A Retrospective CBCT Study of the Relationship between Mandibular Symphysis Bone Density and Mandibular Growth Direction

Jong-Moon Chae*/ Jay Gousman**/ Jung Won Seo***/ R Curtis Bay****/ Seong-Suk Jue*****/ Jae Hyun Park******

Objective: *The objective of this retrospective study was to investigate the relationship between mandibular symphysis bone density (BD) and mandibular growth direction in adolescent patients by facilitating the measurement of cortical and cancellous BDs at the mandibular symphysis using cone beam computed tomography (CBCT).* ***Study Design:*** *224 adolescent patients (98 males and 126 females) were categorized by sex, age, and mandibular growth direction. Cortical and cancellous BDs were measured along with a sagittal slice at multiple locations.* ***Results:*** *Females exhibited higher cortical BD than males at menton (Me, P =0.002). Patients with a posterior growth direction exhibited a higher cortical BD than those with anterior and normal growth direction at Me (P <0.021, P <0.001, respectively), pogonion (Pog, P =0.037, P =0.037, respectively) and genion (Ge, P =0.007, P =0.008, respectively). Patients with a posterior growth direction exhibited a higher cortical BD than those with anterior growth direction at B point (P =0.009).* ***Conclusions:*** *Significant differences in BD were identified across anthropometric categories. These findings may be useful in determining mandibular growth direction in adolescents.*

Keywords: *Mandibular symphysis, Growth Direction, Bone Density, CBCT*

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INTRODUCTION

Assessment of mandibular growth can be used as a clinical tool to aid in orthodontic diagnosis and treatment planning. Being able to better estimate mandibular growth can provide clinicians with the ability to make better therapeutic decisions such as the timing of intervention, duration of treatment, appliance selection, extraction sequence, and need for surgery.

For many years, clinicians and researchers have sought a reliable method to determine mandibular growth.[1-3] Many variables have been studied in an attempt to assess mandibular growth with varying success. Bjork[3] found success in determining mandibular growth by using the condylar inclination, the curvature of the mandibular canal, the shape of the mandibular lower border, and the interincisal angle. Skieller *et al*[1] found four mandibular variables were the best predictors of mandibular growth direction with an 86% success rate; mandibular inclination, intermolar angles, the shape of the mandibular lower border and inclination of the mandibular symphysis.[1] Aki *et al*[2] discovered a relationship between mandibular symphysis morphology such as symphysis height, depth, and angulation with mandibular growth direction. As proven by these studies,[1,2] the mandibular symphysis can be an important factor in determining mandibular growth direction.

Computed tomography (CT) has enabled clinicians to better assess anatomical structures to gain detailed information for a more comprehensive treatment plan.[4] While CT has advantages, there are also drawbacks such as exposure to a high dose of radiation during the scanning process.[5] Fortunately, cone-beam computed tomography (CBCT) reduces the amount of radiation exposure to the patients while providing a detailed, three-dimensional map of their anatomy.[6-8] Using CBCT to evaluate anatomical landmarks in the mandible allows clinicians to closely examine neurovascular pathways, bone thickness, and bone density (BD).

Bone deposition and mineralization aids in the morphology of the mandible. It has been shown that cortical bone mineralization varies with changes in mandibular length, gonial angle, and masseter cross-sectional area.[9] Several studies[10-13] using animal experimentation or robotics, and finite element analysis have shown that there is distortion of the mandible during functional movement such as biting, closing, and mastication. This distortion may have a compounding effect on the cortical and cancellous BDs of the mandibular symphysis. With recent advances in technology, cortical and cancellous bone mineralization can now be measured using CBCT. Measuring specific locations in the symphysis of the mandible may provide insight into mandibular growth patterns and thus provide clinicians with additional information to make better treatment plans for growing patients.

The purpose of this study was to use CBCT to determine if BD of the mandibular symphysis is a critical location that can aid in determining mandibular growth direction in adolescent patients based on measurements of cortical and cancellous BDs.

MATERIALS AND METHODS

Sample size calculation

A power analysis using G*Power (version 3.19.2; Franz Faul, Christian-Albrechts-Universitat, Kiel, Germany) was performed to estimate the sample size required for this study. To detect a pairwise difference between group means, Cohen's d =.65, 40 participants per category would be necessary to achieve a power exceeding .80, p=.05, two-tailed.

Subjects, eligibility criteria, and CBCT

224 patients from the postgraduate orthodontic program at the Arizona School of Dentistry and Oral Health met the following inclusion criteria: (1) between the ages of 10 to 20 (2) no prior history of orthodontic or orthognathic surgical treatment (3) no severe asymmetry (4) no current or history of dental abnormalities such as congenitally missing teeth or supernumerary teeth in the lower anterior.

As required for a specific treatment, CBCT images were initially taken for pretreatment assessment. Two-dimensional (2D) lateral cephalometric images were obtained by converting these three-dimensional (3D) images and tracings were made on each patient's images using Dolphin 3D imaging software (version 11.7; Dolphin Imaging & Management Solutions, Chatsworth, Calif). Lateral cephalometric data were used to further categorize the patients based on skeletal features. The following cephalometric measurements were recorded: (1) anterior facial height (AFH, Nasion-Me) (2) posterior facial height (PFH, Sella-Gonion). From the lateral cephalometric data, facial height ratios (FHR), the ratio of PFH to AFH was calculated to determine the mandibular growth direction. Counterclockwise is considered to be an anterior growth direction and is defined as an FHR greater than 65% but less than or equal to 80%. Clockwise is considered to be posterior growth direction and is defined as an FHR greater than or equal to 56% but less than 62%. Normal growth direction does not exhibit a specific direction and is defined as an FHR greater than or equal to 62% but less than or equal to 65%.

The current retrospective study was approved and determined to be exempt from continuing review by the Institutional Review Board and was approved by Arizona School of Dentistry & Oral Health research committee.

Study design (CBCT reorientation and assessment)

CBCT data were reoriented to the Frankfort horizontal plane (FHP) defined through the right and left orbitales (Or) and the right porion (Po) using Dolphin 3D software (Figure 1). The mid-sagittal image of the mandibular symphysis was selected by focusing on the interproximal space between the two central incisors of the mandible and enlarging it by seven times for accurate reproducibility. Cortical bone densities were measured at the following point locations: B point, pogonion (Pog), genion (Ge), and menton (Me) (Figure 2). Dolphin software was used to provide BD values in Hounsfield Units (HU) for each point location. Ge is defined as the most posterior point of the symphysis in the area of the genial tubercles.

Basal cancellous bone densities of the mandibular symphysis were measured using SimPlant Pro 3D software (SimPlant 3-D Pro; Materialize, Leuven, Belgium). Each image was reoriented such that the mandibular plane was parallel to the horizontal axis using a red reference box with a height of 5 mm, drawn parallel to the mandibular plane. The mid-sagittal image was selected by choosing the interproximal space between two central incisors of the mandibular symphysis (Figure 3). The root apex was located and the red reference box was relocated to the root apex parallel to the mandibular plane to depict the difference between alveolar and basal BDs. Using the "create graft volume" function, basal cancellous BD was measured (Figure 4). The area was selected manually along the cortical and cancellous bone borders. The software provided a mean BD value in HU for each area of symphysis selected. Data were categorized based on sex, mandibular growth direction, and age categories.[14]

Statistical analysis

Two investigators (J.S. and J.G.) performed the measurements on 224 subjects. To evaluate the reliability of the measurements, 30 subjects were randomly selected for re-measurement two weeks after the initial measurement. Both the intra-rater and inter-rater intraclass correlation coefficients (ICC) showed excellent BD measurement reliability. ICC's (single measure, consistency) for intra-rater reliability all exceeded .99, and ICC's for inter-rater reliability all exceeded .98.

Summary statistics are provided including means (standard deviations) and counts (percentages). Preliminarily, Shapiro-Wilk tests were conducted to ensure that the data met normality assumptions. A generalized linear model approach was used to evaluate the effect of sex, mandibular growth direction, and age category on BD, concurrently. Post-hoc tests were adjusted using Tukey's Honestly Significant Difference (HSD) test. Post-hoc tests were

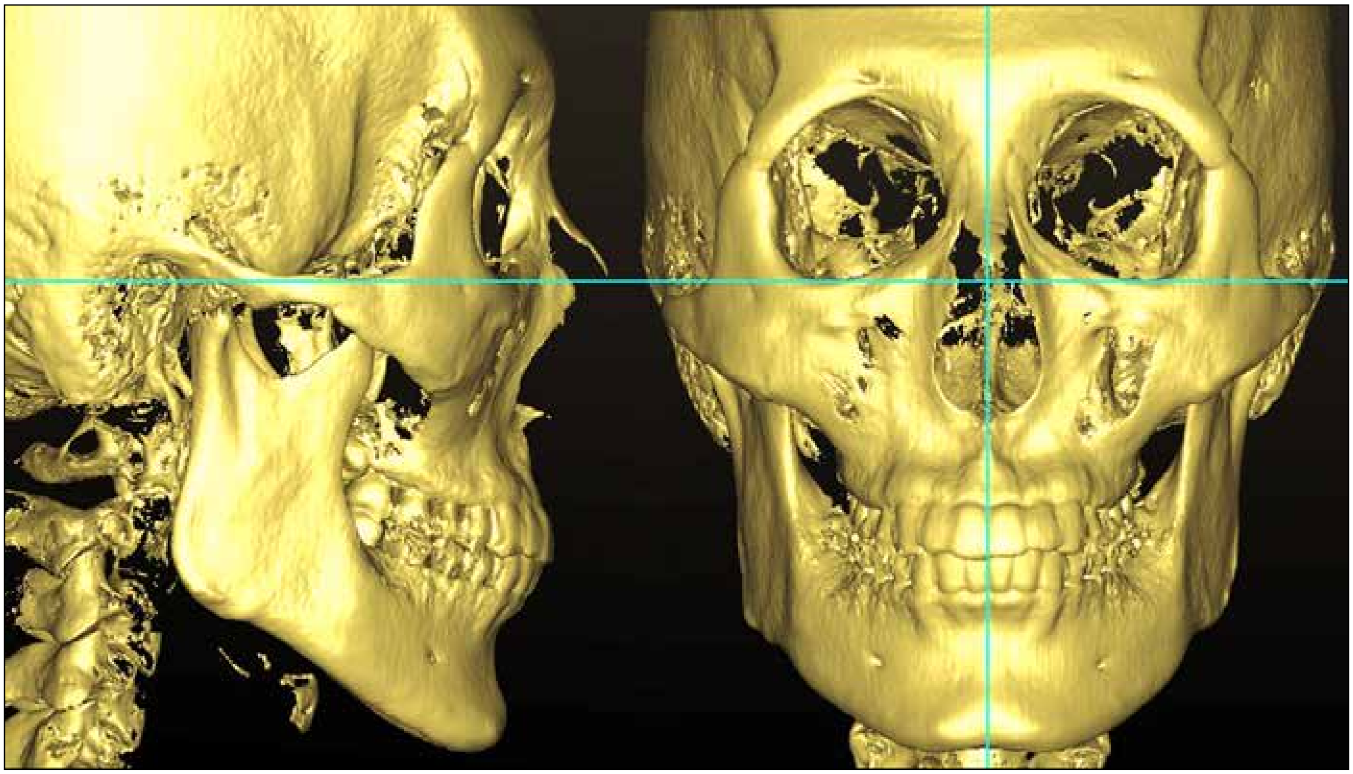

Figure 1. Sagittal and transverse images reoriented to the Frankfort horizontal plane defined through the right and left orbitales (Or) and the right porion (Po).

conducted only if the omnibus F-value for the equation was statistically significant. Significance was established at $P<0.05$, two-tailed. SPSS software (version 24; IBM, Armonk, NY) was used for statistical analyses.

RESULTS

Table 1 provides descriptive statistics for BD, categorized by sex, age, and growth direction. Table 2 provides results for the generalized linear models. Females exhibited higher mean cortical BD than males at Me ($P=0.002$). Segregating by growth direction, posterior direction was related to higher mean cortical BD than anterior and normal direction at Me ($P<0.001$, $P=0.021$, respectively), Pog ($P=0.037$, $P=0.037$, respectively) and Ge ($P=0.008$, $P=0.007$, respectively). Also, there was a higher mean cortical BD with the posterior direction than with the anterior direction at B point ($P=0.009$).

DISCUSSION

Skeletal maturation can be determined by several methods such as six-month serial lateral cephalograms, hand-wrist analysis, cervical vertebral maturation, the formation of third molars, secondary sex characteristics, height, and chronological age.[15] Despite the numerous modes of maturation evaluation, determining mandibular growth can be challenging. Using CBCT in connection with orthodontic treatment has not only allowed clinicians to determine the current skeletal maturation state, but also the possibility of determining the direction of growth.[16]

The ability to reliably determine mandibular growth allows a clinician to create a proper treatment plan in accordance with the patient's growth. Definitive mandibular assessments can allow

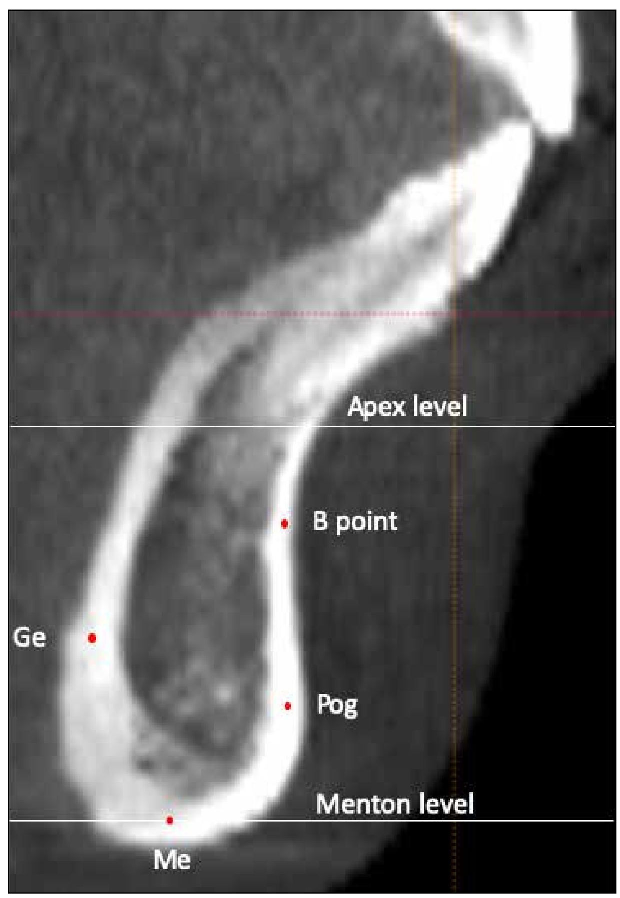

Figure 2. Locations for symphysis bone density measurements on a mid-sagittal slice of C-mode CBCT image: genion (Ge); menton (Me); pogonion (Pog); B point.

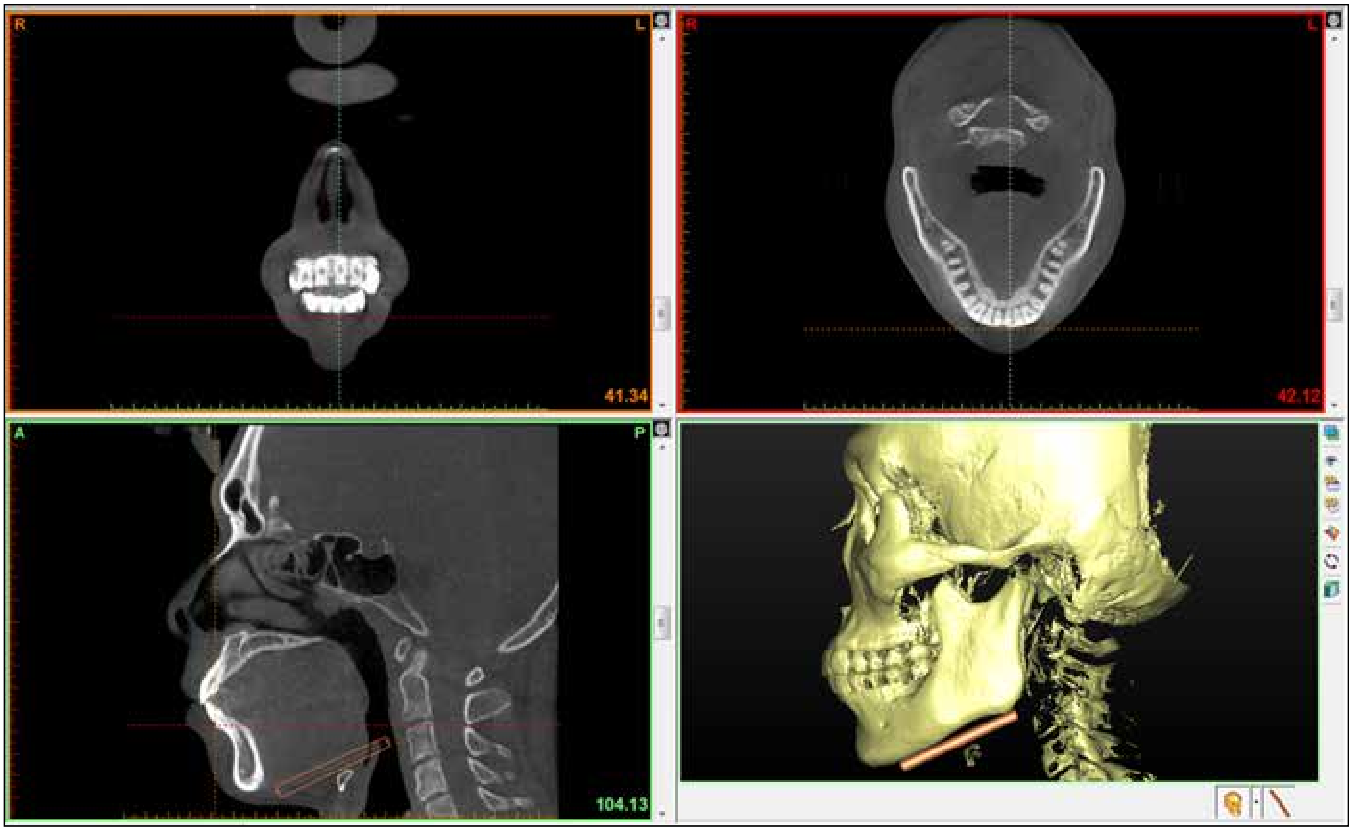

Figure 3. Four panel windows with coronal, sagittal, and axial slices of a C-mode CBCT image. A red reference box drawn parallel to the mandibular plane was used to define the boundary between the alveolus and basal bones in the mandibular symphysis.

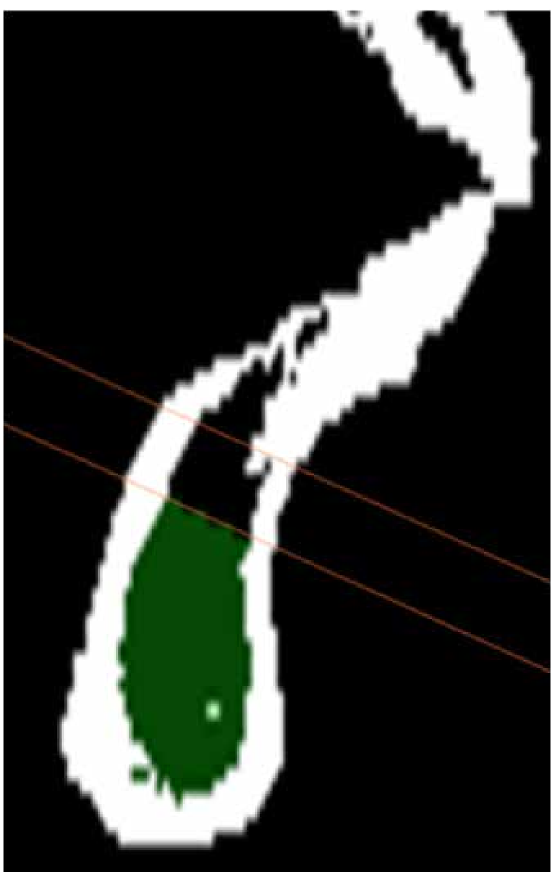

Figure 4. Mid-sagittal slices of a C-mode CBCT image; total basal cancellous bone density.

clinicians to conduct proactive rather than reactive treatment in the case of mandibular excess or deficiency. Based on mandibular symphysis BD measurements, the use of functional therapy may enhance the esthetics and functional outcome for the patient. Therefore, the purpose of this study was to explore the relationship between sex, age category, mandibular growth direction, and BD to identify mandibular symphysis locations that might assist in predicting mandibular growth direction.

The mandibular symphysis is divided into two sections; the alveolar symphysis and the basal symphysis. Each segment consists of cortical bone surrounding cancellous bone. Certain morphologic characteristics of the mandibular symphysis have been studied to aid in the determination of mandibular growth. These characteristics are depth, height, and angulation of the mandibular symphysis.[2] Due to the significance of the mandibular symphysis as a dependable predictor of mandibular growth direction, four cortical bone point locations and one cancellous bone area within the symphysis were identified as areas of interest when measuring BD.[1-3] Digital Imaging and Communications in Medicine (DICOM) scans of the mandibular symphysis BD served as a comparison of the growth direction with the lateral cephalometric digital images. The data collected were categorized based on sex dichotomy, adolescent stage, and mandibular growth direction. In total, eight statistically significant differences (P <0.05) were identified **(**Figure 5).

Mean cortical BD was greater in females than in males at Me which showed similar results with the previous studies although they were measured in the different regions such as alveolar bone, palate, and condyle.[17-19] This suggests that BD is related to sex.

Table 1. Mandibular symphysis bone density according to sex, age and growth direction (HU)

	Mean (standard deviation)							
	Male (n=98)	**Female (n=126)**	**Early: 10≤y<14 (n=118)**	**Middle: 14≤y<17 (n=74)**	**Late: 17≤y<20 (n=32)**	**Anterior: 65%<FHR≤80% (n=119)**	**Normal: 62%≤FHR≤65% (n=45)**	**Posterior: 56%≤FHR<62% (n=60)**
Menton (Me)	1643.27 (235.36)	1753.40 (242.43)	1673.78 (257.11)	1719.76 (234.61)	1787.50 (203.76)	1647.23 (244.98)	1707.84 (216.95)	1818.25 (228.06)
Pogonion (Pog)	1632.93 (257.82)	1671.12 (268.57)	1618.30 (265.89)	1679.68 (250.83)	1729.16 (272.37)	1633.18 (254.34)	1608.64 (264.82)	1730.85 (270.81)
Genion (Ge)	1645.54 (181.92)	1674.32 (189.64)	1651.29 (190.87)	1680.07 (178.29)	1657.81 (190.91)	1645.13 (180.32)	1619.38 (207.75)	1726.42 (167.27)
B-Point	1301.23 (299.77)	1337.70 (288.25)	1278.81 (301.96)	1362.39 (299.55)	1386.06 (218.85)	1278.76 (268.35)	1323.42 (313.99)	1405.73 (310.73)
Basal Cancellous BD	617.00 (230.37)	629.25 (213.37)	612.73 (219.24)	645.62 (192.97)	614.79 (281.26)	639.67 (234.34)	614.16 (193.30)	599.91 (212.10)

HU; Hounsfield units.
FHR; Facial height ratio (%).
Ge; Posterior point of the symphysis in the area of the genial tubercles.

Table 2. Prediction of mandibular symphysis bone density by sex, age, and growth direction (HU)

		Wald 95% Confidence Interval		
	Mean Difference	**Lower**	**Upper**	***P* value**
Menton (Me)				
Sex (Male minus Female)	-96.73	-156.73	-36.74	0.002**
Growth Direction (FHR)				
Normal vs Anterior	55.45	-21.84	132.73	0.160
Normal vs Posterior	-113.80	-213.21	-14.39	0.021*
Anterior vs Posterior	-169.25	-254.95	-83.55	<0.001***
Age Group				
Early vs Middle	-63.98	-139.04	11.07	0.112
Early vs Late	-99.23	-207.19	8.74	0.083
Middle vs Late	-35.24	-129.39	58.90	0.463
Pogonion (Pog)				
Sex (Male minus Female)	-29.66	-97.76	38.43	0.393
Growth Direction (FHR)				
Normal vs Anterior	-24.78	-112.50	62.94	0.580
Normal vs Posterior	-125.93	-246.44	-5.42	0.037*
Anterior vs Posterior	-101.15	-197.91	-4.39	0.037*
Age Group				
Early vs Middle	-70.27	-155.45	14.92	0.129
Early vs Late	-107.81	-230.35	14.72	0.106
Middle vs Late	-37.55	-144.40	69.30	0.491
B Point				
Sex (Male minus Female)	-26.47	-102.02	49.08	0.492
Growth Direction (FHR)				
Normal vs Anterior	46.22	-51.10	143.54	0.352
Normal vs Posterior	-87.15	-212.34	38.03	0.237
Anterior vs Posterior	-133.37	-241.29	-25.46	0.009**

Table 2. Prediction of mandibular symphysis bone density by sex, age, and growth direction (HU) (continued)

		Wald 95% Confidence Interval		
	Mean Difference	**Lower**	**Upper**	***P* value**
Age Group				
Early vs Middle	-95.95	-196.89	5.00	0.069
Early vs Late	-104.14	-231.43	23.14	0.133
Middle vs Late	-8.20	-126.74	110.34	0.892
Genion (Ge)				
Sex (Male minus Female)	-28.24	-76.38	19.90	0.250
Growth Direction (FHR)				
Normal vs Anterior	-25.70	-87.71	36.32	0.417
Normal vs Posterior	-108.66	-193.87	-23.46	0.007**
Anterior vs Posterior	-82.97	-147.35	-18.58	0.008**
Age Group				
Early vs Middle	-36.14	-100.47	28.19	0.536
Early vs Late	-3.45	-74.38	67.48	0.924
Middle vs Late	32.69	-53.70	119.08	0.793
Basal Cancellous BD				
Sex (Male minus Female)	-16.62	-75.01	41.78	0.577
Growth Direction (FHR)				
Normal vs Anterior	-24.90	-110.93	61.13	>0.99
Normal vs Posterior	12.92	-76.55	102.38	>0.99
Anterior vs Posterior	37.82	-45.60	121.23	0.833
Age Group				
Early vs Middle	-30.12	-108.15	47.91	>0.99
Early vs Late	0.93	-85.42	87.29	>0.99
Middle vs Late	31.05	-73.50	135.61	>0.99

HU; Hounsfield units. FHR; facial height ratio (%). **P*<0.05, ***P*<0.01 ****P*<0.001. Ge; Posterior point of the symphysis in the area of the genial tubercles.

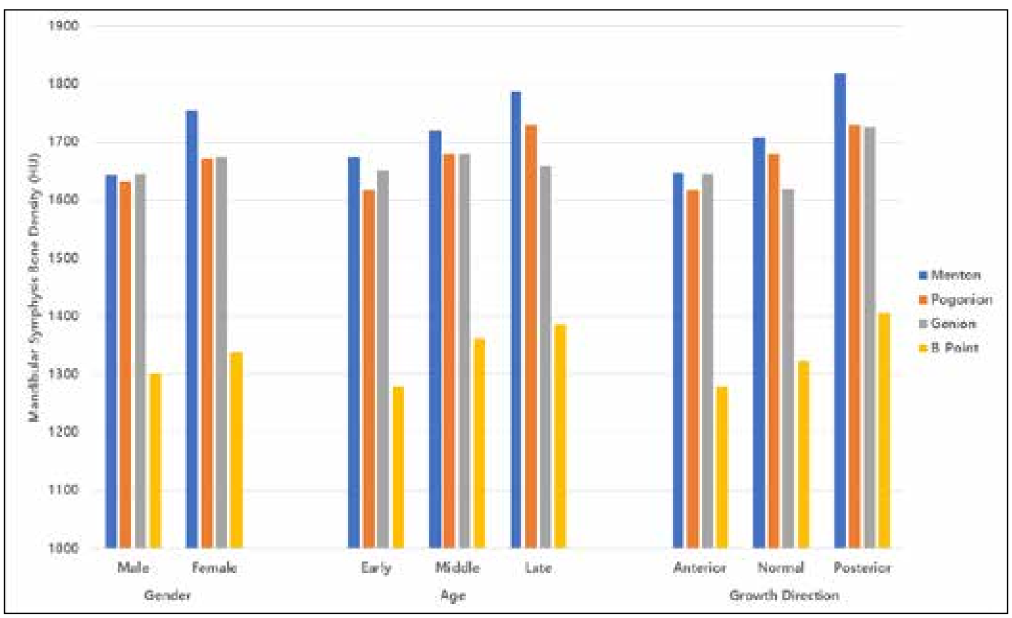

Figure 5. Comparisons of cortical bone density measurements by site, gender, age, and growth direction. Menton (Male vs Female: *P* =0.002, Growth Direction (Posterior to Anterior, Posterior to Normal): *P* <0.001, *P* =0.021). Pogonion (Growth Direction (Posterior to Anterior, Posterior to Normal): *P* =0.037, *P* =0.037). Genion (Growth Direction (Posterior to Anterior, Posterior to Normal): *P* =0.008, *P* =0.007). B Point (Growth Direction (Posterior to Anterior: *P* =0.009).

Estrogen and cytokines play a critical role in regulating the activity of osteoblasts and osteoclasts in the bone remodeling process. Estradiol helps to maintain higher levels of BD and thus it can be inferred that females will exhibit a higher level of BD than males. A study conducted to determine the effects of estrogen deficiency or estrogen replacement therapy in osteoporotic women found that women with estrogen replacement therapy exhibit denser bone than those without therapy.[20]

In this study, the mandibular growth direction seemed to correspond to BD at Me, Pog, Ge, and B Point. When the mean cortical BD was higher, there seemed to be a positive correlation with posterior growth direction more so than with either anterior or normal growth directions. Likewise, a higher mean cortical BD corresponded with normal growth direction more than with anterior growth direction; however, this was not statistically significant and is only an observation. Above all, there was a consistent statistically significant relationship between BD at Me and sex dichotomy, indicating that BD at Me may be the critical factor in determining mandibular growth direction.

Studies[21,22] reported that increased loading of the jaw associated with masticatory muscle function increased sutural growth and stimulated bone apposition, which is associated with an anterior growth direction. Tsunori *et al*[23] reported correlations between morphological characteristics of the mandibular body and facial type. They found that basal cortical bone thickness of the lower incisor section was greater in the short-faced group than in the average and long-faced groups, and concluded that facial types, which relate to masticatory function, were associated with the cortical bone thickness of the mandibular body. Al-Masri *et al*[24] also evaluated the bone thickness and density in the mandibular incisor's region to examine the relationship between thickness and density in different horizontal skeletal patterns. They found that apical buccal thickness was greater in Class I and II patients than in Class III patients. Thus, it might be inferred that bone thickness may correlate to BD. However, because thickness and BD are inconsistent from one location to another, a future study should be considered to compare BD and bone thickness as a determiner of growth direction.

In our study, FHR was used to determine the mandibular growth direction. We found that individuals with anterior growth direction exhibited lower mean cortical BD than those with posterior growth direction at every measured location. These results were similar to the previous studies although they were performed in the condyle area. They concluded that patients with the posterior growth pattern of mandibular retrognathism showed higher bone densities due to a developmental disorder associated with an imbalance of bone metabolism by a combination of bone formation and resorption.[19,25,26]

This retrospective study had several limitations. First, the sample size was limited so caution should be exercised when generalizing the results to a given population. Secondly, because all CBCTs were taken before orthodontic treatment, no post-treatment or progress CBCTs were taken. Ideally, CBCTs would be taken annually and collected over the years of adolescence to have an accurate comparison of the same individual over each period to accurately track growth. As it would not be realistic to expose patients unnecessarily to radiation, patients were grouped based on other current growth direction patterns using the Roth-Jarabak cephalometric analysis.[27]

In this study, CBCT images were used to measure mandibular symphysis BD. It has been reported that BD measurements using CBCT are not as accurate as multiple detectors computed tomography (MDCT).[28] However, studies[28-31] have shown that it might be possible to evaluate bone mineral content (BMC) from the voxel values (VV) of CBCT. With CBCT, the dimensional accuracy is also comparable with CT, but in contrast to CT, the gray density values of the images (VV) are not absolute.[29] In this study, the comparison of CBCT BD measurements was not based on absolute numerical values but based on relative values. In contrast to medical computed tomography images, where -1000 HU always indicates air and 0 HU always indicates water, attenuation coefficients in CBCT images are not standardized. However, according to Cassetta *et al*[30] a linear relationship exists between CBCT gray density values and those of CT, which allows CBCT gray density values (VV) to be converted into absolute values (once the correct conversion rate has been established).[29] England *et al*[32] found that bone density can be assessed by using CBCT; however, calibration is required to compare absolute values between different CBCT scanners. Therefore, the authors are planning future studies to derive conversion factors between several CBCT scanners and MDCT to obtain absolute values.

The findings of this study provide information that can be used clinically. Functional appliance therapy is an adjunct treatment modality used by clinicians to help correct both vertical and anteroposterior discrepancies. The success of any appliance is dependent on many factors, one of which is timing. A properly timed implementation of a functional appliance can allow the clinician to capture as much growth as possible.[33] By understanding that a lower BD in the mandibular symphysis is indicative of anterior growth direction, a clinician may have the foresight to know the existence of a favorable growth pattern is present in the presence of a skeletal Class II. However, if the patient presents with higher BD in the mandibular symphysis, the clinician will have the foresight to understand a favorable growth pattern is not present and implement an alternative functional appliance to help lessen the complexity of the treatment, giving the clinician the ability to be proactive rather than reactive in treatment. Understanding the mandibular symphysis BD in conjunction with other growth factors can allow the clinician to have a better treatment plan, reduce treatment time, and improve treatment outcomes.

CONCLUSIONS

In this study, the mandibular symphysis BDs were measured and compared in adolescent patients with various mandibular growth directions.

1. Patients with a higher cortical BD were more likely to show a posterior growth direction than an anterior or normal growth direction.
2. Menton was the most meaningful area, having the greatest statistical significance in predicting mandibular growth direction in adolescents.
3. The mandibular symphysis cortical BD at menton was higher in females than in males.
4. The mandibular symphysis cancellous BD showed no statistical relationship with growth direction.

DECLARATION SECTION

Ethics Approval and Consent to Participate

Ethics Approval: The current retrospective study was approved and determined to be exempt from continuing review by the Institutional Review Board and was approved by the Arizona School of Dentistry & Oral Health research committee, Curt Bay, PhD (IRB #2016-144)

Consent for Publication

Not Applicable

Availability of data and supporting materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Funding

No funding was provided for this research

Authors' Contribution

JC conceived of the study, and participated in its design and coordination and helped to draft the manuscript, JG performed measurements, collected data, formulated data tables, and figures and drafted the manuscript, JS performed measurements and collected data, CB statistical analysis, JP help draft the manuscript. All authors read and approved the final manuscript.

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