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Evaluation of the Maxillary Skeletal Transverse Dimension in Untreated Orthodontic Patients

Andrew J. Ply
Medical University of South Carolina

"EVALUATION OF THE MAXILLARY SKELETAL TRANSVERSE DIMENSION IN UNTREATED ORTHODONTIC PATIENTS"

by:

Dr. Andrew J. Ply

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Department of Orthodontics

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Approved by:

Dr. Timothy J. Tremont
____
(Name of mentor)
Chairman Advisory Committee

Dr. Martin Steed
____
(Name of committee member)

Dr. Loring Ross
____
(Name of committee member)

Dr. Zachary Evans
____
(Name of committee member)

Evaluation of the maxillary skeletal transverse dimension in untreated orthodontic patients

Abstract

Introduction: Currently, there is no consensus in the orthodontic or OMFS literature regarding diagnosis of transverse dental arch discrepancies and to what extent discrepancies in underlying maxillary and mandibular transverse jaw dimensions are an etiology. In addition, there is an absence of discussion regarding possible differences in maxillary anterior versus posterior transverse jaw discrepancies. The purpose of this investigation was to: 1) evaluate a dental cast versus CBCT method for diagnosing skeletal transverse discrepancies, 2) assess whether dental cast or CBCT determined posterior transverse discrepancies differ from anterior transverse discrepancies, and 3) assess if any differences exist in skeletal transverse discrepancies between patients with Class I, II and III skeletal malocclusions. **Methods**: Retrospective data including intraoral scans of the maxillary and mandibular arches and CBCT scans were collected from 40 patients prior to orthodontic treatment. The sample was divided into CI (12 subjects), CII (18 subjects) and CIII (10 subjects) subgroups based on their skeletal anteroposterior diagnosis. Using maxillary and mandibular digital casts, dental arch widths were measured at the canines, first premolars and first molars and the measurements adjusted for optimal tooth inclinations. CBCT measurements were also made between the right and left first molars (M), first premolars (P) and canines (C) at the following vertical levels: 1) the estimated center of resistance of the tooth, 2) the root apices and 3) an estimated center of basal bone. Finally, a posteroanterior cephalogram was rendered from each subject's CBCT scan and the distance between right and left Jugale was compared to the distance between right and left Antegonion. The differences between maxillary and mandibular measurements (Δ) on the digital models, CBCTs and PA cephalograms were compared. **Results**: For the digital cast analysis Δ at each location (canine, premolar and molar) was significantly different, however, the average Δ for each location was not significantly different between subgroups. For the CBCT analysis, there were significant differences between each location ($p<.0001$) but no consistency between vertical points for each location. Additionally, the average Δ was significantly different between subgroups at each location, indicating no correlation. For the PA cephalogram analysis, no significant differences were found in the average skeletal widths or the average Δ between subgroups. We found no significant correlation between Δ at each location on the digital models and CBCTs. **Conclusions**: When maxillary skeletal transverse discrepancies are present, they often differ between the anterior and posterior. Transverse discrepancies were not significantly different between skeletal Class I, Class II and Class III subjects. No maxillary and mandibular skeletal landmarks were identified to assess transverse skeletal discrepancies. A dental cast analysis appears to be a more effective method for assessing transverse jaw discrepancies.

Introduction

Successful orthodontic treatment cannot be attained without a proper diagnosis of a patient's malocclusion. The correct diagnosis will dictate the clinical decisions made regarding treatment. Several methods have been proposed to assess the presence of a transverse discrepancy. Ricketts *et al* initially proposed a maxillomandibular transverse differential index, comparing the widths between the right and left jugale points and the right and left antegonial points on PA cephalograms[1]. The expected maxillomandibular difference, an established norm for different ages, is subtracted from the actual measured maxillomandibular difference. Vanarsdell *et al* later determined a maxillomandibular transverse differential index in excess of 5mm may indicate surgically assisted expansion[2,3]. Jugale and Antegonion have been widely used to assess maxillary and mandibular skeletal base width, respectively. Allen et al compared skeletal and dental arches of children with and without posterior crossbites and found that the difference between J-J and Ag-Ag alone accounted for only 4% of the variation in the difference between UM-UM and LM-LM[22]. There are inherent limitations associated with using Jugale and Antegonion to identify transverse discrepancies, namely the difficulty of reliably identifying them on a PA cephalogram. Jugale is not an anatomical structure, it is a constructed point that is subject to identification error due to superimposition of other anatomic structures, image magnification and projection errors. Additionally, these landmarks are arbitrarily selected to determine maxillary and mandibular skeletal base width, respectively, and may not accurately represent the transverse width of basal bone[4].

The term “basal bone” was first described in 1944 by Tweed as the bone over which the mandibular central incisors must be situated to minimize the propensity for post-orthodontic relapse[5]. It has since been described in the literature as the bone over which teeth should be positioned for optimal stability and periodontal health.

Post-treatment stability should be a major consideration when determining arch form. Other factors include efficiency, smile esthetics, cost, training and pretreatment arch form. There is no evidence in the literature of a universal arch form, or if it should routinely be changed[6]. This may in part be due to the difficulty in defining existing arch form, particularly when teeth are maloccluded, and the variation in arch form with facial shape, ethnicity and gender[7]. Commercial arch wires currently available range from five to eight forms and three to seven sizes, none of which routinely fit naturally occurring arch forms. The difference between the narrowest preformed arch form (G&H Bioform) and the widest (Damon) is 4-6mm per side in the bicuspid region, or 8-12 mm total[7]. Is such a large degree of bicuspid expansion stable? Davis and BeGole found after 20 years post treatment in non-extraction cases, 0.7mm net expansion in the first bicuspid area was stable and any more may be related to relapse of arch form[8]. The thickness of alveolar bone defines the boundaries of tooth movement, and any dental arch expansion past these limits may compromise the periodontium and post treatment stability. Because the vast majority of patients do not wear removable retainers long term and fixed retainers do not maintain posterior expansion, customizing the arch form to the individual patient is paramount.

There is little agreement among clinicians and researchers as to which landmarks should be used to shape archwires. In a study by Begole, one third of clinicians reported using the maxillary study model to choose the arch form for both upper and lower archwires[15]. Andrews proposed using WALA ridge as a landmark for assessing mandibular arch width and shape[9,10]. The WALA ridge is defined as a band of soft tissue coronal to the mandibular mucogingival junction that is suggested to be at or near the level of the center of resistance of the teeth. A study by Glass and Tremont analyzing CBCTs found that the WALA ridge and estimated center of resistance of the mandibular teeth had the same vertical position, and that the latter was centrally located in the alveolar ridge[18]. From a biomechanical perspective, applying a single force to the crown results in tipping of the tooth, with a moment and center of rotation near the tooth’s center of resistance. An arch wire shaped to the WALA ridge would therefore provide a single buccal force to the mandibular teeth, tipping them to an upright position while maintaining the position of the center of resistance within the alveolar ridge. When optimally positioned in this way, there is a significant statistical correlation between mandibular teeth’s facial axis point (center of the crown’s facial surface) and the WALA ridge (Figure 1).

When mandibular anterior and posterior teeth are optimally positioned, their roots are centered within the alveolar ridge and their crowns are at an ideal inclination for interfacing the maxillary dentition[9,10,11,12] (Figure 2). The distance between the central fossa of the mandibular first molars is then considered to be the optimal mandibular arch width, which can provide a template for the maxillary arch form. Maxillary first molars should have a level occlusal table, indicating the teeth are decompensated, and the distance between the mesiolingual cusp tips of the right and left maxillary first molars should be equal to the distance between the mandibular right and left central fossa. Many patients with transverse problems will not present with a posterior crossbite due to dental compensation in the form of lingually inclined mandibular posterior teeth and buccally inclined maxillary posterior teeth. Therefore, analyzing dental casts without correcting these compensations will not reveal the true nature of the skeletal discrepancy.

Tancan *et al* analyzed the transverse dimension of dental models and found that severe skeletal Class III patients had greater mandibular intercanine and intermolar widths[20]. A previous study by Staley *et al* reported no differences in mandibular intercanine widths between Class I and Class II Division I subjects, while Gupta *et al* reported significantly greater mandibular intercanine widths in Class II subjects compared with Class I[16]. The latter study found only a 0.7mm difference, which is unlikely to be clinically significant. The inconsistency among studies may be due to the use of different anatomic landmarks for measuring dental arch widths. Perhaps patient age is also a factor, as adolescents used in previous studies may differ from adult patients. Gupta reported no differences between dental arch widths in Class I children and Class I adults but found significant changes between Class II children and Class II adults[16]. They later concluded, however that only 0.18% of the variance in canine width was due to age.

As cone-beam computed tomography becomes increasingly widespread in orthodontics, the question of whether maxillary or mandibular skeletal landmarks exist that can be used to identify transverse discrepancies becomes more pertinent. Bayome evaluated the relationship between the mandibular dental and basal arches by comparing CBCTs to digital models and found a strong correlation in the anterior and posterior segments[21]. In a study by Zou, the crown's FA point and the WALA ridge were used to represent dental and basal arch forms, respectively. It was concluded that dental arch width is partly determined by basal bone width, with a moderate correlation in the canine area and a strong correlation in the molar area[20]. However, there is no consensus in the literature on the definition and location of the "basal arch." Bayome defines basal bone as "a horizontal band that passes through centers of roots at the junction between the gingival and middle thirds of canines." Howes suggested that basal bone is the narrowest region of the alveolar bone 8 mm below the marginal gingiva[20]. Other studies claim that root apices are unreliable landmarks due to the high variability in root position and form, and a constructed landmark may be more useful.

There is no consensus in the orthodontic or OMFS literature regarding diagnosis of transverse dental arch discrepancies and to what extent discrepancies in underlying maxillary and mandibular transverse jaw dimensions are an etiology. In addition, there is an absence of discussion regarding possible differences in maxillary anterior versus posterior transverse jaw discrepancies. The purpose of this investigation was to: 1) evaluate a dental cast versus CBCT method for diagnosing skeletal transverse discrepancies, 2) assess whether dental cast or CBCT determined posterior transverse discrepancies differ from anterior transverse discrepancies, and 3) assess if any differences exist in skeletal transverse discrepancies between patients with Class I, II and III skeletal malocclusions.

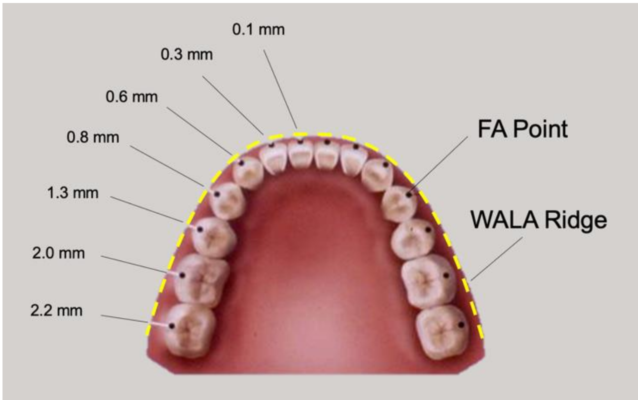


Figure 1. Drawing depicting the distinct average relationship of the FA Points of mandibular crowns to the WALA Ridge from a study of orthodontically untreated optimal occlusions. *"Adapted from Andrews LF: Andrews Journal of Orthodontics Orofacial Harmony. Winter; 2000; with permission"*

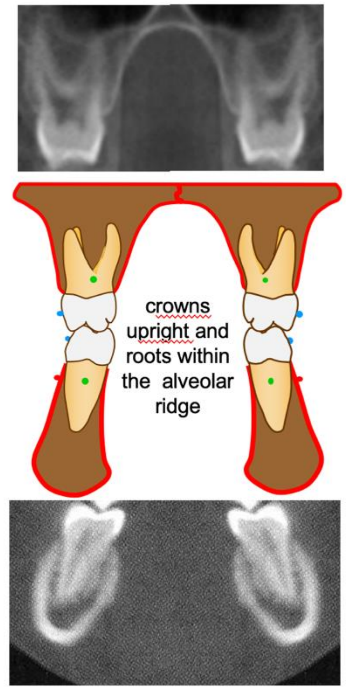


Figure 2. Schematics, and accompanying CBCT images, demonstrating optimally positioned molars and incisor roots within the alveolar ridge and crowns at optimal inclinations. Blue dots depict FA Points; Red dots depict WALA Ridge points; Green dots depict tooth centers of resistance. "A*dapted from Tremont TJ: Diagnosis and treatment planning for orthognathic surgery course manual, 2019; with permission".*

Materials and methods

Prior to the start of this study, the Medical University of South Carolina's Institutional Review Board for Human Research deemed this to be "not human research" and therefore exempt from IRB oversight (Pro00092044). Pre-treatment orthodontic records including intraoral scans of the maxillary and mandibular arches and cone beam computed tomography scans were obtained from two separate orthodontic private practices. The sample consisted of records of 40 patients, further divided into three subgroups based on their skeletal anteroposterior diagnosis. The Class I subgroup consisted of 12 patient's records, 18 in the Class II subgroup and 10 in the Class III subgroup, for a total of 40 pairs of digital dental casts and 40 CBCTs.

Inclusion criteria consisted of adolescent and adult patients with a full permanent dentition (excluding third molars), undistorted pretreatment CBCT and maxillary/mandibular intraoral scans, and no previous orthodontic treatment. The intraoral scans were analyzed using OrthoCAD version 5.9.0.36. CBCT scans were exported in DICOM format, and Invivo 6 (Anatomage) was used to digitize, view and measure the scans.

Digital cast measurements

Prior to digital cast measurements, all canines, first bicuspids and first molars were adjusted for optimal tooth inclinations. This involved derotating cuspids or uprighting posterior teeth. These adjustments were recorded as positive or negative values depending on the direction of the crown movement (+0.5 indicates 0.5mm of buccal crown movement, whereas -0.5 indicates 0.5mm of lingual crown movement). As seen in figure 2, when posterior teeth are optimally inclined their roots are centered in bone and their occlusal table is nearly level. In untreated subjects with a Class I occlusion, when a tangent of the maxillary canines FA point is at -7 degrees to the occlusal plane, or a tangent of the mandibular canines FA point is at -11 degrees to the occlusal plane, the roots are centered within alveolar bone[12]. Digital cast corrections were made to approximate these optimal inclinations.

An occlusal view of maxillary and mandibular casts was used to evaluate the transverse width of the dental arches. Using digital calipers, arch widths were measured at the canines, first premolars and first molars. For the maxillary canines, the distance between the right and left mesiolingual cusps was measured. For the maxillary first bicuspids and first molars, the distance between the right and left palatal cusp tips was measured. The mandibular intercanine distance was measured using the right and left distofacial cusps, where the maxillary canines' mesiolingual cusps would interface in a Class I dental relationship. Similarly, the mandibular interpremolar and intermolar widths were measured using the corresponding fossa-to-fossa distance of the lower posterior teeth. The differences between the maxillary and mandibular measurements at the canine, first premolar and first molar were expressed as ∆C, ∆P and ∆M, respectively (Figure 1).

All measurements were made by one investigator and repeated on 10 sets of dental casts 2 weeks later. The intrarater reliability was assessed.

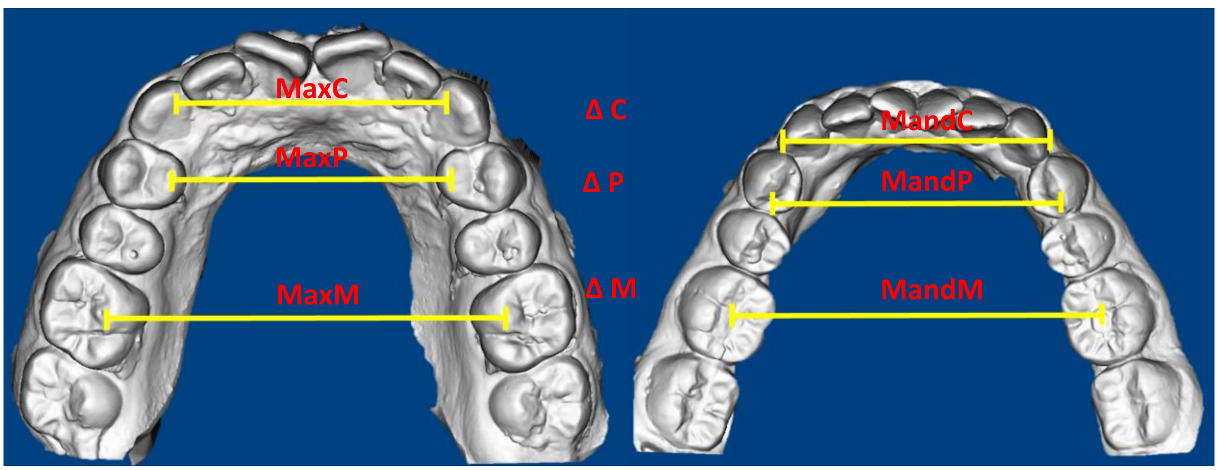


Figure 1. The measured distance between right and left canines, first premolars and first molars. Anatomical landmarks chosen are where the teeth would interface in an ideal Class I dental relationship. The difference between the maxillary and mandibular measurements is represented by ∆ at each location.

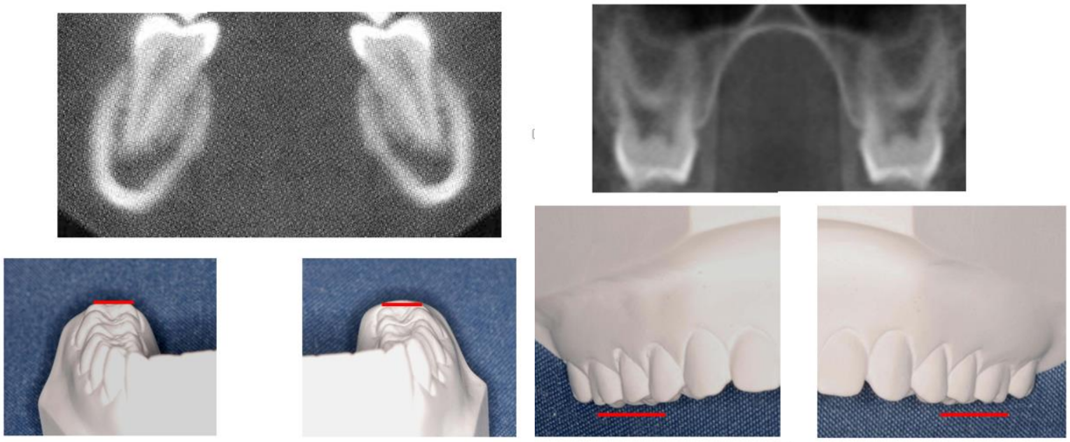


Figure 2. CBCT images showing well centered and optimally inclined molars. Photos of casts demonstrating optimally inclined molars indicated by nearly level occlusal tables. "A*dapted from Tremont TJ: Diagnosis and treatment planning for orthognathic surgery course manual, 2019; with permission".*

CBCT measurements

All CBCT dicom files were de-identified and analyzed with Anatomage InVivo6 software. Measurements were made between the right and left first molars (*M*), first premolars (*P*) and canines (*C*) at the following vertical levels- 1) the estimated center of resistance of the tooth (*cr*), 2) the root apices (*a*) and 3) an estimated center of basal bone (*b*). This was done for both the maxillary and mandibular arches of all subjects (*Max and Mand*, respectively). It is important to note that the three levels above demarcate the vertical location from which measurements took place, however, the skeletal width was determined by measuring between the right and left buccal-lingual midpoint of the alveolar ridge. The alveolar bone's buccal to lingual internal cortex distance was measured at each vertical level, and the value was divided in half to determine the center of the alveolar ridge.

As determined from previous studies by Smith and Burstone, the center of resistance of first molars was estimated to be at the furcation of the roots. For premolars and canines, the center of resistance was estimated to be 1/3 of the distance from the alveolar crest to the root apices[13]. Apices were defined as the most apical point of the root; for multi-rooted teeth we chose the apex of the longest root. The mandibular basal bone was defined as the vertical midpoint between the inferior cortex of the mandible and the apices of the teeth. Identifying maxillary basal bone was more difficult. For the maxillary canines and premolars, basal bone was defined as the junction of the buccal and palatal cortices apical to the tooth apices. Due to the maxillary sinus involvement apical to the first molars, it was difficult to reliably identify a point representing maxillary basal bone and was therefore not attempted (Figure 4). All CBCT measurements were made using an axial view- the coronal view depicted in Figure 4 is for improved visualization of the teeth. The differences between the maxillary and mandibular measurements at the canine, first premolar and first molar were expressed as Δ at each vertical level. Because MaxMb was not defined, ΔMb was calculated as the difference between MaxMa and MandMb.

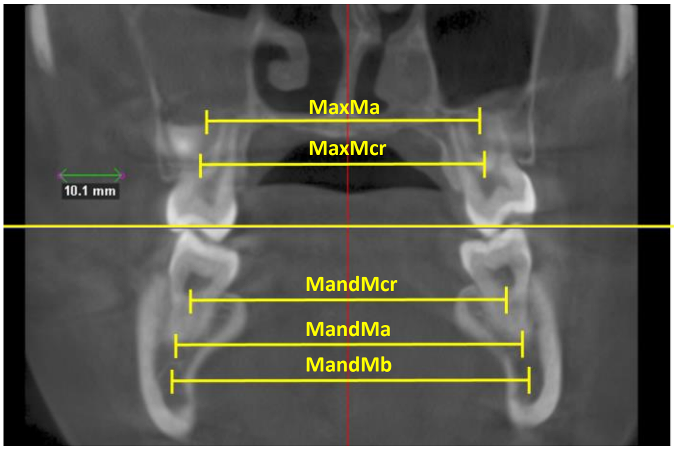
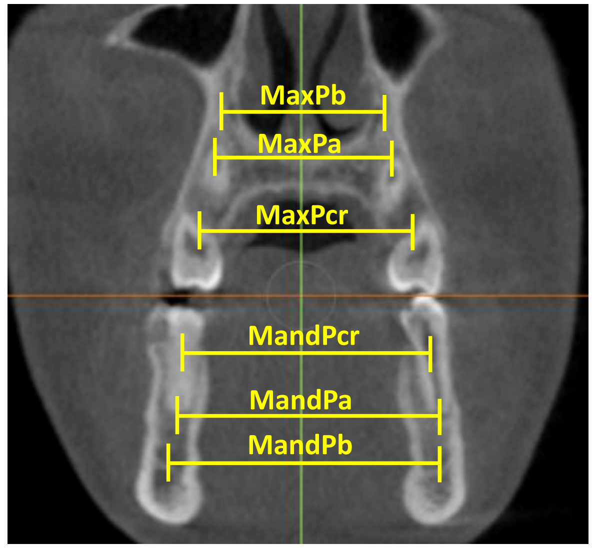


Figure 4. The measured distance between right and left first premolars and first molars (canines not shown, though same method was used). Measurements taken at the estimated center of resistance (cr), apices (a) and estimated basal bone (b).



PA cephalogram measurements

Using InVivo6, a posteroanterior cephalogram was rendered from each subject's CBCT scan. Consistent with previous studies by Chen *et al*, the linear distance between right and left Jugale (*J-J*) was measured to determine maxillary skeletal base width, and the linear distance between right and left Antegonion (*Ag-Ag*) was measured to determine mandibular skeletal base width[14]. Jugale was defined as the intersection of the maxillary tuberosity and zygomatic buttress. Antegonion was defined as the deepest point on the curvature of the antegonial notch (Figure 6). The difference between the maxillary and mandibular skeletal base widths was expressed as ∆J-J/Ag-Ag.

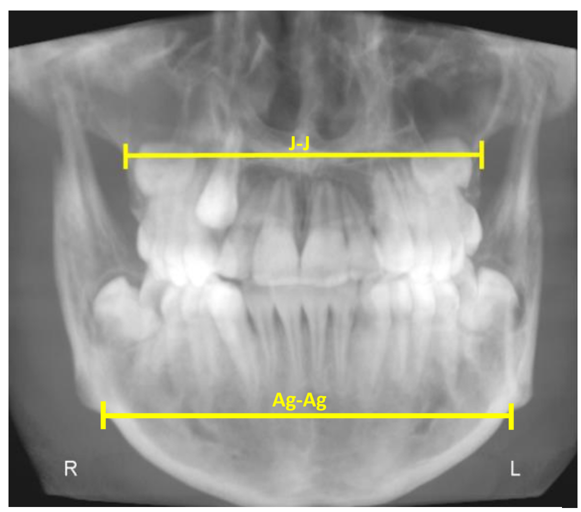


Figure 6. The measured distance between right and left Jugale and between right and left Antegonion

The average ∆ at each location on the digital casts, CBCTs and PA cephalograms were compared to 1) identify a correlation between them, 2) determine differences between subgroups and 3) determine differences between the anterior and the posterior.

Data analysis

All descriptive statistics were done using Microsoft Excel. Data was analyzed using a repeated measures generalized linear model.

Results

Digital cast measurements

No adjustments for optimal tooth inclinations were made for the maxillary molars in the Class I subgroup. The largest average adjustment was -0.94 for the Class II subgroup at the maxillary canines, indicating that in these subjects the teeth are displaced labially and orthodontic treatment would result in approximately 1mm of palatal tipping (0.5mm per side). For the canines, premolars and molars of all subjects, the adjustments made ranged from -2 to 2. The next largest average adjustment was 0.7mm at the mandibular molars of the Class III subgroup, indicating the teeth were tipped buccally 0.35mm per side, on average (Table 1). After making adjustments to decompensate the teeth, maxillary and mandibular arch measurements were compared (Table 2). There were no significant differences found in the average maxillary arch widths between subgroups. In the Class III subgroup, the average mandibular measurements were larger than those of the Class I and II subgroups, however, the differences were not statistically significant.

Table 3 displays descriptive statistics for Δ at the canine (C), first premolar (P) and first molar (M) for all subjects. C was significantly different than M (p-value=0.0184) and P (p-value=0.0021) and M was significantly different than P (p-value<0.0001).

Table 4 displays descriptive statistics for Δ at the canine (C), first premolar (P) and first molar (M) within each subgroup. The average Δ was not statistically significantly different between subgroups, despite a 1.5mm difference between ΔC in the Class I and Class III subgroup.

Although the mean difference between maxillary and mandibular measurements provides useful information, it is important to highlight the wide variation between subjects in all subgroups. Some individuals presented with a Δ 5mm greater at the molars when compared to the canines. Conversely, other subjects have a 4mm Δ at the canine, but 0mm Δ at the molar. Finally, some subjects have an equal Δ at the canine and molar.

Diagnosis	MaxM	MaxP	MaxC	MandM	MandP	MandC
CI mean	0	0.16	-0.29	0.33	-0.03	0.38
CII mean	-0.42	0.39	-0.94	0.47	0.11	-0.08
CIII mean	-0.65	0.15	-0.3	0.7	0.2	0.55

Table 1. Corrections were recorded as either positive or negative values depending on the direction of crown uprighting. Positive values indicate buccal tipping and negative values indicate lingual tipping. Averages are provided at each location between subgroups.

Diagnosis	MaxM	MaxP	MaxC	MandM	MandP	MandC
CI mean	39.18	29.9	27.98	42.05	31.43	29.68
CII mean	39.36	30.67	28.78	42.52	31.90	30.97
CIII mean	40.85	32.14	28.42	44.18	33.59	31.63

Table 2. Mean maxillary and mandibular arch measurement at the canine (C), first premolar (P) and first molar (M) within each subgroup (CI, CII and CIII).

Location	N	Mean	Median	Std Dev	25th Pctl	75th Pctl
C	40	-2.30	-2.50	1.41	-3.15	-1.75
M	40	-3.12	-3.35	1.88	-4.65	-1.50
P	40	-1.39	-1.70	1.34	-2.30	-0.35

Table 3. Descriptive statistics for Δ at the canine (C), molar (M) and premolar (P) for all subjects.

Diagnosis	Location	N	Mean	Median	Std Dev	25th Pctl	75th Pctl
CI	C	12	-1.70	-1.95	1.36	-2.55	-0.50
	M	12	-2.88	-1.95	1.97	-4.55	-1.35
	P	12	-1.50	-1.65	1.33	-2.10	-0.45
CII	C	18	-2.19	-2.45	1.27	-2.80	-2.10
	M	18	-3.16	-3.40	1.88	-4.50	-2.30
	P	18	-1.29	-1.70	1.29	-2.20	-0.30
CIII	C	10	-3.21	-3.55	1.36	-3.80	-2.60
	M	10	-3.33	-3.70	1.95	-5.00	-1.40
	P	10	-1.45	-1.90	1.54	-2.50	-0.80

Table 4. Descriptive statistics for Δ at the canine (C), molar (M) and premolar (P) for subjects within each subgroup (CI, CII and CIII).

CBCT measurements

Maxillary and mandibular measurements at each location (C, P and B) and vertical level (cr, a and b) were compared. There were no significant differences found in the average maxillary and mandibular arch widths between subgroups. However, when compared to the Class I subgroup, the average measurements in the Class III subgroup were nearly 3mm or greater at the following locations: maxillary premolar and canine basal bone, mandibular molar apices and basal bone, and mandibular canine apices and basal bone (Table 5).

Table 6 displays descriptive statistics for Δ at each location for all subjects. There were significant differences between each location ($p<.0001$) but no consistency between vertical points for each location. One would expect the Δ at the centers of resistance and apices of the same teeth to be similar, but this was not the case. Table 7 displays descriptive statistics for Δ at all locations within each subgroup. The average Δ was significantly different between subgroups at each location, indicating no correlation. However, the mean Δ of 2.36mm at the CI Canine apices and 2.35mm at the CIII Canine apices was not determined to be similar. The lack of statistical significance may be due to the number of variables compared.

Diagnosis	CI mean	CII mean	CIII mean
MaxMcr	44.01	45.29	44.92
MaxMa	42.09	44.06	43.07
MaxPcr	34.88	36.57	35.36
MaxPa	29.06	31.65	30.46
MaxPb	25.19	29.58	29.13
MaxCcr	28.46	29.91	29.17
MaxCa	22.09	25.68	24.8
MaxCb	18.90	23.56	24.03
MandMcr	45.18	45.34	46.32

MandMa	49.58	51.71	52.33
MandMb	52.81	54.11	55.24
MandPcr	31.21	31.52	32.37
MandPa	29.47	29.09	31.3
MandPb	31.11	29.17	31.94
MandCcr	23.02	22.83	23.38
MandCa	19.73	20.51	22.45
MandCb	20.40	19.64	23.82

Table 5. Mean maxillary and mandibular arch measurements at the canine (Ca, Cb and Ccr), molar (Ma, Mb and Mcr) and premolar (Pa, Pb and Pcr) within each sub-group (CI, CII and CIII).

Location	N	Mean	Median	Std Dev	25th Pctl	75th Pctl
Ca	40	3.62	3.55	4.42	0.45	7.60
Cb	40	1.37	1.13	5.63	-2.35	4.40
Ccr	40	6.27	6.05	2.06	5.20	8.10
Ma	40	-8.00	-8.45	4.23	-10.75	-5.40
Mb	40	-10.78	-10.95	4.43	-13.10	-8.60
Mcr	40	-0.72	-0.56	2.69	-2.10	1.10
Pa	40	0.82	0.65	4.15	-1.70	4.05
Pb	40	-2.29	-1.70	5.81	-6.90	1.52
Pcr	40	4.12	4.55	2.39	2.55	5.85

Table 6. Descriptive statistics for Δ at the canine (Ca, Cb and Ccr), molar (Ma, Mb and Mcr) and premolar (Pa, Pb and Pcr) for all subjects.

Diagnosis	Location	N	Mean	Median	Std Dev	25th Pctl	75th Pctl
CI	Ca	12	2.36	1.35	4.32	-0.65	5.75
	Cb	12	-1.50	-1.80	3.13	-3.35	0.80
	Ccr	12	5.44	5.55	2.17	3.35	7.55
	Ma	12	-7.49	-8.05	4.41	-10.70	-3.15
	Mb	12	-10.72	-11.60	5.68	-14.70	-6.00
	Mcr	12	-1.17	-0.40	3.57	-2.45	1.10
	Pa	12	-0.41	-0.65	4.98	-4.15	3.40
	Pb	12	-5.92	-6.90	4.92	-9.15	-2.00
	Pcr	12	3.68	4.40	2.76	1.90	5.30
CII	Ca	18	5.17	4.75	4.66	3.40	8.66
	Cb	18	3.92	3.95	5.29	0.70	8.10
	Ccr	18	7.09	7.55	1.99	5.84	8.20
	Ma	18	-7.65	-7.95	4.81	-10.30	-3.90
	Mb	18	-10.04	-10.40	4.25	-12.30	-7.72
	Mcr	18	-0.05	-0.48	2.54	-1.50	1.80
	Pa	18	2.56	2.84	3.12	0.00	5.00
	Pb	18	0.41	0.35	4.99	-3.30	4.90
	Pcr	18	5.05	5.50	2.21	3.40	6.80
CIII	Ca	10	2.35	1.95	3.47	0.40	4.90
	Cb	10	0.21	1.00	6.84	-2.50	2.90

	Ccr	10	5.79	5.55	1.63	5.10	6.70
	Ma	10	-9.26	-9.40	2.77	-11.40	-6.50
	Mb	10	-12.17	-12.05	2.89	-13.90	-10.00
	Mcr	10	-1.40	-2.05	1.38	-2.10	0.00
	Pa	10	-0.84	-0.35	3.84	-3.90	2.00
	Pb	10	-2.81	-1.05	6.10	-8.10	1.00
	Pcr	10	2.99	2.75	1.68	1.30	4.90

Table 7. Descriptive statistics for ∆ at the canine (Ca, Cb and Ccr), molar (Ma, Mb and Mcr) and premolar (Pa, Pb and Pcr) for subjects within each subgroup (CI, CII and CIII).

PA cephalogram measurements

The average distance between right and left Jugale and Antegonion for all subjects was 61.32mm and 79.12mm, respectively. The average maxillary and mandibular skeletal widths within each subgroup were compared (Table 8). There were no significant differences found in the average skeletal widths between subgroups. The mean difference between J-J and Ag-Ag for all subjects was -17.8mm. Although the Class II subgroup had an average ∆ of -16.62mm compared to -19.33mm in the Class III subgroup, this was not determined to be a statistically significant difference.

Diagnosis	J-J	Ag-Ag	∆
CI mean	60.55	78.83	-18.28
CII mean	61.8	78.42	-16.62
CIII mean	61.39	80.72	-19.33

Table 8. Maxillary and mandibular PA cephalogram measurements at right and left Jugale and right and left Antegonion for each subject in each subgroup (CI, CII and CIII). ∆, the difference between J-J and Ag-Ag is given for each subject.

Comparing ∆ at each location on the digital casts, CBCTs and PA cephalograms, we found no significant correlation between them.

Discussion

In this study, prior to measuring dental arch widths, necessary corrections were made to account for the decompensation of teeth that would occur during orthodontic treatment. These adjustments consisted of derotating or uprighting teeth to what is considered to be an optimal crown inclination in naturally occurring dental arches. In Andrews study of 120 untreated subjects with a Class I occlusion, the occlusal table of the posterior teeth were level. For the mandibular first premolars, mandibular canines and maxillary canines, a tangent of the crown's facial axis point was determined to be at a specific inclination to the occlusal plane (-17, -11 and -7 degrees, respectively)[9,12]. When viewing the hypothetically treated tooth's new position from a coronal perspective on a CBCT, the roots are centered buccolingually within the alveolar ridge. The Andrew's bracket prescription therefore reflects these ideal inclinations that naturally occur in patients without malocclusion. In contrast to the ideas heavily adopted by Roth, filling the bracket slot and fully expressing the prescription should be avoided. Due to variation in morphology, the facial axis of tooth crowns has a range of inclination and having a small degree of "slop" in the bracket will allow for normal masticatory forces to allow for ideal interdigitation of the upper and lower teeth during function. Assuming an objective of orthodontic treatment is to keep the roots centered in alveolar bone and the crowns at an optimal inclination for interfacing with their maxillary counterpart, the adjustments to the digital models in this study were appropriate.

As shown in table 1, no adjustments were made to the maxillary molars of the Class I subgroup, whereas the Class II and Class III subgroups had an average adjustment of -0.42mm and -0.65mm, respectively. The Class I subjects presented with a level occlusal table to their maxillary first molars; in contrast, the skeletal Class II and III subjects (on average) required palatal tipping of their maxillary molars to upright them. While 4 of the 12 Class III subjects required no correction of the maxillary molars (they were already upright), the other eight required as much as 0.75mm of palatal tipping on each side. In a previous study by Zou *et al*, they concluded that mandibular teeth are more compensated, or lingually inclined in skeletal Class III patients[20]. Our findings are in agreement, as the skeletal Class III subjects required more buccal tipping at the mandibular molars and canines than either the skeletal Class I or II subgroups. Whether these skeletal Class III patients have a maxillary AP deficiency or a mandibular AP excess, a wider portion of the lower arch is occluding with a narrower portion of the upper arch (assuming a typical U-shaped dental arch; exceptions would apply with a square-shaped dental arch form). The maxillary molars therefore often compensate with excessive buccal inclination and the mandibular molars with excessive lingual inclination.

It is important to note that in all subgroups there were patients that did not require adjustments to the posterior teeth. Although dental compensation may be more likely in Class II or III patients, it is not ubiquitous. While one patient in the Class II subgroup required 3mm of buccal tipping at the mandibular molars, 12 of the 16 Class II subjects needed no correction to the lower molars. It is therefore critical to evaluate each case on an individual basis. Optimal position of the mandibular teeth, whether existing or corrected, can define a lower arch form that is unique to each individual and will serve as a template for the size and shape of the maxillary arch.

In this study, the difference in mandibular intercanine distance between Class I and II subgroups was 1.3mm, which was not statistically significant but may be clinically. One possibility for this finding is the occlusion of the mandibular canines with a wider portion of the maxillary arch, and the resulting tendency for the mandibular canines to move labially.

If a maxillary skeletal transverse discrepancy is identified, it is critical to evaluate the difference between the anterior and the posterior transverse discrepancy, as this may dictate how treatment should be rendered. As shown in Figure 7, there are three possible scenarios. The anterior and posterior maxillary skeletal transverse discrepancy can be equal, or one can be greater than the other. If equal, both the anterior and posterior dimension require equal amounts of expansion. If the anterior skeletal transverse discrepancy is greater than the posterior, or vice versa, differential expansion is required[19].

In this study, as determined by the digital model analysis, the maxillary anterior skeletal transverse discrepancy (ΔC) differed from the posterior (ΔM). For all 40 subjects, the mean discrepancy was 2.3mm at the canines and 3.12mm at the molars and 1.39mm at the premolars, which were determined to be statistically significantly different. Interestingly, these findings are not consistent between skeletal Class I, II and III patients. In our Class I subgroup, the maxillary anterior skeletal transverse discrepancy was 1.7mm, whereas it was 3.2mm in the Class III subjects. Although not determined to be statistically significant, a 1.5mm average difference between patients may be clinically significant. It is also worth noting that the average maxillary skeletal transverse discrepancy at the anterior and posterior was larger in the skeletal Class II and Class III subjects than the Class I. Patients who present with these skeletal malocclusions may require maxillary expansion more often than those with a harmonious anterior-posterior position of the jaws. The mean discrepancy at the canine and molar for all Class III patients was 3.2mm and 3.3mm, respectively. Treating a 3mm maxillary skeletal transverse discrepancy without maxillary expansion, simply by tipping upper teeth buccally and lower teeth lingually, would compromise the inclination of the teeth and increase the risk of extrusive and protrusive interferences during function.

It is imperative that each individual patient is diagnosed appropriately so that the correct clinical decisions can be made. Maxillary crowding only, in the absence of an antero-posterior jaw discrepancy, may indicate a maxillary skeletal transverse discrepancy. Without active transverse correction, the occlusal relationship at the end of treatment will not be correct. In a skeletal Class I subject in this study, the maxillary skeletal transverse discrepancy at the molars is 5mm, and just 0.5mm at the canines. Treating this patient with rapid maxillary expansion would not be appropriate, as maxillary resistance is least in the anterior and the majority of expansion would occur there. To treat this patient to an optimal occlusion, a segmental LeFort with increased posterior expansion would be required. Any other treatment plan would result in a compromised occlusion and the clinician must be aware of this prior to beginning treatment.

It is important to consider that mandibular dental arch width alone may not be a clinically useful measurement. The mandibular intermolar width is only meaningful when compared to its corresponding maxillary intermolar width. An above average mandibular intermolar width is not a problem that requires correction if the maxillary intermolar width is equally above average. Much of the orthodontic literature overemphasizes mandibular dental arch measurements alone, searching for a universal number that may indicate maxillary expansion, while the discrepancy between the upper and lower jaws is far more useful.

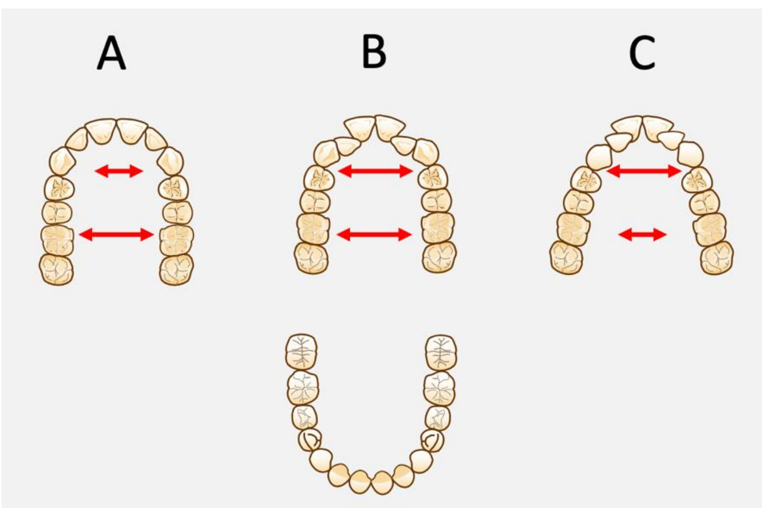


Figure 7. Schematic illustrating three possible scenarios regarding maxillary skeletal transverse discrepancies. A, Posterior maxilla needs more expansion than the anterior. B, Posterior maxilla and anterior maxilla need equal expansion. C, Anterior maxilla needs more expansion than the posterior. "A*dapted from Tremont TJ: Diagnosis and treatment planning for orthognathic surgery course manual, 2019; with permission".*

Correlation to CBCTs

This study chose three vertical points at the canines, first premolars and first molars of both arches to attempt to find any landmark that may consistently demarcate the "basal arch". Rather than using root apices or the center of resistance of displaced teeth, the labiolingual center of the alveolar ridge was used at each vertical point. This may be more clinically relevant, as the alveolar process houses the teeth and keeping them centered within the ridge should be an objective of treatment.

When comparing the difference between maxillary and mandibular dental arch width to the difference between maxillary and mandibular skeletal widths, no statistically significant intergroup similarities were found. We also evaluated the ratio between the anterior and posterior transverse discrepancies, as determined by the virtual models and the CBCT analysis, to determine any correlation. This ratio was described as the Δ at the canine divided by Δ at the molar (C/M), and Δ at the premolar divided by Δ at the molar (P/M). It was compared to the CBCTs ratio at each vertical level: Ccr/Mcr, Ca/Ma, and Cb/Mb, and Pcr/Mcr, Pa/Ma, and Pb/Mb. We found no correlation between all subjects, or for each subgroup independently. Perhaps a larger sample size with a greater representation of Class I, II and III subjects is required. Nevertheless, this study was unable to locate skeletal landmarks that may useful in identifying the presence of a transverse discrepancy.

Correlation to PA cephalograms

The difference between right and left Jugale and right and left Antegonion had no correlation with either the digital model differences or the CBCT skeletal differences. It is suggested in the literature that the maxillomandibular width differential varies between races and genders, however, there is little agreement on what those differences are[3]. Only 6 of the patients (3 Class I and 3 Class III) in this study had an maxillomandibular width differential greater than 5mm. When compared to models and CBCT measurements, there was no correlation between ΔJ-J/Ag-Ag and other variables studied. Although Antegonion and Jugale are bony landmarks, the likely provide a poor representation of arch width and should be used with caution when analyzing the skeletal transverse dimension.

There are limitations of dental arch expansion that must be respected during orthodontic treatment. Failure to do so may result in bone loss, gingival recession and a high risk of dental relapse. One important biologic limitation may be a patient's available alveolar bone, therefore preserving the original pretreatment arch form will likely increase posttreatment periodontal health and stability. As it is unlikely that a universal arch form exists, customizing archwires is required. Choosing the mandibular arch form and using the WALA ridge as a landmark for shaping working archwires is critical for translating the concept of arch form preservation and archwire customization into clinical practice. Although three-dimensional imaging is valuable in orthodontics and may improve diagnosis and treatment planning, it may not be necessary for evaluating the transverse dimension.

In the absence of identifiable skeletal landmarks, assuming the objectives of orthodontic treatment are to keep the teeth in an upright position and the roots centered within alveolar bone, a practical and effective means of identifying a maxillary skeletal transverse discrepancy and differentiating anterior versus posterior discrepancies may be to first adjust teeth on digital models to hypothetically optimal positions. Then, measure the maxillary right-to-left cusp-to-cusp distance and compare it to the corresponding mandibular right-to-left fossa-to-fossa distance. If the maxillary intercanine or intermolar width is less than the mandibular intercanine or intermolar width, a skeletal transverse discrepancy is present. The mandible is rarely expanded surgically, so maxillary expansion is indicated. The presence or absence of a crossbite will accurately represent the nature of a transverse discrepancy only if the teeth are at their optimal inclinations.

Dental compensation will camouflage the underlying deficiency and therefore must be accounted for and corrected to be able to accurately diagnose the transverse dimension.

Conclusions

1. Average differences between maxillary and mandibular measurements were significantly different at the canine, first premolar and first molar for all subjects, in both the digital model and CBCT analyses. This indicates that maxillary skeletal transverse discrepancies often differ between the anterior and posterior.
2. Using either a digital cast or CBCT analysis, average differences between maxillary and mandibular transverse discrepancies were not significantly different between skeletal Class I, Class II and Class III subjects.
3. No correlation was found between the digital model, CBCT and PA cephalometric analyses for all subjects or between Class I, II and III subgroups.
4. Maxillary and mandibular skeletal landmarks could not be identified for assessing transverse discrepancies using CBCT scans.
5. A dental cast analysis appears to be a more effective method for assessing transverse jaw discrepancies.

References

1. Ricketts RM Roth RH Chaconas SJ Schulhof RJ et al.Orthodontic Diagnosis and Planning. Rocky Mountain Data Systems, Denver1982
2. Betts NJ, Vanarsdall RL, Barber HD, Higgins-Barber K, Fonseca RJ. Diagnosis and treatment of transverse maxillary deficiency. Int J Adult Orthodon Orthognath Surg. 1995;10(2):75-96.
3. Vanarsdall RL Jr. Transverse dimension and long-term stability. Semin Orthod. 1999;5(3):171-180. doi:10.1016/s1073-8746(99)80008-5
4. Chung, C.-H. (2019). "Diagnosis of transverse problems." Seminars in Orthodontics 25 (1): 16-23.
5. Tweed CW. A philosophy of orthodontic treatment. Am J Orthod Oral Surg. 1945;31:74–103.
6. Rudge SJ. Dental arch analysis: arch form. A review of the literature. Eur J Orthod. 1981;3(4):279-284. doi:10.1093/ejo/3.4.279
7. Ronald Gallerano. “Arch Form: The forgotten factor in finishing.” AAO 2019 Annual Session.
8. Davis L, BeGole EA. 1998. Evaluation of orthodontic relapse using the cubic spline function. American Journal of Orthodontics and Dentofacial Orthopedics 113:300-306.
9. Andrews LF. The six keys to normal occlusion. Am J Orthod Dentofacial Orthop. 1972;62(3):296–309.
10. Andrews LF. The 6-elements orthodontic philosophy: treatment goals, classification, and rules for treating. Am J Orthod Dentofacial Orthop. 2015;148:883–887.
11. Andrews LF. Andrews Journal of Orthodontics and Orofacial HarmonyVol. 1. San Diego (CA): L.A. Wells Co.; 2000.
12. Andrews LF. Straight wire: the concept and appli- ance. San Diego (CA): L.A. Wells Co.; 1989.
13. Smith RJ, Burstone CB. Mechanics of tooth move- ment. Am J Orthod Dentofacial Orthop 1984;85(4): 294–307.

14. Chen F, Terada K, Wu L, Saito I. Dental arch widths and mandibular-maxillary base width in Class III malocclusions with low, average and high MP-SN angles. Angle Orthod. 2007;77(1):36-41. doi:10.2319/011006-15R.1
15. BeGole EA, Fox DL, Sadowsky C. Analysis of change in arch form with premolar expansion. Am J Orthod Dentofacial Orthop. 1998;113(3):307-15.
16. Gupta D, Miner RM, Arai K, Will LA. Comparison of the mandibular dental and basal arch forms in adults and children with Class I and Class II malocclusions. Am J Orthod Dentofacial Orthop. 2010;138(1):10 e1-8; discussion -1.
17. Ball RL, Miner RM, Will LA, Arai K. Comparison of dental and apical base arch forms in Class II Division 1 and Class I malocclusions. Am J Orthod Dentofacial Orthop. 2010;138(1):41-50.
18. Glass TR, Tremont TJ. A CBCT evaluation of root po- sition in bone, long axis inclination and relationship to the WALA Ridge. Semin Orthod 2019;25(1): 24–35.
19. Tremont TJ. Diagnosis and treatment planning for orthognathic surgery course manual. Cannonsbug, PA: Ortho Gnathics, LLC; 2019).
20. Zou, W., et al. (2015). "Relationship between mandibular dental and basal bone arch forms for severe skeletal Class III patients." Am J Orthod Dentofacial Orthop 147(1): 37-44.
21. Bayome M, Park JH, Han SH, Baek SH, Sameshima GT, Kook YA. Evaluation of dental and basal arch forms using cone-beam CT and 3D virtual models of normal occlusion. Aust Orthod J. 2013;29(1):43-51.
22. Allen D, Rebellato J, Sheats R, Ceron AM. Skeletal and dental contributions to posterior crossbites. Angle Orthod. 2003;73(5):515-524.