	0.024	<0.001		0.307	0.458	0.607	0.885	0.361	0.398	0.471	0.427
CEJ-Me	0.003	0.024	0.244	0.047	0.126	0.961	0.137	0.031		0.075	0.177	0.320	0.022	0.410	0.176	0.144	0.427

(orange)	Pattern unchanged
(red)	Significant → Not significant
(green)	Not significant →Significant

Table IV.13.a Correlations with age

	2D	3D
Variables	**Age**	**Age**
Age		
Symphyseal components		
Volume	-	0.424
I-A	-0.046	0.153
I-C	-0.122	NS
CWA	-0.029	-0.251
CWD	0.028	0.145
D-A	0.006	0.495
D-Me	0.013	0.405
Ant slope	0.206	0.219
Post slope	-0.143	-0.165
AP slope	NS	NS
BB1	NS	NS
CEJ-Me	0.036	0.496
Cranial base measurements		
SN	0.070	0.319
SN/H	0.003	NS
SN-Ar	NS	NS
S-Ar	0.011	0.287
Relationship between jaws		
SNA	-0.061	NS
SNB	-0.012	NS
ANB	NS	NS
PP/MP	-0.177	NS
MP/SN	-0.124	NS
LFH/TFH	-0.114	NS
PP/H	0.044	NS
Jaw specific measurements		
Go-Pog	0.057	0.465
Ar-Go	0.039	0.433
Co-Gn	-0.020	0.542
Ar-Gn	-0.001	0.507
Go-Me	0.023	0.501
Co-Go	0.025	0.557
Ar-Go-Me	-0.113	-0.293
Co-Go-Me	-0.137	-0.248
ANS-PNS	0.034	0.294
Relationship between teeh and jaws		
U1-Na	NS	NS
U1/Na	NS	-0.253
U1/SN	NS	-0.226
U1/PP	NS	-0.257
L1-NB	-0.242	NS
L1/NB	NS	-0.113
L1/MP	NS	NS
U1/L1	NS	0.253
OB	0.102	0.211
OJ	NS	-0.178

Table IV.13.b Correlations with age among growing and adults

	2D		3D	
Variables	**G**	**NG**	**G**	**NG**
Age				
Symphyseal components				
Volume	-	-	0.409	NS
I-A	0.141	NS	0.217	NS
I-C	0.276	NS	NS	NS
CWA	NS	NS	NS	NS
CWD	0.244	NS	0.244	NS
D-A	0.325	0.131	0.452	NS
D-Me	0.303	0.160	0.374	NS
Ant slope	0.186	NS	0.199	NS
Post slope	-0.201	NS	-0.249	NS
AP slope	NS	NS	NS	NS
MP/H	-0.218	NS	NS	NS
BB1	-0.169	NS	NS	NS
CEJ-Me	0.347	0.162	0.494	NS
Cranial base measurements				
SN	0.437	NS	0.342	NS
SN/H	-0.246	0.121	NS	NS
SN-Ar	NS	NS	NS	NS
S-Ar	0.356	0.135	0.288	NS
Relationship between jaws				
SNA	0.308	NS	NS	NS
SNB	0.285	-0.136	NS	NS
ANB	NS	0.162	NS	NS
PP/MP	-0.131	NS	NS	NS
MP/SN	-0.169	NS	NS	NS
LFH/TFH	NS	0.153	NS	NS
PP/H	0.203	-0.214	NS	NS
Jaw specific measurements				
Go-Pog	0.339	NS	0.439	NS
Ar-Go	0.469	NS	0.430	NS
Co-Gn	0.419	-0.017	0.524	NS
Ar-Gn	0.433	NS	0.475	NS
Go-Me	0.408	NS	0.470	NS
Co-Go	0.456	0.139	0.579	NS
Ar-Go-Me	NS	-0.203	-0.228	-0.197
Co-Go-Me	NS	-0.192	-0.194	NS
ANS-PNS	0.486	NS	0.340	NS
Relationship between teeth and jaws				
U1-Na	NS	NS	NS	NS
U1/Na	NS	-0.133	-0.173	NS
U1/SN	NS	NS	NS	NS
U1/PP	NS	-0.146	NS	NS
L1-NB	NS	NS	NS	NS
L1/NB	NS	NS	NS	NS
L1/MP	0.0172	0.141	NS	NS
Relationship between teeth				
U1/L1	NS	NS	NS	NS
OB	0.195	NS	0.222	NS
OJ	NS	NS	NS	NS

Table IV.14.a Correlations with age across different facial patterns in the 2D sample

Variables	Hypo	T. Hypo	T. Hyper	Hyper
Age				
Symphyseal components				
Volume	NS	NS	NS	NS
I-A	0.294	NS	NS	NS
I-C	0.328	NS	NS	NS
CWA	-0.244	-0.292	-0.254	-0.292
CWD	NS	-0.026	0.273	NS
D-A	0.527	0.594	0.644	0.594
D-Me	0.239	0.333	0.518	0.333
Ant slope	0.169	0.290	NS	0.290
Post slope	-0.422	NS	NS	-0.281
AP slope	0.256	-0.039	NS	NS
MP/H	-0.332	0.019	-0.197	NS
Bb1	0.196	NS	NS	NS
CEJ-Me	0.489	0.603	0.610	0.603
Cranial base measurements				
SN	0.369	0.489	0.508	0.296
SN/H	NS	NS	-0.195	NS
SN-Ar	NS	NS	NS	NS
S-Ar	0.312	0.403	-0.077	0.363
Relationship between jaws				
SNA	NS	NS	0.254	NS
SNB	NS	NS	NS	NS
ANB	NS	NS	NS	NS
PP/MP	-0.269	NS	NS	NS
LFH/TFH	NS	NS	0.298	0.194
PP/H	NS	NS	NS	NS
Jaw specific measurements				
Go-Pog	0.424	0.551	0.361	0.183
Ar-Go	0.617	0.667	0.391	0.332
Co-Gn	0.503	0.618	0.449	0.326
Ar-Gn	0.533	0.625	0.453	0.313
Go-Me	0.373	0.612	0.436	0.320
Co-Go	0.623	0.671	0.416	0.361
Ar-Go-Me	-0.400	-0.339	NS	NS
Co-Go-Me	-0.435	-0.394	NS	NS
ANS-PNS	NS	0.531	0.562	0.456
Relationship between teeth and jaws				
U1-Na	NS	NS	NS	NS
U1/Na	NS	NS	NS	NS
U1/SN	NS	NS	NS	NS
U1/PP	NS	NS	NS	NS
L1-NB	NS	NS	0.231	0.180
L1/NB	NS	NS	NS	NS
L1/MP	NS	NS	NS	NS
Relationship between teeth				
U1/L1	NS	0.018	NS	NS
OB	NS	0243	NS	NS
OJ	NS	NS	NS	NS

Table IV.14.b Correlations with age across different facial patterns in the 3D sample

Variables	Hypo	T. Hypo	T. Hyper	Hyper
Age				
Symphyseal components				
Volume	NS	NS	NS	NS
I-A	NS	0.274	NS	NS
I-C	NS	0.202	NS	NS
CWA	-0.281	-0.281	NS	-0.511
CWD	NS	NS	NS	NS
D-A	0.463	0.613	0.400	0.526
D-Me	0.262	0.535	0.330	0.457
Ant slope	0.418	NS	NS	0.436
Post slope	NS	NS	NS	NS
AP slope	NS	NS	NS	NS
MP/H	NS	NS	NS	NS
BB1	NS	NS	NS	0.349
CEJ-Me	0.357	0.639	0.475	0.616
Cranial base measurements				
SN	NS	0.413	0.266	NS
SN/H	NS	NS	NS	NS
SN-Ar	NS	NS	NS	NS
S-Ar	NS	0.355	NS	0.323
Relationship between jaws				
SNA	NS	NS	NS	NS
SNB	NS	NS	NS	NS
ANB	NS	NS	NS	NS
LFH/TFH	NS	NS	NS	NS
PP/H	NS	NS	NS	NS
Jaw specific measurements				
Go-Pog	0.346	0.454	0.518	0.573
Ar-Go	0.391	0.516	0.489	NS
Co-Gn	0.435	0.570	0.617	0.573
Ar-Gn	0.405	0.538	0.528	NS
Go-Me	0.353	0.553	0.487	0.653
Co-Go	0.430	0.583	0.660	0.500
Ar-Go-Me	NS	-0.369	-0.304	NS
Co-Go-Me	NS	-0.270	-0.303	NS
ANS-PNS	NS	0.386	NS	0.374
Relationship between teeth and jaws				
U1-Na	NS	NS	NS	NS
U1/Na	-0.286	-0.209	NS	NS
U1/SN	-0.307	-0.218	NS	NS
U1/PP	-0.419	NS	NS	NS
L1-NB	NS	0.209	NS	NS
L1/NB	-0.318	NS	NS	NS
L1/MP	-0.280	NS	NS	NS
Relationship between teeth				
U1/L1	0.483	NS	0.263	NS
OB	0.044	0.004	NS	NS
OJ	0.003	NS	NS	-0.371

Table IV.15.a Comparison between 2D and 3D samples

Variables	2D Mean	2D Median	2D Range	3D Mean	3D Median	3D Range	p-Value Mann-Whitney test
Cranial base							
SN	65.66 (4.79)	65.4	4.79-77.9	64.71 (3.81)	64.6	53.7-75.3	0.003
SN/H	10.4 (4.21)	10.5	0.4-29.0	12.28 (4.49)	12.55	0.2-24.7	<0.001
SN-Ar	124.3 (5.69)	124.45	104.8-143.2	126.17 (5.5)	126.35	111.3-140.9	<0.001
Relationship between jaws							
SNA	81.84 (4.15)	82.05	68.4-94.7	82.69 (3.49)	82.7	73.7-91.8	0.004
ANB	2.95 (5.27)	3.0	-12.4-92.6	4.17 (2.75)	4.5	-3.8-11.4	<0.001
MP/SN	32.43 (6.84)	32.0	11.5-61.9	31.19 (5.55)	30.8	9.0-46.4	0.023
PP/H	-2.03 (3.83)	-1.9	-15.3-8.8	-2.78 (4.21)	-2.5	-16.2-9.8	0.008
Jaw specific measurements							
Ar-Go	44.85 (6.62)	43.85	27.9-70.1	43.27 (5.13)	42.6	32.2-65.5	0.016
Co-Gn	109.8 (11.58)	108.5	73.2-171.1	107.01 (8.05)	106.35	88.6-134.0	0.001
Ar-Gn	105.66 (10.97)	104.5	69.4-163.7	102.69 (7.63)	101.8	87.5-127.1	<0.001
Co-Go	53.5 (7.38)	52.3	35.2-83.7	51.76 (5.34)	51.0	39.3-73.0	0.004
Co-Go-Me	120.17 (6.59)	120.0	98.6-142.4	121.21 (5.63)	120.9	102.6-136.3	0.025
ANS-PNS	49.71 (5.33)	49.6	26.3-64.8	50.89 (3.97)	51.0	40.5-66.7	<0.001
Relationship between teeth and jaws							
U1-Na	4.02 (3.07)	3.85	-3.0-33.6	3.0 (1.96)	2.7	0-9.7	<0.001
U1/Na	22.51 (8.79)	23.25	0-42.6	20.23 (8.29)	20.65	0.1-44.2	<0.001
U1/SN	104.19 (9.44)	104.8	69.4-127.9	102.6 (8.78)	103.2	72.6-127.0	0.008
L1/NB	25.3 (7.59)	25.45	0.2-47.2	27.43 (7.76)	28.55	2.9-42.8	<0.001
L1/MP	93.72 (9.41)	94.5	59.6-120.2	96.69 (8.56)	97.25	68.6-115.9	<0.001
Relationship between teeth							
OB	2.56 (2.62)	2.5	-7.7-11.0	3.29 (2.32)	3.3	-4.0-8.5	0.002
OJ	2.89 (3.34)	3.0	-13.8-12.6	3.85 (2.84)	3.0	-3.5-12.5	<0.001
U1/L1	129.59 (13.25)	129.4	97.5-169.5	128.27 13.11)	125.75	99.4-172.0	0.032
Symphyseal components							
I-A	21.42 (2.22)	21.0	13.4-29.9	23.68 (2.23)	23.45	18.2-30.5	<0.001
I-C	8.46 (1.09)	8.4	5.1-11.0	9.37 (0.97)	9.3	6.5-13.5	<0.001
CWA	9.03 (2.17)	9.0	3.6-18.6	11.02 (1.72)	10.9	4.9-16.2	<0.001
CWD	12.87 (1.87)	12.8	3.3-17.7	13.44 (1.54)	13.4	9.1-17.8	<0.001
D-A	8.76 (2.65)	8.5	3.5-18.1	7.23 (1.91)	7.0	3.0-13.9	<0.001
D-Me	9.23 (1.43)	9.0	5.6-14.3	8.46 (1.27)	8.4	5.3-13.8	<0.001
Ant slope	9.81 (8.07)	9.2	-22.0-33.8	12.31 (8.97)	10.9	0-57.2	0.001
Post slope	19.32 (8.75)	18.8	0.1-49.2	15.02 (8.75)	14.5	0-74.5	<0.001
AP slope	29.14 (8.11)	29.1	4.0-56.1	27.34 (10.74)	26.6	5.9-98.5	<0.001
BB1	7.99 (5.5)	8.0	10.1-20.1	7.67 (5.67)	6.55	2.3-10.2	0.117
CEJ-Me	30.94 (3.9)	30.5	20.3-43.8	30.01 (3.47)	29.8	22.5-43.5	0.004

Table IV.15.b Comparison between males in 2D and 3D samples

	2D			3D			p-Value Mann-Whitney test
Variables	Mean	Median	Range	Mean	Median	Range	
Cranial base							
SN/H	9.7 (4.17)	9.7	0.4-23.9	5.99 (4.33)	5.35	3.7-5.3	<0.001
SN-Ar	123.45 (5.55)	123.3	104.8-141.6	122.07 (4.38)	122.15	100.3- 140.3	<0.001
Relationship between jaws							
ANB	2.9 (6.76)	3.0	-2.4-8.6	8.71 (3.76)	8.5	-3.1-9.4	0.001
Jaw specific measurements							
Ar-Go	46.21 (7.42)	45.9	31.5- 70.1	68.62 (6.1)	68.45	55.5-81.6	0.007
Co-Gn	112.41 (12.76)	111.8	82.3-171.1	143.94 (6.24)	143.0	132.2- 165.5	0.027
Ar-Gn	108.21 (12.15)	107.1	78.8-163.7	109.15 (9.48)	107.85	89.2- 134.0	0.016
Co-Go	55.23 (8.32)	55.3	38.5- 83.7	65.46 (5.98)	64.7	52.9- 80.1	0.003
Co-Go-Me	120.29 (6.66)	120.1	98.6-142.4	127.94 (5.62)	127.85	112.2-140.9	0.009
Relationship between teeth and jaws							
U1-Na	4.11 (3.1)	3.7	-2.8-28.2	-2.47 (4.43)	-2.3	-16.2-9.8	0.001
L1/NB	24.9 (7.32)	24.9	6.6- 46.9	24.69 (2.13)	24.7	5- 50.0	<0.001
L1/MP	93.57 (9.59)	94.1	59.6-120.2	98.03 (7.28)	98.0	68.9-124.1	0.001
Relationship between teeth							
OB	2.63 (2.79)	2.6	-7.7- 11.0	7.66 (1.42)	7.57	4.78-11.0	0.029
OJ	2.6 (3.61)	3.0	-13.8- 10.1	3.28 (2.51)	3.3	-4.0- 8.5	0.044
U1/L1	129.82 (12.91)	130.2	97.6-160.4	97.12 (8.19)	97.65	80.7-115.9	0.007
Symphyseal components							
I-A	21.97 (2.38)	21.5	18.1- 29.9	26.95 (2.52)	25.55	17.2-20.2	<0.001
I-C	8.71 (1.15)	8.7	5.2- 11.0	9.27 (2.26)	9.5	6.7-12.5	<0.001
CWA	9.23 (2.23)	9.2	4.2- 18.6	9.7 (1.05)	9.7	7.0-13.5	<0.001
CWD	13.12 (1.88)	13.1	3.3- 17.7	11.53 (1.63)	11.5	6.9-16.2	<0.001
D-A	9.11 (2.84)	8.8	3.6- 17.1	13.83 (1.55)	13.7	10.4-17.8	<0.001
D-Me	9.7 (1.49)	9.7	6.3- 14.3	7.09 (1.81)	7.1	3.0-12.6	<0.001
Post slope	19.34 (9.38)	19.5	0.2-49.2	10.89 (7.46)	10.0	0-35.3	<0.001
AP slope	28.98 (8.49)	29.2	4.0 50.6	15.32 (9.85)	14.45	0.7-74.5	0.001
CEJ-Me	28.28 (3.04)	28.0	20.2-41.0	29.15 (6.01)	28.25	26.2-50.6	0.001

Table IV.15.c Comparison between females in 2D and 3D samples

	2D			3D			p-Value
Variables	Mean	Median	Range	Mean	Median	Range	Mann-Whitney test
Cranial base							
SN/H	11.08 (4.15)	11.0	0.4-29.0	13.94 (3.25)	14.05	14.2-16.1	<0.001
S-Ar	30.45 (3.24)	30.6	20.8-40.2	25.91 (5.37)	25.8	20.3-39.4	0.039
Relationship between jaws							
SNA	81.65 (4.18)	81.9	68.4- 94.7	83.45 (5.21)	83.5	70.0-99.7	0.008
ANB	3.02 (3.27)	3.2	-6.7-10.7	2.3 (3.73)	2.5	-6.8-7.6	<0.001
Jaw specific measurements							
Ar-Gn	103.21 (9.09)	102.8	69.4-138.1	105.75 (6.79)	105.65	88.6 - 123.6	0.014
ANS-PNS	48.52 (5.1)	48.6	26.3-64.8	31.16 (3.23)	31.2	23.7- 40.1	<0.001
Relationship between teeth and jaws							
U1-Na	3.93 (3.06)	3.9	-3.0-13.6	2.97 (4.07)	2.55	-1.6.0-8.7	<0.001
U1/Na	22.27 (8.83)	23.6	7-42.6	21.87 (1.87)	22.5	9-40.6	0.001
U1/SN	103.64 (9.75)	104.6	69.4-127.9	102.75 (8.22)	102.55	69.3-126.5	0.025
L1/NB	25.69 (7.82)	26.5	12.0-47.2	24.41 (2.45)	24.3	11.7-35.3	0.037
L1/MP	93.86 (9.26)	94.6	62.0-117.6	92.07 (8.02)	92.1	62.9-112.8	0.004
Relationship between teeth							
OB	2.49 (2.44)	2.4	-6.7-10.2	6.85 (1.27)	6.82	3.86-10.82	0.042
OJ	3.17 (3.06)	3.0	-8.1-12.6	3.3 (2.21)	3.3	-3.6-8.1	<0.001
Symphyseal components							
I-A	20.88 (1.91)	20.6	13.428.0	19.05 (1.42)	16.75	12.5-27.8	<0.001
I-C	8.22 (0.97)	8.1	5.1-10.9	7.33 (2.15)	7.05	4.9-10.4	<0.001
CWA	8.84 (2.09)	8.9	3.6-18.1	9.17 (0.86)	9.2	6.5 11.3	<0.001
CWD	12.63 (1.83)	12.6	4.6- 17.1	10.73 (1.71)	10.7	4.9- 16.0	<0.001
D-A	8.42 (2.42)	8.1	3.5-18.1	13.21 (1.49)	13.2	9.1- 17.5	<0.001
D-Me	8.77 (1.2)	8.6	5.6-12.4	7.32 (1.97)	7.0	3.4- 13.9	<0.001
Ant slope	9.99 (8.24)	9.1	-12.6-32.3	8.3 1.17)	8.30	5.3 13.8	0.003
Post slope	19.3 (8.12)	18.7	0.1-45.9	13.16 (9.67)	11.2	0-57.2	<0.001
AP slope	29.29 (7.75)	29.1	6.0- 56.1	14.85 (8.06)	14.65	0-37.4	0.027

Table IV.15.d Growing sample: 2D vs 3D

	2D			3D			p-Value Mann-Whitney test
Variables	Mean	Median	Range	Mean	Median	Range	
Cranial base							
SN/H	10.74 (4.01)	10.9	0.9-23.9	12.13 (4.32)	12.05	0.2-23.3	0.0001
SN-Ar	123.99 (5.45)	124.4	104.8-139.9	126.28 (5.42)	126.7	111.3-140.7	<0.001
S-Ar	30.38 (3.63)	30.3	20.1-40.5	31.29 (3.71)	31.05	21.4-43.0	0.028
Relationship between jaws							
SNA	81.51 (4.0)	81.6	70.9-94.6	82.69 (3.45)	82.7	73.7-91.8	<0.001
ANB	2.85 (3.41)	3.0	-12.4-10.3	4.27 (2.67)	4.5	-3.8-11.4	<0.001
LFH/TFH	54.76 (2.17)	54.9	49.7-59.8	55.2 (2.29)	55.4	48.8-61.2	0.039
PP/MP	24.48 (5.15)	23.9	11.3-39.3	23.23 (4.88)	23.35	8.0-36.9	0.022
MP/SN	33.08 (6.31)	32.5	19.3-55.6	31.41 (5.2)	31.1	18.5-46.4	0.008
Jaw specific measurements							
Go-Me	61.66 (6.38)	60.9	42.2-85.3	63.1 (5.28)	62.15	50.8-77.9	0.004
ANS-PNS	48.04 (4.98)	47.7	34.7-64.8	50.44 (4.03)	50.6	40.5-66.7	<0.001
Relationship between teeth and jaws							
U1-Na	3.87 (2.87)	3.5	-2.8-28.2	3.01 (1.94)	2.7	0-9.7	0.0002
U1/Na	22.82 (8.53)	23.6	0.7-42.6	21.68 (7.62)	21.4	0.1-44.2	0.033
L1/NB	25.81 (7.31)	25.6	0.2-47.2	28.49 (7.35)	29.05	4.7-42.8	<0.001
L1/MP	94.0 (8.79)	94.3	70.1-117.8	97.65 (8.51)	97.9	68.6-115.9	<0.001
Relationship between teeth							
OB	2.43 (2.46)	2.3	-6.7-8.4	3.0 (2.14)	3.1	-4.0-8.0	0.005
OJ	3.03 (3.32)	3.0	-8.8-12.6	4.27 (2.89)	4.5	-3.5-11.9	<0.001
U1/L1	128.5 (12.71)	128.8	97.6-160.1	125.64 (11.61)	123.95	99.4-172.0	0.002
Symphyseal components							
I-A	21.14 (2.0)	20.8	13.4-27.5	23.61 (2.08)	23.35	18.5-30.5	<0.001
I-C	8.34 (1.05)	8.3	5.1-10.9	9.39 (0.92)	9.3	6.9-13.5	<0.001
CWA	9.39 (2.13)	9.4	4.1-18.6	11.37 (1.58)	11.25	7.5-16.2	<0.001
CWD	12.65 (1.92)	12.7	3.3-17.3	13.39 (1.52)	13.35	9.1-17.4	<0.001
D-A	7.54 (2.06)	7.2	3.6-16.2	6.71 (1.63)	6.6	3.0-11.8	<0.001
D-Me	8.81 (1.33)	8.7	5.6-13.8	8.19 (1.15)	8.2	5.3-12.2	<0.001
Ant slope	8.16 (7.42)	7.9	-22.0-28.8	11.14 (7.98)	9.7	0-36..9	0.001
Post slope	21.1 (8.47)	20.9	1.3-49.2	15.44 (9.15)	14.9	0-74.5	<0.001
AP slope	29.27 (8.44)	29.2	4.74-56.1	26.59 (10.69)	25.85	7.2-98.5	0.0001
BB1	8.14 (3.07)	8.0	0.2-41.0	9.4 (3.8)	9.2	20.8-31.8	<0.001

Table IV.15.e Non-growing sample: 2D vs 3D

	2D			3D			p-Value Mann-Whitney test
Variables	Mean	Median	Range	Mean	Median	Range	
Cranial base							
SN	67.29 (4.67)	67.2	46.7-77.9	65.86 (3.78)	65.5	56.1-74.2	0.003
SN/H	10.05 (4.39)	10.0	0.4-29.0	12.58 (4.82)	13.05	1.2-24.7	<0.001
Relationship between jaws							
ANB	3.07 (6.67)	3.0	-12.3-92.6	3.97 (2.91)	3.5	-3.2-10.1	0.009
PP/H	-1.88 (3.82)	-1.8	-15.3-8.8	-3.22 (4.58)	-2.95	-16.0-9.2	0.008
Jaw specific measurements							
Ar-Go	47.27 (6.64)	46.9	32.0-70.1	45.53 (5.52)	45.4	33.4-65.5	0.014
Co-Gn	114.29 (10.99)	113.1	87.7-171.1	110.89 (7.24)	109.65	95.0-134.0	0.005
Ar-Gn	110.06 (10.41)	103.4	85.1-163.7	106.34 (6.88)	105.55	91.9-127.1	<0.001
Co-Go	56.56 (7.2)	56.6	37.2-83.7	54.46 (5.49)	53.7	42.9-73.0	0.003
Relationship between teeth and jaws							
U1-Na	4.17 (3.27)	4.2	-3.0-33.6	2.96 (2.01)	2.6	0.2-9.7	<0.001
U1/Na	22.19 (9.05)	22.6	0-39.9	17.39 (8.85)	18.1	0.9-36.6	<0.001
U1/SN	104.04 (10.17)	104.5	69.4-127.9	99.53 (9.83)	100.0	72.6-119.1	0.0001
U1/PP	112.22 (9.44)	112.9	82.8-133.1	108.87 (9.15)	109.55	86.0-128.5	0.001
Relationship between teeth							
OB	2.7 (2.77)	2.6	-7.7-11.0	3.87 (2.55)	3.55	-1.4-8.5	0.0004
Symphyseal components							
I-A	21.7 (2.39)	21.3	16.7-29.9	23.82 (2.51)	23.5	18.2-29.5	<0.001
I-C	8.57 (1.11)	8.6	5.2-11.0	9.31 (1.05)	9.3	6.5-12.0	<0.001
CWA	8.66 (2.15)	8.5	3.6-18.1	10.34 (1.8)	10.2	4.9-14.7	<0.001
CWD	13.1 (1.79)	13.0	7.2-17.7	13.54 (1.6)	13.5	9.9-17.8	0.026
D-A	10.01 (2.61)	9.8	3.5-18.1	8.26 (2.03)	8.1	4.3-13.9	<0.001
D-Me	9.65 (1.4)	9.6	6.5-14.3	8.99 (1.33)	8.9	6.6-13.8	<0.001
Ant slope	11.51 (8.37)	11.3	-6.9-33.8	14.61 (10.3)	13.7	0-57.2	0.020
Post slope	17.48 (8.67)	17.4	0.1-44.0	14.2 (7.89)	12.9	0-32.0	0.001
BB1	-7.83 (2.13)	7.7	-16.9-1.9	9.16 (3.83)	9.05	7.09-28.2	<0.001
CEJ-Me	32.79 (3.73)	32.9	23.8-43.8	31.76 (3.58)	31.5	24.7-43.5	0.015

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APPENDIX

Intra-class examiner correlation of all the variables for repeated measurements in 10% of the samples

Variables	p-value	
	2D	**3D**
SN (mm)	0.934	0.967
SN/H (°)	0.910	0.909
SN/Ar (°)	0.975	0.945
S-Ar (mm)	0.971	0.956
SNA (°)	0.982	0.947
SNB (°)	0.932	0.912
ANB (°)	0.927	0.944
PP/MP (°)	0.967	0.983
MP/SN (°)	0.899	0.901
LFH/TFH (%)	0.953	0.918
PP/H (°)	0.895	0.901
MP/H (°)	0.945	0.987
Go-Pog (mm)	0.981	0.945
Ar-Go (mm)	0.971	0.954
Co-Gn (mm)	0.967	0.933
Ar-Gn (mm)	0.978	0.942
Go-Me (mm)	0.969	0.978
Co-Go (mm)	0.905	0.957
Ar-Go-Me (°)	0.956	0.962
Co-Go-Me (°)	0.971	0.933
ANS-PNS (mm)	0.980	0.912
U1-Na (mm)	0.945	0.970
U1/Na (°)	0.946	0.929
U1/SN (°)	0.899	0.981
U1/PP (°)	0.946	0.973
L1-NB (mm)	0.967	0.941
L1/NB (°)	0.929	0.956
L1/MP (°)	0.978	0.927
U1/L1 (°)	0.986	0.954
OB (mm)	0.941	0.983
OJ (mm)	0.955	0.972
I-A (mm)	0.954	0.965
I-C (mm)	0.953	0.976
CWA (mm)	0.966	0.932
CWD (mm)	0.980	0.958
D-A (mm)	0.978	0.965
D-Me (mm)	0.912	0.934
Ant slope (°)	0.945	0.956
Post slope (°)	0.978	0.945
Ant+Post slopes (°)	0.981	0.934
BB1 (mm)	0.967	0.912
CEJ-Me (mm)	0.965	0.934