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The Transverse Dimension: Diagnosis and Relevance to Functional Occlusion

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Summary

Much focus of orthodontic diagnoses is placed on the sagittal and vertical dimensions. However, a proper evaluation of the transverse dimension must also have equal importance. Research has shown that interferences from an exaggerated Curve of Wilson due to a maxillary transverse deficiency play a role in centric relation (CR)/Central occlusion (CO) discrepancies, adverse periodontal stresses, and craniofacial development. This article illustrates three scientifically validated methods for evaluating the transverse dimension: Ricketts' P-A cephalometric analysis, Andrews' Element III analysis, and the University of Pennsylvania Cone-Beam CT Transverse analysis. The aim is to show methods using traditional cephalometry, study models, and cone-beam computed tomography, not to compare one method to another. The reader must then choose to use the method that is most appropriate for his practice.

Introduction

The goals of orthodontic treatment are well established for static and functional occlusal relationships. In order to achieve Andrews' six keys to normal occlusion for the dentition,[1] the jaws must be optimally proportioned in three planes of space and positioned in CR. Orthodontists have well-established methods for diagnosing the skeletal relationship of the maxilla to the mandible in the sagittal and vertical dimensions.[2–6] Several analyses for the transverse dimension are also available,[3,6,7] but these analyses are not well accepted as forming part of traditional orthodontic diagnosis.

In the sagittal dimension, when the jaws do not relate optimally, the dentition will attempt to compensate, resulting in excessively proclined or retroclined anterior teeth.

In the transverse dimension, when the jaws do not relate optimally, usually due to a deficiency in the width of the maxilla,[7,8] the teeth will erupt into a crossbite or reconfigure their inclinations to avoid a crossbite. This compensation typically involves lingual tipping of the mandibular posterior teeth, which are then described as being excessively negatively inclined. In addition, the maxillary posterior teeth are tipped facially. These teeth are then described as being excessively positively inclined (Figure 1).
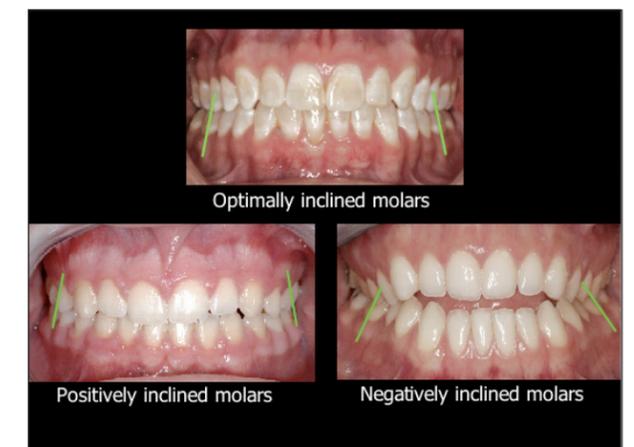

Figure 1 *Example of excessive tooth angulations.*

Transverse Deficiency and CR/CO Discrepancy

In the prosthodontic literature, these transverse tooth compensations have been graphically illustrated with a cross-arch arc constructed through the buccal and palatal cusps of

the maxillary molars. This is known as the curve of Wilson. With excessive inclination of the maxillary molars to compensate for insufficient maxillary width, the curve of Wilson is greatly exaggerated, and the palatal cusps are positioned below the buccal cusps (Figure 2).
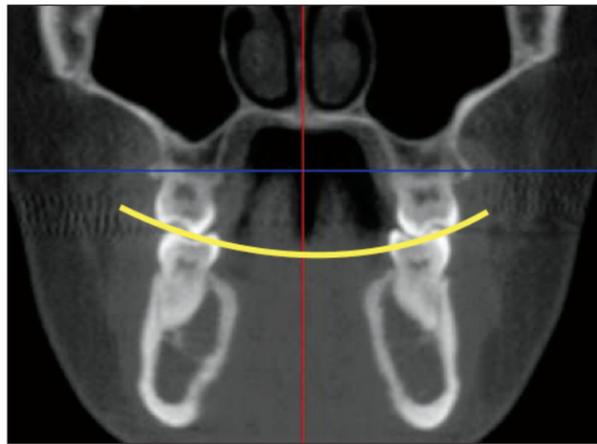

Figure 2 An exaggerated curve of Wilson (note palatal cusps below buccal cusps).

Many articles that describe the impact of CR/CO discrepancies on occlusion focus on how these discrepancies affect diagnosing the sagittal and vertical dimensions. The literature has suggested that the "plunging" palatal cusps shown in Figure 3 are often the primary contacts that induce vertical condylar distraction on closure from CR. From a seated condylar position, the patient may fulcrum off the premature contacts of the terminal molars to obtain the maximal intercuspal position. The Panadent Condylar Position Indicator (CPI) and the SAM Mandibular Position Indicator (MPI) graphically identify this vertical component of condylar distraction.[9-12]
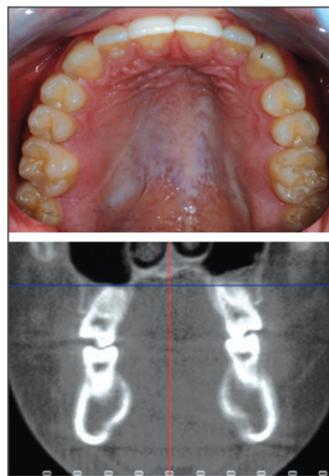

Figure 3 Note plunging palatal cusps and extreme curve of Wilson on molars of an arch that was expanded with arch wires and brackets only.

According to McNamara and Brudon,[13] "the orientation of the lingual cusps of the maxillary posterior teeth… often lie[s] below the occlusal plane… This common finding in patients with malocclusion often is due to maxillary constriction and subsequent dentoalveolar compensation in which the maxillary posterior teeth are in a slightly flared orientation." The results of a study by McMurphy and Secchi[14] indicate that vertical distraction of the condyles in CR/CO discrepancies can be related to an exaggerated curve of Wilson, secondary to a transverse deficiency of the maxilla. These authors conclude that in the absence of a posterior crossbite, the plunging palatal cusps and exaggerated curve of Wilson become the fulcrum point for the vertical condylar distraction from CR to maximum intercuspation. Furthermore, extrapolation of this statement suggests that if the transverse skeletal dimension is normalized, the curve of Wilson is flattened and the arches are coordinated, an important component of the CR/CO discrepancy is eliminated.

Transverse Deficiency and Working/Nonworking Interferences

It has been a prosthetic maxim that an exaggerated curve of Wilson increases the potential for working and non-working side interferences. Studies have shown that posterior occlusal contacts or interferences are linked to increased masticatory muscle activity.[15,16] In studies where these interferences have been removed, it has been demonstrated that the activity of the closing musculature is reduced.[16,17] In addition, a study that artificially created non-working interferences reported increased muscle activity.[18] These results suggest that it is prudent to normalize the transverse jaw relationship and flatten the curve of Wilson to eliminate the potential for excursive posterior interferences or contacts.

Transverse Deficiency and the Periodontium

Herberger and Vanarsdall[19] have shown an increased risk for gingival recession in the orthodontic patient with a narrow maxilla when the skeletal transverse issue is camouflaged with dental expansion. The envelope of treatment in the transverse, with expansion of only the dentition, is more limited than the envelope of treatment in the sagittal dimension.[20] Due to the constraints of the thin layer of cortical bone of the alveolus, as shown in Figure 4 [see next page], very little tooth movement needs to occur before the roots are fenestrated, the volume of buccal alveolar bone is reduced, and, with thinning gingival tissues, the risk of gingival recession increases.

In recent studies, Harrell[21] and Nunn and Harrell[22,23] have shown that the elimination of working and nonworking interferences enhances the long-term periodontal prognosis in patients susceptible to periodontal disease. Therefore, normalizing the transverse jaw relationship to eliminate an exaggerated curve

Figure 4 Patient with gingival recession due to orthodontic treatment in the presence of an undiagnosed severe skeletal transverse discrepancy. Note minimal alveolar bone on the buccal surface of the maxillary molars.

of Wilson and nonworking interferences would be beneficial for adult patients who are periodontally at risk, and might prophylactically reduce the risk for younger patients.

Transverse Deficiency and the Airway

Ricketts' description of "adenoid facies"[24] also suggests a relationship between a constricted nasopharyngeal airway and a narrow maxilla. Ricketts states children with any impairment of the nasal passages become predominantly mouth breathers. Since the tongue is positioned in the floor of the mouth to allow airflow, it cannot provide support to shape the developing palate; thus pressure from the circumoral musculature acts unopposed. The palate is narrowed, and an exaggerated curve of Wilson develops upon tooth eruption. Because the tongue is positioned low in the mouth, the patient may also develop a retruded, high-angle mandibular shape, which can increase the risk for sleep apnea.[25] An example of adenoid facies is shown in Figure 5.
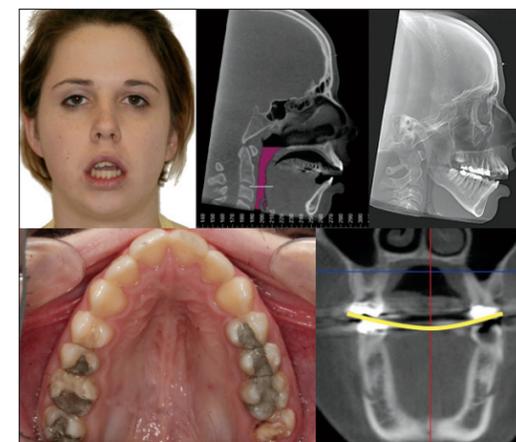

Figure 5 Patient with adenoid facies and corresponding dental, skeletal, and airway features.

In one recent study,[26] patients with transverse deficiencies due to a narrow maxilla who were treated with rapid palatal expansion, showed an increase of 8% to 10% in the volume of the upper airway. In another study,[27] patients with dental posterior crossbites who were treated with palatal expansion also showed an increase in the volume of the upper airway. Oliveria de Felippe, et al[28] found that palatal expansion decreased nasal resistance and improved nasal breathing. While additional research in this area is certainly needed, the current literature suggests that any improvement in the volume of the airway, as an effect of palatal expansion to optimize the transverse dimension of the jaws, may greatly benefit overall growth and development.

Methods of Transverse Diagnosis

With a transverse deficiency due to a narrow maxilla, the temporomandibular joints, musculature, periodontal tissue, and airway can be adversely affected in the susceptible patient. Our goal as orthodontists should be to develop skeletal relationships and a functional occlusion that are as close to optimal as possible, to lessen the role that any discrepancies of the occlusion would play in exacerbating the detrimental effects to the joints, periodontium, or dentition. In order to achieve this, a correct skeletal and dental diagnosis in all three planes of space is mandatory.

In this section, we present three different methods for diagnosing the transverse dimension—one using traditional cephalometry, one using dental casts, and one using cone-beam CT (computed tomography). We do not endorse any one of these methods over the others; our purpose here is simply to describe all three methods, so that readers will be able to incorporate a transverse skeletal diagnosis into their practice, no matter what level of technology is available. Regardless of which of these methods one chooses, one still must keep optimal treatment goals in mind as a rationale to normalizing the transverse dimension (Figures 6 and 7).
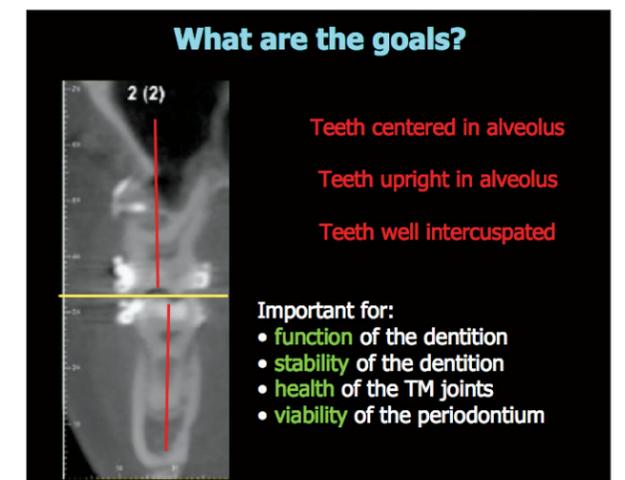

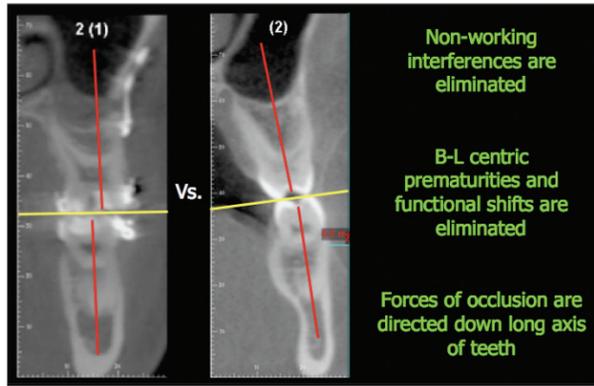*Figure 6 Goals for normalizing the transverse dimension.*

Figure 7 Rationale for normalizing the transverse dimension.

Ricketts' P-A Analysis

In 1969, Ricketts introduced analysis of the transverse skeletal dimension as part of his method of cephalometric diagnosis.[3] His method uses the frontal, or posteroanterior (P-A) cephalogram, and is based on the dimensions of the jaws compared to a table of age-adjusted normative values. The premise of the analysis is based on locating two skeletal points to determine maxillary width and two additional skeletal points to determine mandibular width (Figure 8).
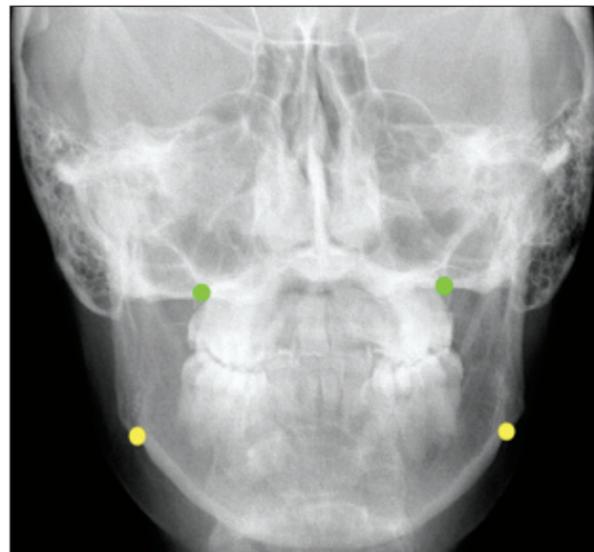

Figure 8 Locations of Mx (green) and Ag (yellow).

For the maxilla, the jugal point (Mx) is located on the right and left sides of the maxillary skeletal base at "the depth of the concavity of the lateral maxillary contours, at the junction of the maxilla and the zygomatic buttress."[3] The maxillary width is determined by the horizontal distance connecting these two points. For the mandible, a similar measurement is taken between the two antegonial notches (Ag). These notches are located on the right and left sides of the mandibular body at the "innermost height of contour along the curved outline of the inferior mandibular border,

below and medial to the gonial angle."[3]

Once the measurements have been taken, the mandibular width (Ag-Ag) is subtracted from the maxillary width (Mx-Mx) to get the difference in width between the jaws. Ricketts then determined skeletal age-determined normative relationships between the maxilla and the mandible (Figure 9). This allows the analysis to accommodate growing patients, and allows for the differential growth rates and potentials of the maxilla and the mandible.

AGE	MAXILLA	MANDIBLE	DIFFERENCE	RATIO
9	62.0 mm	76.0 mm	14.0 mm	81.6 %
10	62.6 mm	77.4 mm	14.8 mm	80.9 %
11	63.2 mm	78.8 mm	15.6 mm	80.2 %
12	63.8 mm	80.2 mm	16.4 mm	79.5 %
13	64.4 mm	81.6 mm	17.2 mm	78.9 %
14	65.0 mm	83.0 mm	18.0 mm	78.3 %
15	65.6 mm	84.4 mm	18.8 mm	77.7 %
16	66.2 mm	85.8 mm	19.6 mm	77.4 %

Figure 9 Table for determining the age-normal difference between the maxilla and the mandible.

In order to determine the skeletal age of a patient, a hand-wrist film is taken and is compared to an atlas of male and female skeletal age standards.[29] To determine the amount of expansion needed, the age-adjusted expected difference between the jaws is subtracted from the measured difference. An example of the Ricketts method is shown in Figure 10.

Figure 10 Example of Ricketts' P-A analysis.

Andrews' Element III Analysis

In 1970, L. F. Andrews published his landmark paper describing the six keys to normal static occlusion.[1] Over the next several decades, he and his son, W. A. Andrews, worked to develop the six elements philosophy of orthodontic diagnosis. One of the diagnostic criteria, Element III, is devoted to analyzing the transverse relationship of the maxilla and mandible and is based on both bony and dental landmarks.[10]

The Element III analysis is based on the assumption that the WALA (named after Will Andrews and Larry Andrews)

ridge determines the width of the mandible. According to Andrews' definition, the WALA ridge is coincident with the most prominent portion of the buccal alveolar bone, when viewed from the occlusal surface (Figure 11).

Figure 11 Demarcation of the WALA ridge.

The WALA ridge is essentially coincident with the mucogingival junction and approximates the center of resistance of the mandibular molars. In a mature patient, the WALA ridge and the width of the mandible cannot be modified with conventional treatment. Thus the WALA ridge forms a stable basis for the Element III analysis.[6]

The Element III analysis is based on the width change, if any, of the maxilla needed to have upper and lower posterior teeth upright in bone, centered in bone, and properly intercuspated. To determine the discrepancy, the first step is to determine the width of the mandible, or the horizontal distance from the WALA ridge on the right side to the WALA ridge on the left side. According to Andrews, optimally positioned mandibular molars will be upright in the alveolus, and their facial axis (FA) point, or center of the crown, will be horizontally positioned 2 mm from the WALA ridge. With this information, the width of the mandible is then defined as the WALA-WALA distance minus 4 mm.[6]

Figure 12 Determination of mandibular WALA-WALA and FA-FA distances.

The width of the maxilla is based on optimization of the angulation of the maxillary molars. To determine this width, one measures the horizontal distance from the FA point of the left molar to the FA point of the right molar and records the measurement.
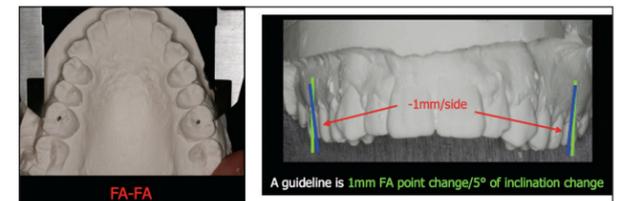

Figure 13 Determining maxillary FA-FA distance and estimating the change in maxillary molar inclination.

One then looks at the angulation of the maxillary molars and estimates the amount of horizontal change that will occur between the FA points of the right and left molars when they are optimally angulated. The estimated amount of change is subtracted from the original FA-FA measurement. The result represents the width of the maxilla.[6]

In order to have optimally positioned and optimally inclined molar teeth that intercuspate well, Andrews states that the maxillary width must be 5 mm greater than the mandibular width.[6] In order to determine the amount of transverse discrepancy, or Element III change, needed to produce an ideal result, one takes the optimal mandibular width, adds 5 mm, and subtracts the maxillary width. An example of the entire analysis is shown in Figure 14.

Figure 14 Example of Andrews' Element III transverse analysis.

University of Pennsylvania Cone-Beam CT Analysis

The trend in orthodontic imaging and diagnosis is toward three-dimensional analysis. With the advent of cone-beam imaging, orthodontists can obtain precise measurements without any distortion caused by radiographic projections or ambiguity of point identification. The same rationale can subsequently be applied to the transverse measurement of the maxilla and the mandible. Ricketts' and Andrews' methods for determining the amount of transverse discrepancy between the jaws are based on using readily discernable landmarks that represent the width of the base of the alveolar housing. For Ricketts, these landmarks are Mx-Mx for the maxilla and Ag-Ag for the mandible. For Andrews, these landmarks are the two sides of the WALA ridge and the FA points of the maxillary and mandibular molars. The WALA-WALA measurement represents the width of the mandible, and the FA-FA points are used, as described above, to determine the width of the maxilla. Both of these methods have merit. However, with cone-beam CT imaging, it is no longer necessary to have a measurement dictated by ease with which landmarks can be identified to represent the widths of the jaws.

Before choosing a method for measuring the base of the jaws, we must first decide what location to use for measurement. In determining the location of the WALA ridge, Andrews stated that the WALA ridge is an approximation of the center of resistance of the mandibular teeth. Above the WALA ridge, the alveolus can be dimensionally molded and altered, depending on the change in angulation of the teeth. However, the same cannot be said for the portion of the alveolus below the WALA ridge. Thus, in a mature patient, any portion of the alveolus apical to the WALA ridge can be assumed to be reasonably dimensionally stable during tooth movement, and, therefore, can define the dimensions of the patient's arch. In Ricketts' analysis, Ag-Ag represents the basal portion of the mandible. However, when one looks at the position of Ag on a three-dimensional image, one sees that its correlation with the base of the alveolus is relatively weak in all three planes of space for mature patients (Figure 15).
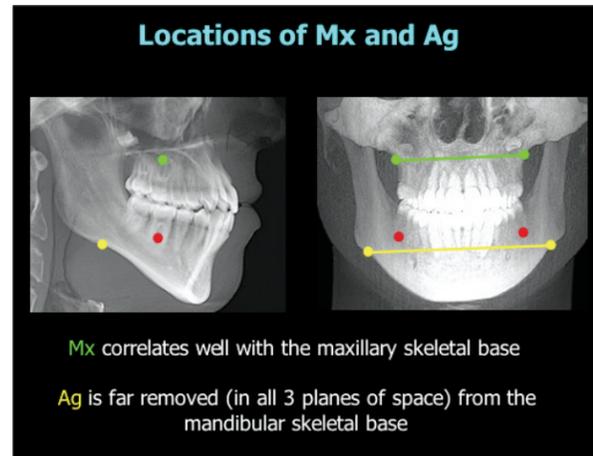

Figure 15 Correlations of Mx and Ag to skeletal bases in adults.

Thus, to locate the beginning of the base of the mandible with a CT scan, it would seem best to find the skeletal representation of the WALA ridge. This is approximately at the edge of the cortical bone opposite the furcation of the mandibular first molars. We can also use this technique to locate the beginning of the base of the maxilla. If we assume that the maxilla begins at the projection of the center of resistance of the maxillary teeth onto the buccal surface of the cortical bone, Ricketts' use of Mx to determine maxillary width appears to be at approximately at the same horizontal position. Additionally, by using Mx point, any exostoses present along the buccal portion of the alveolus will not interfere with the measurement. Andrews' method, on the other hand, has no directly definable skeletal landmark for the maxilla; it relies on estimated changes in the angulation of the molars to determine the skeletal transverse discrepancy. Therefore, Ricketts' method of defining the basal skeletal width of the maxilla appears to be more appropriate.

We begin, then, by defining locations for measuring maxillary and mandibular skeletal basal width. Next, we explore concepts for defining these locations on cone-beam CT imaging. The basic premise for the mandible is to locate the most buccal point on the cortical plate opposite the mandibular first molars at the level of the center of resistance. According to Katona, this location is approximately coincident with the furcation of the roots of the molars.[30] As we explained above, the authors chose this point due to the relative immutability of the alveolus apical to this location with orthodontics and because it represents the absolute minimal width of the basal bone for each jaw.

For the purposes of this technique, the authors used Dolphin 3D, release 11, but the concepts can be applied to any software with the capability to analyze a cone-beam CT image. After properly orienting the image, we open the multiplanar view (MPV) screen to see simultaneous axial, sagittal, and coronal cuts of the image.
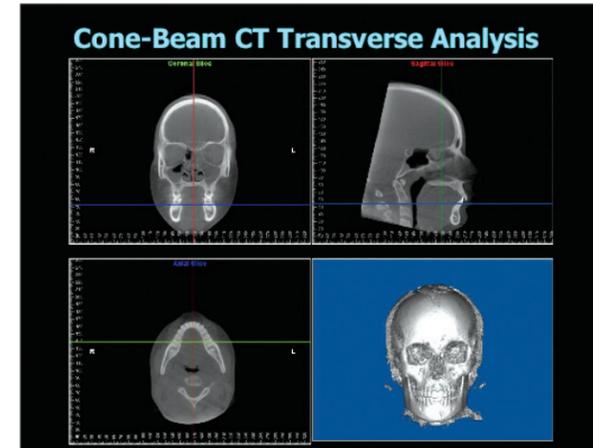

Figure 16 MPV of a cone-beam CT scan.

To determine the width of the mandible, we scroll down through the image until we locate the furcation of the first molar. Then we scroll posteriorly through the scan until we locate the coronal cross-section through the center of the mandibular first molars.
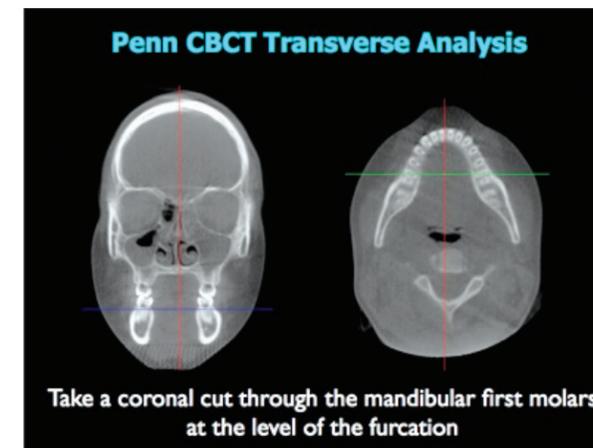

Figure 17 Location of the mandibular axial and coronal cuts.

Now we switch to full-screen axial view. Using the cut lines as a guide, we measure the width of the mandible from the intersection of the cut line with the most buccal portion of the cortical plate on both the right and left sides.
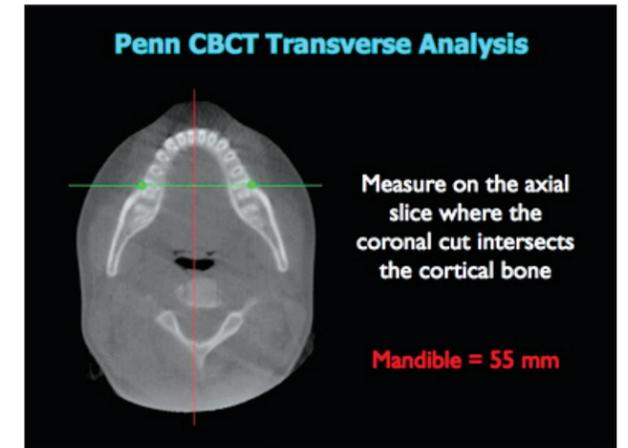
Figure 18 Measurement of mandibular skeletal width.

For the maxilla, a similar method is employed. The only difference is that the axial and coronal cuts must be taken at the position Mx-Mx, and the same measurement as in the Ricketts' analysis is used.

Figure 19 Measurement of maxillary axial and coronal cuts.

Figure 20 Measurement of maxillary skeletal width.

The analysis of the width of the maxilla and mandible at the level of the first molars is straightforward once we have taken the measurements of both jaws. By subtracting the

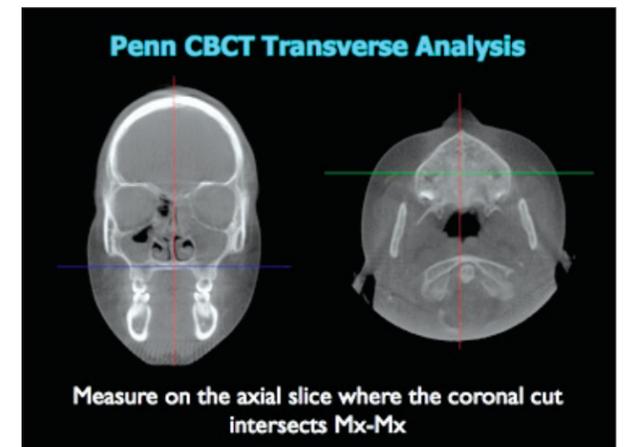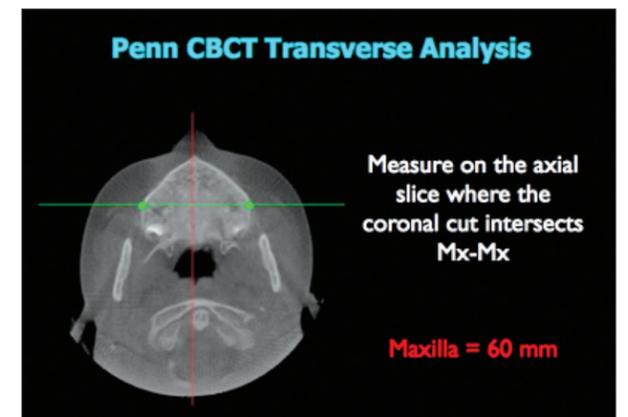mandibular width from the maxillary width, we determine the difference between the two jaws. Both Ricketts' and Andrews' analyses demonstrate that the optimal transverse difference between the maxilla and mandible is 5 mm in mature patients. A preliminary analysis of 5 cases where the maxillary and mandibular molars were upright in the alveolus, centered in the alveolus, and well intercuspated produced measurements where the difference between the width of the jaws approximated 5 mm on a consistent basis. Therefore, the seemingly ideal difference for the width of the jaws in mature patients using the Penn CBCT analysis would also appear to be 5 mm. To determine the amount of expansion necessary to achieve an ideal jaw relationship in the transverse dimension, the measured difference between the jaws should be subtracted from 5.
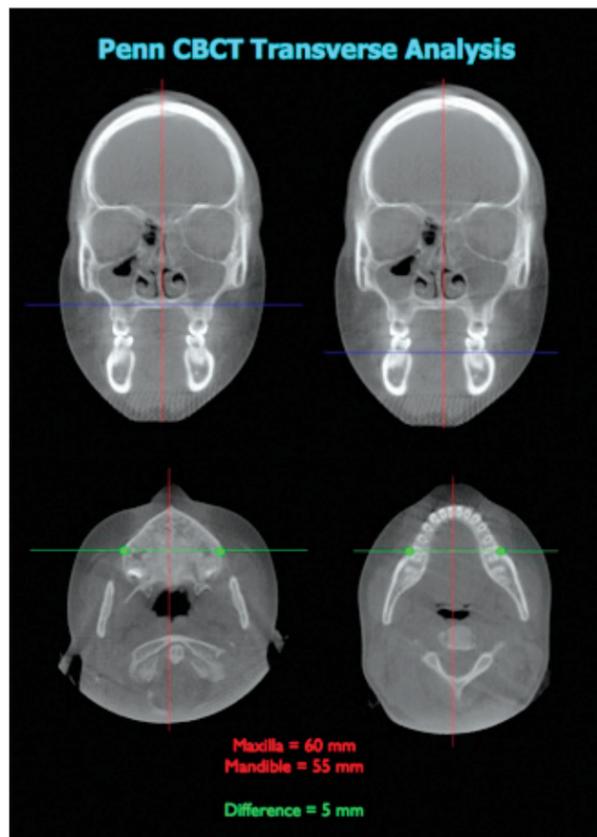

Figure 21 *Example of optimal transverse skeletal relationships using cone-beam CT analysis.*

Research performed by Simontacchi-Gbologah, et al[31], has verified the validity of the University of Pennsylvania CBCT analysis for the transverse diagnosis. However, the difference between the described method here and the method in the aforementioned research is that the measurements were taken on coronal cuts, not axial ones. Due to the cross section of the mandibular coronal cut being taken at an angle that is not perpendicular to the alveolus, a false perception of

the thickness of cortical bone is possible, as shown in Figure 22. Therefore, to reduce errors in judgment and to improve visualization of the most buccal portion of the cortical bone, the authors believe that the axial cut allows for greater precision of measurement over the coronal cross section.
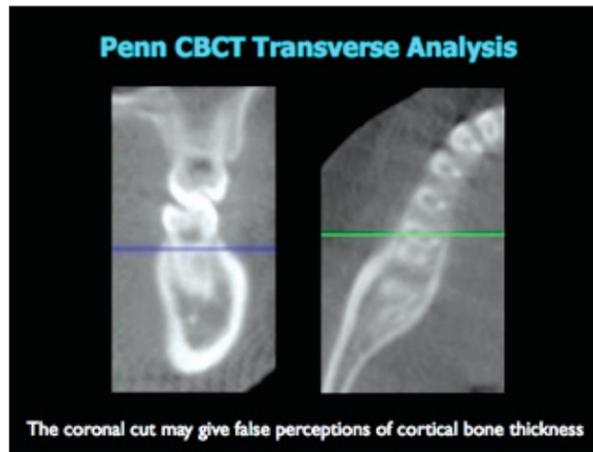

Figure 22 *Visualization of cortical bone thickness on coronal and axial cuts of the same patient*

Future Directions

Now that the methodology of the Penn CBCT analysis has been verified, the next goal will be to extrapolate the analysis to determine a diagnostic transverse relationship for the canines. With this, the goal will be to determine the appropriate arch form for proper stability and function on an individual basis. An additional study's aim will be to develop age-specific transverse normative criteria for Penn CBCT analysis, similar to Ricketts' norms for the P-A ceph. ∎

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Hinge Axis: The Need for Accuracy in Precision Mounting Part 2

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Summary

This is the second part of a two-part paper discussing the need for accuracy in the mounting of dental models for orthodontic diagnosis and treatment. Part 1 discussed the accuracy differences between an arbitrary hinge axis (AHA) mounting and a true hinge axis (THA) mounting. Part 2 discusses the differences between two popular true hinge axis recording devices, the Panadent Axi-Path system and the Axiograph III system.

The Axi-Path System

Many clinicians use the Panadent Axi-Path system for the following purposes: (Figure 17)
- To locate the true hinge axis (THA)
- To determine the sagittal anterior condylar path inclination, non-working-side sagittal lateral condylar path inclination, and the Bennett movement to select the Motion Analog Blocks
- To assess the functional structural conditions of the temporomandibular joint

Figure 17 *Axi-Path recording: Panadent Company.*

The upper head frame of the Axi-Path recorder is composed of two symmetrical arms that move around a hinge joint at the center of the frame (Figure 18). The upper frame is fitted and fastened to the head by tightening the hinge with a thumbscrew. A straight ruler can be used to make the two flag tables parallel to each other. (Figure 19).
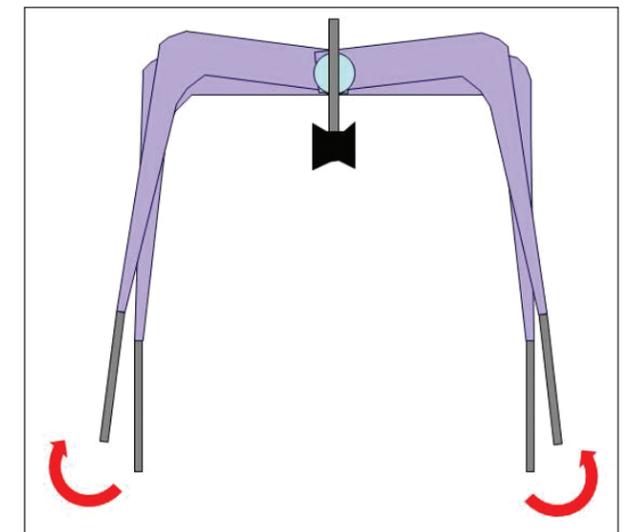

Figure 18 *Head frame (upper frame).*