Associations between cephalometric values and radiographic osseous temporomandibular joint diagnoses in an adolescent orthodontic population

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Abstract

AIMS: To identify skeletal features and relationships associated with the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) osseous temporomandibular joint (TMJ) diagnoses in an adolescent population undergoing comprehensive orthodontic treatment, and to evaluate the reliability and validity of the cervical vertebral maturation (CVM) method for predicting mandibular growth.

METHODS: Fifty-nine orthodontic patients were included in the study. Pre-treatment and post-treatment diagnoses of each TMJ were previously made by Anderson[1] using the RDC/TMD. For each subject, a lateral cephalometric radiograph was extracted from existing pre-treatment and post-treatment cone beam computed tomography (CBCT) images. Each radiograph was assessed with cephalometric analysis and staged using the CVM method. Statistical analyses were performed with one-way ANOVA and Pearson and Spearman correlation coefficients.

RESULTS AND CONCLUSIONS: The pre-treatment mandibular plane angle (FMA) and Wits appraisal had a fair degree of positive correlation with the pre-treatment TMJ diagnosis. However, no associations were found when the change in TMJ diagnosis over the course of orthodontic treatment was compared to cephalometric variables or measures of growth, nor did the pre-treatment cephalometric measurements predict changes in the TMJ diagnosis. The pre-treatment CVM stage was inversely correlated to mandibular growth observed during treatment, with no growth seen in subjects with a pre-treatment CVM stage of 6.

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INTRODUCTION

The effect of orthodontic treatment on the temporomandibular joints (TMJs) has been of interest for decades. While studies have shown that orthodontic treatment neither causes nor cures temporomandibular disorders (TMDs),[2] the topic remains controversial. The use of cone beam computed tomography (CBCT) imaging in orthodontics has allowed for continued research in this field, as these images provide an accurate representation of the bony components of the TMJs and other facial structures.

Anderson[1] used the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD)[3] to diagnose the osseous components of the TMJ of a predominantly adolescent orthodontic population. The study found that on average there was no significant change in the radiographic diagnosis from before to after comprehensive orthodontic treatment; however, there were significant percentages of subjects whose diagnoses either improved or worsened.

Experience shows that skeletal patterns affect patients' responses to orthodontic treatment, and recent research has revealed associations between such patterns and TMD.[4-13] Therefore, it is plausible that specific skeletal patterns predispose patients to changes in their TMJs during orthodontic treatment. Anderson's study did not seek to identify commonalities among patients with either improved or worsened TMJ diagnoses. However, using a derivative of Anderson’s population, the present study builds on his findings by aiming to identify relationships between skeletal characteristics and the RDC/TMD osseous diagnosis and between the RDC/TMD diagnosis and growth of the mandible.

LITERATURE REVIEW

TEMPOROMANDIBULAR DISORDERS

Temporomandibular disorders (TMDs) encompass a spectrum of pathologies affecting the temporomandibular joint (TMJ), the masticatory muscles and/or surrounding structures.[14] Historically, the triad of muscle and/or TMJ pain, TMJ sounds and alteration of mandibular movement has been used to characterize these disorders,[15] although degenerative bony changes are also commonly associated with TMDs.[16] TMDs are a significant source of orofacial pain with a prevalence similar to other major dental diseases.[17]

Etiology

While the etiology of TMD is not fully understood, it is clearly multifactorial. A host of risk factors have been identified, including advancing age, systemic illness, hormonal factors, occlusion and mechanical factors (such as trauma, parafunction and functional overloading).[18] Associations with psychological factors like stress and anxiety have also been noted[19]—in just one example, a cohort study following an adolescent population into adulthood saw that subjects initially judged to have high self-esteem had decreased likelihood of developing TMD.[20]

Classification

Because of the wide range of signs and symptoms of TMD, classification is complicated. To simplify it, De Rossi et al[14] describe two main categories of TMDs: non-articular and articular. Non-articular disorders present primarily as myofascial pain and include fibromyalgia and myopathies. Articular disorders include inflammatory conditions like rheumatoid arthritis and non-inflammatory conditions like displacement of the articular disc (internal derangement) and osteoarthritis (OA). (Emerging research, however, shows that OA is actually inflammatory in nature, contrary to the longstanding belief.[21])

Various methods and indices have been proposed to standardize the classification of TMDs, the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) being one such system. Introduced in 1992 and revised in 2010, the RDC/TMD have been used widely throughout the research community in the years since their development.[22,23] The system consists of two parts: Axis I, which is used to diagnose myofascial pain (group I), disc displacement (group II) and arthralgia, arthritis or arthrosis (group III); and Axis II, which assesses psychological status and pain-related disability.[23] Although the RDC/TMD underwent a further revision and renaming to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) in 2014, [24] the present study utilizes the RDC/TMD—specifically, the group III disorders of Axis I, which deal with the osseous components of the TMJ.

Epidemiology

Studies have reported the prevalence of TMD to be 7% to 84% when considering populations ranging from ages 3 to 74 years.[2] Signs of TMD are more common than symptoms, with a prevalence of 33% to 86% for signs and 16% to 59% for symptoms.[18] Such a wide range of reported values, which is likely a result of differing methods for assessing the condition and/or selecting the study population, is unfortunately not particularly useful in understanding this condition.

Manfredini et al[15] attempted to address these disparities in a review of studies that utilized the RDC/TMD for classification. In populations of TMD patients, there was an overall prevalence of 45.3% for muscle disorder diagnoses (group I), 41.1% for disc displacements (group II) and 30.1% for joint disorders (group III). In the general population, the group reported a prevalence of 9.7% for myofascial pain (group I), 11.4% for disc displacement with reduction (group IIa) and 2.6% for arthralgia (group IIIa). As might be expected, studies that used imaging to supplement clinical criteria found a higher prevalence of group III disorders, which involve osseous changes to the TMJs.

It is generally agreed that symptoms of TMD affect females more than males by a ratio of at least 2:1,[15,25] although the difference between sexes has been shown to disappear when considering signs of TMD instead.[26] The majority of symptomatic patients are from 20 to 50 years of age,[25,27] but symptoms are not uncommon in adolescents. Egermark-Eriksson et al[28] found the frequency of TMD signs and symptoms to increase between ages 7 and 15, with as many as 25% reporting occasional symptoms. Following a cohort of subjects, Macfarlane et al[20] found that TMD prevalence was only 3.2% at age 11 to 12, had increased to 17.6% at age 19 to 20, but then decreased to 9.9% at age 30 to 31.

In accordance with these findings, in 1996 the National Institutes of Health (NIH), concluded that signs and symptoms of TMD are self-limiting and fluctuate over time.[27] Despite the apparent prevalence of TMD within the population, demand for treatment ranges from 3% to 7% in the adult population,[18] with the overall need estimated at 16%.[29]

Osteoarthritis

Progression of TMD is not well understood, but according to Murphy et al,[25] "the primary pathology appears to be a degenerative condition, known as osteoarthritis (OA) or osteoarthrosis." (Osteoarthritis and osteoarthrosis are technically different entities, with osteoarthritis involving pain. Despite this distinction, these names are often used interchangeably, along with the term degenerative joint disease [DJD].[3]) OA is the most common joint disease occurring in the TMJ,[18,30] is more common in women[31] and increases in prevalence and severity with age.[16,32] It is not limited to older individuals, however—Zhao et al[31] found radiographic signs of TMJ OA in nearly 15% of adolescents ages 11-19 with clinical diagnoses of TMD.

Traditionally, OA has been considered a disease of overuse resulting in loss of cartilage in a joint, but recent research suggests that it involves release of inflammatory mediators from the cartilage, bone and synovial membrane.[30] In the event of diminished adaptive ability or overloading of a joint, the effect may be degenerative changes including destructive lesions like bony erosions and proliferative lesions such as osteophytes.[18,25,30,33] Associations between OA and severe skeletal malocclusions (especially Class II) have been noted, suggesting that OA may affect mandibular growth.[5,30] Zarb and Carlsson[34] state that "the disease can be crippling, leading to a vast range of morphologic and functional deformities," although TMJ OA rarely progresses to such an extent.

While TMJ OA involves osseous changes, not all osseous changes are pathologic. Bone remodeling is a physiologic process that allows load-bearing joints such as the TMJ to adapt,[25] and may present as articular surface flattening and/or subcortical sclerosis.[3,30] TMJ remodeling has been reported as a common finding in asymptomatic patients,[35,36] and discerning remodeling from OA is not always straightforward. Katakami et al[37] studied condyles from human cadavers and found that joints with radiographic signs of OA did not have histologic signs of OA, but rather of physiologic remodeling. Differentiation between remodeling and OA has been noted to be especially difficult in growing patients.[30] Thus, remodeling is only considered to be abnormal when the radiographic appearance is severe or it is accompanied by clinical signs and symptoms of TMD.[38]

IMAGING OF THE TEMPOROMANDIBULAR JOINT

Radiographic imaging of the TMJs may be helpful in supporting clinical findings or determining treatment for TMD, although it is not always indicated.[39] The 2010 revisions to the RDC/TMD by Schiffman et al[22] maintain that imaging should supplement clinical examination when diagnosing intra-articular disorders. The initial RDC/TMD guidelines did not thoroughly describe methods for imaging assessment, but this shortcoming was addressed in 2009, when Ahmad et al[3] published a comprehensive method of assessment for magnetic resonance imaging (MRI), panoramic radiography and computed tomography (CT) imaging as part of the RDC/TMD Validation Project.

Magnetic Resonance

MRI is the gold standard for viewing the soft-tissue components of the TMJ and is useful for imaging when internal derangement is suspected.[38] The weakness of MRI lies in assessment of the osseous portions of the TMJ, as it has low specificity for detecting osseous changes.[40] For imaging of bony structures, other modalities such as panoramic radiography, tomography and CT have been used.

Panoramic

Panoramic radiography is useful for detecting gross morphological changes of the condyles, and has high specificity for the detection of OA.[3] However, it has low reliability and sensitivity for detecting osseous changes to the TMJs.[3,38] Inter-examiner reliability in the RDC/TMD Validation Project, which assessed OA in 724 subjects using novel criteria, was poor (k = 0.16).[3] As a result of superimposition and distortion, even assessment of osteophytes is poor with this imaging modality; only large lesions can be seen reliably.[33]

Tomography

Due to the shortcomings of panoramic radiography, linear and complex motion tomography have been used to assess the bony structures of the TMJ.[38] This technique improves on panoramic imaging by minimizing superimposition and distortion.[38] Barghan et al[38] cite that detection of osseous changes with tomography has reported sensitivity from 53% to 90% and specificity from 73% to 95%. Hussain et al's[33] systematic review of imaging modalities for assessing erosions and osteophytes of the TMJ found that tomography adequately diagnoses osteophytes, although the size and location of these lesions may affect accuracy of diagnosis. Regarding the accuracy of detecting erosions, they cited conflicting reports. Multiple studies have found that early degenerative changes are not accurately detected, limiting tomography's usefulness.[33,38]

Computed Tomography

A 3-dimensional imaging technique, CT is useful for assessing a wide range of bony pathology. Schiffman et al[22] state that for definitive diagnosis of osteoarthritis (group IIIb) and osteoarthrosis (group IIIc) using the RDC/TMD, CT imaging should be used due to its ability to detect osseous changes. Using autopsy specimens, sensitivity of 75% and specificity of 100% has been reported for detection of bony changes,[41] and Ahmad et al[3] found the inter-examiner reliability of CT for hard tissue diagnosis of OA to be good (k = 0.71). The systematic review by Hussain et al[33] concluded that while CT does not seem to add additional information to what is seen with axially corrected sagittal tomography, cone beam computed tomography (CBCT) may be an effective alternative.

CBCT, which was introduced in the late 1990s, has rapidly gained use in craniofacial imaging. Multiple studies have shown its diagnostic efficacy to be better than panoramic radiography and linear tomography.[38] Honda et al[42] demonstrated that CBCT has diagnostic efficacy as good as medical CT, while Katakami[37] found that limited-view CBCT images more accurately represented the true morphological characteristics of mandibular condyles than images from helical CT. Furthermore, Lukat et al[43] compared detection of OA changes between 76μm and 300μm voxel sizes and found no significant difference. Although the authors did admit that image quality was superior with the smaller voxel size, the findings provide further support for the use of CBCT imaging, whose scan times and radiation doses can be reduced by utilizing a larger voxel size. Considering these benefits, CBCT has been suggested as the technique of choice when the aim is to investigate bony changes of the TMJ.[44]

RELATIONSHIP BETWEEN OCCLUSION AND TMD

There is a lack of strong evidence that occlusal factors cause TMD,[2] although some associations have been found. Comparing groups of patients with differing degrees of TMD (controls, disc displacement, OA and myalgia) with measurements of overbite and overjet, Pullinger and Seligman[45] reported that the only significant associations were increased overjet and decreased overbite in patients with OA. The authors speculated that increased overjet and minimal overbite may be a consequence of condylar changes rather than a predisposing factor for TMD; in addition, since these findings are common among patients without TMD, they lack specificity for identifying TMD-prone patients. Nonetheless, patients with skeletal anterior open bite were strongly associated with OA diagnoses.

In Danish children from ages 7 to 13, Sonnesen[46] found that a number of occlusal characteristics—distal molar occlusion, extreme overjet, open bite, unilateral crossbite and midline shift—were significantly associated with clinical signs and symptoms of TMD. However, in a 20-year follow-up study by Egermark et al,[47] the only statistically significant correlations between malocclusion and TMD were greater incidences of lateral shifts and unilateral crossbites in the patients with TMD, and both these features had only moderate correlations ($r = 0.34$ and 0.38). These findings seem to be consistent with those in adult patients with TMD. Almăşan et al[48] reported increased overjet, increased interincisal angle and greater midline shift in patients with TMD than in those without TMD, although these differences were largely insignificant.

RELATIONSHIP BETWEEN ORTHODONTIC TREATMENT AND TMD

The role of orthodontics in the production or alleviation of signs and symptoms of TMD has long been argued. According to McNamara, it wasn't until the late 1980s that interest in this relationship was heightened, after a court judgment that orthodontic treatment had caused TMD.[49] Subsequently, there was a substantial increase in the amount of research focusing on the relationship between orthodontic treatment and the development of TMD.

Reviews of the literature have generally found minimal to no association between the prevalence of TMD and whether or not orthodontic treatment was previously performed.[49,50] Conversely, meta-analysis has not shown an increase or decrease in the prevalence of TMD following conventional orthodontic treatment.[51] Egermark et al[47] and Macfarlane et al[20] conducted long-term follow-up studies of 402 and 1018 children, respectively. Even at a 20-year follow-up, neither study found significant differences in the prevalence of TMD in patients who had received orthodontic treatment when compared to those who did not.

Anderson[1] applied the RDC/TMD principles from Ahmad et al[3] to assess the osseous elements of the TMJs in a population of individuals undergoing comprehensive orthodontic treatment. Based on CBCT images taken before and after orthodontic treatment, the following osseous findings were recorded: articular surface flattening, subcortical sclerosis, osteophyte, surface erosion and subcortical cyst. These findings were used to make diagnoses of normal, remodeling (used interchangeably with the term "indeterminate") and DJD (grade I and grade II) according to the criteria in **Table I**.

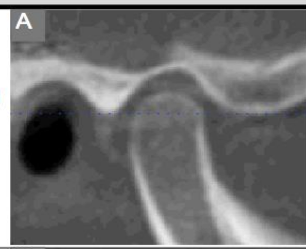
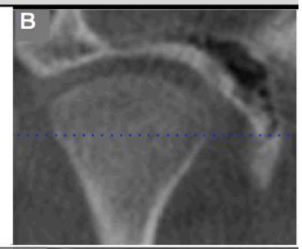
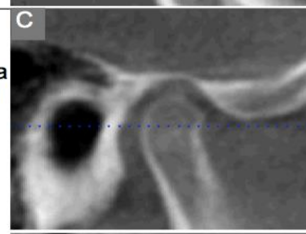
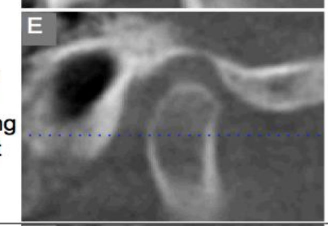
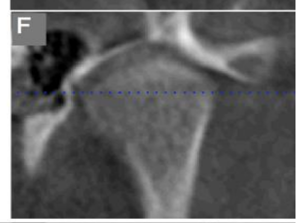
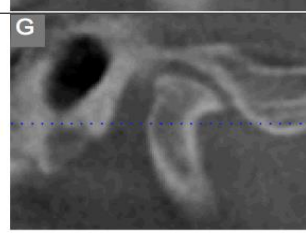
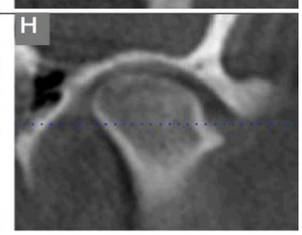
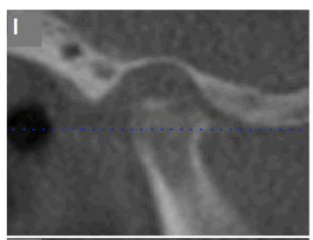
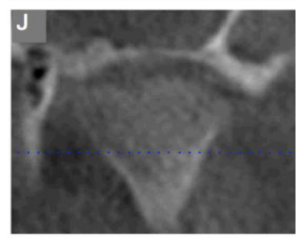
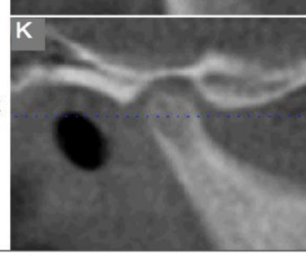
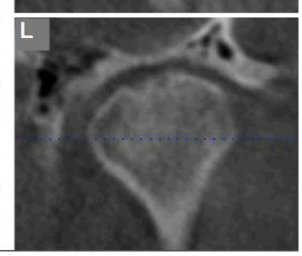
Diagnosis	Finding	Example: Sagittal	Example: Coronal
Normal	No subcortical sclerosis or articular surface flattening, and no deformation due to subcortical cyst, surface erosion, or osteophyte		
Remodeling	**Articular surface flattening**—a loss of the rounded contour of the surface		
	and/or		
	Subcortical sclerosis—any increased thickness of the cortical plate in the load bearing areas relative to the adjacent non-load bearing areas		
DJD (grade I and grade II)	**Osteophyte**—marginal hypertrophy with sclerotic borders and exophytic angular formation of osseous tissue arising from the surface		
	or (grade I)/and/or (grade II)		
	Surface erosion—loss of continuity of articular cortex		
	or (grade I)/and/or (grade II)		
	Subcortical cyst—a cavity below the articular surface that deviates from normal marrow pattern		

Table I. *(From Anderson[1])* Diagnostic criteria and image examples from matched subjects in the study. **A, B,** No findings. **C,** Slight flattening of anterior slope. **D,** Flattening of superior margin. **E, F,** Sclerosis of superior margin. **G,** Osteophyte at anterior margin. **H,** Osteophyte at lateral margin. **I,** Surface erosion. **J,** Surface erosion. **K,** Cyst below posterosuperior margin. **L,** Cyst below superior margin. (Note: In this left joint, surface erosion present medially to cyst.)

In a population of 348 pre-orthodontic patients, Anderson found that the overwhelming majority of subjects had radiographic findings of remodeling or DJD at the time of the pre-treatment CBCT image. Only 7.5% of subjects had a normal diagnosis, with another 6.9% having an equivocal normal diagnosis. Sclerosis and articular surface flattening, both indicative of remodeling, were the most common findings. **Table II** shows the percentage of patients in the screening population with each type of osseous finding recorded.

Radiographic Finding	% of Total
Flattening	78.2
Sclerosis	58.6
Osteophyte	16.1
Erosion	4.0
Cyst	3.7
Total	100

Table II. *(From Anderson[1])* Radiographic findings in the pre-orthodontic screening population (N = 348).

From the screening population, an age- and gender-matched subset (N = 78) comprised of 3 equal groups of subjects with normal, remodeling and DJD diagnoses (DJD I and DJD II were included in the same group) was randomly selected. Definitive pre-treatment and post-treatment TMJ diagnoses were independently made for each joint in this population, and the pre-treatment to post-treatment change in diagnosis was recorded using the number of diagnostic categories by which each joint's TMJ diagnosis worsened or improved.

Anderson found that there was overall no statistically significant change in the diagnosis over the course of orthodontic treatment, which supports prior findings that, on average, orthodontic treatment has a neutral effect on the TMJs. Nonetheless, while 52.6% of the diagnoses remained the same from pre-treatment to post-treatment, 25% worsened and 22.4% improved (**Table III**). This raises further questions: Do similarities exist between the patients whose diagnosis either worsened or improved? Can the orthodontist predict a patient's response to treatment?

Change by (-) = better diagnosis at post-treatment than pre-treatment Change by (+) = worse diagnosis at post-treatment than pre-treatment			
Changes in Diagnoses by Scale		**Overall Changes**	**%**
Change by -3	0	Better = 34	22.4
Change by -2	3		
Change by -1	31		
Change by 0	80	Same = 80	52.6
Change by +1	35	Worse = 38	25.0
Change by +2	3		
Change by +3	0		
Total	152	152	100%

Table III. *(From Anderson[1])* Changes in joint diagnoses by scale and overall from pre-treatment to post-treatment in the matched subset (after exclusion of 4 joints; N = 152 joints).

ASSOCIATIONS BETWEEN CEPHALOMETRICS AND THE TMJ

A growing body of knowledge shows that there are associations between the morphology of the TMJs and occlusal relationships, cephalometric measures and facial types. Katsavrias[52] assessed corrected TMJ tomograms of pre-orthodontic patients and found different condyle and glenoid fossa shapes among Class II Division I, Class II Division II and Class III patients. Succucci et al[53] reported higher condylar volumes in patients with low mandibular plane angles, and Ari-Demirkaya et al[54] found greater prevalence of condylar erosion in patients with open bites and of condylar flattening in patients with deep bites.

There is not a clear link between cephalometric characteristics and the presence of TMD signs and symptoms, however mandibular retrusion does appear to be associated. Cuccia and Caradonna[6] used clinical measures to classify young adult women into TMD and non-TMD groups. Upon cephalometric analysis, the TMD group was shown to have a smaller mean SNB angle and greater mean overjet. Additionally, the TMD group had a decreased palatal plane-mandibular plane (PP-MP) angle, decreased lower face height and greater overbite, which the authors attributed to a more hypodivergent skeletal type. However, the TMD group also had steeper occlusal planes and there was no difference in sella-nasion to mandibular plane angles, indicating that the decreased PP-MP angle was a result of the steep occlusal plane rather than a hypodivergent mandible.

A number of researchers have studied relationships between internal derangement of the TMJ, as diagnosed with MRI, and cephalometric characteristics. Schellhas et al[4] studied 128 consecutive children age 14 years or younger who had signs or symptoms of

TMD. While the cephalometric imaging requirements were not well controlled, the authors found that 56 of 60 retrognathic subjects in their population had at least one TMJ with internal derangement, and subjects with the most advanced derangements generally had severe mandibular retrusion. Sanromán et al[7] also found a higher incidence of internal derangement in skeletal Class II individuals than in Class I or Class III subjects. Supporting these findings, a comparison of asymptomatic patients without disc displacement and symptomatic patients with and without bilateral disc displacement showed that symptomatic patients with disc displacement had significantly decreased SNB angles.[8,55] However, disc displacement may alter the condylar positions and result in a more retruded mandibular position, so these associations do not imply causation.

Unlike the SNB angle, the SNA angle is unaffected by degenerative changes within the TMJ. However, Gidarakou et al[9,55] found decreased SNA angles in symptomatic subjects with either disc displacement with reduction or degenerative joint disease (OA), indicating that there could be a relationship between dentofacial development and TMD. This is not conclusive, though. A study by Brand et al[56] showed that while females with internal derangements had significantly smaller maxillae and mandibles than controls, they did not differ in other cephalometric measures like SNA, SNB or mandibular plane angles.

Byun et al[10] reported progressive decreases in mandibular ramus height, mandibular body length and effective mandibular length with worsening TMJ internal derangement (normal disc position, disc displacement with reduction, disc displacement without reduction) in young adult females with open bites. In other studies, adolescent females with bilateral disc displacement were shown to have decreased ramus and posterior face heights and increased mandibular and palatal planes,[11] and young adult females with disc displacements had decreased ramus heights and increased mandibular plane angles.[12,13,57]

There is certainly evidence supporting relationships between cephalometric measures and both clinical measures of TMD and internal derangement. Additionally, a correlation between internal derangement and OA has been established, with as many as 70% of TMD patients presenting with displaced discs.[18] A recent study reported associations between cephalometric characteristics and radiographic signs of OA in orthodontic patients with severe antero-posterior discrepancies,[5] however this link has not been elucidated in subjects with more common facial types.

EFFECT OF MANDIBULAR GROWTH ON THE TMJ

When dealing with the TMJs of adolescent patients, growth of the mandible must also be considered. The major component of horizontal mandibular growth through adolescence results from apposition along the posterior border of the ramus, while resorption occurs at the anterior border.[58] This translates the mandible anteriorly. Growth also occurs at the condyle, where endochondral bone formation is responsible for vertical lengthening of the ramus.[58] Early beliefs were that the mandibular condyle had intrinsic growth potential; however, it has been shown to be a secondary site of growth rather than a growth center, and current thinking is that its growth is subject to modification and response to surrounding structures.[59,60] Even still, the condyle is a major growth site of the mandible. [61]

In growing rabbits, Bryndahl et al[62] saw that induction of disc displacement without reduction led to changes in condylar cartilage, the severity of which were inversely related to the amount of mandibular growth that occurred during the study. Similar research with growing rabbits found that even though the condylar cartilage did not undergo degenerative changes, the underlying bone remodeled.[63] When the experiment was conducted with fully grown animals, however, degenerative changes consistent with OA occurred in both the bone and cartilage.[64] The differences between growing and non-growing animals suggest the likelihood of false positives when radiography is used for diagnosis of OA in adolescents, as those individuals may have osseous condylar changes even though the articular surface is normal.[62]

The RDC/TMD imaging guidelines contain an indeterminate (remodeling) diagnosis which is made when articular flattening and/or subcortical sclerosis are present. However, imaging should be interpreted with caution—as Bryndahl et al[62] found, histologically normal condyles may have an altered radiographic appearance. Thus, while radiographically "abnormal" condyles are not uncommon in adolescents, the meaning of such findings is not well understood. Do they indicate active growth, early degenerative changes or should they be largely ignored? A more thorough understanding would be helpful to clinicians as they encounter these findings in their patients.

TIMING OF MANDIBULAR GROWTH

The timing of the growth of the jaws is important in the orthodontic profession, as orthopedic treatments involving modification of growth can be optimized by timing the treatment along with the pubertal growth spurt. It is well-known that females undergo this period of rapid growth earlier than males; however, there is considerable variation, lending chronological age to be a poor predictor of the onset of puberty.[65] As a result, other methods have been developed to predict the timing of this growth spurt.

Cervical Vertebral Maturation Method

Maturational changes in cervical vertebrae have been studied for many years, with Lamparski[66] the first to introduce a method to assess vertebral changes as a means of predicting mandibular growth potential. In 2002, Baccetti et al[67] introduced a version of the CVM method consisting of 5 maturational stages based on the morphology of the bodies of C2-C4. Three years later, the same group released a modified version of this method that consisted of 6 stages, CS1 through CS6.[68] Assignment of each stage is made by analyzing the shapes of C2-C4; with maturation, the inferior borders of these vertebrae develop concavities and the bodies of C3 and C4 change from being horizontally rectangular to vertically rectangular (**Figure I).**

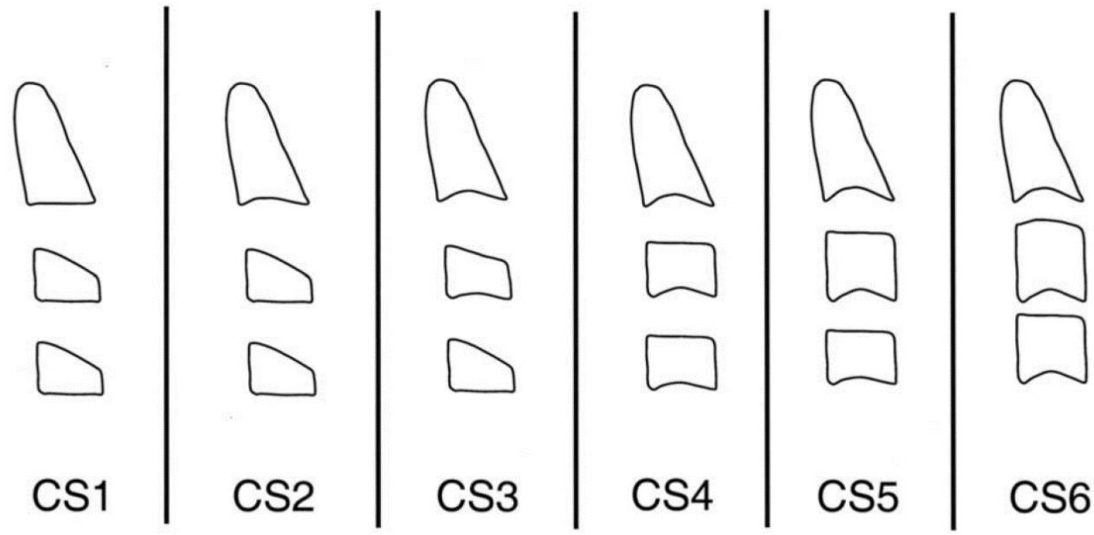


Figure I. (*From Baccetti et al*[68]) Schematic representation of the CVM method. The first three stages, CS1-CS3, are differentiated by concavities at the inferior borders of C2 and C3. CS4 is marked by development of a concavity on C4, but the bodies of C3 and C4 are still rectangular horizontal. For CS5, one or both of the bodies of C3 and C4 is/are square, whereas a rectangular vertical body distinguishes CS6.

Baccetti et al[68] claim that the peak in mandibular growth occurs between CS3 and CS4, and that CS6 occurs at least 2 years following this peak. However, the reliability and accuracy of the CVM method has been questioned since its introduction. Ball et al[69] studied the records of 90 males from the Burlington Growth Center in Toronto, Ontario, Canada. They found difficulty in determining the onset of peak mandibular growth using the 6-stage CVM method. Time spent in each stage varied significantly among subjects and CS4 was the stage where peak mandibular growth occurred most commonly, which is at odds with Baccetti et al's[68] suggestion that peak growth occurs between CS3 and CS4. However, this difference may be due to the Ball et al sample only including males—using the 5-stage CVM method, Litsas et al[70] found that males entered the period of peak growth at a slightly later CVM stage than females. Regardless, the conflicting results of various studies underscore the variability in growth patterns within the general population and the difficulty in accurately predicting exactly when and how much a patient will grow.

In regard to reproducibility of CVM staging, Nestman et al[72] found that practicing orthodontists trained in the CVM method had low inter-observer agreement for identifying the shapes of C3 and C4 as either rectangular horizontal, square or rectangular vertical. This resulted in low overall reproducibility of the CVM method. It should be noted, however, that in this study the CVM stage for each radiograph was generated from answers to separate questions regarding the shapes of C2-C4 rather than each orthodontist's clinical judgment of the appropriate stage. Thus, in addition to appropriate training and familiarity with the system, there may an aspect of subjective and experiential judgment in determining the appropriate CVM stage.

Controversy also surrounds the CVM method's ability to predict mandibular growth compared to other methods. Mellion et al[73] studied records of 100 children from the Bolton-Brush Growth Study Center in Cleveland, Ohio and compared chronologic age, height, hand-wrist stage and CVM stage to changes in facial size as measured on serial lateral cephalograms. Their findings showed that the hand-wrist assessment was best at determining that peak velocity of maturation had been reached, with chronologic age almost as good. The CVM stage was the worst predictor.

Other groups have reached differing conclusions. Baccetti et al[65] compared chronologic age to skeletal maturity as determined by the CVM method in 600 subjects, and found that chronologic age was not able to identify the onset of the pubertal growth spurt. However, this study did not measure growth in any way, assuming that CVM method accurately represented skeletal maturity.

Pasciuti et al[71] compared three methods of skeletal maturity assessment—hand-wrist, CVM and medial phalanges of the third finger (MP3)—in 100 growing individuals. Inter-examiner and intra-examiner reliability measures were very good ($k \geq 0.90$) for each of the three methods, and there was agreement among all methods for 70% of subjects. The authors concluded that the CVM method is as reliable and reproducible as other techniques for skeletal maturity assessment, with the added benefit of not requiring additional radiation exposure beyond a standard lateral cephalogram. However, two contributing authors in this study, Franchi and Baccetti, were also involved in the development of the CVM method; their expertise with the system likely had a positive influence on the reproducibility reported.

Several other studies have also reported good correlations between the CVM and hand-wrist methods.[70,74-76] Even if these methods are comparable, though, such a relationship does not prove that they are accurate indicators of mandibular growth.

RATIONALE FOR THE CURRENT STUDY

Despite each individual being unique, much of the existing research into orthodontics and TMDs has focused on population averages. Orthodontists, however, routinely make assessments of different facial types and skeletal patterns using lateral cephalometric radiography, utilizing this knowledge to develop treatment plans. Since orthodontists possess this specific information about their patients, the present study attempts to identify cephalometric variables predictive of improvement or worsening of the radiographic appearance of the TMJs as a result of orthodontic treatment.

If associations exist between cephalometric measures and the response of the TMJs to orthodontic treatment, they could be invaluable to practitioners. For example, predicting how patients' TMJs may respond to treatment will allow for more thorough informed consent. Additionally, the information could be useful when developing treatment plans, selecting treatment mechanics, or monitoring treatment progress.

This study has the following specific aims:

(1) to identify relationships between cephalometric characteristics and the RDC/TMD osseous diagnosis prior to orthodontic treatment;

(2) to identify relationships between the changes in cephalometric characteristics and osseous diagnoses before and after orthodontic treatment;

(3) to identify relationships between the osseous diagnosis and growth of the mandible during orthodontic treatment.

A secondary aim is to evaluate the reliability of the CVM method and its accuracy in identifying mandibular growth potential.

MATERIALS AND METHODS

IRB INFORMATION

The IRB approved this study on March 14, 2014. The IRB code number is 1402M48269.

METHODS

Sample Selection

The study population for this project originated from an existing patient population, from Anderson.[1] Anderson's population (N = 76) was selected from 381 consecutively-treated patients who underwent comprehensive orthodontic treatment with fixed appliances in the graduate orthodontics clinic at the University of Minnesota School of Dentistry between July 1, 2008 and November 30, 2011. All patients had received pre-treatment and post-treatment CBCT scans taken in maximum intercuspal position with a Next Generation i-CAT scanner (Imaging Sciences International, LLC, Hatfield, PA). Machine settings were 120 kVp and 37.10 mA, with a resolution of 0.3 mm voxels. The acquisition time for each scan was 17.8 seconds.

Patients whose CBCT files were missing, corrupt or not diagnostic were excluded, as were those with a history of prior orthodontic treatment, orthognathic surgery or had a craniofacial anomaly (n = 33). Utilizing i-CAT Vision software (Imaging Sciences International, LLC, Hatfield, PA), Anderson then used the RDC/TMD imaging guidelines from Ahmad et al[3] to make the following diagnoses for the population in his study: normal, remodeling (indeterminate), grade I degenerative joint disease (DJD I) and grade II degenerative joint disease (DJD II). DJD I is described as the presence of only one finding of osteoarthritis, whereas DJD II is defined by the presence of two or more of these findings (**Table I**).

Screening diagnoses were made for 348 subjects (after exclusions) to classify each individual into one of three groups: control (normal diagnosis), indeterminate (remodeling diagnosis), or case (DJD I or DJD II diagnosis). The worse of the two joints was used to classify each patient into one of these groups. Anderson's final study population was selected based on these screening diagnoses, with each group consisting of 26 patients matched for age (+/- 2 years) and gender (N = 78; 57 females, 21 males).

Both TMJs of each subject in the final age- and gender-matched population were independently given definitive diagnoses for both the pre-treatment and post-treatment CBCT images. Two patients were further excluded due to the CBCT images not being of diagnostic quality, resulting in a final population of 76 subjects. **Figure II** depicts the design of Anderson's study.

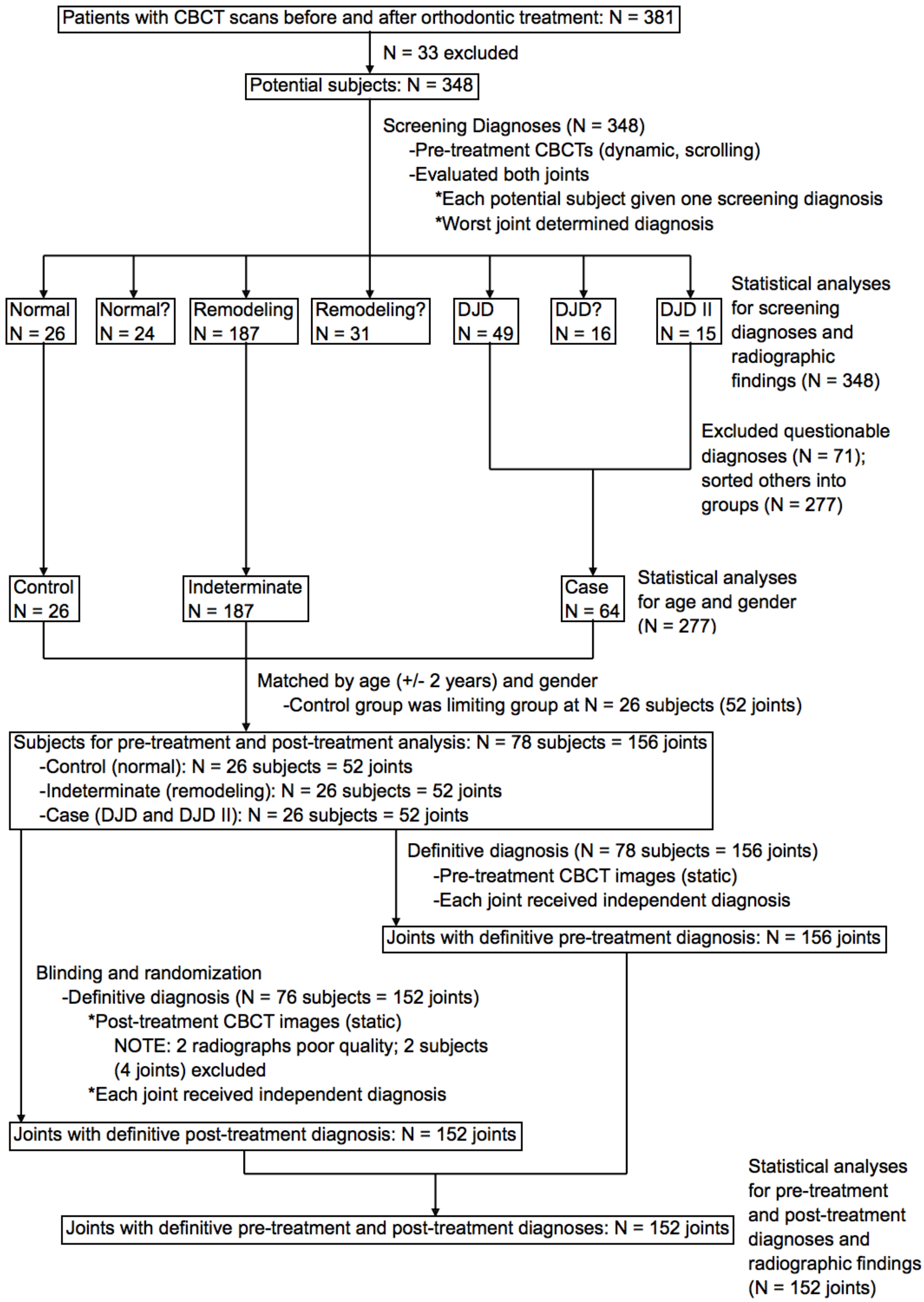


Figure II. (*From Anderson*[1]) Graphical representation of the study from which the present population is derived.

Cephalometric Measurements

For the present study, the CBCT images of the final population from Anderson (N = 76) were accessed in Dolphin Imaging 3D (Dolphin Imaging and Management Solutions, Chatsworth, CA) by the primary investigator (K.K), who uses the software regularly. Proceeding through the files in a random order, the CBCT volume of each subject was oriented to Frankfort Horizontal (**Figure III**) and an orthogonal (0% magnification) 2-dimensional lateral cephalometric radiograph was extracted. Immediately after producing this image, it was traced digitally in Dolphin Imaging 2D using a customized set of cephalometric measures **(Figure IV)**.

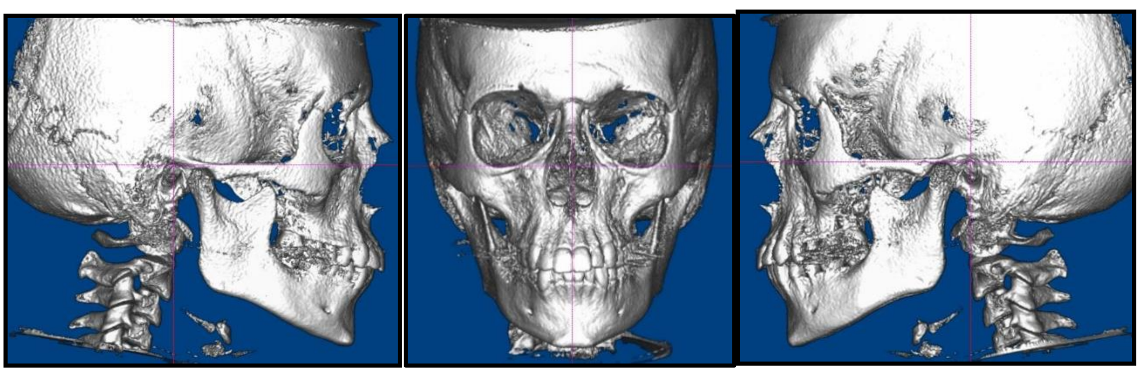
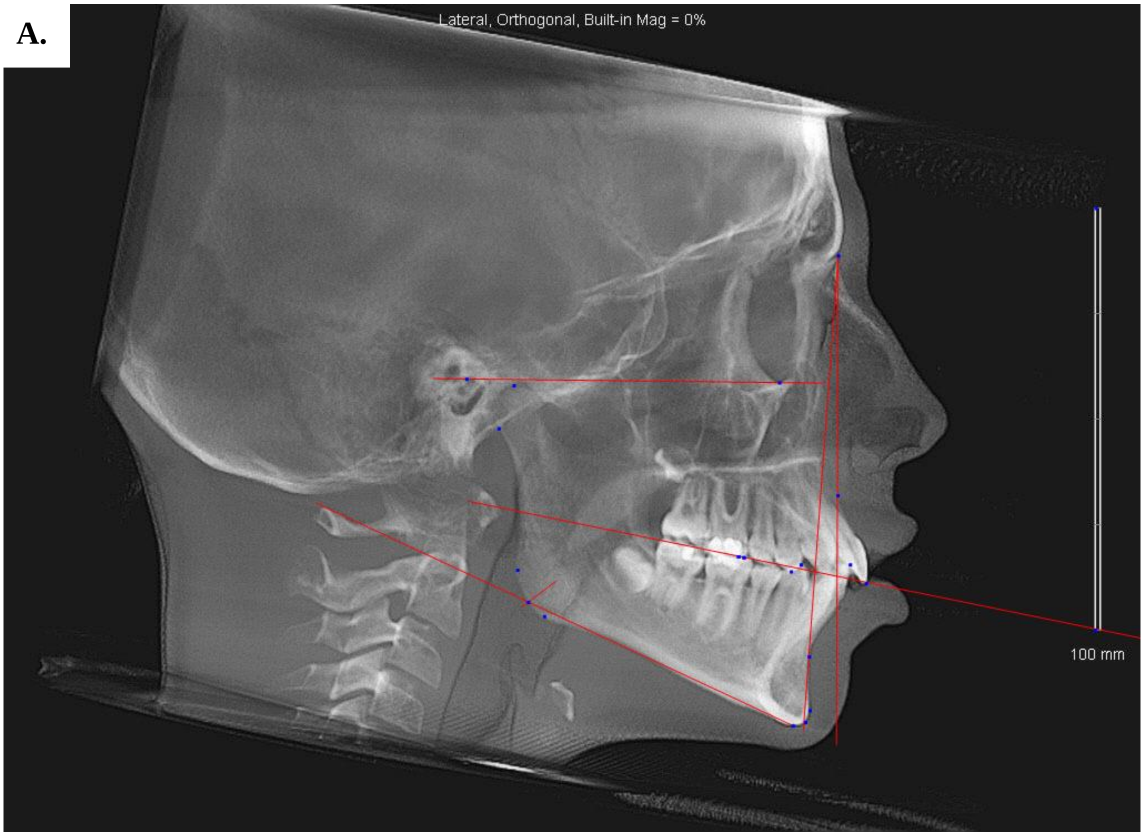


Figure III. Orientation of CBCT volumes. The 3-D CBCT images were oriented to Frankfort Horizontal utilizing a horizontal line to represent a plane passing through the superior aspects of the external auditory meatus and the inferior borders of the orbits. In cases of asymmetry, a "best fit" approach was used.

A.



B.

Cephalometric Measures
ANB (°)
Wits appraisal (mm)
FMA (MP-FH) (°)
Mandibular length (Co-Gn) (mm)
Ramus height (Co-Go) (mm)
Body length (Go-Pg) (mm)
Overjet (mm)
Overbite (mm)

Figure IV. Lateral cephalometric measurement. **A.** Representative lateral cephalometric radiograph extracted from CBCT image. **B.** Cephalometric measurements recorded. 'Wits appraisal' uses functional occlusal plane, defined by 1st premolar and 1st molar cusp tips. 'Ramus height' and 'Body length' use constructed gonion, the point along the border of the mandible crossed by a line bisecting the angle formed by the posterior border of the mandibular ramus and the inferior border of the mandibular body.

Patients who were not in maximum intercuspation in one or both CBCT images were excluded (n = 10), as determined by comparing the lateral cephalometric radiograph to the corresponding pre-treatment or post-treatment photos stored in Dolphin Imaging. Another patient (n = 1) was excluded due to early discontinuation of treatment as a result of rampant caries. Subjects who were 18 years of age or older at the time of the pre-treatment CBCT scan were also excluded (n = 6). After these exclusions, the final population consisted of 59 patients (N = 59; 43 females, 16 males).

Extraction and tracing of the lateral cephalograms was completed for all patients within a two-week period. Approximately 6 weeks after the initial data collection, 24 radiographs (20%) from the final population (118 total pre-treatment and post-treatment radiographs) were randomly selected and digitized again by the primary investigator, who was blinded to the initial tracings.

Cervical Vertebral Maturity Assessment

In addition to cephalometric analysis, subjects were assessed for growth potential using the visual assessment technique described in the most recent CVM method published by Baccetti et al.[67] The pre-treatment and post-treatment lateral cephalograms for all 59 subjects in the sample (118 total radiographs) were saved as JPEG files and randomized. No patient identifiers were present on either the images themselves or their file names. Each radiograph was blindly and independently scored by two persons, one the primary investigator (K.K) and the other an American Board of Orthodontics examiner comfortable with the CVM method (J.K.). Each examiner scored all radiographs in a single session. Each radiograph was assigned a single stage ranging from

1 through 6; no intermediate values were given (e.g. 3.5). Radiographs with poor image quality or truncation of the 4th cervical vertebrae that prevented accurate CVM assessment were excluded.

Three weeks later, after randomizing the radiographs again and renaming the files, the radiographs were independently scored by each examiner for a second time. All data was compiled, and radiographs which had not been assigned the same stage in all four previous sessions were reviewed together by the examiners and a consensus decision was reached regarding the appropriate CVM stage.

RDC/TMD Diagnosis

Each condyle, at both pre-treatment and post-treatment time points, was previously diagnosed by Anderson[1] using the RDC/TMD. These data were used in the current study. Each subject received a single numerical score at each time point based on the more severe of the two condylar diagnoses. If both condyles were normal, a score of 0 was given. If the most severe condylar diagnosis was indeterminate, a score of 1 was given. This determination continued with for other diagnoses, with DJD I receiving a 2 and DJD II receiving a 3.

To quantify the change in diagnosis, a whole number from -3 to +3 was used to denote the number of levels by which the diagnosis worsened (+) or improved (-) from pre-treatment to post-treatment. For example, the change in condylar diagnosis for a subject with a pre-treatment diagnosis of normal and a post-treatment diagnosis of DJD I was +2, and the change for a subject with a pre-treatment diagnosis of DJD I and a post-treatment diagnosis of indeterminate was -1.

RESULTS

Reliability Statistics

Intra-examiner reliability statistics for cephalometric measurements were calculated and are shown in **Table IV**. The correlation coefficients of nearly all measures were above 0.95. Reliability was lowest, but still in the excellent range, for initial overbite (0.82) and final overjet (0.79).

	Correlation	P-value
Initial ANB	0.9894	<0.0001
Initial Wits	0.9215	<0.0001
Initial FMA	0.9895	<0.0001
Initial OB	0.8242	<0.0001
Initial OJ	0.9691	<0.0001
Initial Go-Gn	0.9959	<0.0001
Initial Co-Go	0.9919	<0.0001
Initial Go-Pg	0.9924	<0.0001
Final ANB	0.9936	<0.0001
Final Wits	0.8718	0.0105
Final FMA	0.9904	<0.0001
Final OB	0.9191	0.0034
Final OJ	0.7885	0.0351
Final Go-Gn	0.9866	<0.0001
Final Co-Go	0.9724	0.0002
Final Go-Pg	0.9983	<0.0001

Table IV. Correlation coefficients for duplicated tracings (24 of 118) of lateral cephalograms.

Inter-examiner and intra-examiner reliability statistics were also calculated for the CVM analysis. Using weighted kappa statistics, intra-examiner reliability was 0.69 for J.K. and 0.85 for K.K. For inter-examiner reliability, weighted kappa values were 0.77 for the first trial and 0.61 for the second. These values all fell within the ranges of substantial (0.61-0.8) or near perfect (0.81-1.00) agreement.[77]

Description of the Sample

The final sample (N = 59; 43 females, 16 males) had a mean age of 13.44 years at pre-treatment and 15.46 years at post-treatment, yielding a mean elapsed time between pre-treatment and post-treatment images of 2.02 years (**Table V**). Although there were more females than males, the sexes were similar in age. Because some radiographs were unacceptable for CVM assessment, only 54 of the 59 subjects were given pre-treatment CVM stages; 52 were staged at both time points. The mean pre-treatment CVM stage was 4.00 (SD = 1.41; minimum = 1, maximum = 6) and the mean post-treatment stage was 4.98 (SD = 0.92; minimum = 3, maximum = 6).

	Mean ± SD	**Minimum**	**Maximum**
Initial age (overall)	13.44 ± 1.67	10.56	17.25
females	13.40 ± 1.55	10.56	17.25
males	13.54 ± 2.02	10.58	17.16
Final age (overall)	15.46 ± 1.66	12.19	19.32
females	15.30 ± 1.50	12.44	18.84
males	15.87 ± 2.01	12.19	19.32
Treatment time	2.02 ± 0.51	1.00	3.24

Table V. Initial age, final age and treatment time statistics for study population (all units in years).

At pre-treatment, there were 15 patients with normal diagnoses, 23 with indeterminate diagnoses of indeterminate, 15 with DJD I diagnoses and 6 with DJD II diagnoses. At post-treatment, there were 13 with normal diagnoses, 28 with indeterminate diagnoses, 15 with DJD I diagnoses and 3 with DJD II diagnoses. One-way ANOVA showed no significant differences in sex, pre-treatment age or post-treatment age among these diagnostic groups. From pre-treatment to post-treatment, the TMJ diagnoses of 18 subjects worsened, 28 remained unchanged and 13 improved.

As expected in a sample of adolescents, mandibular growth was observed in almost all subjects. The rates of observed mandibular growth (mm/year) decreased as the initial age increased, and were greater in males than females for all three measures of mandibular length. **Figure V** shows the yearly rate of growth in terms of effective mandibular length (Co-Gn).

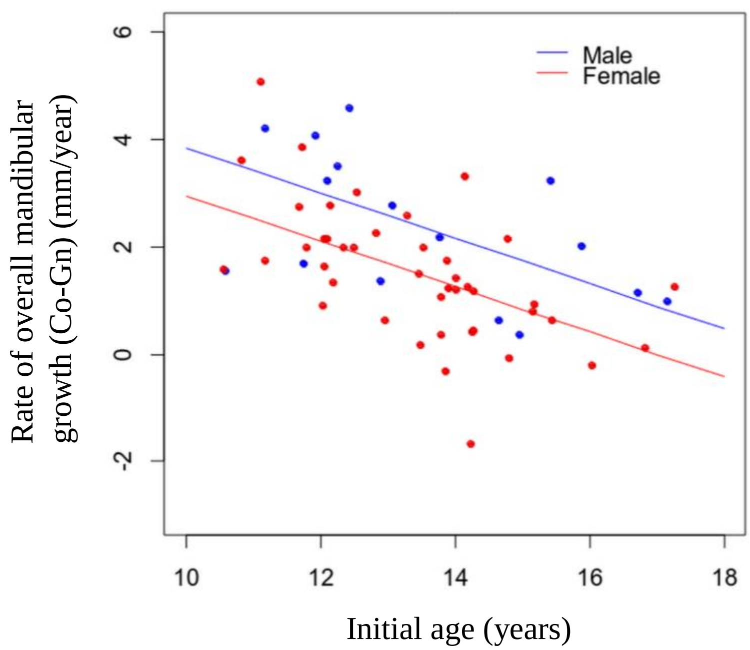


Figure V. Rates of mandibular growth by initial age and gender. Scatter plot with regression lines comparing rates of mandibular growth observed for both females and males, based on pre-treatment age.

ASSOCIATIONS BETWEEN CEPHALOMETRIC VALUES AND TMJ DIAGNOSES

Pre-Treatment Cephalometric Values vs. Pre-Treatment TMJ Diagnosis

Statistical analysis with one-way ANOVA was used to answer the following question: Is there an association between the pre-treatment RDC/TMD osseous diagnosis and the pre-treatment cephalometric characteristics of the subjects (**Table VI**)? When four categories were used for the diagnosis variable (normal, indeterminate/remodeling, DJD I, DJD II), no comparisons reached statistical significance.

However, the initial mandibular plane angle (FMA) approaches a statistically significant association with initial diagnosis ($p = .0684$). With Spearman correlation coefficients, treating the TMJ diagnosis as a continuous variable, the initial FMA is moderately correlated with the initial diagnosis ($r = .3009$, $p = .0206$). Thus, increased mandibular plane angle may be associated with a worse diagnosis.

Like FMA, the initial Wits appraisal approached statistical significance using one-way ANOVA ($p = .0731$) in relation to initial TMJ diagnosis. With Spearman correlation coefficients, the initial Wits appraisal was moderately correlated with initial diagnosis ($r = -0.3327$, $p = 0.01$). As the TMJ diagnosis worsened, the Wits appraisal decreased, indicating a possible association between skeletal Class III type and DJD.

This is consistent with the trend seen for ANB angle. Progressing from the normal to the DJD II diagnostic groups, there was a trend toward reduction in the ANB angle. The normal group had a mean of 3.57° while the DJD group had a mean of 2.65°, although there was no statistically significant difference among the four diagnostic groups ($p = 0.6225$). The mean ANB angle of the entire sample was 3.03° (SD = 1.95), which indicates a slightly greater Class II tendency than the generally accepted normative value published by Steiner (2°).[78]

Dental relationships were not studied extensively. However, in agreement with the statistically insignificant trend seen for ANB angle, patients in the DJD II group had the highest mean overjet at 5.47 mm, while the mean of the normal diagnosis group was 4.04 mm. There was no statistically significant difference among the groups ($p = .1309$).

Because it may be more clinically relevant to identify the presence of DJD rather than the severity, these data were also grouped and analyzed in different ways. A separate one-way ANOVA was performed with three diagnostic categories, combining DJD I and DJD II into one group. With this analysis, the initial FMA reached statistical significance ($p = 0.0336$), as did the initial Wits appraisal ($p = 0.0459$).

Furthermore, since the indeterminate diagnosis is not considered pathologic, a two-category analysis was performed that looked at only the presence or absence of DJD. In this analysis, normal and indeterminate groups were combined and compared to the combined DJD I and DJD II group. Initial FMA ($p = 0.0122$) and initial Wits appraisal ($p = 0.0371$) reached further levels of statistical significance. The pre-treatment overbite also approached statistical significance ($p = 0.0772$), with the normal group having slightly increased overbite when compared to the DJD group. The trend of increasing overjet with worsening diagnosis that was seen with the four-category analysis disappeared in the two-category analysis, with almost no difference (and certainly no statistically significant difference) between the groups.

A	All Subjects (N=59)	Initial Diagnosis				P-value
		Normal (N=15)	Remodeling (N=23)	DJD I (N=15)	DJD II (N=6)	
Initial FMA	23.25 ± 4.70	21.45 ± 3.86	22.57 ± 4.26	25.67 ± 5.68	24.32 ± 3.70	0.0684
Initial Wits	-0.98 ±3.05	0.44 ± 2.59	-0.90 ± 2.83	-2.47 ± 3.16	-1.15 ± 3.63	0.0731
Initial ANB	3.03 ± 1.95	3.57 ± 1.06	2.99 ± 2.08	2.71 ± 2.28	2.65 ± 2.47	0.6225
Initial OB	3.61 ± 1.61	3.55 ± 1.85	4.11 ± 1.46	2.98 ± 1.47	3.45 ± 1.66	0.2050
Initial OJ	4.21 ± 1.65	4.04 ± 1.07	4.36 ± 1.74	3.65 ± 1.69	5.47 ± 1.99	0.1309

B	All Subjects (N=59)	Initial Diagnosis			P-value
		Normal (N=15)	Remodeling (N=23)	DJD (N=21)	
Initial FMA	23.25 ± 4.70	21.45 ± 3.86	22.57 ± 4.26	25.29 ± 5.14	0.0336*
Initial Wits	-0.98 ± 3.05	-0.98 ± 3.05	0.44 ± 2.59	-0.90 ± 2.83	0.0459*
Initial ANB	3.03 ± 1.95	3.57 ± 1.06	2.99 ± 2.08	2.69 ± 2.27	0.4111
Initial OB	3.61 ± 1.61	3.55 ± 1.85	4.11 ± 1.46	3.11 ± 1.50	0.1197
Initial OJ	4.21 ± 1.65	4.04 ± 1.07	4.36 ± 1.74	4.17 ± 1.92	0.8371

C	All Subjects (N=59)	Initial Diagnosis		P-value
		Absence of DJD (N=38)	DJD (N=21)	
Initial FMA	23.25 ± 4.70	22.13 ± 4.09	25.29 ± 5.14	0.0122*
Initial Wits	-0.98 ± 3.05	-0.37 ± 2.79	-2.09 ± 3.27	0.0371*
Initial ANB	3.03 ± 1.95	3.22 ± 1.75	2.69 ± 2.27	0.3236
Initial OB	3.61 ± 1.61	3.89 ± 1.63	3.11 ± 1.50	0.0772
Initial OJ	4.21 ± 1.65	4.23 ± 1.50	4.17 ± 1.92	0.8817

Table VI. One-way ANOVA comparing pre-treatment cephalometric variables and pre-treatment TMJ diagnoses. Data shown are means ± standard deviations. Statistical significance ($p \leq 0.05$) is denoted by *. **A:** Analysis using 4 categories of TMJ diagnosis. **B:** DJD I and DJD II have been combined to yield 3 categories.
C: 2 category "Yes/no" diagnosis (normal + remodeling vs. DJD I + DJD II).

Pre-Treatment TMJ Diagnosis vs. Cephalometric Changes

It was also of interest to know if any relationships exist between the TMJ diagnosis and the pattern or direction of growth. To study this, the pre-treatment to post-treatment changes in cephalometric values were compared to the pre-treatment TMJ diagnosis using one-way ANOVA (**Table VII**). Change in overbite and overjet were not considered for this analysis since they are directly affected by orthodontic treatment. There was not statistical significance for any of the variables in this analysis, although there appeared to be some trends.

When using a four-category diagnosis, the normal group had the greatest reduction in ANB angle, with a general trend toward decreasing reduction as the TMJ diagnosis worsened; however, this is not significant ($p = .1894$). This trend approached statistical significance ($p = 0.0842$) when using a two-category diagnosis. Similarly, for the change in Wits appraisal, the normal group had a reduction from pre-treatment to post-treatment, indicating growth in the Class III direction. There was no statistically statistical association among the four diagnostic groups, though ($p = 0.4556$).

The change in FMA also did not have a statistically significant association with the initial TMJ diagnosis for any of the analyses (all $p \geq 0.2777$). However, in the three-category analysis, the mean of the normal group indicated flattening of the mandibular plane from pre-treatment to post-treatment, whereas the means of the other diagnostic groups indicate steepening of the mandibular plane.

A	All Subjects (N=59)	Initial Diagnosis				P-value
		Normal (N=15)	Remodeling (N=23)	DJD I (N=15)	DJD II (N=6)	
FMA Change	0.08 ± 1.42	-0.27 ± 0.97	0.07 ± 1.46	0.55 ± 1.75	-0.12 ± 1.31	0.4569
Wits Change	0.34 ±2.64	-0.57 ± 1.96	0.80 ± 2.33	0.61 ± 3.39	0.12 ± 3.24	0.4556
ANB Change	-0.16 ± 1.17	-0.58 ± 1.08	-0.22 ± 1.25	0.35 ± 1.17	-0.20 ± 0.81	0.1894

B	All Subjects (N=59)	Initial Diagnosis			P-value
		Normal (N=15)	Remodeling (N=23)	DJD (N=21)	
FMA Change	0.08 ± 1.42	-0.27 ± 0.97	0.07 ± 1.46	0.36 ± 1.63	0.4294
Wits Change	0.34 ± 2.64	-0.57 ± 1.96	0.80 ± 2.33	0.47 ± 3.27	0.2892
ANB Change	-0.16 ± 1.17	-0.58 ± 1.08	-0.22 ± 1.25	0.19 ±1.09	0.1463

C	All Subjects (N=59)	Initial Diagnosis		P-value
		Absence of DJD (N=38)	DJD (N=21)	
FMA Change	0.08 ±1.42)	-0.07 ±1.29)	0.36 ± 1.63)	0.2777
Wits Change	0.34 ± 2.64)	0.26 ± 2.27)	0.47 ± 3.27)	0.7720
ANB Change	-0.16 ± 1.17)	-0.36 ± 1.19)	0.19 ± 1.09)	0.0842

Table VII. One-way ANOVA comparing pre-treatment to post-treatment cephalometric changes and pre-treatment TMJ diagnoses. Data shown are means ± standard deviations. Statistical significance ($p \leq 0.05$) is denoted by *. **A:** Analysis using 4 categories of TMJ diagnosis. **B:** DJD I and DJD II have been combined to yield 3 categories. **C:** “Yes/no” diagnosis (normal + remodeling vs. DJD I + DJD II).

Pre-Treatment Cephalometric Values vs. Change in TMJ Diagnosis

A third question that can be asked regarding the associations between skeletal types and TMJ diagnoses is the following: Can initial cephalometric values be used to predict improvement or worsening of the TMJ diagnosis over the course of orthodontic treatment?

To do this, the change in diagnosis from pre-treatment to post-treatment was recorded as a whole number denoting the number of categories by which the TMJ diagnosis worsened (+1, +2 or +3), remained the same (0) or improved (-1, -2, -3). Spearman correlation coefficients were used to compare ANB angle, FMA and Wits appraisal values at pre-treatment to the number of categories by which the TMJ diagnosis changed from pre-treatment to post-treatment. For all three variables, no relationships were found (all $p \geq 0.6312$).

One-way ANOVA was also performed with these data (**Table VIII)**. Tendencies toward worsening of the diagnosis were seen with increasing mandibular plane angle and increasing Class II features (less negative Wits appraisal, greater ANB angle and increasing overjet), however none of the comparisons were statistically significant. Thus, for the population studied, no specific cephalometric characteristics were found to be associated with either improvement or worsening of the TMJ diagnosis over the course of comprehensive orthodontic treatment.

	All Subjects (N=59)	Change in Diagnosis			P-value
		Worsen (N=18)	No Change (N=28)	Improve (N=13)	
Initial FMA	23.25 ± 4.70	23.47 ± 5.25	23.38 ± 4.95	22.67 ± 3.50	0.8824
Initial Wits	-0.98 ± 3.05	-0.63 ± 3.07	-1.13 ± 2.57	-1.15 ± 4.06	0.8435
Initial ANB	3.03 ± 1.95	3.17 ± 1.88	3.13 ± 1.91	2.62 ± 2.21	0.6911
Initial OB	3.61 ± 1.61	3.56 ± 1.82	3.93 ± 1.31	3.02 ± 1.86	0.2498
Initial OJ	4.21 ± 1.65	4.49 ± 1.70	4.19 ± 1.64	3.88 ± 1.65	0.5986

Table VIII. One-way ANOVA comparing pre-treatment cephalometric values and pre-treatment to post-treatment changes in TMJ diagnoses. Data shown are means ± standard deviations. No comparisons reach statistical significance ($p \leq 0.05$).

Change in Cephalometric Values vs. Change in TMJ Diagnosis

Finally, analyses were conducted to compare changes in cephalometric values over the course of treatment to the change in TMJ diagnosis during the same period. This addresses the question of whether certain types or directions of growth influence the improvement or worsening of the radiographic appearance of the TMJs.

Treating the change in diagnosis as a continuous variable, Spearman correlation coefficients found no relationship between the magnitude or direction of this change and the changes in cephalometric measures. Additionally, when the subjects were split into three groups (worsened, no change and improved TMJ diagnoses), one-way ANOVA showed the differences among the groups to be highly insignificant ($p \geq 0.6510$ for all variables; see **Table IX**). These data indicate the lack of relationship between differing growth patterns and changing RDC/TMD diagnosis over the course of orthodontic treatment.

	All Subjects (N=59)	Change in Diagnosis			P-value
		Worsen (N=18)	No Change (N=28)	Improve (N=13)	
Δ FMA	0.08 ± 1.42	0.06 ± 1.20	0.04 ± 1.65	0.22 ± 1.26	0.9331
Δ Wits	0.34 ± 2.64	0.01 ± 2.72	0.68 ± 2.76	0.06 ± 2.38	0.6510
Δ ANB	-0.16 ± 1.17	-0.11 ± 0.87	-0.14 ± 1.36	-0.30 ± 1.18	0.8940
Δ OB	-1.52 ± 1.69	-1.51 ± 1.89	-1.70 ± 1.63	-1.17 ± 1.62	0.6572
Δ OJ	-1.20 ± 1.82	-1.48 ± 1.99	-1.16 ± 1.76	-0.89 ± 1.80	0.6785

Table IX. One-way ANOVA comparing pre-treatment to post-treatment cephalometric changes and pre-treatment to post-treatment changes in TMJ diagnoses. Data shown are means ± standard deviations. No comparisons reach statistical significance ($p \leq 0.05$).

ASSOCIATIONS BEWEEN GROWTH AND TMJ DIAGNOSES

To study associations between TMJ diagnoses and growth and development, both growth predictors and measured mandibular growth were utilized. Two growth predictors, age and CVM stage, were used in the study. The pre-treatment age was not associated with the pre-treatment TMJ diagnosis, irrespective of the number of categories used for the TMJ diagnosis (all $p \geq 0.2497$). This was also true for the pre-treatment CVM stage. However, when the two-category diagnosis was used, the initial CVM stage approached statistical significance ($p = 0.1030$), with the DJD group having a mean stage of 4.44 and the non-DJD group having a mean of 3.78.

In terms of mandibular growth, there were no statistically significant associations using one-way ANOVA, either by growth rate (mm/year) or absolute growth (**Table X**). Despite the lack of statistical significance, the normal diagnosis group had the greatest rate of growth for total mandibular length (Co-Gn change of 2.15 mm/year), and this rate decreased as the pre-treatment TMJ diagnosis worsened. However, there were no associations between initial diagnosis and the change in Co-Gn, Co-Go or Go-Pg using Spearman correlation coefficients. Thus, patients who were actively growing (or grew at some point during treatment) were no more likely to have a particular initial TMJ diagnosis than those who did not grow.

	All Subjects (N=59)	**Initial Diagnosis**				**P-value**
		Normal (N=15)	**Remodeling (N=23)**	**DJD I (N=15)**	**DJD II (N=6)**	
Co-Gn Rate (mm/year)	1.75 ± 1.31	2.15 ± 1.36	1.79 ± 1.47	1.41 ± 1.11	1.40 ± 0.96	0.4240
Co-Go Rate (mm/year)	1.37 ± 1.20	1.56 ± 0.86	1.55 ± 1.39	0.96 ± 1.11	1.28 ± 1.39	0.4607
Go-Pg Rate (mm/year)	0.71 ± 0.83	0.81 ± 0.85	0.68 ± 0.96	0.84 ± 0.66	0.26 ± 0.49	0.5014

Table X. One-way ANOVA comparing pre-treatment TMJ diagnoses and rates of mandibular growth (mm/year) observed during orthodontic treatment. Data shown are means ± standard deviations. No comparisons reach statistical significance ($p \leq 0.05$).

ASSOCIATIONS BETWEEN GROWTH PREDICTORS AND OBSERVED MANDIBULAR GROWTH

The pre-treatment age and CVM stage were compared to the mandibular growth observed from pre-treatment to post-treatment. After adjusting for the treatment period, Pearson's partial correlation coefficients showed associations with both age and initial CVM stage. Initial CVM stage had moderately strong correlations with the changes in effective mandibular length (Co-Gn) and ramus length (Co-Go), and fair correlation with mandibular body length (Go-Pg). Initial age had a moderately strong correlation with the change in Co-Gn and fair correlations with changes in Co-Go and Go-Pg (**Table XI**).[79]

		Co-Gn Rate (mm/year)	Co-Go Rate (mm/year)	Go-Pg Rate (mm/year)
Initial Age	*r*	-0.5247	-0.4612	-0.3383
	p	<0.0001	0.0002	0.0088
	n	59	59	59
Initial CVM	*r*	-0.6585	-0.5428	-0.4741
	p	<0.0001	<0.0001	0.0003
	n	54	54	54

Table XI. Associations between growth predictors and observed rates of mandibular growth. Each cell contains the Pearson correlation coefficient, the respective p-value and the number of observations.

For all three measures of mandibular length, there was an inverse relationship between the initial CVM stage and the rate of growth between time points. The number of CVM stages through which a patient progressed from pre-treatment to post-treatment was also significantly positively associated with the mandibular growth measures. For cervical stages 1 through 5 (CS1-CS5), 95% confidence intervals showed growth of the mandible; for stage 6 (CS6), no significant growth was seen during the treatment period (**Figure VI**).

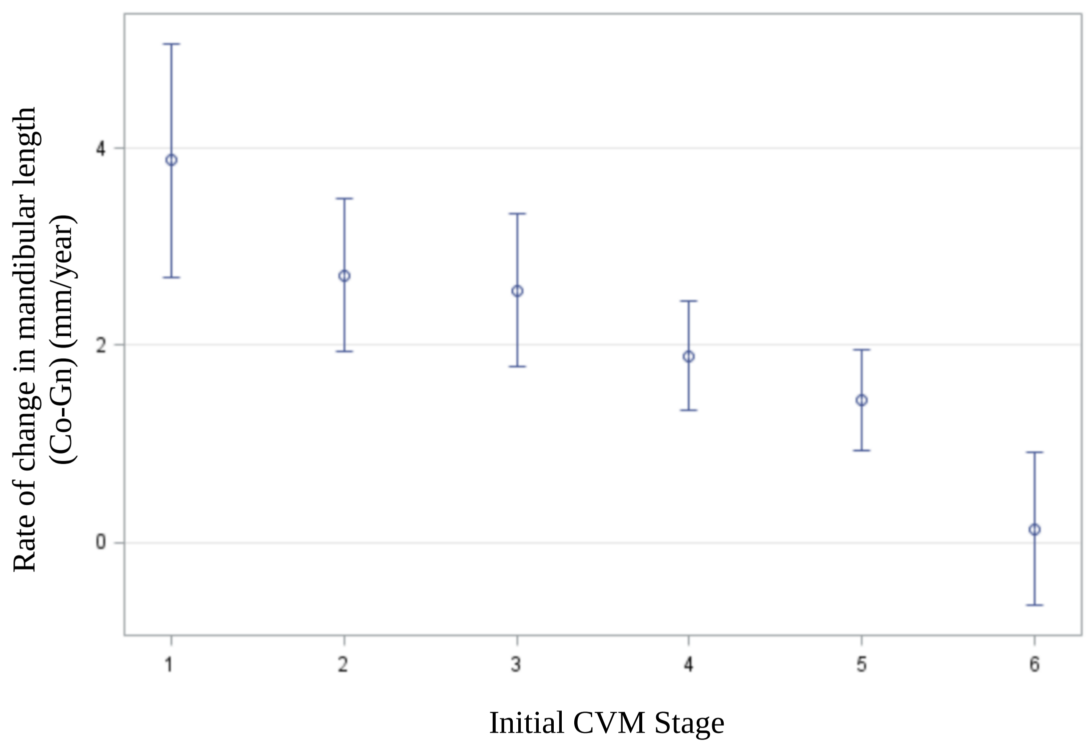


Figure VI. Relationship between pre-treatment CVM stage and mean rate of mandibular growth (Co-Gn; mm/year) during orthodontic treatment. 95% confidence limits are shown.

DISCUSSION

Associations between Cephalometric Values and TMJ Diagnoses

Correlation coefficients for the repeated measures were in the high or very high ranges (≥0.70) for all of the cephalometric variables, indicating that the primary investigator was consistent in landmark identification. The lowest values were for initial overbite and final overjet, which is likely explained by difficulties in identifying the lower incisor tip due to excessive overbite at pre-treatment and incisor coupling at post-treatment.

When considering the first aim of the study, which sought to identify relationships between cephalometric characteristics and the TMJ diagnosis prior to orthodontic treatment, several associations were noted. Perhaps the most significant was the association between increasing FMA and a worsening diagnosis. Spearman correlation coefficients indicated a statistically significant moderate correlation ($r = .3009$, $p = .0206$) between these variables. While one-way ANOVA did not show significant differences between diagnoses when four categories were used, the results were significant when DJD I and DJD II were combined.

Saccucci[53] reported increased condylar volume in patients with decreased mandibular plane angles. Presuming it would also lead to an increase in the surface area, an increased condylar volume may allow for better dispersion of forces. Since overloaded joints develop osteophytes in an effort to increase the surface area,[18,25] it is likely that condyles which initially have a greater surface area will be more resistant to degenerative changes. The findings of the current study do not disagree with this idea, although condylar volume was not measured to confirm it. It is plausible that subjects with higher mandibular plane angles have smaller condyles and are more likely to have a worse TMJ diagnosis.

Another relationship noted was a decrease in the pre-treatment Wits appraisal as the TMJ diagnosis worsened. This relationship was statistically significant with one-way ANOVA when considering both the three-category and two-category analyses, and was close to reaching statistical significance with a four-category diagnosis. With Spearman correlation coefficients, the initial Wits Appraisal showed a low negative correlation with initial diagnosis ($r = -0.3327$, $p = 0.01$).

The decreasing Wits appraisal along with worsening TMJ diagnosis points to a greater likelihood of having osseous signs of DJD in patients with a skeletal Class III relationship. This is consistent with some previous findings,[80,81] however it is at odds with others that have found associations between TMD and Class II occlusion and/or a retrognathic mandible.[4,8,46,82] Fernández Sanromán et al[7] compared Class II and Class III patients who were planned for orthognathic surgery to Class I controls. They found that Class II patients had a significantly higher incidence of clinically diagnosed TMD and internal derangement than Class I and Class III patients. However, as Almăşan et al[48] also found, the Wits appraisal for the DJD group of the current study had a greater standard deviation than the normal group, which may indicate that both decreased and increased Wits appraisals are associated with DJD. It is important to note that the study population’s mean Wits appraisal at pre-treatment was -0.98 mm (SD = 3.05), which is nearly identical to the published normative value for Caucasian males.[83] Given females have on average a less negative Wits appraisal (0 mm) and there were significantly more females studied than males, it is apparent that the population provided ample representation of the Class III skeletal type.

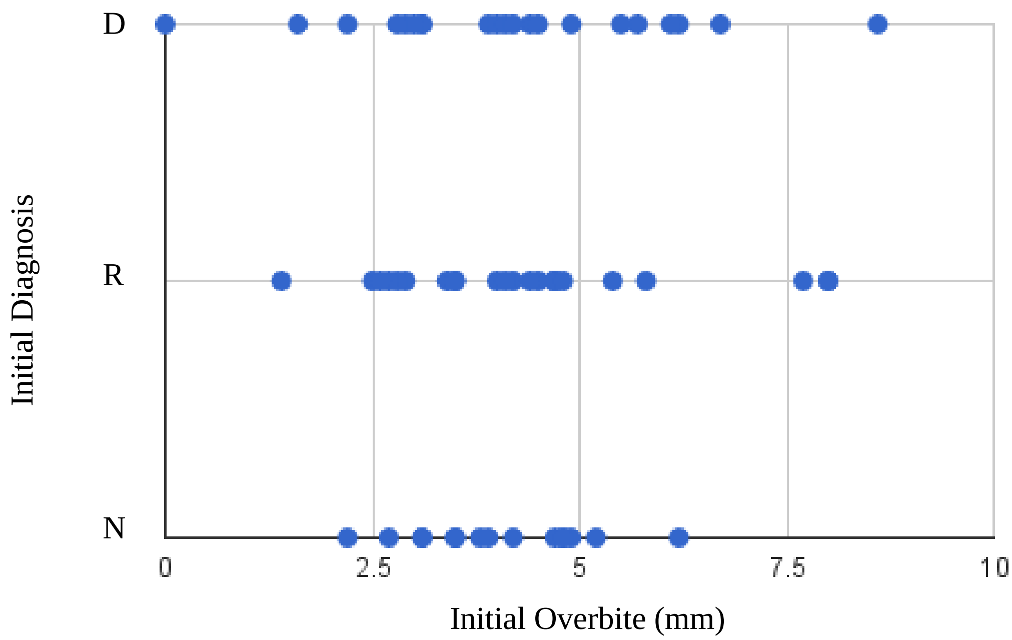
The results for ANB angle were similar to those for Wits appraisal. Although not statistically significant ($p = 0.6225$), there was a trend toward reduction in the ANB angle as the four-category TMJ diagnosis worsened. However, in contrast to the slight Class III tendency of the sample seen with the Wits appraisal, the mean ANB angle was 3.03° (SD = 1.95), which indicates a slightly more Class II tendency than Steiner's published normative value of 2°.[78] This draws attention to one weakness of cephalometric analysis, whereby different measures of the same characteristic can be at odds.[84] The ANB angle, for example, is affected by the position of nasion as well as the inclination of the occlusal plane.

While statistically significant relationships were found for both FMA and Wits appraisal, the differences among the different TMJ diagnoses were relatively minimal. When considering a three-category diagnosis, the normal group had a mean FMA of 21.45 (SD = 3.86) and the DJD I + DJD II group had a mean of 25.29 (SD = 5.14). For Wits appraisal, the normal group mean was 0.44 (SD = 2.59) and the DJD I + DJD II mean was -2.09 (SD = 3.27). Though it is reasonable to believe the associations seen do exist, the differences seen are not drastic enough to be used in a predictive manner. This idea provokes the following question: How much more likely are patients with significantly increased mandibular plane angles or highly negative Wits appraisals to have radiographic signs of DJD? Unfortunately, the size and distribution of the current sample does not permit useful analysis of this question.

For the dental relationships studied—overbite and overjet—there were no statistically significant findings. Despite the lack of statistical significance, when comparing all four categories for the TMJ diagnosis, the mean overjet of the DJD II group was largest (5.47 mm). Multiple studies have found associations between increased overjet and signs and/or symptoms of DJD, so this trend is not unexpected.[6,9,45,46,48,80] It does, however, disagree with this study's findings for Wits appraisal, which indicate greater predilection of DJD in Class III individuals. Initial overbite approached a statistically significant ($p = 0.0772$) relationship with the initial diagnosis when the two-category diagnosis was used. However, with the difference between the means being less than 1 mm (3.89 mm for the normal group, 3.11 mm for the DJD group), the trend is not of clinical relevance.

A downside of using ANOVA for these comparisons is that each group is represented by its mean, which negates the effects of extremes. Perhaps the extremes of both incisal relationships (large overjet vs. negative overjet and anterior open bite vs. deep overbite) are in fact associated with DJD diagnoses, but the means of the DJD group yield values consistent with the means of the normal group. The scatter plot of the data for initial overjet **(Figure VII**) indicates this may be the case, since the overjet measurements become more widely distributed as the diagnosis worsens. Despite this, the vast majority of patients in the DJD group had overjet measurements similar to those of the normal group, so there are clearly other factors involved.

A.



B.

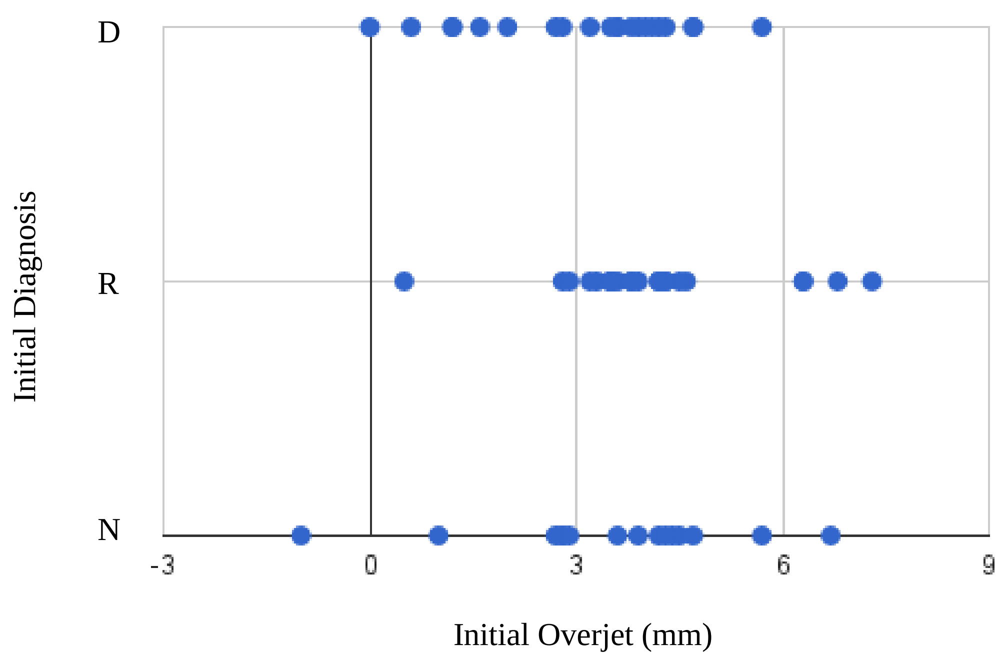


Figure VII. Pre-treatment TMJ diagnoses (N = normal, R = remodeling, D = DJD I + DJD II) compared to pre-treatment overjet (**A**) and overbite (**B**).

The scatter plots in **Figure VII** also point out that certain groups of patients may be present in the study population. Only one patient had an end to end anterior relationship, and no patients had an anterior crossbite at pre-treatment. Similarly, only one patient had an anterior open bite in this sample, and surprisingly, that patient had a normal initial TMJ diagnosis. Subjects with anterior open bite and/or negative overjet would likely fit the cephalometric profile (increased FMA, decreased Wits appraisal) this study found to be associated with worsening TMJ diagnoses. Therefore, a greater representation of these subjects in the population would be useful.

Along these lines, Krisjane et al[5] assessed CBCT images of the TMJs of Class I, severe Class II (mean ANB = 6.6°) and severe Class III (mean ANB = -4.4°) patients using the RDC/TMD guidelines from Ahmad et al.[3] They diagnosed osteoarthritis in only 3.3% of joints in Class I subjects, but in 20.4% of Class III subjects and 42.9% of Class II subjects, suggesting an association between OA and both extremes of horizontal skeletal relationships. Considering the population from Krisjane et al[5] was slightly older (mean age = 21.9 years) and comprised of three distinct morphological groups, it is difficult to make direct comparisons with the present study. Similar results would not be surprising, though, if the population in the present study was more heavily represented by subjects with significant deviations from normative values.

When comparing the initial RDC/TMD diagnoses to the cephalometric changes that occurred during the course of orthodontic treatment, there were no statistically significant findings. Despite this, there tended to be less reduction of the ANB angle and Wits appraisal as the initial osseous diagnosis increased. For Wits appraisal, patients with an initial normal TMJ diagnosis had a negative change (mean = -0.57 mm) and patients in the remodeling and DJD groups had a positive change (means of 0.80 mm for remodeling group, 0.61 mm for DJD I group and 0.12 mm for DJD II group). Thus, perhaps the patients with a greater horizontal direction of growth are more likely to have a normal TMJ diagnosis. With the exception of several subjects in the DJD group with negative changes in Wits appraisal, these trends are supported graphically **(Figure VIII)**.

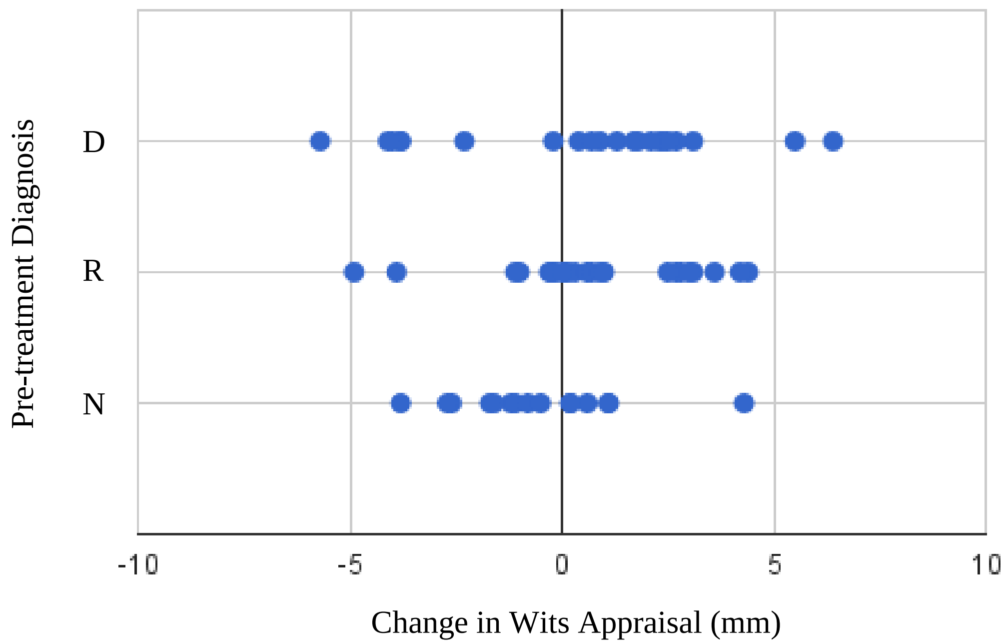


Figure VIII. Pre-treatment TMJ diagnoses (N = normal, R = remodeling, D = DJD I + DJD II) compared to the pre-treatment to post-treatment change in Wits appraisal.

In terms of FMA, patients with worse initial diagnoses tended to have increasing mandibular plane angles, but this difference did not reach statistical significance. With the exception of a single outlier in the DJD group with a significantly increased FMA, the scatter plot of these data (not shown) does not indicate a difference among the diagnostic groups.

It is possible that with a more diverse patient population, these trends would have been statistically significant. Even if that were the case, a cause and effect relationship could not be established regarding whether a patient's pattern of facial growth leads to radiographic signs of DJD or if the presence of degenerative changes alters the direction and/or pattern of growth. Regardless, the results of the current study show that an orthodontic patient with a particular pre-treatment TMJ diagnosis cannot be expected to grow differently from a patient with a different diagnosis throughout the course of orthodontic treatment.

Additionally, independent of the pre-treatment TMJ diagnosis, it appears as though comprehensive orthodontic treatment was not associated with considerable changes in skeletal cephalometric measures. The study population had varying treatment plans and there was no control over the treatment rendered, so it likely provides a realistic cross-section of orthodontic treatments. However, due to the nature of this study, it was not possible to utilize a group of orthodontically untreated controls to test this definitively.

The findings of Anderson's[1] investigation indicated that while slightly over half of the subjects' RDC/TMD diagnoses remained the same from pre-treatment to post-treatment, about a quarter worsened and a quarter improved. The present study was therefore interested in exploring whether the pre-treatment cephalometric findings could be used to predict which patients might show improvement or worsening in the TMJ diagnosis after orthodontic treatment. For pre-treatment FMA, ANB angle and Wits appraisal, no relationships were found. Similarly, no associations were found when comparing the pre-treatment to post-treatment changes in cephalometric variables to the changes to the RDC/TMD diagnosis. These analyses used either one-way ANOVA or Spearman correlation coefficients, and all p-values were highly insignificant (≥ 0.6117). Thus, at least on the basis of the cephalometric measures used in the present study, there is no way of distinguishing which patients' TMJs will respond favorably or unfavorably to orthodontic treatment. Considering the multi-factorial nature of TMDs, it can be assumed that a host of other factors are related to the bony changes that were seen in this study.

It is also of note that the cephalometric measures used in this study were limited. If additional measures had been included, it is possible that there would be findings of greater significance. However, associations involving obscure cephalometric measurements would be of little practical use to orthodontists, and analyzing a multitude of measurements would increase the odds of Type I error. For these reasons the cephalometric analysis was limited to some of the most commonly used orthodontic measures of horizontal and vertical relationships.

Furthermore, the diagnostic reliability and efficacy for the RDC/TMD have not been validated in growing patients such as the ones used in this study. Using CBCT images, Lei et al[85] found that the first sign of subchondral bone formation in the condyles was seen at ages 12 to 13 for females and 13 to 14 for males, and complete formation was not seen until age 21 for females and 22 for males. For the population in this study, Anderson[1] made diagnoses independent of the severity of the findings. Thus, it is quite likely that at least some of the patients in the study population diagnosed with sclerosis did not actually have sclerosis, but rather incomplete development of cortical bone.

Hussain et al[33] cite that changes to bony structures may be underestimated by imaging techniques, since a 30% change in mineral content is required before the change is seen on radiographs. In the current study, where the time between pre-treatment and post-treatment CBCTs was an average of about 2 years, some changes may have not have been detected. Moreover, some or all of the changes that were seen may not be of clinical relevance. It is well known that orthodontic treatment can induce severe transient malocclusions. Perhaps these transient malocclusions are able to initiate remodeling events that are detected upon completion of orthodontic treatment, but will spontaneously resolve in time.

Associations between Mandibular Growth and TMJ Diagnosis

Total effective mandibular length, ramal length and body length were all measured cephalometrically. When considering the rate (mm/year) or absolute change in these three variables from pre-treatment to post-treatment, there were no significant associations with the initial RDC/TMD diagnosis.

It did appear, however, that change in total effective mandibular length decreased with a worsening pre-treatment TMJ diagnosis, which would indicate an age- or maturity-related association with degenerative signs. Overall, though, this idea was not supported by the data, as neither pre-treatment age nor CVM stage was associated with the pre-treatment TMJ diagnosis in any of the analyses performed. However, one-way ANOVA using the two-category RDC/TMD diagnosis showed that the initial CVM stage for the DJD group was slightly higher than the normal group, a difference that approached statistical significance ($p = 0.1030$).

It is worth noting that the DJD II group had the greatest mean change in Co-Go length and the smallest change in Go-Pg length. This trend appears to indicate greater growth at the condyle than in normal subjects, which would be unexpected for patients with DJD. Furthermore, increasing ramal length would rotate the mandible counter-clockwise and decrease the FMA, an effect that was not seen in this study. Thus, it must be considered that in at least some instances, condyles with radiographic findings of DJD could instead be condyles that are actively growing.

However, there were no associations between initial diagnosis and the change in Co-Gn, Co-Go or Go-Pg using Spearman correlation coefficients. Patients who were actively growing (or grew at some point during treatment) were no more likely to have a particular initial TMJ diagnosis than those who did not grow. This appears to demonstrate that active growth at the condyle does not present itself in manner that consistently dictates a particular RDC/TMD diagnosis. This statement cannot be proven with the present study, though, since the exact timing of observed growth is unknown—only changes which occurred at some point between the pre-treatment and post-treatment CBCT images were measured.

Observed Mandibular Growth

As expected, males showed greater mandibular growth than females of the same age. Surprisingly, almost all the subjects showed some amount of mandibular growth during the course of treatment, even those who had a pre-treatment age approaching 18 years. Linear regression indicated that for females, Co-Gn growth was not complete until approximately age 17; for males, this age was beyond 18 years. These characteristics show the study population to be representative of an actively growing orthodontic patient population, confirming its appropriateness in relation to the present research.

Greater increases were seen for mandibular ramus lengths than for the mandibular body, with the mean annual growth of Co-Go (1.56 mm/year) nearly twice that of Go-Pg (0.81 mm/year). This suggests that growth at the condyle exceeded the rate of horizontal growth due to bone apposition along the posterior border of the ramus. Baumrind et al[86] studied the displacement of mandibular landmarks from metallic implants during growth, and found the amount of condylar displacement to exceed that of both gonion and the symphysis. From age 12.5 to 15.5, the mean annual displacement of the condyle was 2 mm. This is consistent with the current study, which noted a slightly lower rate of Co-Go growth but included subjects from age 10 to 19. While increases in Co-Go could also be due to inferior displacement of gonion, the posterior lower border of the mandible is an area of resorption.[58] Thus, increases in Co-Go must be a result of growth at the condyle, the true extent of which could be masked by superior movement of gonion as a result of resorption along the inferior mandibular border.

There were several subjects with small decreases in effective mandibular length from pre-treatment to post-treatment. Two potential explanations for this exist, the first being measurement error. Although the correlation coefficients for the measures of mandibular growth were all in the excellent range, only 20% of the radiographs were retraced to produce them. Errors in landmark identification could have been made in any of the remaining 80% of radiographs.

If this was the case, it is likely that the errors occurred in identifying condylion, which has greater inter-examiner and intra-examiner variation than many other cephalometric landmarks.[87] Because of this, many studies have used articulare as a substitute. However, while articulare has been shown to be reliable for determining overall mandibular length, it is not appropriate for measuring ramal length.[88] The lateral cephalograms used in the current study were extracted from CBCT images without magnification and imaging filters were used when tracing the radiographs, simplifying identification of condylion. For these reasons, condylion was used in this study rather than articulare.

Another explanation for decreasing mandibular length could be condylar resorption. In recent years, there has been interest in the development of anterior open bites seen with idiopathic condylar resorption in teenage girls ("cheerleader's syndrome"). Wolford and Cardenas[89] report that females with this condition generally have high occlusal and mandibular plane angles and Class II relationships.

Further review of the subjects with decreased Co-Gn lengths (n = 4) shows that all were female. Of these, one had a significantly elevated FMA and another's TMJ diagnosis worsened by two categories and was accompanied by a Wits appraisal that became significantly more Class II over the course of treatment. Given these findings, these patients could certainly have undergone condylar changes resulting in decreased mandibular lengths. The other two patients had late CVM stages and changes in Co-Gn of only -0.1 mm and -0.2 mm, which suggests that they were not growing and the decreased mandibular lengths are instead a result of normal measurement error.

Validity of the CVM Method

A secondary aim of the study was to determine the reliability of the CVM method, as well as its accuracy in predicting patients with mandibular growth potential. Two raters scored every subject's pre-treatment and post-treatment radiographs on two separate occasions. Guidelines for interpretation of weighted kappa statistics show that the raters had substantial to near perfect intra-rater reliability; the same is true for inter-rater reliability at both time points.

For the radiographs which the raters did not give the same stage, the difference was generally by only one stage and never more than two stages. Additionally, these discrepancies were generally made in the later stages. This is consistent with Nestman et al's[72] findings that identifying the shapes of C3 and C4—crucial to proper identification of stages 4-6—is the most difficult and least reliable aspect of the CVM method. Nestman et al concluded that the CVM method is therefore unreliable. However, in terms of clinical usefulness, it can be argued that simply distinguishing between the early and late stages is relevant—either the patient has substantial or minimal growth potential.

The results of this portion of the study indicate moderately strong correlations between a subject's initial CVM stage and the rates of overall mandibular growth and ramal growth, with a slightly weaker correlation with the rate of mandibular body growth. When using the total amounts of growth rather than the rates of growth, all three coefficients are in the moderately strong range, with that of overall mandibular growth approaching very strong levels of correlation.

A limitation of these data is that it is not known at which point in time or between which CVM stages the observed growth occurred. The system developed by Baccetti et al[68] describes the peak growth velocity as occurring between stages 3 and 4; however, the present results simply show that the greatest observed growth occurred in patients with an initial CVM stage of 1 and that the growth decreased with each increase in initial CVM stage. Additionally, the greater the number of stages a patient passed through during the treatment time, the more growth that occurred. No significant mandibular growth was seen during the treatment period in the patients who had a CVM stage of 6 at the pre-treatment time point.

Previous studies have reported varying findings regarding the ability of the CVM method to predict growth in comparison to other methods of growth prediction. While chronological age has previously been reported to be a better predictor of mandibular growth than CVM stage,[73] the present study supports the opposite. Correlation coefficients for all three measures of mandibular length show that initial CVM is more strongly associated with total growth and rate of growth during treatment than is the initial age (**Table XI**). Regarding another growth prediction technique, Verma et al[90] concluded that vertical growth of the mandibular ramus cannot be predicted by growth assessment using hand-wrist radiographs. The present study, however, did find a moderate correlation between the CVM stage at pre-treatment and the amount of mandibular ramus growth (Co-Go).

Overall, the results of this study validate the inverse relationship between CVM stage and mandibular growth potential. This supports the use of the CVM method as a tool to assess mandibular growth potential during orthodontic diagnosis and treatment planning, although because the correlations with growth are far from perfect it should not be used exclusively.

Determination of the cessation of mandibular growth is also of importance to orthodontists, especially for Class III patients. Superimposition of lateral cephalograms taken at least 6 months apart is the gold standard for determining completion of mandibular growth. The results of this study support the use of CS6 as a measure of growth completion, as on average, no significant growth was seen in patients at CS6 at pre-treatment. However, the sample was relatively small and there were still some patients in this category that had slight mandibular growth during treatment, so it cannot be considered as reliable as superimposition of serial cephalometric radiographs.

Additionally, the results show moderate to high intra-rater and inter-rater reliability for CVM stage identification. In this study, each rater read the article by Baccetti et al[68] and used the descriptions and examples provided as a reference. No further training or calibration was performed, although it is likely that these procedures would have resulted in even higher measures of reliability.

LIMITATIONS OF THE STUDY

Being a retrospective study of orthodontic patients, there was no untreated control group. Factors related to the treatment provided to each subject were also uncontrolled, so the sample includes cases with and without extractions, use of rubber bands, headgear and various treatment mechanics. However, this lack of control means that the sample population likely includes good representation of treatment modalities for non-surgical, comprehensive orthodontics.

The data used for TMJ diagnoses was pre-existing, and findings were recorded irrespective of severity (consistent with the guidelines by Ahmad et al[3]). This, in addition to the presence of physiologic remodeling that occurs in growing individuals, may have inflated the numbers of subjects presenting with radiographic “abnormal” findings.

Furthermore, no clinical correlations were made. Prior research has yielded conflicting evidence regarding the association between clinical and radiographic evaluations. Using two methods of analysis, one being the guidelines from Ahmad et al,[3] Palconet et al[91] found poor correlation between clinical signs and symptoms of TMJ OA and osseous changes seen with CBCT imaging in subjects presenting for TMD treatment. These findings conflict with the findings of Su et al,[92] who reported a moderate positive correlation ($r = 0.561$, $p \leq 0.0001$) between Helkimo’s Di score (a clinical index of TMD) and condylar bony changes detected on CBCT images in patients diagnosed with TMJ OA using the RDC/TMD. However, both these studies utilized mostly adult populations. Inclusion of clinical signs and symptoms of TMD as independent variables would be useful in determining which radiographic findings are of relevance in a population of pre-orthodontic adolescents such as in the present study.

As mentioned previously, the sample population has limited representation of patients with anterior open bites and/or negative overjet. Since it appears that patients with these presentations could be more likely to have radiographic signs of DJD, greater representation in the sample would be beneficial.

CONCLUSIONS

Primary aims of the study were to: (1) to identify relationships between cephalometric characteristics and the RDC/TMD osseous diagnosis in a pre-orthodontic adolescent population; (2) to identify relationships between the changes in cephalometric characteristics and osseous diagnoses before and after comprehensive orthodontic treatment; and (3) to identify relationships between the osseous diagnosis and growth of the mandible during orthodontic treatment. A secondary aim of the study was to evaluate the reliability of the CVM method and its accuracy in identifying mandibular growth potential. With regard to these goals, the following conclusions were made:

1) Patients with skeletal Class III types or steep mandibular planes, as determined by Wits Appraisal and FMA, were more likely to have worse RDC/TMD osseous diagnoses prior to orthodontic treatment. However, in the present population, the differences seen were not large enough to be clinically relevant.
2) There was no association between patients' pre-treatment cephalometric values or the changes to them during orthodontic treatment, and the change in RDC/TMD diagnosis from pre-treatment to post-treatment.
3) The pre-treatment RDC/TMD diagnosis was not associated with the rate or total amount of mandibular growth during the observation period.
4) The pre-treatment CVM stage was inversely related to the rate and total amount of mandibular growth observed during orthodontic treatment. Additionally, these correlations were higher than for pre-treatment age.

FUTURE DIRECTIONS

A major concern with the radiographic diagnostic criteria used in this study is their usefulness in growing patients. The screening population in Anderson's[1] study had only a small percentage of subjects with radiographically "normal" TMJs, although it was likely that the majority did not have clinical signs or symptoms of TMD. Additionally, in the present study no associations were found between mandibular growth and the RDC/TMD diagnosis. Thus, what is "normal" for this age group? Clinical correlations with these data would allow for a better understanding, and such data may warrant revisions to image analysis guidelines for growing subjects.

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