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The correlation of condylar characteristics to facial morphology and their prediction of treatment outcomes in Class II patients.

by

Gail M. Burke ©

A Thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Masters of Science in Orthodontics

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DEDICATION

This work is dedicated to my wonderful parents Norm and Joyce and to my loving husband Mark. Thank you to my parents, for providing me with the continual encouragement, love and education needed to pursue my dreams. A very special thank you to my husband, for without his constant support, patience and positive attitude this last thirty months would have been impossible.

ABSTRACT

The objective of this retrospective study was to determine correlations between condylar characteristics and facial morphology and assess their prediction of treatment outcomes in Class II patients, treated with edgewise appliances and extraoral traction. A total of eight condylar characteristics measured from pre-orthodontic tomograms were compared to patients displaying a vertical or horizontal skeletal growth tendency as determined by cephalometric measurements. Condylar head inclination and superior joint space proved to be significantly correlated to facial morphology (p-values ranged from .010-.018). Patients with vertical facial morphology displayed decreased superior joint spaces and posteriorly angled condyles. Increased superior joint spaces and anteriorly angled condyles were significantly correlated to patients with a horizontal facial morphology. There were no significant correlations between the other condylar characteristics and facial morphology. Favourable or unfavourable treatment outcomes of the horizontal group treated with cervical headgear could not be predicted in this sample. This study suggests that increased superior joint space and posterior condylar head inclination were able to predict a counter-clockwise growth tendency or favourable treatment outcome in the vertical group treated with highpull headgear.

TABLE OF CONTENTS

TABLE OF CONTENTS

CHAPTER TWO **Page No.**

TABLE OF CONTENTS

TABLE OF CONTENTS

CHAPTER FOUR **Page No.**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter One

Introduction
and
Literature Review

1.1 - INTRODUCTION

Orthodontists have been particularly interested in facial growth and development because of the dental and skeletal abnormalities that may result. Facial growth proceeds along a vector composed of variable amounts of horizontal and vertical growth, as a result of osseous development at facial sutures, alveolar processes, mandibular condyles and tooth eruption.[1] Although the whole dentofacial complex contributes to the development of facial pattern, the role of mandibular growth has especially intrigued practicioners due to its variability and relative unpredictability. The moveable nature and position of the mandible is important as it allows for mastication, speech as well as overall facial esthetics. It is the combination of mandibular development and function that orthodontists must comprehend in order to correctly diagnose and apply this information to patient treatment.

As the mandible articulates with the cranium, it is paramount that proportionate growth be achieved between anterior and posterior facial heights or resultant clockwise or counter-clockwise mandibular rotation may occur. Extreme cases of increased vertical growth and clockwise rotation will result in the hypodivergent, steep mandibular plane facial pattern or more specifically the difficult orthodontic Class II malocclusion. This type of malocclusion continues to present itself as one of the most challenging orthodontic treatment situations. In 1985, Bishara and Jakobsen[2] longitudinally and cross-sectionally compared the dentofacial relationships of 35 individuals between 5 and 25.5 years of age, with long, average and short facial types. Their findings revealed that approximately 77 percent of the sample maintained the same facial type and growth pattern at the age 25 as they did at the early age of 5. The recognition that considerable individual variation in craniofacial growth may occur in the remaining 23 percent is what continues to perplex and become occasionally troublesome to the orthodontist.

To this end, it has been the aim of numerous researchers to study growth and development of the dentofacial complex to predict facial and treatment outcomes. This information would be vital in applying the most efficient orthodontic treatment modalities to enhance and modify the final functional and esthetic result. As a result, this has led to the quest to corroborate the role of mandibular growth and establish parameters to successfully predict mandibular growth direction and treatment outcomes. Although a number of examiners have provided commendable scientific information regarding mandibular growth prediction, to date, the ability to accurately predict the exact growth pattern of the lower jaw still eludes the orthodontic community and the quest to find a tangible solution continues. Therefore it may be concluded, that further clinical and research investigation is warranted to gather additional information regarding the complicated yet fascinating role of mandibular growth in dentofacial morphology.

1.2 - STATEMENT OF THE PROBLEM

Orthodontists are continually challenged with complicated treatment cases as a result of variable and occasionally unexpected growth patterns and the resultant facial morphology. There is little doubt that research literature, to date, has provided useful information regarding dentofacial morphological characteristics as well as a variety of guide-lines to assist in prediction of facial outcomes and mandibular growth prediction. However, although these parameters may provide some indication of future growth patterns, no one measure has proved to accurately enhance the orthodontist's ability to predict future growth. This has led to the overall consideration that additional methods to determine associations between craniofacial characteristics, growth patterns and treatment outcomes must be investigated.

1.3 - PURPOSE

The purpose of this retrospective research study is to examine condylar characteristics and facial morphology of adolescents and utilize the information to aid in assessing mandibular growth and treatment outcomes. This will be accomplished by examining various tomographic and cephalometric radiographs of adolescent males and females prior to and at the completion of their orthodontic treatment. The data retrieved from the radiographs will be analyzed to determine if relationships exist between specific condylar characteristics and facial morphology. It is also the intent of this research project to determine if condylar morphology can be used to predict treatment outcome in orthodontic patients.

By analysing this data in depth, it is hoped that the findings will provide orthodontists with a data source which could be applied to recognize specific adolescent condylar characteristics that are indicative of specific growth patterns of the dentofacial complex. This early detection would be invaluable to practicioners as it would provide a diagnostic tool for determining the optimal treatment plan and potentially predicting treatment outcome for difficult Class II orthodontic cases. In addition, by being able to predict treatment outcomes, orthodontists will be able to initiate corrective measures which could reduce unnecessary treatment techniques and minimize treatment time and trauma to patients.

1.4 - RESEARCH QUESTIONS

1. **Is there a relationship between condylar characteristics measured from pre-orthodontic treatment tomograms of pre-adolescent patients and their related facial morphological pattern?**

2. **Does a correlation exist between condylar characteristics and mandibular growth direction in treated Class II malocclusions?**

1.5 - HYPOTHESES

1. A correlation exists between the position, size, angulation and shape of the condyle as viewed on tomographs and facial morphology in pre-adolescent patients displaying a Class II malocclusion;
   a. Posterior condylar head and neck inclination to the posterior border of the ramus will result in clockwise rotation of the mandible and a dolichocephalic facial form.
   b. Condyles exhibiting reduced size and surface area will contribute to clockwise rotation of the mandible and a dolichocephalic facial form.
   c. A condyle/fossa relationship exhibiting a reduced anterior and superior joint space will indicate clockwise rotation of the mandible and a dolichocephalic facial form.
   d. Patients displaying a dolichocephalic facial form or vertical skeletal characteristics will exhibit condyles with flattened contours.
   e. No significant differences in condylar characteristics will be detected in individual contralateral joints of pre-adolescent patients.

2. Correlations exist between condylar characteristics of shape, size, position and angulation and mandibular growth direction in the treatment of adolescent Class II malocclusions.

1.6 - LITERATURE REVIEW

1.6.1 - GROWTH AND DEVELOPMENT

Pre-natal growth of the mandible commences with the migration of embryonic neural crest cells that originate in the mid and hindbrain regions of the neural folds.[3] These pluripotential cells coalesce underneath the ectoderm layer to form the branchial arches which continue to form the facial processes and eventually the mandible. The mandible is derived from the first branchial arch which contains a central core of cartilage, as well as a muscular, vascular and nervous component. The initial structure, to develop in the region of the lower jaw, is the mandibular division of the trigeminal nerve. By the fifth week of inter-utero development, the mandible has developed bilateral rodlike condensations of membranous bone lateral to the central cartilage core, namely Meckel's cartilage.[1] During the sixth week of development, Meckel's cartilage begins to chondrify coincident with intramembranous ossification at the site of the mental foramen, lateral to the rodlike condensations. This wave of ossification extends posteriorly to form the remainder of the mandibular body and partial ramus, and extends anteriorly to form the eventual fusion of the mandible symphysis. The mandible is therefore formed by direct osseous activity while Meckel's cartilage almost completely resorbs. The remaining cartilage forms the malleus and incus, sphine of the sphenoid and the sphenomandibular ligament.[3]

Although Meckel's cartilage acts a template for osseous formation of the mandible, it does not contribute to the formation of cartilage located at the condylar, the coronoid and the symphyseal processes. These cartilagenous areas are known as secondary cartilage due to their formation irrespective of Meckel's cartilage and the first branchial arch. Secondary cartilage located on the condyle is derived from mesenchymal cells and grows towards the developing temporal bone. At approximately 12 weeks, two cavities are created with an intermediate layer to form the articular disc which ultimately unites anteriorly with the lateral pterygoid muscle. Embryologically, the temporomandibular joints (TMJ's) can be recognized at approximately 16 weeks.[3]

Post-natal growth of the mandible including mandibular body length and ramus height progresses at a fairly regular rate with an obvious increase during the pubertal growth spurt. The mandible at birth is proportionally smaller vertically and has an obtuse gonial angle which gives the appearance of a ramus continuous with the mandibular corpus. As the individual matures, the mandible increases in its size with growth in width dimension completed first, followed by mandibular length and finally vertical growth which continues in minimal amounts throughout life.[1] Enlow and Harris[4] studied post-natal development of the mandible and recognized that a series of osseous apposition and resorption patterns contribute to the overall dimensional increase of the mandible. This was represented by posterior growth of the ramus, developing in synchrony with the laterally expanding cranial floor. The coronoid processes grow superiorly and laterally, with the anterior edges of the rami being resorbed in the process. Concurrently, the condyles are developing in a posterior, superior and lateral direction. Apposition is evident on the inner surface of the coronoid and condylar processes, on the buccal surface of the lower part of the ramus, and on a large segment of the basal segment of the basal portion. As well, resorption is noticed below the mylohyoid ridge, laterally on the superior aspect of the ramus and inferior to the anterior teeth.[1] There have been numerous discussions as to which anatomical components contribute to mandibular growth. Charles[5] postulated that growth occurring from the top of the condyle was responsible for completely controlling mandibular growth. This led to the traditional view that the condyle was a primary growth centre controlled by intrinsic factors. A growth centre can be defined as places of endochondral ossification with tissue separation force, contributing to the increase of skeletal mass.[1] According to early theories, therefore, endochondral ossification at the condyle would result in an increase of mandibular dimensions as well as its displacement in a downward and forward direction.[6]

Moss[7] developed an opposing position to Charles and his supporters and formulated the functional matrix theory. This theory states that the origin, growth, and maintenance of the skeleton depend almost exclusively upon the functional matrix, that is to say, those tissues, organs, and functioning spaces related to any given skeletal element. The condyle was therefore regarded more as a growth site which is defined as a region of periosteal or sutural bone formation and modeling resorption adaptive to environmental influences.[1] Moss also postulated that the only direct genetic influence is on the initiation of ossification within the skeletal tissues. The functional matrix theory accepts the proposition that extrinsic factors control growth at the condyle, and therefore mandibular growth occurs as a response to the effects of the surrounding musculature and functional components of the oral cavity.

In order to determine if growth of the condyle is controlled by intrinsic or extrinsic factors, experiments have been conducted ranging from condylar transplantations and histologic studies to experimental condylectomies on animal subjects. In separate studies, Gianelly and Moorrees[8] and Das et al[9] completed bilateral condylectomies on three to five week old rats and produced contradictory conclusions. Gianelly and Moorrees's results supported the condyle as an important regulator of mandibular growth, whereas Das et al opposed this view. Additional animal studies have also revealed a variety of results. Pimenidis and Gianelly[10] determined that bilateral condylectomies of one day old rats resulted in relatively minor changes in post-natal length and spatial positioning of the rat mandible. They concluded that the role of the condyle is therefore secondary and compensatory. These findings support Moss's functional matrix theory that the expansion of the oropharyngeal cavity is the primary growth mechanism, causing a passive translatory downward and forward movement of the whole mandible which results in its spatial repositioning. Bernabei and Johnston[11] examined condylar growth to determine if a correlation could be determined between mandibular translation and condylar growth. Their study suggests that the condyles can grow without mandibles, but mandibles cannot grow normally without condyles. Condyles, therefore have an independent growth potential and may contribute to mandibular translatory growth. Finally, Arena and Gianelly[12] resected the mandibular body of rats to establish its effect on mandibular growth. They determined that it is possible to produce a minor impairment of mandibular growth by a surgical procedure. This alteration, however, may be due not to the lack of a growth site but to the surgical intervention on the growing rat mandible.

Weinreb et al[13] examined malnourished rats inoculated with substances to determine mandibular growth and histologic changes in condylar cartilage. Experimental animals demonstrated significant reduction in width of the condylar cartilage as well as a significant retardation in growth of the mandible. Intoxicated animals showed an increased retardation in mandibular growth compared to the undernourished rats. It has therefore been suggested, that the condyle is essential for normal mandibular growth, but would not appear to be the main controlling factor for post-natal development of the mandible.[6,13]

Berraquero et al[14] studied the role of condylar cartilage in mandibular growth of four newborns who died at birth. The subjects were diagnosed at autopsy with a lethal osteochondrodysplasia known as thanotophoric dysplasia. Their results supported the hypothesis that condylar cartilage is a secondary growth site instead of being a primary growth centre as mandibles showed a normal longitudinal growth despite the severe disturbance of the condylar cartilage. The author stated that it is not possible to determine what postnatal mandibular growth potential exists in this condition. However, he notes that the normal size of the mandible at birth may suggest that the condyle is not the main determinant to control mandibular growth rate, at least in the pre-natal period.

As evidenced from the above literature review, numerous experiments have been completed to determine the role of the condyle in mandibular growth. According to Ranly,[1] conflicting opinions still exist. However, the majority of scientific evidence indicates that mandibular condyles respond as growth sites.

Other researchers have examined additional components of the temporomandibular joint to assess its effect on mandibular growth.[15,16] Relative changes in position of the glenoid fossa during facial development can occur as a result of local remodelling within the fossa or as a result of spatial repositioning of the entire temporal bone. Droel and Isaacson[15] determined that growth may result in the glenoid fossa being positioned anteriorly or posteriorly. This could result in an abnormal position of the mandible relative to the maxilla in spite of favourable amounts and direction of growth when the condyles were properly positioned in the glenoid fossa. Their study of 62 Class I and II patients, aged 12-15 years, revealed that the Class II group had the fossa positioned posteriorly relative to the Class I group. Agronin and Kokich[16] also agreed that as the glenoid fossa remodels with growth, it can affect condylar position and may contribute to forward positioning of the mandible or create mandibular rotation. Their research evaluated displacement of the glenoid fossa in 175 orthodontically treated patients by comparing the position of articulare from pre and post-treatment lateral cephalograms. Patients were divided into vertical, horizontal or intermediate groups according to the direction of facial growth prior to treatment. Results indicated that articulare is displaced posteriorly and inferiorly during craniofacial development with treatment. As well, patients with vertical growth patterns showed significantly greater posterior displacement of articulare than patients with horizontal growth patterns. Therefore, its relative position during facial development can truly affect mandibular position, growth direction and rotation.

Growth and development of the mandible is a complex process which involves a variety of interactions within the mandible itself and from external influences. The mandible is just one of the many bones of the craniofacial complex that act in concert to create the final facial form. Although mandibular interactions are responsible for the majority of mandibular growth, the simultaneous formation of the maxilla and cranium may affect overall positional changes of the mandible.

1.6.2 - MANDIBULAR GROWTH AND ROTATION

In the 1960's, Bjork[17,18] and his colleagues, became acutely aware of the importance of mandibular growth rotation and initiated experiments to study this process. Longitudinal growth studies incorporating metallic implants as stable reference points for longitudinal cephalometric growth studies were used to analyse the positional changes that occurred during growth. Results from Bjork's studies revealed areas of growth and resorption in the skeletal complex, as well as the degree of mandibular rotation which directly affects the vertical jaw relationship or esthetic effect of the individual. He determined that growth direction of the mandible truly varied amongst individuals and therefore proceeded to isolate trends in mandibular growth direction. Bjork concluded from his implant studies, regarding mandibular rotation, that an anterior inclination of the condylar head could be associated with counter-clockwise mandibular rotators. He also postulated that counter-clockwise mandibular rotators could be correlated with greater curvatures of the mandibular canal than that of the mandibular contour. Conversely, a clockwise rotating mandible could be associated with increased concavity of the lower mandibular border and increased osseous apposition inferior to the symphysis.

Schudy[19] examined mandibular rotation and determined that variation in growth at the condyles and at the molar area is responsible for the rotation of the corpus of the mandible. He determined that clockwise rotation is a result of more vertical growth at the molar areas and counter-clockwise rotation is a result of more condylar growth than vertical growth at the molars.

Lavergne and Gasson[20] agreed through their implant studies, that variety exists in the direction and intensity of mandibular rotation. They felt that rotation of the mandible during growth is not only dependant on mandibular intrinsic factors, but also is strongly related to the intensity of growth of both jaws. Dibbets[21] study of mandibular rotation and lower face height indicators concluded that condylar endochondral tissue production results in 50 to 97 percent of mandibular growth. Counterbalancing rotation indeed must therefore be considered a mechanism capable of neutralizing condylar incremental growth and resultant clinical implications. Finally, Baumrind et al[22] examined mandibular remodelling measured on cephalograms by examining osseous changes relative to superimposition on metallic implants. A total of 31 patients with metallic implants, between the ages of 8.5-15.5 were monitored annually. Their results revealed that mean displacement at the condyle was larger than that at any other landmark. In the cases examined, horizontal displacement of the condyle extended from 7.3mm posterior to 3.4mm anterior. The range was similar in the vertical direction, represented by a 10mm difference. These results were similar in magnitude and direction to the observations of Bjork[17,18] indicating the variability of mandibular growth rotation amongst individuals.

Although Bjork and his colleagues identified important growth information through the implant studies, other researchers have attempted to rationalize mandibular growth through mathematical or geometrical theories. Moss[23,24] described rotational growth of the mandible as a logarithmic spiral. He fixed small lead markers to skulls of American Indians who died at various ages. The markers were attached at the locations of the foramen ovale, mandibular foramen, and mental foramen. Moss determined that the foramina were situated on a single curve or a logarithmic spiral. He postulated that as growth occurs, the foramina separate and the mandible assumes a position where there is less curvature of the spiral. Moss concluded that mandibular growth results in the mandible changing in size while maintaining the same shape with a rotation of the spiral.

Ricketts[25] agreed with the concept that mandibular growth includes rotation, and developed a method to determine the arc of growth of the mandible which he derived through a series of longitudinal cephalometric records. He named his theory the Principle of Arcial Growth. The essence of his principal was; a normal human mandible grows by superior-anterior vertical apposition at the ramus on a curve or arc. The radius of this circle is determined by using the distance from mental protuberance (Pm) to a point at the forking of the stress lines at the terminus of the oblique ridge of the medial side of the ramus. He believed that the discovery of an arc of a circle which, when extended and properly located, would permit the clinical projecting or forecasting of the natural growth of the normal mandible well within desirable clinical limits of accuracy. Ricketts accepted that the mandible must grow on an arc as it was shown to bend in form.

Mitchell et al[26] evaluated Rickett's method for predicting the form and size of the mandible, to determine the clinical reliability. Although their study only examined eight patients, they concluded that the arcial method appears valid for prediction of mandibular growth. They noted however, that orthodontists must be aware that the prediction method assumed the same rates of growth of the mandibles, irrespective of anatomic features.

There is no doubt that mandibular growth involves a certain degree of mandibular rotation.[17,18] Bjork and Skieller[27] defined total rotation of the mandible as internal rotation. The direction of internal rotation is determined by the amount of matrix rotation or rotation around the condyle and intramatrix rotation or rotation centred within the body of the mandible. The amount of rotation can vary amongst individuals ranging up to 10 to 15 degrees, and can result in an array of vertical and horizontal facial proportions.[28] It is the combination of matrix and intramatrix rotation along with influences from neuromuscular factors that determines the final growth pattern and resultant facial morphology.

1.6.3 - FACIAL MORPHOLOGY

To date, researchers have comprehensively studied dentofacial growth and developed theories to aid in the explanation of growth trends. Although genetics play a major role in determining the final facial outcome one must not ignore other factors which can influence mandibular growth. These may include, congenital defects, environmental influences at all stages of development, predisposing metabolic climate and disease as well as nutritional deficiencies and habits.[3,28] In addition, altered muscle function due to tongue position, adenoid or tonsil size and breathing mode,[29-31] as well as tooth contacts in excursive mandibular positions,[32] may influence mandibular growth magnitude, duration and direction. These factors can potentially have a direct affect on the resulting facial morphology.

In terms of categorizing or assessing facial morphology, a number of studies have established terminology to describe the most common facial forms. The facial complex is routinely examined in three planes of space, and it has become necessary to establish specific terminology of facial morphology in these different dimensions. Vertical dysplasias are defined as hyperdivergent and hypodivergent.[33,34] Ricketts[35] utilized facial categorisation of facial types in the transverse plane by defining the brachyfacial (wide), mesofacial (normal) and dolichofacial (narrow) facial morphological patterns. Sassouni[36] defined four basic facial types to identify individuals with vertical and anteroposterior disproportions. These included the skeletal deep-bite, skeletal open-bite, skeletal Class I and skeletal Class III malocclusion. Schendel[37] examined facial dysmorphology of patients exhibiting excessive vertical growth and developed the term long face syndrome. This term includes those patients who have typically been referred to as; extreme clockwise mandibular rotation, high angle type, adenoid faces, idiopathic long face, total maxillary alveolar hyperplasia and vertical maxillary excess.[36,38] Schendel also divided long face syndrome facial types into an openbite and non-openbite group. Opdebeeck[39] defined patients with reduced vertical facial growth as exhibiting a short face syndrome. These patients have been described as having a vertical maxillary deficiency, idiopathic short face, extreme counterclockwise mandibular rotation, low angle as well as a skeletal deep-bite.[36,38,40]

In 1964, Schudy,[34,40] one of the early pioneers to search for correlations between growth patterns and facial morphology, examined 270 individuals between the ages of 11 and 14 years, to assess correlations between various cephalometric measurements, facial height and facial morphology. He reported the occlusal to mandibular plane angle and S-N to mandibular plane angle were excellent indicators of facial type and that growth of the mandible was a principle determining factor of facial morphology. Implant studies by Bjork[17,18] and his colleagues revealed that the degree of mandibular growth and rotation has a direct affect on vertical facial proportions or esthetics. They concluded that a counter-clockwise rotating mandible could be associated with reduced or normal facial proportions and a clockwise rotating mandible could be associated with increased concavity of the lower mandibular border, increased osseous apposition inferior to the symphysis and facial features of the long face type.

A 1985 study by Sirwat and Jarabak[31] was successful in determining specific correlations between Angle class of malocclusion and vertical facial dimensions. The authors assessed 500 randomly selected orthodontic patients who ranged in age from eight to twelve and found that a neutral growth pattern was dominant in Class I and Class II Division I malocclusions. In addition, they noted that a hypodivergent pattern was dominant in Class II Division II as well as Class III malocclusions. The majority of females displayed a neutral growth pattern versus a hypodivergent pattern in males.

Within the last decade more and more emphasis has been placed on the role of tongue position, adenoid and tonsil size as well as breathing mode on the position of the mandible and resultant facial morphology. Linder-Aronson[29] examined children aged five to seven with nasopharyngeal obstruction. His research revealed that their growth direction was altered in a more horizontal direction following adenoidectomy. These results, however, were only statistically significant for the female patients in the study. The remainder of the patients initially displayed significantly longer lower face heights, steeper mandibular plane angles and more retrognathic mandibles as compared to the control group. Tourne[31] stated that typical dental and morphological characteristics of individuals with impairment of the nasopharyngeal airway mimic patients who exhibit long face syndrome. This led to further research to examine the effects on facial morphology with the elimination of nasopharyngeal impairment. Kerr et al[30] completed a five year follow-up study of 26 children treated for nasal obstruction by adenoidectomy. As a result of the surgical procedure, the children exhibited a changed breathing mode post-operatively. The results revealed a more anterior direction of symphyseal growth in the adenoidectomy group following surgery as well as some reversal of the initial tendency to a posterior rotation of the mandible.

With the growing interest in the clinical significance of the condyle-fossa relationship of the temporomandibular joint, the relationship between condylar morphology and various malocclusions has been examined. Previous investigations of condylar shape have demonstrated correlations between osseous changes, Angle Class of malocclusion and facial morphology.[42,43] Dibbets[42] reported that children with irregular condylar contours of the condyles at the start of orthodontic treatment had a typical cephalometric configuration with a steep mandibular plane, short mandibular corpus and consequently a retrognathic chin. As well, tomography has allowed condylar position within the glenoid fossa to be compared to Angles's classification of malocclusion. It has been published[44-47] that normal and abnormal joints display a variety of condyle positions and variable correlations have been demonstrated between anterior and posterior condylar positions in patients and specific malocclusions. An anterior or posterior condylar position within the fossa may have a direct affect on the anteroposterior and vertical position of the mandible, which would have a direct effect on facial morphology.

Orthodontists have been specifically interested in facial growth and development because of the potential malocclusions that may result. Cases with excessive vertical growth and clockwise mandibular rotation will result in the hypodivergent, steep mandibular plane facial pattern. This type of malocclusion continues to present itself as one of the most challenging orthodontic treatment situations. As well, cases with excessive growth patterns can have profound functional, esthetic and psychological effects on individuals. Further research is required to discover and understand the relationships between craniofacial characteristics and facial morphology.

1.6.4 - CONDYLAR MORPHOLOGY

One method to study specific characteristics of condylar shape, size, surface characteristics and macroscopic features has been through examination of autopsy materials. The purpose has been to establish morphological categorisation and apply the findings to aid in the understanding of Temporomandibular joint function and dysfunction. Yale et al[48], applied laminagraphic cephalometry to dry skull material in order to evaluate variation in mandibular condylar morphology. Their findings led them to conclude that a true roentgenographic image of the condyle could be produced. This observation led to further studies by Yale et al,[49,50] where they proceeded with descriptive epidemiological assessments of mandibular condyle types by providing a qualitative geometric description of the superior, anterior and posterior surfaces of the mandibular condyle. As well, they measured the direction and magnitude of horizontal and vertical condylar angles.

Oberg, Carlsson and Fajers,[51] visually recorded shapes of 115 condyles obtained from autopsy and suggested that joint contours may continue to change in response to tooth attrition or tooth loss throughout life. The sample included temporomandibular joints of subjects from birth to over 70 years of age. They determined that the TMJ increased in size until approximately the age of 20, particularly in the mediolateral width at which time the condylar cartilage has been almost entirely replaced by bone. On the average, they found that the mediolateral width was twice the size of the anteroposterior direction. Sagne[52] and Wedel et al,[53] continued examination of condylar dimensions by studying medieval skull material. They concluded that the anteroposterior dimension of condyles did not differ significantly with gender or age.

Hinton[54] adopted a historical approach by examining human skeletal samples dated from 800 AD to the early 20th century. The skulls were representative of a broad spectrum of subsistence practices and tooth use. He examined measurements relating to the size of mandibular condyles and fossae to aid in understanding potential variation in joint size. Considerable differences in joint size were noted among groups roughly consistent with known or presumed intensity of masticatory stress. As well, his results indicated that with the exception of condylar breadth, male joint dimensions were not relatively larger than females when corrected for differences in craniofacial size. It was concluded from this study that although the influence of genetic factors cannot be omitted, differences in the nature or intensity of tooth use during growth may account for the observed differences in joint size.

Pandis et al,[55] evaluated condyle position at various depths of cut in 50 dry skulls by means of submentovertex radiographs and axially corrected tomograms. The condyles were classified into four groups according to anterior surface and shape as viewed on the submentovertex radiograph. Their results indicated that 30 condyles were classified as having a flat anterior surface, 27 as convex, 19 as concave and 24 as triangular. Osborn,[56] confirmed the existence of joint size variation in his research measuring directions of joint forces on the mandible. As part of his experiment, 43 condyles were examined and their shape noted from the frontal plane. It was determined that shapes of the articular surfaces of the condyles observed on the dry skulls varied significantly.

It is obvious that numerous researchers have observed condylar variations and have searched for answers to rationalize the structural and gender variations between individuals. Common theories include adaptational responses to biomechanical forces and orofacial stimuli, adaptive responses to alteration in articular fit and function, correlation to the overall size of the cranium and face, and active growth periods potentially reflected by seasonal changes.[53,54,57]

In terms of condylar shape, the appearance of flattened condylar projections has sparked curiosity in research. Experimental evidence from animal studies has revealed that in the rat, elongated flattened condyles can be cultured which exhibit seasonal fluctuations.[58,59] Rats have demonstrated increased mitotic cell activity with a maximum number of divisions in May, and a minimum between November and January.

It was therefore hypothesized by Copray,[60] that certain elongated contours could reflect the dynamic growing condition. Dibbets et al[21,42]observed the appearance of flattened and elongated mandibular condyles in some patients as growth maintained the mandible in correct juxtaposition with the maxilla. They also noted that this condylar flattening was temporary and after a specific time period, the condylar contour regained its original shape. In 1991, Dibbets and van der Weele[57] also hypothesized, that flattened projections should be more prominent during a period of extra growth activity. After examining 161 adolescents between the age of eight to 15, their results suggested that condylar flattened projections in children exhibit seasonal variation and may possibly be interpreted as the reflection of a temporarily active growth vector.

Acceptance of scientific evidence that variations exist in condylar morphology, has prompted other researchers to conduct studies to determine if relationships exist between condylar morphology and various malocclusions. Dibbets et al[42] reported flattened or irregular condylar contours in 16 percent of pre-treatment orthodontic patients with various Angle classifications of malocclusions. The majority of flattened condyles assessed from transcranials, were noted in the Class II malocclusions which accounted for 69 percent of the sample size. This study also revealed that children with deformed appearance of the condyles at the start of orthodontic treatment had a typical cephalometric configuration with a steep mandibular plane, a short mandibular corpus and a retrognathic chin.

More recently, Peltola[43] examined panoramic radiographic characteristics in mandibular condyles of 625 orthodontic patients before treatment aged 4y-0m to 15y-9m. He noted that osseous changes of the condyle were only detected in 2.2 percent of the sample and associated with an Angle Class II molar malocclusion. This study, however, represented a larger age range and Peltola himself, states that the lower percentages of radiographic characteristics, as compared to the results of Dibbets et al[42], may be partly due to the different radiographic technique used.

It is apparent that more clarification is required regarding the correlation of condylar characteristics to horizontal and vertical growth patterns and resultant facial morphology. In addition, it is vitally critical to evaluate these features with specific attention to subjects age, their growth potential and the type of radiographic method employed.

1.6.5 - CONDYLAR POSITION

Technological advances have resulted in the development of a variety of imaging techniques to analyse the anatomical and spatial components of the temporomandibular joints. Availability of this information has allowed clinicians to improve their understanding of temporomandibular joint mechanisms and determine variations from normal to augment their clinical diagnosis. Condyle-disc-fossa and condyle-disc-eminence relationships have been analysed from a series of radiological techniques to aid in understanding temporomandibular dysfunction as well as examine joint relationships in various malocclusions. Numerous imaging techniques have been analysed over the years including panoramic and cephalometric radiography as well as transcranials, arthrography, tomography and magnetic resonance imaging. Panoramic radiographs have been criticized for their limited use for TMJ analysis, as only condylar versus temporal characteristics can be interpreted due to the rotational nature of the radiographic technique.[61] Although limitations of the panorex do exist, recent researchers feel that panoramic radiography can still be utilized for successful assessment of the condyles.[43,62]

Arthrography was first introduced in 1944 by Norgaard,[63] and although it is an invasive procedure, several researchers have utilized this technique to assess TMJ relationships. Katzberg et al,[64] examined condylar position in centric occlusion of subjects experiencing painful dysfunction of the TMJ as diagnosed by arthrography. Their condyle-fossa relationships were compared to normal or asymptomatic subjects and the results indicated that the groups did not differ by linear or area determinations of the posterior joint space to anterior joint space ratio. Katzberg et al, did not find a difference in condyle position between joints with confirmed disc displacement and arthrographically normal joints. Whereas, Westesson[65] identified posterior condyle positions in 18 of 45 patients arthrographically diagnosed as having anteriorly displaced discs.

Although transcranial radiography was very popular in verification of mandibular condyle position, it has been criticized by a number of researchers.[66,67] It has been faulted for displaying a two-dimensional view as well as being technique sensitive to standardize repeated imaging. As well, transcranials have been described as limited due to bony superimposition and a lack of detail. Tomograms have become more popular for TMJ imaging as they have been shown to correlate closely with the actual condyle position in histologic sectioned joint specimens.[68]

Pullinger and Hollender[69] completed a study to determine whether condyle position shown by transcranial radiographs differs from that shown by tomograms on the same temporomandibular joints. A total of 20 matched pairs of transcranials and tomograms collected from a temporomandibular disorder clinic were used for the purposes of the study. Their results revealed that the transcranial radiographs tended to exaggerate nonconcentricity of the condyle in 30 percent of the cases. They stated that although still clinically helpful, the use of transcranial radiographs to monitor small changes in condylar position relative to the tomogram was questionable.

Hatcher et al[70] concluded that pertinent information with respect to joint space analysis may be determined from conventional radiography. He states, however, that the most accurate representation is obtained from techniques that analyse the joint in three dimensions. To date, corrected tomography has become more widely used as a component of pre-treatment records and has been applied in assessing condylar position changes as a result of orthodontic treatment and various jaw relationships. Although the tomogram is currently popular, modern research and increased interest in determining the radiographic position of the TMJ disc, has resulted in increased use of magnetic resonance imaging.[71,72]

The growing interest in temporomandibular joint internal derangement and the continual controversy of the clinical significance of the condyle-fossa relationship in the TMJ has resulted in a number of condylar position studies. Condylar position has been evaluated by a number of measurement techniques[73-76] and is classified as either anteropositioned, concentric or retropositioned. Early studies by Ricketts[77] stated that in normal patients, the mandibular condyle is situated in a central position within the glenoid fossa and this led researchers to examine the ideal condyle-fossa relationships. Madsen[73] found that, in most individuals, the condyles were centred beneath the fossae, though he acknowledged that posterior and anterior condyle positions were also seen occasionally in normal subjects. Ismail and Rokni[78] investigated spatial differences in the condyle-to-fossa relationship when the mandible is in centric relation and centric occlusion positions. A total of 40 adult patients aged 20 to 30 years with Class I occlusions were examined. Their results indicated that in the centric relation position, both condyles were more posteriorly and superiorly positioned than in the centric occlusion position. As well, both condyles were symmetrically positioned in the fossa with equal spatial distances anteriorly and posteriorly in the centric occlusion position.

Blaschke and Blaschke[79] assessed normal TMJ bony relationships in centric occlusion of 50 adult, asymptomatic TMJ's. The results indicated that although the condyles were centred in the fossa in most cases, the condyles assumed varying positions between the left and right joints in the centric occlusion position. Pullinger[80] conducted a tomographic study of mandibular condyle position in an asymptomatic population to clarify the controversy concerning the clinical significance of the condyle-fossa relationship in the TMJ. His purpose was to estimate the linear tomographic variability of normal condyle position in clinically asymptomatic young adults who had no history of orthodontic or occlusal treatment. Radiographically concentric condyles were found in 50-65 percent of subjects with a substantial range of variability. The distribution of nonconcentric condyles was significantly more anterior in men and more posterior in women.

More recently, Alexander[72] used articular mountings and magnetic resonance imaging to evaluate the existence of distinct jaw positions and the condyle-disc-fossa relationships in a symptom-free population. A total of 28 males aged 22 to 35 with an Angle Class I occlusion were examined. Condylar concentricity was observed in half of the group and it was shown to remain constant in centric occlusion as well as centric relation.

Once it was established that normal and abnormal joints could display a variety of condyle positions, researchers became interested in assessing condylar position in various Angle classifications. Questions were also raised regarding the relationship between occlusal factors and joint positions. Non-concentric condyle position has been associated with condylar displacement secondary to anterior disc displacement, deflective occlusal interferences in centric relation, loss of posterior occlusal support, tipping of lower molars, and severe vertical overlap of incisors.[81,82]

Pullinger[44] noted that in Class II, Division I malocclusions, the condyle is generally situated in a more anterior position. He examined tomograms of 44 young adults with varying malocclusions, screened from 253 students. Each individual had no history of orthodontic or occlusal therapy and no signs of masticatory dysfunction. Results revealed that 11 of 30 Class I cases were bilaterally concentric compared with one of ten cases for Class II, Division I malocclusion. In contrast, the condylar positions in the Class II, Division II cases were slightly retropositioned. Logsdon and Chaconas[45] also found condyles to be more anteriorly positioned in Class II cases, whereas Bacon et al[46] found the condyle was in a more retrusive position represented by an increased distance from Nasion to the condylar neck.

Recent research by Cohlmia et al,[47] examined tomograms of 232 orthodontic patients ranging in age from 9-4 to 42-6 years. The patients were classified into specific malocclusions according to Angle's classification. No significant differences in condylar position were detected between Class I and Class II malocclusions although, skeletal and dental Class II patients displayed more anteriorly positioned condyles.

It is interesting to note, that the information obtained from the above research projects depends upon the analysis of the bony structures viewed from a various radiographs. Pullinger et al[84] completed a study to examine the osseous architecture of the temporal component of 51 temporomandibular joints of young adults during autopsy. He was interested in examining histologic sections of the temporal components and assessing their relationship to articular soft tissue thickness and disc displacement. The results of his study suggest that the osseous contours seen on radiographs may not accurately predict the actual articular surface of the temporal component. It is obvious from this last statement, that this could question results of studies assessing joint dimensions. This may also suggest that radiographic techniques that examine hard and soft tissue components may be necessary.

1.6.6 - GROWTH PREDICTION

No other facial bone has undergone such complex analysis as the mandible in an attempt to determine its growth mechanisms. In order to understand the complexity and patterns of mandibular growth, numerous experimental methods have been employed, ranging from histologic studies[85] to implant studies.[17,18,26] The ability to accurately predict mandibular growth direction has been a controversial topic ever since it was advocated by Rickett's Arcial Growth Theory in 1957.[86] It was described as the addition of equal growth increments onto the existing facial pattern with continuation of growth along the existing direction. This followed the early beliefs of Brodie[87,88] that individual patterns of craniofacial growth are established at an early age and once attained, do not change. However, further research evidence suggested that individual growth patterns do, indeed, change with regard to both growth amount and growth direction and may vary according to race and gender.[89,90] The prevalence of growth patterns in non-equal and non-linear growth increments has concluded that growth prediction systems are necessary to predict mandibular growth.

Perhaps some of the most dramatic and enlightening research on mandibular growth and prediction has been completed by Bjork.[17,18,90] He concentrated on experimental design using the metallic implant method in the study of facial growth, with specific emphasis on prediction of mandibular growth rotation. In terms of growth prediction methods, Bjork examined the longitudinal, metric and structural basic systems which could be utilized. The longitudinal method consisted of following the course of development by annual radiographic cephalograms. Bjork noted the limited use of this method, as the remodelling process at the lower border of the mandible to a large extent, masks the actual rotation. He also reported that the metric method, which aims at prediction based on a metric description of the facial morphology at a single stage of development, has not proved to be of significant value. Finally, he presented a structural method in which it may be possible to predict, from a single cephalogram, the course of rotation, where a feature is marked. Thus, the commencement of numerous metallic implant studies followed.

Several additional growth predictive methods have been used in orthodontics which include growth templates and grids,[91,92] cephalometric measurements,[93-95] computerized growth forecasts,[96-97] genetic analysis,[98] as well as individualized prediction based on morphological characteristics.[99-101] Early attempts at mandibular growth prediction were based on the valuation of the craniofacial complex as assessed from a single cephalometric film. Measurements examined include Y-axis to SN,[93] mandibular plane angle,[93] facial axis,[95] anterior and posterior face height ratios and Jarabak's sum total based on the summation of three facial angles.[94] However, reliability of these characteristics, as accurate representatives of growth, has been questioned. Studies by Bjork[17] and Lulla and Gianelly[102] suggested that the mandibular plane angle cannot be regarded as an accurate representation of mandibular rotation. This has been supported by later research[103] indicating that individuals with high mandibular plane angles can still have both clockwise and counterclockwise mandibular growth patterns. In addition, the magnitude of mandibular growth rotation may not be truly represented as the lower border of the mandible is subject to bony remodelling changes with growth.

Other authors[104-106] have also shown that consistency of mandibular growth prediction is difficult from cephalometric measurements. Schmuth and Madre[104] assessed cephalograms of 870 patients to predict the direction of mandibular growth using Jarabak's Facial Height Ratio and the sum of the saddle, the articulare and the gonial angles. Their results indicated that no correlation was found between actual direction of growth and the size of the cephalometric Sum of Angles and Facial Height Ratio. However, one must emphasize that normal growth was not being observed within the study as all the patients were undergoing active orthodontic treatment. As well, patients ranged in age from 10 to over 20 years, indicating that patients were at different stages of growth and development. Hagg and Attstrom[106] stated that conventional cephalometric analysis may not be as reliable as traditionally envisaged, due to factors which could affect the estimates of mandibular growth. These may include, growth direction of the condyle, apposition of the bony symphysis as well as accuracy of superimposition techniques.

To date, several authors have concentrated on characteristics of mandibular morphology as potential parameters for mandibular growth prediction. Bjork's[18] implant studies revealed that a clockwise rotating mandible could be associated with increased concavity of the lower border of the mandible and increased apposition inferior to the symphysis. A counter-clockwise rotating mandible displayed an increased curvature of the mandibular canal and anterior inclination of the condylar head. Thompson and Popovich,[107] determined that a small gonial angle at an early age indicates a more horizontal growth pattern and a larger mandibular body length.

Singer et al,[99] examined the depth of the mandibular antegonial notch as an indicator of mandibular growth potential. This study comprised of 50 orthodontically treated patients, 25 with deep and 25 with shallow mandibular antegonial notching. Their results indicated that the clinical presence of a deep mandibular antegonial notch was indicative of a diminished mandibular growth potential and a vertically directed mandibular growth pattern. Deep notch cases had more retrusive mandibles with a shorter corpus, smaller ramus height, and a greater gonial angle than did shallow notch cases. The presence of a prominent mandibular antegonial notch has been a reported finding in subjects with disturbed or arrested growth of the mandibular condyles.[42,108] Similar results to those of Singer et al[99] were confirmed in recent research, examining craniofacial characteristics of 80 untreated patients with deep and shallow antegonial notches.[109]

Rossouw et al[100] proposed that the frontal sinus can be used to augment mandibular growth prediction methods. They cephalometrically analysed 103 adults with Class I and Class III malocclusions and compared the measurements to the surface area of the frontal sinus. Their findings indicated that a large frontal sinus may be correlated to vertical growers.

Ricketts[110] suggested that symphysis morphology could be used as a parameter for prediction of mandibular growth direction. This theory was supported by Aki et al[101] who examined the correlation between height and width dimensions of the mandibular symphysis and mandibular growth direction. Their analysis of cross-sectional data obtained from cephalometric radiographs of 115 adults indicated that symphysis ratio of height and depth was strongly related to the direction of mandibular growth in males. As well, a mandible with a posterior growth direction was significantly correlated to a symphysis with a large height, small depth and small angle to the mandibular plane.

The advent of computers has resulted in the development of computerized prediction systems to forecast growth. Ricketts[96] created a system which adds average incremental growth values on to a patient's existing facial dimensions. The incremental growth values are determined according to the patient's age, gender and racial group. Although computerized systems are quite efficient, they have been criticized for their inability to account for individual variability in growth as well as the influence of environmental and genetic factors.[98]

Thames et al[97] completed a study to test the accuracy of commercially available forecasting systems in predicting the effects of growth and orthodontic treatment on Class II high-angle cases. Hard and soft tissue landmarks from pre-treatment cephalograms of 33 patients, aged 8-14 years, with high mandibular plane angles were submitted for analysis. The computer-generated post-treatment predictions were compared to the actual post-treatment cephalograms, using linear and angular measurements. The computer was found to be accurate in predicting the effects of growth and treatment on maxillary position and rotation, mandibular length, upper face height, and incisor positions. It was found to be inaccurate in predicting the effects of growth and treatment on maxillary length, mandibular rotation, lower anterior and posterior face heights, the horizontal and vertical positions of the molars, and over 50 percent of the soft-tissue parameters.

It has been the aim of numerous researchers to study growth and development of the dentofacial complex to predict facial and treatment outcomes. This information would be vital in applying the most efficient orthodontic treatment modalities to enhance and modify the final functional and esthetic result. Although a number of researchers have provided commendable scientific information regarding mandibular growth prediction, it is evident that prediction is extremely difficult and unfortunately not completely accurate. It may, therefore be concluded, that further clinical and research investigation is warranted to gather additional information regarding the complicated yet fascinating role of mandibular growth in dentofacial morphology. Discovery of new and innovative growth prediction methods would be beneficial to augment the methods that currently exist.

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Chapter Two

First Research Study And Results

2.1 - INTRODUCTION

Orthodontists have been specifically interested in facial growth and development because of the potential dental and skeletal abnormalities that may result. Facial growth tends to proceed along a vector composed of variable amounts of horizontal and vertical growth as a result of, osseous development at facial sutures, alveolar processes, mandibular condyles as well as tooth eruption.[1] As the mandible articulates with the cranium, it is essential that proportionate growth be achieved between anterior and posterior face heights or excessive clockwise or counter-clockwise mandibular rotation may occur. Extreme cases of increased vertical growth and clockwise mandibular rotation will result in the hypodivergent, steep mandibular plane facial pattern. This type of malocclusion continues to present itself as one of the most challenging orthodontic treatment situations. Extreme growth patterns can have profound functional, esthetic and psychological effects on specific individuals. This has led to the continued quest to discover and understand the relationships between craniofacial growth patterns and the dentofacial morphologies that can result.

In terms of categorizing or assessing facial morphology, a number of studies have established terminology to describe the most common facial forms. Vertical dysplasias are defined as hyperdivergent and hypodivergent.[2,3] Ricketts[4] adapted anthropometric terms to categorize facial types in the transverse plane by defining brachyfacial (wide), mesofacial (normal) and dolichofacial (narrow) facial morphological patterns. Sassouni[5] defined four basic facial types to identify individuals with vertical and anteroposterior disproportions. These included the skeletal deep-bite, skeletal open-bite, skeletal Class I and skeletal Class III malocclusion. Schendel[6] examined facial dysmorphology of patients exhibiting excessive vertical growth and developed the term long face syndrome. This term includes those patients who have typically been referred to as; extreme clockwise mandibular rotation, high angle type, adenoid faces, idiopathic long face, total maxillary alveolar hyperplasia and vertical maxillary excess.[5,7] Opdebeeck[8] defined patients with reduced vertical facial growth as exhibiting a short face syndrome. These patients have been described as having a vertical maxillary deficiency, idiopathic short face, extreme counter-clockwise mandibular rotation, low angle as well as a skeletal deep-bite.[5,7,9]

Schudy,[3,10] was one of the early pioneers to search for correlations between morphological patterns and facial morphology. He examined 270 individuals between the ages of 11 and 14 years to assess correlations between various cephalometric measurements, facial height and facial morphology. He reported the occlusal to mandibular plane angle and S-N to mandibular plane angle were excellent indicators of facial type and that growth of the mandible was a principle determining factor of facial morphology. Bjork[11,12] and his colleagues became acutely aware of the importance of mandibular growth and rotation in facial development. Their numerous longitudinal implant studies revealed, that the amount of mandibular growth and rotation has a direct affect on vertical facial proportions or esthetics. They concluded that a counter-clockwise rotating mandible could be associated with reduced or normal facial proportions and a clockwise rotating mandible could be associated with increased concavity of the lower mandibular border, increased osseous apposition inferior to the symphysis and facial features of the long face type. A 1985 study by Sirwat and Jarabak[13] was successful in determining specific correlations between the Angle class of malocclusion and vertical facial dimensions. The authors assessed 500 randomly selected orthodontic patients who ranged in age from eight to twelve and found that a neutral growth pattern was dominant in Class I and Class II Division I malocclusions. In addition, they noted that a hypodivergent pattern was dominant in Class II Division II as well as Class III malocclusions. The majority of females displayed a neutral growth pattern versus a hypodivergent pattern in males.

Additional factors which influence craniofacial growth and the resultant facial morphology include: congenital defects; environmental influences at all stages of development; predisposing metabolic climate and disease; nutritional deficiencies and habits;[14,15] altered muscle function due to tongue position; adenoid and tonsil size and breathing mode;[16-18] and tooth contacts in excursive mandibular positions.[19]

With the increased interest in the clinical significance of the condyle-fossa relationship of the temporomandibular joint, the relationship between condylar morphology and various malocclusions has been examined. Previous investigations of condylar shape have demonstrated correlations between osseous changes and Angle Class of malocclusion and facial morphology.[20,21] Dibbets[20] reported that children with irregular condylar contours of the condyles at the start of orthodontic treatment had a typical cephalometric configuration with a steep mandibular plane, short mandibular corpus length and consequently a retrognathic chin. As well, alternate radiographic techniques have allowed condylar position within the glenoid fossa to be compared to Angles's classification of malocclusion. Normal and abnormal joints display a variety of condyle positions and variable correlations have been demonstrated between anterior and posterior condylar positions in patients and specific malocclusions.[22-25] An anterior or posterior condylar position within the fossa may have a direct affect on the anteroposterior and vertical position of the mandible. This in turn, could have a direct effect on facial morphology.

There is no doubt that a paucity of information exists on the morphological assessment of the dentofacial complex and the factors that may or may not contribute to its growth. Clarification is required regarding the relationship of temporomandibular joint morphology to specifics of craniofacial morphology. The need to examine the importance or meaning of various condylar characteristics to the horizontal or vertical facial growth patterns and the resultant facial morphologies is a high priority. It is important to evaluate these features with specific attention to subjects age and their

The purpose of this retrospective study was to determine the relationship between condylar characteristics measured from pre-orthodontic treatment tomograms of pre-adolescent, Class II patients and their vertical facial morphological pattern.

2.2 - MATERIALS AND METHODS

2.2.1 - Sample selection

The sample of convenience for this study consisted of pre-treatment lateral cephalograms and tomograms of 136 pre-adolescent patients obtained from the private practices of two Edmonton orthodontists. The criteria for patient selection were as follows:

1. Class II malocclusion with an ANB angle greater than 4.5 degrees.
2. Age range of 10-0 to 12-6 years for males and 9-0 to11-6 years for females.
3. Pre-orthodontic treatment lateral cephalogram and tomogram.
4. Facial growth in the vertical or horizontal direction, determined by satisfying a minimum of three of the five cephalometric measurements listed in Table 2-1.

The sample was divided into two groups with the vertical group consisting of 36 males and 32 females, with an average pre-treatment age of 11-0 years. The horizontal group also consisted of 29 males and 39 females, with an average pre-treatment age of 10-9 years. (Table 2-2)

2.2.2 - Radiographic Analysis

All radiographs were viewed, traced and measured by the same observer under standardized conditions. Each image was traced onto acetate overlays with a 0.3mm diameter lead pencil. Cephalometric and tomographic images were coded separately and cross referenced with identification codes to ensure randomization and blinding of the measurements and order of data collection.

Lateral cephalograms were taken by an Orthoceph 10* machine with a source-film distance of 60 inches and the patient's head placed in a standardized position. Tracings were digitized utilizing a digital converter and analyzed with

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*Siemens Electrical Medical Systems, 1180 Courtney Park Dr., Mississauga, Ont

OTP for windows* computer software.

Pre-treatment axially corrected tomograms (linear motion using an Axial Tome** unit or hypocycloidal motion using a Tomax*** unit), were taken of the right and left TMJ's in the sagittal plane. Prior to tomography, a submentovertex projection was used to correct for orientation of the condylar heads with respect to the midline and to calculate the depth of the cut. For the purpose of this research, 2mm thick, left and right central cuts with teeth in maximum intercuspation and lips in repose were analysed. Correction for magnification differences between the two tomograph machines was mathematically computed as part of data collection. For each tomograph, a total of eight tomographic measurements (left and right) were calculated and are described as follows:

1. Anterior, superior and posterior joint space - Joint space measurements were completed according to the format described by Kamelchuk et al.[36] (Figure 2-2)
2. Condylar head inclination and posterior condylar ramus inclination - A line representing the angle of the posterior border of the ramus was drawn from the ramus image on the tomographic tracing. A second line representing the anterior cant of the condylar head was also drawn. The condylar head and posterior condyle ramus inclination angle was determined by a third line perpendicular to the Frankfort horizontal plane of reference.[36] (Figure 2-3)
3. Condylar neck width - Condylar neck width was determined as the narrowest region of the condylar neck perpendicular to the ramus inclination.
4. Condylar surface area - The two-dimension cross-sectional surface area of

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*Pacific Coast Software, Inc., 11770 Bernardo Plaza., San Diego, CA, 92128

**AxialTome Corporation, San Carlos, CA, USA

***Incubation Industries Inc., 429 Easton Rd., Warrington, PA 18976 the condylar head was calculated for the area superior to the narrowest region of the condylar neck by means of a pen-grasp digitizer.(Mop-3*)

5. Condylar shape - Condylar shape was subjectively categorized as flat, convex, angled or concave. (Figure 2-4)

All linear measurements were completed with a Nikon Shadowgraph**.

2.2.3 - Statistical Analysis

Reliability of measurement techniques, landmark identification, tracing method and inter-rater reliability were statistically analysed prior to commencing the study. Ten randomly selected tomographs and lateral cephalograms were randomly traced five times on separate days. Resultant measurements on interval variables were averaged and tested for significance by means of an ANOVA F-test. A one-factor repeated measure model was fitted to each variable separately and significance values were set at $p < .05$. Reliability of nominal condylar characteristics (variables) was determined using an ANOVA model with significance level set at $p < .05$.

To identify 'best' predictors of vertical or horizontal facial morphology, a logistic discriminant analysis was used with significance level set at $p < .05$. Correct classification percentages were calculated for statistically significant variables using chi-square tests. Using the logistic regression model, predicted probabilities of the significant variables were computed. A cluster analysis was completed on the significant variables to form three clusters. Numerical ranges separating these clusters were then calculated. Chi-square tests to measure association between significant variables and facial morphology were computed. Significance level was set

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*Carl Zeiss Canada Ltd., 45 Valleybrook Dr., Don Mills, Ont, Canada

**Nippon Kogaku (USA) Inc., 111, 5th Ave, New York, NY, USA at $p < .05$. Finally, cross validation was completed on a random selection of the sample cases to verify the predictive value of the statistically significant variables.

2.3 - RESULTS

Statistical analysis was completed to determine reliability of measurement techniques, landmark identification, tracing method and inter-rater reliability. All of the cephalometric and tomographic measurements displayed p values > .05. This indicated that no significant variability was noted between tracings.

Significance levels of the condylar characteristics as predictors of vertical or horizontal facial morphology are listed in Table 2-3. Logistic discriminant analysis revealed the most significant variables to be left and right superior joint space (p-value .011 and .0185 respectively) as well as left and right condylar head inclination (p-value .0111 and .0104 respectively). Results indicate that when the most significant variables were used as predictors, correct classification occurred in 65.44% of the cases. Correct classification with all 16 variables equalled 72.79%. Individual coefficients of specificity are listed in Table 2-4. No significant correlations between the other six condylar characteristics with facial morphology were reported.

Chi-square tests revealed significant associations between condylar head inclination, superior joint space measurements and vertical and horizontal facial morphology. (Table 2-5) Patients with vertical facial morphology displayed a high prevalence to posterior condylar head inclination. Conversely, patients in the horizontal group consistently displayed condylar head inclinations in the anterior direction. (Table 2-6) With respect to superior joint space, vertical patients displayed decreased joint spaces and horizontal patients increased measurements. (Table 2-7)

Cross validation using the four most significant variables as predictors from a random sample of Group 1 and 2 confirmed their reliability with a 64% correct classification rate. (Table 2-8) Percentage distribution of condylar shapes for the vertical and horizontal groups are listed in Table 2-9.

2.4 - DISCUSSION

The correlations obtained between condylar head inclination and facial morphology are consistent with results previously reported in early literature.[11,12] Posterior rotation of the condyles has been shown to dominate in individuals with the classic long face syndrome, and anterior inclination of the condylar head can be associated with counter-clockwise mandibular rotators.[26] It has also been reported in the literature that reduced condylar growth represents clockwise rotation of the mandible in relation to the cranial base.[27] Proliferation of condylar cartilage and endochondral ossification of the condyle occurs via a complex of biomechanical interactions. The magnitude, direction and duration of the resultant condylar growth may be influenced by genetic determinants as well as intrinsic and extrinsic control factors. Copray[28] stated that adaptability of the condylar cartilage cells to mechanical stimuli and pressure from the functional environment determine the ultimate condylar shape and set up the boundaries of condylar growth. In addition, pressure relief at the TMJ's can elicit cell activity and formation of new matrix. Animal studies have shown that mandibular protrusive appliances can result in increased chondrocytic proliferation and subsequent osseous development of the condyle in a posterior and posterosuperior direction.[29-33] The magnitude of the temporomandibular joint's adaptability and subsequent alteration will also be dependant upon maturational age, adaptive potential and neuromuscular function.

Facial proportions are determined by the interplay between anterior and posterior vertical and anteroposterior increments. Balance between condylar growth and the dentoalveolar processes act as an equalizing factor in producing normal occlusion and stable facial structures.[3,10] Findings of this study indicate that decreased superior joint spaces were consistent with Class II patients exhibiting a hyperdivergent tendency. Increased superior joints spaces were also consistent with Class II patients in the hypodivergent group. This suggests that patients exhibiting a vertical facial pattern may reflect a reduction in condylar soft tissue. Patients exhibiting reduced condylar tissues could represent reduced growth potential, minimal distraction within the glenoid fossa and therefore reduced superior joint spaces. As well, reduced condylar growth may allow increased development of anterior face height from growth of the nasomaxillary complex and dentoalveolar development. The result would be an imbalance in anterior and posterior face heights, decreased ramus height, clockwise rotation of the mandible and increased vertical development.

The reduced superior joint space noted in the patients with a vertical facial pattern, may also be representative of factors influencing joint space and spatial relationships. Joint space is occupied by the disc, disc attachments and articular soft tissues, which may structurally change throughout an individual's lifetime.[34,35] This may be due to remodelling and degenerative changes of the osseous and soft tissues, disc displacement with thinning of the posterior band, as well as postural positioning of the mandible.[35] Reduced superior joint spaces may suggest reduced condylar growth potential. However, it still remains to be determined if condylar growth and structural adaptations occur as a result of functional stimulation inherent within the joint or as a result of altered function of the dentofacial complex.

Analysis of the data was unable to establish significant correlations between condylar shape with Class II malocclusion. Dibbets et al[20] reported flattened or irregular condylar contours in 16 percent of pre-treatment orthodontic patients with Angle Class I , II and III malocclusions. The majority of flattened condyles assessed from transcranials, were noted in the Class II malocclusions which accounted for 69 percent of the sample size. Peltola[21] examined panoramic radiographic characteristics in mandibular condyles of 625 pre-orthodontic patients aged 4-0 to15-9 years with a mean age 11.4 years. He noted that osseous changes of the condyle were only associated with an Angle Class II molar malocclusion. His study, however, represented a larger age range and Peltola, stated that the lower percentages of radiographic characteristics, as compared to the results of Dibbets et al,[20] may be partly due to the different radiographic method employed.

In this study, 23.6 percent of adolescents with Class II malocclusions showed condylar flattening in the left condyle. Flattening of the right condyle was detected in 24.2 percent of the sample. The significance of flattening in these patients in not clear. Condylar shape categorized as flat, convex, angled or concave was not correlated with vertical facial morphology. Shape differences may represent normal individual variability or staging of development.

With respect to anteroposterior condylar position, no correlations to facial morphology were discovered. This is also in contrast to existing literature. Pullinger[22] noted that in Class II, Division I malocclusions, the condyle is generally situated in a more anterior position. He examined tomograms of 44 young adults with varying malocclusions, screened from 253 students. Each individual had no history of orthodontic or occlusal therapy and no objective signs of masticatory dysfunction. Results revealed that 11 of 30 Class I cases were bilaterally concentric compared with one of ten cases for Class II, Division I malocclusion. In contrast, the condylar positions in the Class II, Division II cases were slightly retropositioned. Logsdon and Chaconas[23] also found condyles to be more anteriorly positioned in Class II cases, whereas Bacon et al[24] found the condyle was in a more retrusive position represented by an increased distance from Nasion to the condylar neck.

Recent research by Cohlmia et al,[25] examined tomograms of 232 orthodontic patients ranging in age from 9-4 to 42-6 years. The patients were classified into specific malocclusions according to Angle's classification. No significant differences in condylar position were detected between Class I and Class II malocclusions although, skeletal and dental Class II patients displayed more anteriorly positioned condyles.

This study was unable to detect correlations between facial morphology and posterior ramus inclination, condylar surface area or condylar neck width. The variation in results from this study may be due in part to differences in selection criteria used amongst related studies. Groups with large age ranges were analysed in some cases, including temporomandibular joints with and without growth potential. This study classified patients as skeletal Class II not only in the anteroposterior plane but in the vertical direction as well. Lastly, all studies were not consistent with including or discluding patients with internal derangements.

Although this study contained a large sample size, it is not without limitations. Data was obtained by a single-examiner and inter-examiner reliability was not tested. Radiographic positioning errors were not specifically analyzed, although a study by Kamelchuk and Major[36] has shown that a ten degree rotation will not influence joint space measurements. Tomographs were only analysed from the central cut in the sagittal plane and it has been reported in the literature that joint dimensions are not consistent in the central, medial and lateral views of the joints.[35] Finally, condylar dimensions may be affected by such factors as normal development, seasonal growth, pathological or remodelling changes which could produce alterations in joint dimension.[37] Patients in this study were not screened for the presence or absence of temporomandibular dysfunction.

This study has shown a relationship between superior joint space and condylar head inclination with horizontal and vertical facial morphology in pre-adolescent patients. Extensions of this study would be beneficial to examine the post-treatment cephalograms of these patients which could assess the resultant growth and its effect on facial morphology and growth direction. By studying this data, it is hoped that the information obtained would allow orthodontists to recognize specific pre-adolescent condylar characteristics that are representative of growth patterns of the dentofacial complex. This early detection would be significant to practicioners as it would provide an additional diagnostic tool in determining the optimal treatment plan and potentially predicting treatment outcome for the difficult Class II orthodontic case.

2.5 - CONCLUSION

Condylar head inclination and superior joint space proved to be the most significantly correlated condylar characteristics to facial morphology. Patients with vertical facial morphology displayed decreased superior joint spaces and posteriorly angled condyles, whereas, patients with horizontal facial morphology demonstrated increased superior joint spaces and anteriorly angled condyles. No significant correlations between the other condylar characteristics and facial morphology were determined.

Table 2-1 Cephalometric Measurements for Determination of Vertical and Horizontal Groups

Cephalometric Measurment	Vertical	Horizontal
Y-Axis (SN to GN)	68 degrees or >	64 degrees or <
MP Angle (SN to Go-Me)	34 degrees or >	30 degrees or <
Facial Axis (Ba-N to Pt-Gn)	87 degrees or <	93 degrees or >
PFH:AFH Ratio (S-Go:N-Me)	62 or <	65 or >
Sum Total (N-S-Ar+S-Ar-Go+Ar-Go-Me)	403 degrees or >	394 degrees or <

Table 2-2 Sample (n & age)

Group	N-Male	N-Female	Mean Age / Range
Vertical	36	32	11y-0m (9y-0m to 12y-6m)
Horizontal	29	39	10y-9m (9y-6m to 12y-6m)

Table 2-3 P-values for Predictive Condylar Characteristics

Condylar Characteristic	Significance Level
AJS-Anterior Joint Space / Left	0.7601
AJS-Anterior Joint Space / Right	0.0951
SJS-Superior Joint Space / Left	0.0110
SJS-Superior Joint Space / Right	0.0185
PJS-Posterior Joint Space / Left	0.1286
PJS-Posterior Joint Space / Right	0.4729
CHI-Condylar Head Inclination / Left	0.0111
CHI-Condylar Head Inclination / Right	0.0104
PCRI-Posterior Condylar Ramus Inclination / Left	0.6431
PCRI-Posterior Condylar Ramus Inclination / Right	0.4921
CW- Condylar Neck Width / Left	0.9465
CW-Condylar Neck Width / Right	0.6371
CSA-Condylar Surface Area / Left	0.5455
CSA-Condylar Surface Area / Right	0.9649
CS-Condylar Shape / Left	0.0621
CS-Condylar Shape / Right	0.0821

Table 2-4 Specificity and Sensitivity Coefficients

Condylar Characteristic	Coef of Specificity	Coef of Sensitivity
SJS - Left	44.10%	48.50%
SJS - Right	42.60%	39.70%
CHI - Left	41.20%	44.10%
CHI - Right	45.60%	47.10%
4 Variables Combined	67.60%	63.20%
16 Variables Combined	72.10%	73.50%

Table 2-5 Significant Associations of Superior Joint Space and Condylar Head Inclination to Facial Morphology P < 0.05

Variable	P-Value	Measure of Association	Regression Coefficient
SJS - Left	0.0048	0.174	0.647
SJS - Right	0.0620	0.215	0.539
CHI - Left	0.0034	0.229	0.041
CHI - Right	0.0082	0.160	0.055

Table 2-6 Observations for Left and Right Condylar Head Inclination

Left TMJ

Group	Anterior	Posterior	Middle	Total
Vertical	12	28	28	68
Horizontal	30	20	18	68

Right TMJ

Group	Anterior	Posterior	Middle	Total
Vertical	15	31	22	68
Horizontal	32	22	14	68

Anterior - Numerical range representing anterior condylar head inclinations.
Posterior - Numerical range representing posterior condylar head inclinations.
Middle - Middle numerical range.

Table 2-7 Observations for Left and Right Superior Joint Space

Left TMJ

Group	Increased	Decreased	Middle	Total
Vertical	15	30	23	68
Horizontal	33	19	16	68

Right TMJ

Group	Increased	Decreased	Middle	Total
Vertical	17	29	22	68
Horizontal	27	17	24	68

Increased - Numerical range representing increased superior joint space.
Decreased - Numerical range representing decreased superior joint space.
Middle - Middle numerical range.

Table 2-8 Cross Validation Table Representing Percent Correct Classification Rate

Groups Assigned by Procedure

	Vertical	Horizontal	
Vertical	45	26	**Correct**
Horizontal	23	42	**Grouping**

N Correct in vertical group = 45
N Correct in horizontal group = 42
N Correct for total group = 87 (64% correct classification rate)

Table 2-9 Percentage Distribution of Condylar Shapes

Condylar Shape	Vertical N =68		Horizontal N =68		Total N =136	
	Left/Right Condyle		Left/Right Condyle		Left/Right Condyle	
Angled	23.5%	20.6%	16.2%	10.3%	19.9%	15.4%
Concave	2.9%	2.9%	2.9%	4.4%	2.9%	3.7%
Convex	70.6%	70.6%	76.5%	73.5%	73.5%	72.1%
Flat	2.9%	5.9%	4.4%	11.8%	3.7%	8.8%

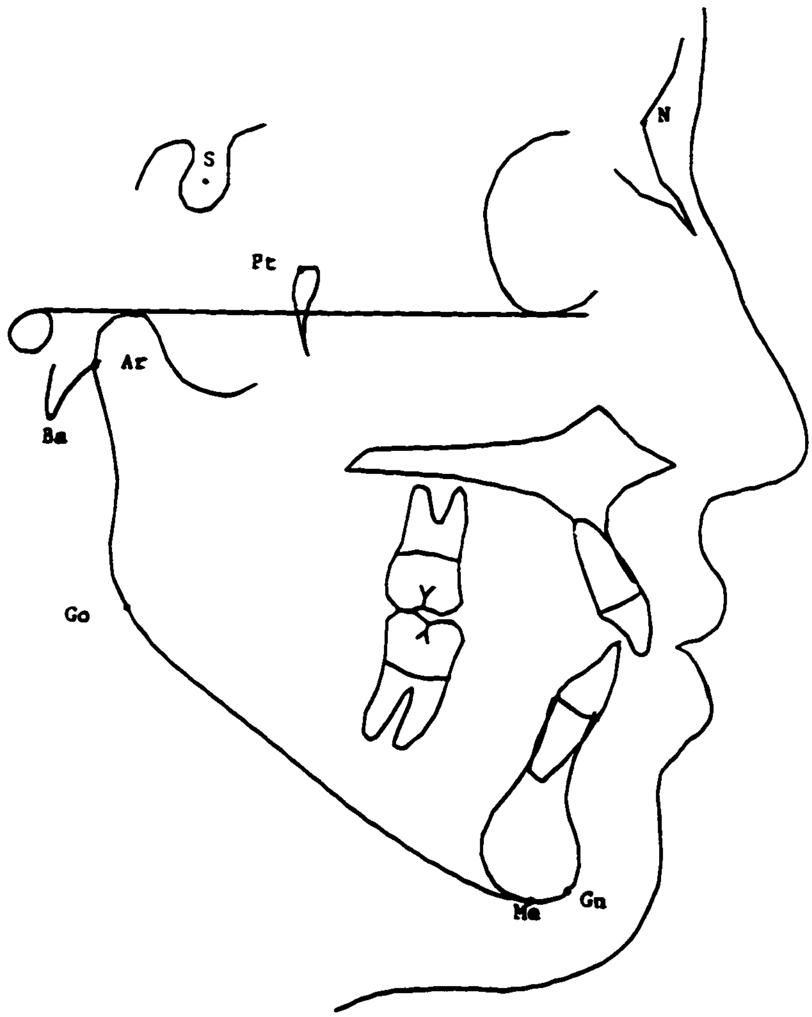

Figure 2-1 **Cephalometric landmarks. 1, Sella turcica (S). 2, Nasion (N). 3, Basion (Ba). 4, Articulare (Ar). 5, Ptertygomaxillary fissure (Pt). 6, Gonion (Go). 7, Menton (Me). 8, Gnathion (Gn).**

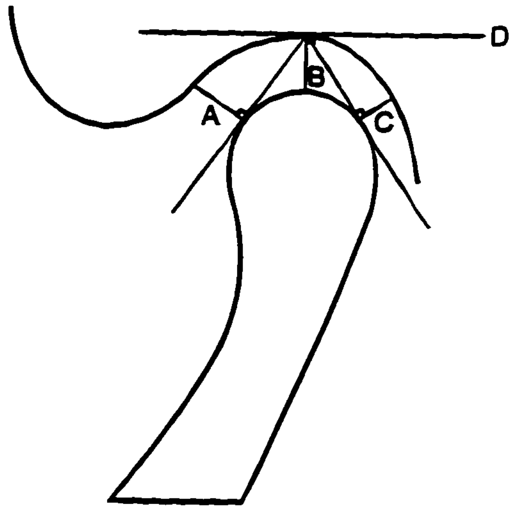

Figure 2-2 Joint space measurements from lateral tomographic acetate tracings. (A) Anterior joint space. (B) superior joint space. (C) posterior joint space, and (D) superior horizontal line parallels Frankfort Horizontal plane.

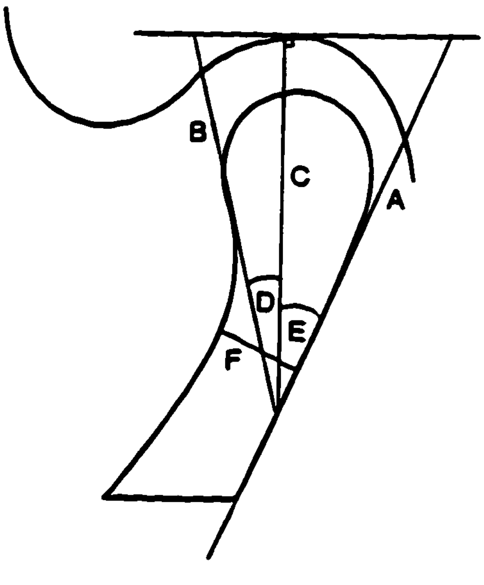

Figure 2-3 Condylar head inclination, posterior condylar ramus inclination and condylar neck width measurements. (A) Line representing the angle of the posterior border of the ramus. (B) line representing anterior cant of the condylar head, (C) line perpendicular to Frankfort horizontal plane of reference, (D) condylar head inclination angle, (E) posterior condylar ramus inclination angle, and (F) condylar width.

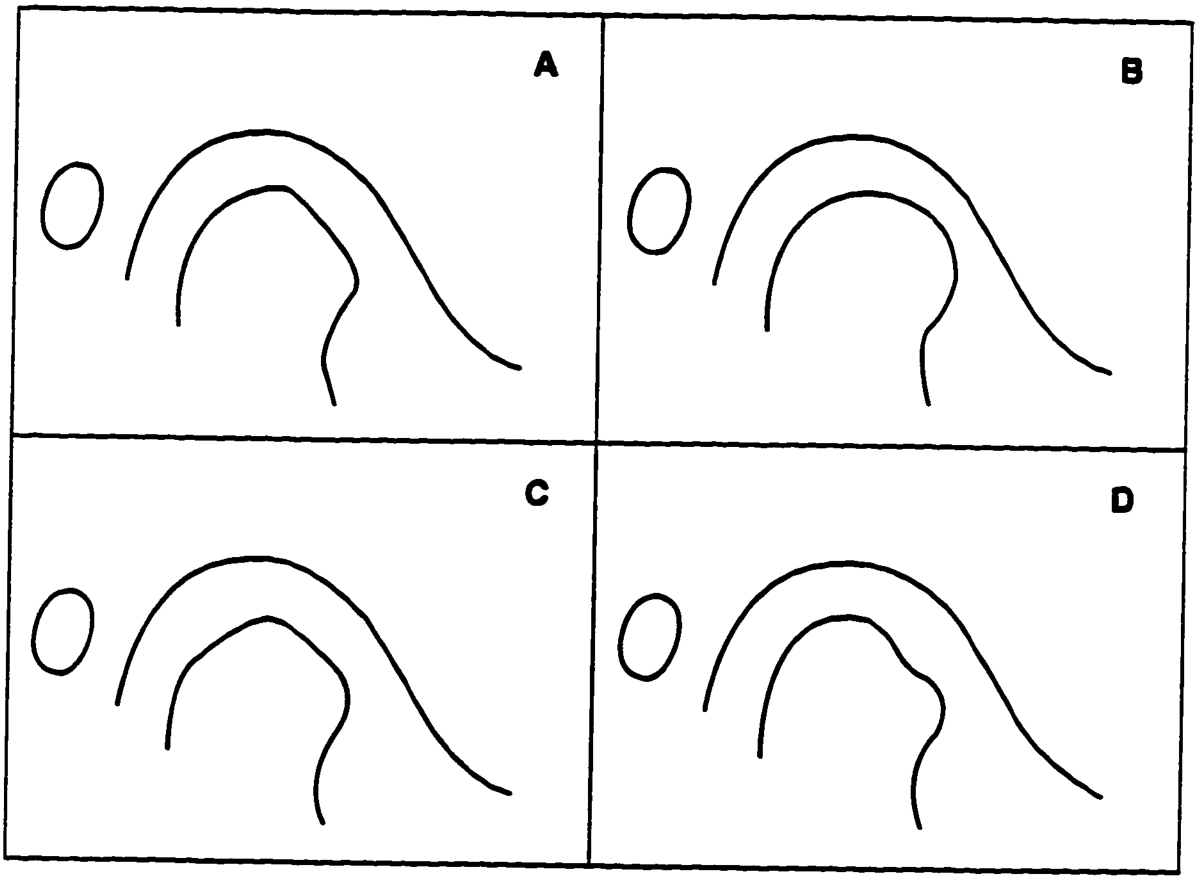

Figure 2-4 Condylar shapes assessed from lateral tomograms. (A) Flat, (B) convex, (C) angled, and (D) concave.

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Chapter Three

Second Research Study And Results

3.1 - INTRODUCTION

Success of orthodontic treatment is determined by the final esthetics, function and stability of the result. In order to achieve this goal, the initial diagnostic process becomes critical in recognizing the factors which may influence the final orthodontic treatment outcome. Although growth of the entire dentofacial complex contributes to development of the skeletal and dental pattern, the role of mandibular growth has especially intrigued practicioners because of its variability and relative unpredictability. No other facial bone has undergone as complex analysis as the mandible in an attempt to determine its growth mechanisms. Bishara and Jakobsen[1] longitudinally and cross-sectionally compared the dentofacial relationships of 35 individuals between 5 and 25.5 years of age, with long, average and short facial types Their findings revealed that approximately 77 percent of the sample maintained the same facial type and growth pattern at the age 25 as they did at the early age of 5. The recognition that considerable individual variation in craniofacial growth may occur in the remaining 23 percent, is what continues to perplex and become occasionally troublesome to the orthodontist. Knowledge of mandibular growth along with accurate growth prediction of potential abnormal mandibular development would obviously enhance treatment planning. It would also aid in predicting treatment outcomes as well as the stability of the orthodontic result during the retention and post-retention period.[2]

Prediction of mandibular growth direction was strongly advocated by Rickett's Arcial Growth Theory in 1957.[3] It was described as the addition of equal growth increments onto the existing facial pattern with continuation of growth along the existing direction. This followed the early beliefs of Brodie[4,5] that individual patterns of craniofacial growth are established at an early age and once attained, do not change. However, further research evidence suggested that individual growth patterns do, indeed, change with regard to both growth amount and growth direction and may vary according to race and gender.[6,7]

Several growth predictive methods have been used in orthodontics which include growth templates and grids,[8,9] cephalometric measurements,[10-12] computerized growth forecasts,[13,14] genetic analysis,[15] as well as individualized prediction based on morphological characteristics.[16-18] Early attempts at mandibular growth prediction were based on the valuation of the craniofacial complex as assessed from a single cephalometric film. Measurements examined include Y-axis to SN,[10] mandibular plane angle,[10] facial axis,[12] anterior and posterior face height ratios and Jarabak's sum total based on the summation of three facial angles.[11] However, reliability of these characteristics as accurate representatives of growth has been questioned.[19-23] Studies by Bjork[24] and Lulla and Gianelly[19] suggested that the mandibular plane angle cannot be regarded as an accurate representation of mandibular rotation. This has been supported by later research[20] indicating that individuals with high mandibular plane angles can still have both clockwise and counter-clockwise mandibular growth patterns. In addition, the magnitude of mandibular growth rotation may not be truly represented as the lower border of the mandible is subject to bony remodelling changes with growth.

Hagg and Attstrom[23] stated that conventional cephalometric analysis may not be as reliable as traditionally envisaged, due to factors which could affect the estimates of mandibular growth. These may include, growth direction of the condyle, apposition at the bony symphysis as well as accuracy of superimposition techniques.

To date, several authors have concentrated on characteristics of mandibular morphology as potential parameters for mandibular growth prediction. Bjork's[24] implant studies revealed that a clockwise rotating mandible could be associated with increased concavity of the lower border of the mandible and increased apposition inferior to the symphysis. A counter-clockwise rotating mandible displayed an increased curvature of the mandibular canal and anterior inclination of the condylar head. Thompson and Popovich,[25] determined that a small gonial angle at an early age indicates a more horizontal growth pattern and a larger mandibular body length.

Additional craniofacial characteristics which have been correlated to mandibular growth patterns include the depth of the antegonial notch,[16,26] the frontal sinus,[17] the mandibular symphysis,[27] and condylar characteristics.[28] Recent research by Burke et al[28] examined the relationship between condylar characteristics measured from tomograms and facial morphology. The sample consisted of 136 pre-adolescent patients displaying either a vertical or horizontal growth tendency. Their findings indicated that superior joint space dimensions and condylar head inclination were significantly correlated to craniofacial morphology. They noted that pre-orthodontic treatment patients with vertical facial morphology displayed decreased superior joint spaces and posteriorly angled condyles. The reverse was true for the patients with a horizontal growth pattern.

Although growth of the craniofacial complex contributes to the final facial pattern, various orthodontic treatment modalities can alter the dental and skeletal response. The use of extraoral traction in Class II patients to produce various orthodontic and orthopedic changes is a common treatment practice.[29] It has been reported that cervical headgear can produce side effects such as tipping and significant extrusion of teeth.[30,31] As well, forces produced by the highpull headgear may result in distal movement of teeth and intrusion.[32,33] These type of results have led many orthodontists to use cervical and highpull headgear in patients displaying horizontal and vertical growth tendencies respectively, in order to reduce detrimental effects on vertical dimension and mandibular rotation. However, a study completed by Baumrind et al,[31] examining headgear effects on 249 Class II patients, reported that all of the extraoral traction appliances produced a slight increase in the mandibular plane angle. They also noted that this increase was not statistically significant between the treated groups. It is the interaction of the skeletal complex to growth and treatment modalities which ultimately creates the final treatment outcome. This result may be altered depending on the type of headgear as well as the patient's compliance, duration of wear, amount and direction of force.

Numerous researchers have studied the combined effects of growth and orthodontic treatment on the dentofacial complex to predict treatment outcomes. This information would be vital in applying the most efficient orthodontic treatment modalities to enhance and modify the final functional and esthetic result. Although a number of researchers have provided commendable scientific information regarding mandibular growth prediction, it is evident that prediction is extremely difficult and, unfortunately, not completely accurate. It may be concluded, that further clinical and research investigation is warranted to gather additional information regarding the complicated mandibular growth associated with dentofacial morphology. Discovery of new and innovative methods to predict treatment outcomes would be beneficial to support the methods that currently exist.

The purpose of this retrospective study was to determine if the pre-treatment values of superior joint space and condylar head inclination could predict mandibular growth response in vertical and horizontal Class II patients, treated with high pull and cervical pull headgear respectively.

3.2 - MATERIALS AND METHODS

3.2.1 - Sample selection

The sample for this study consisted of pre-treatment lateral cephalograms and tomograms of 43 pre-adolescent patients obtained from the private practices of two Edmonton orthodontists. The criteria for patient selection were as follows:

1. Class II malocclusion with an ANB angle greater than 4.5 degrees.
2. Age range of 10y-0m to 12y-6m years for males and 9y-0m to 11y-6m years for females.
3. Pre-orthodontic treatment lateral cephalogram and tomogram.
4. Post-treatment lateral cephalogram.
5. Facial growth in the vertical or horizontal direction, determined by satisfying a minimum of three of the five cephalometric measurements listed in Table 3-1.
6. Patients were treated with fixed edgewise orthodontics and were treated non-surgically.
7. Vertical growth and horizontal growth patients were treated with high-pull and cervical extra-oral traction respectively as part of the orthodontic treatment plan.

The sample was divided into two groups with the vertical group consisting of 14 males and eight females, with an average pre-treatment age of 11y-1m and an average treatment time of 29 months. The horizontal group consisted of 10 males and 11 females, with an average pre-treatment 11y-0m and an average treatment time of 31 months. (Table 3-2)

3.2.2 - Radiographic Analysis

All radiographs were viewed, traced and measured by the same observer under standardized conditions. Each image was traced onto acetate overlays with a 0.3mm diameter lead pencil. Cephalometric and tomographic images were coded separately and cross referenced with identification codes to ensure randomization and blinding of the measurements and order of data collection.

Lateral cephalograms were taken by an Orthoceph 10* machine with a source-film distance of 60 inches and the patient's head placed in a standardized position. Tracings were digitized utilizing a digital converter and analysed with OTP for Windows**computer software. For each cephalogram, a total of ten cephalometric measurements (left and right) were calculated and are listed in Table 3-3.

Pre-treatment axially corrected screening tomograms (linear motion using an Axial Tome*** unit or hypocycloidal motion using a Tomax**** unit), were taken of the right and left TMJ's in the sagittal plane. Prior to tomography, a submentovertex projection was used to correct for orientation of the condylar heads with respect to the midline and to calculate the depth of the cut. For the purpose of this research, 2mm thick, left and right central condylar cuts with teeth in maximum intercuspation and lips in repose were analysed. Correction for magnification differences between the two tomograph machines was mathematically computed as part of data collection. For each tomograph, a total of eight tomographic measurements (left and right) were calculated and are described as follows:

1. Anterior, superior and posterior joint space - Joint space measurements were completed according to the format described by Kamelchuk et al.[34] (Figure 2-2)
2. Condylar head inclination and posterior condylar ramus inclination - A line representing the angle of the posterior border of the ramus was drawn from the ramus image on the tomographic tracing. A second line representing

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*Siemens Electrical Medical Systems, 1180 Courtney Park Dr., Mississauga, Ont, Canada

**Pacific Coast Software, Inc., 11770 Bernardo Plaza., San Diego, CA, 92128

***AxialTome Corporation, San Carlos, CA, USA

****Incubation Industries Inc., 429 Easton Rd., Warrington, PA 18976 the anterior cant of the condylar head was also drawn. The condylar head and posterior condyle ramus inclination angle was determined by a third line perpendicular to the Frankfort horizontal plane of reference.[34] (Figure 2-3)

3. Condylar neck width - Condylar neck width was determined as the narrowest region of the condylar neck perpendicular to the ramus inclination.
4. Condylar surface area - A pen-grasp digitizer(Mop-3*) was used to calculate the two-dimension cross-sectional surface area of the condylar head. This area was represented by the area superior to the narrowest region of the condylar neck.
5. Condylar shape - Condylar shape was subjectively categorized as flat, convex, angled or concave. (Figure 2-4)

All linear measurements were completed with a Nikon Shadowgraph**.

3.2.3 - Statistical Analysis

Reliability of measurement techniques, landmark identification, tracing method and inter-rater reliability were statistically analysed prior to commencing the study. Ten randomly selected tomographs and lateral cephalograms were randomly traced five times on separate days. Resultant measurements on interval variables were averaged and tested for significance by means of an ANOVA F-test. A one-factor repeated measure model was fitted to each variable separately and significance values were set at $p < .05$. Reliability of nominal condylar characteristics (variables) was determined using an ANOVA model with significance level set at $p < .05$.

Relative rate of change from pre-treatment to post-treatment cephalometric values

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*Carl Zeiss Canada Ltd., 45 Valleybrook Dr., Don Mills, Ont, Canada

**Nippon Kogaku (USA) Inc., 111, 5th Ave, New York, NY, USA for every individual in the vertical and horizontal group, were computed by using the following formula:

$$\frac{\text{Pre-treatment - Post-treatment}}{\text{Pre-treatment}} = \text{Relative rate of change}$$

Using these values as dependent variables for all cephalometric values, a regression analysis was performed for each group. Independent variables were the condylar characteristics, superior joint space and condylar head inclination. The purpose of the regression analysis was to identify tomographic characteristics which were the 'best' predictors of the significant cephalometric mean changes. The significance level was set at $p < .05$.

3.3 - RESULTS

Statistical analysis was completed to determine reliability of measurement techniques, landmark identification, tracing method and inter-rater reliability. All of the cephalometric and tomographic measurements displayed p values > .05. This indicated that no significant variability was noted between tracings.

Table 3-4 to 3-7 lists the regression coefficient (RC) estimates for the tomographic characteristics and respective p-values based on linear regression analysis, completed on pre and post-treatment cephalometric differences. A significant positive value regression coefficient implies a positive association between the cephalometric measurement differences and corresponding tomographic characteristic. A significant negative value regression coefficient indicates a negative or opposite association.

In the horizontal group a positive association between condylar head inclination of the right TMJ and facial axis was identified. (RC = .00249, p-value = .038) Regression analysis determined that the left and right superior joint spaces and condylar head inclinations were not valid predictors of the remaining cephalometric changes for subjects in the horizontal group.

Regression analysis determined a greater number of associations between condylar characteristics and cephalometric changes in the vertical group. For the left TMJ a negative regression coefficient was computed for condylar head inclination and the significant change in ramus height. (RC = -.00832, p-value = .021).

The right TMJ revealed positive associations between superior joint space and significant changes in ramus height (RC = .1143, p-value = .001), SNB angle (RC = .03272, p-value = .01), and anterior to posterior face height ratio (RC = .05521, p-value = .01). A negative regression coefficient was computed between superior joint space and the change in sum total. (RC = -.00778, p-value = .04)

Relative rate of change from pre-treatment to post-treatment cephalometric values individuals in the vertical and horizontal group are listed in tables 3-8 and 3-9.

3.4 - DISCUSSION

Structural and positional characteristics of the temporomandibular joint are important considerations in the evaluation of orthodontic patients. Previous studies have examined the relationship of condylar position to facial morphology as well as the changes in condylar position which occur as a result of various orthodontic treatment procedures.

This study was designed to assess the predictive value of TMJ superior joint space and condylar head inclination measurements in orthodontic treatment outcome, of horizontal and vertical developing Class II malocclusions. It has been generally accepted in orthodontics that highpull headgear is utilized in vertical growth cases and cervical headgear in horizontal growth cases.[29] Successful treatment outcome in the context of this study, represents normalization of the facial pattern so that the severity of deviation from cephalometric values representing neutral facial proportions would be reduced. Unsuccessful treatment would occur if vertical cases experienced increases in Y-axis, mandibular plane angle, sum total, SNB angle and gonial angle; decreases in facial axis and S-Go:N-Me; or reduced ramus growth. Successful treatment in vertical cases, would be represented by the opposite reaction of the aforementioned factors.

The results of this study should be interpreted with caution, but there does appear to be trends which warrant further study. A regression analysis was performed to determine if the pre-treatment tomographic measurements of superior joint space and condylar head inclination could identify the differences between the pre and post-treatment cephalometric measurements.

In the horizontal group, condylar head inclination in the right joint was the only variable to be significantly associated with a change in facial axis. The positive regression coefficient implied a positive association. This indicated that an anterior condylar head inclination prior to treatment was predictive of an increase in the facial axis or a more horizontal growth pattern. As well, a more posterior condylar head inclination could be associated with a decrease in facial axis or vertical growth tendency. Analysis of the 0.0 relative rate of change, indicates that it is not possible to relate the condylar head inclination to the direction of facial axis change. However, the minimum and maximum values suggest that changes occurred in the horizontal and vertical direction. Superior joint space and condylar head inclination did not meet P = .05 significance level for predicting changes in the remaining nine cephalometric measurements for the horizontal group. Statistical results for the horizontal group indicate that favourable or unfavourable treatment outcomes of patients treated with cervical headgear cannot be determined from this sample.

In the vertical group condylar head inclination of the left joint was only associated with a significant change in ramus height. The negative regression coefficient and the relative rate of change indicated that a posterior condylar head inclination was predictive of an increase in ramal growth for the vertical patients treated with highpull headgear. In the context of neutralizing the pre-treatment pattern, this represents a favourable outcome. Previous research has[1,2,16] correlated condylar head inclination dimensions to facial morphology. Anterior condylar head inclination and posterior head inclination have been correlated to individuals displaying a horizontal and vertical pattern of growth respectively. In this study posterior condylar head inclination was correlated to patients with a pre-treatment vertical growth tendency.

The superior joint space measurements of the right joint was the most predictive of the significant cephalometric changes in the vertical group. According to the regression coefficients and relative rates of change, an increased superior joint space was correlated with an increase in S-Go:N-Me, SNB and ramus height. Superior joint space was also correlated with a change in sum total, however, the zero relative rate of change could not confirm the direction of change. The above results indicate that the increase in ramus height and S-Go:N-Me are suggestive of horizontal growth in the vertical group. An increase in SNB may suggest clockwise rotation of the mandible. It can be suggest that in this study increased superior joint space was able to predict the increase in ramus height and S-Go:N-Me, indicating counter-clockwise growth or a favourable growth tendency. Previous research[16] has correlated increased superior joint spaces to patients exhibiting a horizontal or counterclockwise facial pattern. Therefore, this study suggests that patients with vertical growth tendencies and increased superior joint spaces may respond favourably to treatment with highpull headgear.

Since this report represents the first attempt to assess the predictive capabilities of condylar characteristics to mandibular treatment response, there is no other data in which to compare the statistical findings of this study.

Findings of this study indicate differences in the predictive capability of tomographic characteristics in the left and right joint. These differences may be attributed to individual anatomical variability, facial asymmetry, radiographic positioning or stage of development. Patients in this study were not screened for any of the aforementioned joint differences, therefore, caution is recommended in interpreting the results of this study.

The results of this study may be due in part to the intraoral orthodontic treatment procedures that the patients received. Sample selection did not take into consideration intraoral treatment modalities which could have an affect on vertical dimension. Growth direction may have been influenced by intermaxillary elastics,[29] as well as extraction versus non-extraction treatment.

There are opposing views[36-39] to the effects of extraction and non-extraction orthodontic treatment on facial dimensions. Earlier research[36,37] has indicated that extraction treatment allows forward movement of the posterior teeth and a resultant reduction in the vertical dimension. More recent research by Chua et al,[38] compared mandibular positional changes in Class I and Class II extraction and non-extraction cases and found that extraction treatment did not result in changes within the lower anterior face height of the sample. Non-extraction treatment did however, result in a downward and backward rotation of the mandible and an increase in lower anterior face height. Stagger[39] examined extraction and non-extraction treatment effects in Class I malocclusions and determined that cephalometric vertical dimensions were increased in both sample groups. One can conclude from the above literature that it is still controversial as to whether extraction pattern may have influenced this study's results.

This study was unable to compare treatment effects in the horizontal and vertical group to a non-treatment control group. This was due to the lack of subjects who have received both tomograms and cephalograms without orthodontic treatment. Further research is therefore, necessary to analyse the specific effects of cervical and highpull headgear on the mandibular growth response and its correlation to the pre-treatment facial pattern.

Sample size used in this study is small and therefore contributes to the limitations of this study. Data was obtained by a single-examiner and inter-examiner reliability was not tested. Radiographic positioning errors were not specifically analyzed, although a study by Kamelchuk et al[34] has shown that a ten degree rotation will not influence joint space measurements. Tomographs were only analysed from the central cut in the sagittal plane and it has been reported in the literature that joint dimensions are not consistent in the central, medial and lateral views of the joints.[40] Patients in this study were not screened for the presence or absence of temporomandibular dysfunction.

This study has shown that tomographic measurements of superior joint space and condylar head inclination were able to predict various post-treatment mandibular growth responses in Class II patients. Further research is necessary, to analyse the effects of cervical and highpull headgear on the mandibular growth response to orthodontic treatment and its correlation to the pre-treatment determination of facial pattern. This study should be repeated with a larger sample size and with more attention to the actual orthodontic treatment procedures performed. As well, a control group is necessary to compare normal growth to the effects of the extraoral traction.

A reliable method to predict orthodontic treatment outcomes would be of enormous clinical value to orthodontist. Accurate growth prediction would allow orthodontists to identify Class II malocclusions which will respond favourably to orthopedic growth modification and those best managed later with orthognathic surgery. Early detection of adverse growth potential would allow the orthodontist to initiate corrective measures which could reduce unnecessary treatment, minimize treatment time and reduce costs.

3.5 - CONCLUSION

Condylar head inclination and superior joint space were unable to predict treatment outcomes of patients treated with cervical headgear and displaying a pre-treatment horizontal growth pattern. This study suggests that posterior condylar head inclination and increased superior joint space were able to predict a counter-clockwise growth tendency or favourable treatment outcome, in the vertical group treated with highpull headgear.

Table 3-1 Cephalometric Measurements for Determination of Vertical and Horizontal Groups

Cephalometric Measurment	Vertical	Horizontal
Y-Axis (SN to GN)	68 degrees or >	64 degrees or <
MP Angle (SN to Go-Me)	34 degrees or >	30 degrees or <
Facial Axis (Ba-N to Pt-Gn)	87 degrees or <	93 degrees or >
PFH:AFH Ratio (S-Go:N-Me)	62 or <	65 or >
Sum Total (N-S-Ar+S-Ar-Go+Ar-Go-Me)	403 degrees or >	394 degrees or <

Table 3-2 Sample (n & age)

Group	N - Male	N - Female	Mean Age / Range
Vertical	14	8	11y-1m (9y-9m to 12y-6m)
Horizontal	10	11	10y-10m (9y-6m to 12y-6m)

Table 3-3 Cephalometric Measurments Obtained from Cephalograms

Cephalometric Measurement
Y-Axis (degree)
MP Angle (degree)
Facial Axis (degree)
S-Go:N-Me (%)
Sum Total (mm)
Ramus Height (mm)
Corpus Length (mm)
SNB (degree)
N-Go-Ar (degree)
N-Go-Ar (degree)

Table 3-4 Regression Coefficients (RC) and P-Values of Condylar Head Inclination as a Predictor in the Horizontal Group

Variable	TMJ	Tomographic Characteristic	RC	P-value
Y-Axis	Left	Condylar Head Inclination	-0.00075	0.627
Y-Axis	Right	Condylar Head Inclination	-0.00074	0.627
MP Angle	Left	Condylar Head Inclination	0.00476	0.370
MP Angle	Right	Condylar Head Inclination	0.00608	0.249
Facial Axis	Left	Condylar Head Inclination	0.00230	0.069
Facial Axis	Right	Condylar Head Inclination	0.00249	*0.038
S-Go:N-Me	Left	Condylar Head Inclination	-0.00066	0.711
S-Go:N-Me	Right	Condylar Head Inclination	-0.00106	0.545
Sum Total	Left	Condylar Head Inclination	0.00014	0.655
Sum Total	Right	Condylar Head Inclination	0.00020	0.525
Ramus Height	Left	Condylar Head Inclination	0.00352	0.242
Ramus Height	Right	Condylar Head Inclination	0.00349	0.234
Corpus Length	Left	Condylar Head Inclination	0.00134	0.456
Corpus Length	Right	Condylar Head Inclination	0.00209	0.280
SNB	Left	Condylar Head Inclination	0.00031	0.802
SNB	Right	Condylar Head Inclination	0.00042	0.727
N-Go-Ar	Left	Condylar Head Inclination	0.00011	0.959
N-Go-Ar	Right	Condylar Head Inclination	-0.00056	0.788
N-Go-Me	Left	Condylar Head Inclination	0.00212	0.205
N-Go-Me	Right	Condylar Head Inclination	-0.00005	0.973

Table 3-5 Regression Coefficients and P- values of Superior Joint Space as a Predictor in the Horizontal Group

Variable	TMJ	Tomographic Characteristic	RC	P-value
Y-Axis	Left	Superior Joint Space	0.01528	0.627
Y-Axis	Right	Superior Joint Space	0.01588	0.223
MP Angle	Left	Superior Joint Space	0.01909	0.689
MP Angle	Right	Superior Joint Space	-0.01861	0.671
Facial Axis	Left	Superior Joint Space	-0.00853	0.438
Facial Axis	Right	Superior Joint Space	-0.01503	0.128
S-Go:N-Me	Left	Superior Joint Space	-0.00541	0.736
S-Go:N-Me	Right	Superior Joint Space	0.00610	0.680
Sum Total	Left	Superior Joint Space	0.00162	0.572
Sum Total	Right	Superior Joint Space	0.00000	0.999
Ramus Height	Left	Superior Joint Space	0.02499	0.356
Ramus Height	Right	Superior Joint Space	0.02785	0.260
Corpus Length	Left	Superior Joint Space	0.02533	0.137
Corpus Length	Right	Superior Joint Space	0.00486	0.763
SNB	Left	Superior Joint Space	-0.00131	0.907
SNB	Right	Superior Joint Space	-0.00473	0.643
N-Go-Ar	Left	Superior Joint Space	0.02664	0.186
N-Go-Ar	Right	Superior Joint Space	0.03534	0.272
N-Go-Me	Left	Superior Joint Space	-0.01185	0.428
N-Go-Me	Right	Superior Joint Space	0.02064	0.394

Table 3-6 Regression Coefficients and P-values of Condylar Head Inclination as a Predictor in the vertical Group

Variable	TMJ	Tomographic Characteristic	RC	P-value
Y-Axis	Left	Condylar Head Inclination	0.00093	0.455
Y-Axis	Right	Condylar Head Inclination	0.00082	0.478
MP Angle	Left	Condylar Head Inclination	0.00289	0.475
MP Angle	Right	Condylar Head Inclination	0.00284	0.450
Facial Axis	Left	Condylar Head Inclination	-0.00005	0.958
Facial Axis	Right	Condylar Head Inclination	-0.00091	0.358
S-Go:N-Me	Left	Condylar Head Inclination	-0.00350	0.094
S-Go:N-Me	Right	Condylar Head Inclination	-0.00032	0.860
Sum Total	Left	Condylar Head Inclination	0.00037	0.314
Sum Total	Right	Condylar Head Inclination	0.00028	0.413
Ramus Height	Left	Condylar Head Inclination	-0.00832	*0.021
Ramus Height	Right	Condylar Head Inclination	-0.00348	0.241
Corpus Length	Left	Condylar Head Inclination	-0.00015	0.960
Corpus Length	Right	Condylar Head Inclination	-0.00271	0.348
SNB	Left	Condylar Head Inclination	0.00113	0.370
SNB	Right	Condylar Head Inclination	0.00035	0.746
N-Go-Ar	Left	Condylar Head Inclination	0.00031	0.907
N-Go-Ar	Right	Condylar Head Inclination	0.00235	0.367
N-Go-Me	Left	Condylar Head Inclination	0.00000	1.000
N-Go-Me	Right	Condylar Head Inclination	0.00176	0.243

Table 3-7 Regression Coefficients and P-values of Superior Joint Space as a Predictor in the Vertical Group

Variable	TMJ	Tomographic Characteristic	RC	P-value
Y-Axis	Left	Superior Joint Space	0.01119	0.401
Y-Axis	Right	Superior Joint Space	-0.02414	0.062
MP Angle	Left	Superior Joint Space	0.02828	0.512
MP Angle	Right	Superior Joint Space	-0.07614	0.068
Facial Axis	Left	Superior Joint Space	-0.01098	0.327
Facial Axis	Right	Superior Joint Space	0.01630	0.132
S-Go:N-Me	Left	Superior Joint Space	-0.01188	0.583
S-Go:N-Me	Right	Superior Joint Space	0.05521	*0.010
Sum Total	Left	Superior Joint Space	0.00325	0.404
Sum Total	Right	Superior Joint Space	-0.00788	*0.040
Ramus Height	Left	Superior Joint Space	-0.00403	0.911
Ramus Height	Right	Superior Joint Space	0.11430	*0.001
Corpus Length	Left	Superior Joint Space	-0.01732	0.594
Corpus Length	Right	Superior Joint Space	0.04171	0.183
SNB	Left	Superior Joint Space	-0.01109	0.410
SNB	Right	Superior Joint Space	0.03272	*0.010
N-Go-Ar	Left	Superior Joint Space	0.01357	0.634
N-Go-Ar	Right	Superior Joint Space	-0.02165	0.436
N-Go-Me	Left	Superior Joint Space	0.01846	0.256
N-Go-Me	Right	Superior Joint Space	-0.00811	0.610

Table 3-8 Relative Rate of Change from Pre-treatment to Post-treatment Cephalometric Values in the Vertical Group

Variable	Average Rate of Change	Minimum	Maximum
Y-Axis	-0.01	-0.20	0.10
MP Angle	0.03	-0.64	0.33
Facial Axis	-0.02	-0.12	0.11
S-Go:N-Me	-0.03	-0.21	0.18
Sum Total	0.00	-0.05	0.04
Ramus Height	-0.18	-0.63	0.26
Corpus Length	-0.13	-0.51	0.19
SNB	-0.01	-0.10	0.14
N-Go-Ar	0.06	-0.20	0.25
N-Go-Me	0.01	-0.16	0.11

Table 3-9 Relative Rate of Change from Pre-treatment to Post-treatment Cephalometric Values in the Horizontal Group

Variable	Average Rate of Change	Minimum	Maximum
Y-Axis	-0.01	-0.15	0.11
MP Angle	-0.04	-0.25	0.30
Facial Axis	0.00	-0.12	0.09
S-Go:N-Me	0.00	-0.16	0.15
Sum Total	0.00	-0.02	0.03
Ramus Height	-0.09	-0.37	0.28
Corpus Length	-0.09	-0.28	0.09
SNB	-0.01	-0.17	0.09
N-Go-Ar	0.04	-0.24	0.18
N-Go-Me	-0.03	-0.13	0.10

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Chapter Four

Discussion
And
Recommendations

4.1 - GENERAL DISCUSSION

Analysis of facial morphology has become a routine component of the diagnostic process in orthodontics. It is recognized that the morphological pattern is a result of growth of the entire dentofacial complex which can display considerable individual variation. The role of mandibular growth, however, has intrigued researchers due to its ability to proceed in a neutral, horizontal or vertical growth direction. Extreme growth patterns in either direction can become troublesome to the orthodontist and can have a direct effect on the function, esthetics, and stability of the orthodontic result. Early detection of adverse growth potential would obviously enhance treatment planning and aid in predicting treatment outcomes for the difficult Class II orthodontic case. This has led to the continued quest to discover and understand the relationships between craniofacial growth patterns and the dentofacial morphologies that can result.

Previous studies have examined the relationship of condylar characteristics to facial morphology. The objective of this study was to investigate the structural and positional characteristics of the temporomandibular joint and to determine specific pre-adolescent condylar characteristics that are representative of growth patterns of the dentofacial complex. It was also the aim of this study to assess the capability of condylar characteristics to predict various post-treatment mandibular growth responses in Class II patients.

The first part of this study examined the relationship between condylar characteristics measured from tomograms and facial morphology in Class II, pre-adolescent patients. Logistic discriminant analysis revealed the most significant variables to be left and right condylar head inclination (p-value .0111 and .0104 respectively) as well as left and right superior joint space (p-value .011 and .0185 respectively). Patients with vertical facial morphology displayed decreased superior joint spaces and posteriorly angled condyles, whereas, patients with horizontal facial morphology demonstrated increased superior joint spaces and anteriorly angled condyles.

No significant correlations between the other condylar characteristics and facial morphology were determined.

The correlations obtained between condylar head inclination and facial morphology are consistent with results previously reported by Bjork.[1,2] Posterior rotation of the condyles has been shown to dominate in individuals with the classic long face syndrome, and anterior inclination of the condylar head can be associated with counterclockwise mandibular rotators.[3] A possible reason for this growth pattern may be attributed to the proliferation of condylar cartilage and endochondral ossification of the condyle. This process occurs via a complex of biomechanical interactions and the magnitude, direction and duration of the resultant condylar growth may be influenced by genetic determinants as well as intrinsic and extrinsic control factors. It has been reported in the literature that reduced condylar growth represents clockwise rotation of the mandible in relation to the cranial base.[4]

Findings of this study indicate that decreased superior joint spaces were consistent with Class II patients exhibiting a vertical growth pattern. Increased superior joints spaces were also consistent with Class II patients in the horizontal group. This suggests that patients exhibiting a vertical facial pattern may reflect a reduction in condylar soft tissue. Patients exhibiting reduced condylar tissues could represent reduced growth potential, minimal distraction within the glenoid fossa and therefore reduced superior joint spaces. As well, reduced condylar growth may allow increased development of anterior face height from growth of the nasomaxillary complex and dentoalveolar development. The result would be an imbalance in anterior and posterior face heights, decreased ramus height, clockwise rotation of the mandible and increased vertical development. Reduced superior joint spaces may suggest reduced condylar growth potential. However, it still remains to be determined if condylar growth and structural adaptations occur as a result of functional stimulation inherent within the joint or as a result of altered function of the dentofacial complex.

With respect to anteroposterior condylar position, no correlations to facial morphology were discovered. This is in contrast to existing literature.[5-8] Pullinger[5] noted that in 44 young adult, asymptomatic, non-orthodontic, Class II Division I patients, the condyle is generally situated in a more anterior position. Tomographic assessment revealed that 11 of 30 Class I cases were bilaterally concentric compared with one of ten cases for Class II, Division I malocclusion. In contrast, the condylar positions in the Class II, Division II cases were slightly retropositioned. Logsdon and Chaconas[6] also found condyles to be more anteriorly positioned in Class II cases, whereas Bacon et al[7] found the condyle was in a more retrusive position represented by an increased distance from Nasion to the condylar neck.

Recent research by Cohlmia et al,[8] examined tomograms of 232 orthodontic patients ranging in age from 9-4 to 42-6 years. The patients were classified into specific malocclusions according to Angle's classification. No significant differences in condylar position were detected between Class I and Class II malocclusions although, skeletal and dental Class II patients displayed more anteriorly positioned condyles.

The variation in results from this study as compared to aforementioned studies[5-8] may be due, in part to differences in selection criteria used amongst related studies. Groups with large age ranges were analysed in some cases, including temporomandibular joints with and without growth potential. This study classified patients as skeletal Class II not only in the anteroposterior plane but in the vertical direction as well. Lastly, all studies were not consistent with including or discluding patients with internal derangements.

Condylar shape categorized as flat, convex, angled or concave was not correlated with vertical facial morphology in this study. In our study, however, 23.6 and 24.2 percent of adolescents with Class II malocclusions showed condylar flattening in the left and right condyle respectively. This was represented by flat or angled condyles. The significance of flattening in these patients in not clear and shape differences may represent normal individual variability or staging of development.

The null hypothesis of this study stated that no significant differences in condylar characteristics should be detected in individual contralateral joints of pre-adolescent patients. It was assumed that two temporomandibular joints connected by a rigid mandible would display a certain degree of morphologic symmetry. Results from this study indicate that differences do exist between condylar characteristics of the left and right joint. These differences may be attributed to individual anatomical variability, natural patterns of skeletal asymmetry[11], postural positioning, differential growth or condylar morphological alterations due to chewing preference patterns.

Although this study contained a large sample size, it is not without limitations. Error may have been introduced into the study from various aspects of the methodology. When choosing the sample for this study, patients were categorized according to chronological age. Due to the fact that individual variety in growth expression exists, it would have been beneficial to group the subjects according to skeletal age. Unfortunately, this was not possible as this was a retrospective study and hand-wrist radiographs were not consistently available. For the purposes of this study, patients were classified as skeletal class II if they displayed an ANB greater than 4.5 degrees. The magnitude of the ANB, however, may be influenced by the anteroposterior differences in jaw position, the vertical height of the face and the anteroposition of nasion. Additional cephalometric measurements to identify jaw disharmony such as the Wits analysis[12] could have been incorporated into the methodology.

In terms of radiographic analysis, data was obtained by a single-examiner. Inter-examiner reliability to test for errors in locating cephalometric landmarks and calculating measurements was not investigated in this study. Radiographic positioning errors in the transverse or frontal plane were not specifically analyzed. A study by Kamelchuk and Major[13], however, has shown that a ten degree rotation will not influence joint space measurements. Nonetheless it is not practical to totally eliminate the possibility of positioning error.

An additional source of error may result from the tomographic section utilized for the study. Tomographs were only analysed from the central cut in the sagittal plane and it has been reported in the literature that joint dimensions are not consistent in the central, medial and lateral views of the joints.[13] Therefore selection of the central tomographic section may not always truly represent the position of the condyle due to differences in condylar shape. Accurate expression of bilateral condylar position should therefore be assessed from all tomographic sections, although this would be a complex process.

Condylar dimensions may be affected by a variety of factors which could influence condylar proportions. These may include normal development, seasonal growth, skeletal asymmetry, pathological or remodelling changes, or temporomandibular dysfunction, which could produce alterations in joint dimension.[14] Patients in this study were not screened for the presence or absence of temporomandibular dysfunction or for any of the aforementioned factors.

The second portion of this study was designed to assess the predictive value of TMJ superior joint space and condylar head inclination measurements in orthodontic treatment outcome of horizontal and vertical developing Class II malocclusion. Superior joint space and condylar head inclination were the only condylar characteristics used in this section, due to their earlier findings of significant correlation with facial morphology. It has been generally accepted in orthodontics to utilize highpull headgear in vertical growth cases and cervical headgear in horizontal growth cases.[15] Successful treatment outcome in the context of this study represents normalization of the facial pattern so that the severity of deviation from cephalometric values representing neutral vertical facial proportions would be reduced. Successful or unsuccessful treatment would occur if vertical cases experienced decreases or increases respectively, in vertical dimension.

The results of this study should be interpreted with caution, but there does appear to be trends which warrant further study. A regression analysis was performed to determine if the pre-treatment tomographic measurements of superior joint space and condylar head inclination could identify the differences between the pre and post-treatment cephalometric measurements.

In the horizontal group, condylar head inclination in the right joint was the only variable to be significantly associated with a change in facial axis. The positive regression coefficient implied a positive association. This indicated that an anterior condylar head inclination prior to treatment was predictive of an increase in the facial axis or a more horizontal growth pattern. As well, a more posterior condylar head inclination could be associated with a decrease in facial axis or vertical growth tendency. Analysis of the 0.0 relative rate of change, indicates that it is not possible to relate the condylar head inclination to the direction of facial axis change. However, the minimum and maximum values suggest that changes occurred in the horizontal and vertical direction. Superior joint space and condylar head inclination did not meet $P = .05$ significance level for predicting changes in the remaining nine cephalometric measurements for the horizontal group. Statistical results for the horizontal group indicate that favourable or unfavourable treatment outcomes of patients treated with cervical headgear cannot be determined from this sample.

In the vertical group condylar head inclination of the left joint was only associated with a significant change in ramus height. The negative regression coefficient and the relative rate of change indicated that a posterior condylar head inclination was predictive of an increase in ramal growth for the vertical patients treated with highpull headgear. In the context of neutralizing the pre-treatment pattern, this represents a favourable outcome. Previous research has[1,2,16] correlated condylar head inclination dimensions to facial morphology. Anterior condylar head inclination and posterior head inclination have been correlated to individuals displaying a horizontal and vertical pattern of growth respectively. In this study posterior condylar head inclination was correlated to patients with a pre-treatment vertical growth tendency.

The superior joint space measurements of the right joint was the most predictive of the significant cephalometric changes in the vertical group. According to the regression coefficients and relative rates of change, an increased superior joint space was correlated with an increase in S-Go:N-Me, SNB and ramus height. Superior joint space was also correlated with a change in sum total, however, the zero relative rate of change could not confirm the direction of change. The above results indicate that the increase in ramus height and S-Go:N-Me are suggestive of horizontal growth in the vertical group. An increase in SNB may suggest clockwise rotation of the mandible. It can be suggest that in this study increased superior joint space was able to predict the increase in ramus height and S-Go:N-Me, indicating counter-clockwise growth or a favourable growth tendency. Previous research[16] has correlated increased superior joint spaces to patients exhibiting a horizontal or counterclockwise facial pattern. Therefore, this study suggests that patients with vertical growth tendencies and increased superior joint spaces may respond favourably to treatment with highpull headgear.

The sources of error listed for the first portion of the study also apply to this section. Additionally, the sample size was small, not randomly sampled and therefore the conclusions obtained may not be truly representative. Caution is recommended in interpreting the results of this study to avoid a type II statistical error.

One of the selection criteria for sample selection was that vertical and horizontal growth patients received extraoral traction with high-pull and cervical headgear respectively as part of the orthodontic treatment plan. This was completed in order to maintain consistency within each group. This study did not, however, specify the duration of headgear wear, compliance or amount of force applied when choosing patients for each group. It is inconclusive to say that extraoral traction effects did not alter the natural growth process and vertical dimension of the patients due to orthopedic and orthodontic changes. Unfortunately, this study was unable to compare treatment effects in the horizontal and vertical group to a non-treatment control group. This was due to the limited availability of subjects who have received tomograms without orthodontic treatment. Further research is therefore, necessary to analyse the effects of cervical and highpull headgear on the mandibular growth response to orthodontic treatment and its correlation to the pre-treatment determination of facial pattern.

The results of this study may be due in part to the orthodontic treatment procedures that the patients received. Sample selection did not take into consideration treatment modalities which could have an affect on the mandibular plane angulation and the patients vertical dimension. Post-treatment growth direction may have been influenced by intermaxillary elastics,[15] as well as extraction versus non-extraction treatment.

There are opposing views[17-20] to the effects of extraction and non-extraction orthodontic treatment on facial dimensions. Earlier research[17,18] has indicated that extraction treatment allows forward movement of the posterior teeth and a resultant reduction in the vertical dimension. More recent research by Chua et al,[19] comparing mandibular positional changes in Class I and Class II extraction and non-extraction cases has shown different results. In his study, it was determined that extraction treatment did not result in changes within the lower anterior face height of the sample. Non-extraction treatment did however, result in a downward and backward rotation of the mandible and an increase in lower anterior face height. Stagger[20] examined extraction and non-extraction treatment effects in Class I malocclusions and determined that cephalometric vertical dimensions were increased in both sample groups. One can hypothesize from the above literature that it is still controversial as to whether extraction pattern may have influenced this study's results.

4.2 - RECOMMENDATIONS FOR FUTURE STUDIES

Despite the inherent weaknesses of this study, the information obtained will still benefit orthodontists in their diagnosis of orthodontic problems. Further research, however, is necessary to continue the investigation into mandibular growth and its effect on treatment outcomes. The following is a list of recommendations which could be implemented in a subsequent study to aid in reducing the limitations and sources of error.

1. This second portion of this study should be repeated with a larger sample size in order to minimize the potential for random chance on the results. As well, improved statistical results would result in more conclusive findings.
2. Random sample selection may improve the reliability of results. This study attempted to minimize sample selection from the records of two orthodontists. It may be necessary to use a multicentre study to increase the ability for random sample selection. The risk of obtaining records from multiple orthodontists, however, is the potential for varied treatment modalities.
3. Introduction of a control group is necessary to compare the effects of orthodontic treatment mechanics to natural growth processes.
4. Classification of patients as skeletal Class II should be completed by more than one cephalometric measurement. Additional measurements, such as the Wits analysis would help eliminate false jaw discrepancies due to variations in vertical height of the face and the anteroposition of nasion.
5. Subjects should be selected according to skeletal age versus chronological age, as determined from hand-wrist radiographs. This would ensure that patients are in a similar stage of development rather than the same age category.
6. Patients should be screened for the presence or absence of factors which could effect condylar position dimensions. These may include temporomandibular joint dysfunction, pathological changes, and facial asymmetries.
7. The parameters for sample selection should be more defined with respect to

extraoral traction requirements and extraction or non-extraction therapy. Patients in the horizontal and vertical group should be similar in duration of headgear wear, compliance and amount of force delivered. Patients should all be treated with similar mechanics either with or without extractions. If the sample size is large enough, separate groups of extraction and non-extraction patients can be formed.

8. Testing of radiographic measurement techniques and data collection should be completed by more than one operator. Inter-examiner reliability could be assessed and this would help reduce operator bias.

9. Additional sections of tomograms could be analysed to determine condylar characteristics to account for variability. This may not be practical, however, depending on the magnitude of the study.

This study has examined the correlation of condylar characteristics to facial morphology and their prediction of treatment outcomes in Class II patients. Further research is necessary to continue exploring these correlations and their importance to growth and development and orthodontic treatment. It is hopeful that continued research in this area of study, with modifications to study design, will provide valuable information in the treatment of Class II patients.

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APPENDICES

APPENDIX 1

Results of Pilot Study

Cephalometric Variable	P-Value for testing variability between tracings	Mean	2 x SD
Y-Axis /degree	0.840	68.01	1.33
MP Angle / degree	0.819	33.89	2.42
Facial Axis/degree	0.872	90.34	1.49
S-Go:N-Me / %	0.934	63.10	2.67
Sum Total / Degree	0.819	393.89	2.42
Ramus Height/mm	0.199	41.07	2.34
Corpus Length/mm	0.220	70.40	2.46
SNB/degree	0.996	75.68	2.18

Tomographic Variable	P-Value for testing variability between tracings	Mean	2 x SD
AJS / mm	0.996	1.94	0.35
SJS / mm	0.586	3.49	0.41
PJS / mm	0.117	2.74	0.43
CW / mm	0.167	8.51	0.35
CSA / sq mm	0.187	80.36	6.00
PCRI / degree	0.485	-7.35	1.03
CHI / degree	0.960	5.45	1.31