International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2025: 7.089

Temporomandibular Joint Spaces and Pharyngeal Airway Dimensions Across Sagittal Skeletal Malocclusion Classes: A Retrospective CBCT Study

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Abstract: ***This study aimed to compare temporomandibular joint (TMJ) spaces and linear pharyngeal airway dimensions across skeletal Class I, II, and III malocclusions. This retrospective cross-sectional CBCT study included 60 adults, with 20 individuals in each skeletal class. Anterior, superior, and posterior joint spaces were measured on the left TMJ only. Group comparisons were performed using Welch's analysis of variance with Games–Howell post hoc tests for TMJ measurements and Kruskal–Wallis tests with Dunn–Bonferroni comparisons for pharyngeal dimensions. Anterior joint space did not differ significantly among the groups ($p = 0.120$), whereas superior and posterior joint spaces showed significant differences (both $p < 0.001$), chiefly between Class II and the other groups. Nasopharyngeal dimensions differed significantly among the skeletal classes ($H = 21.777$; $p < 0.001$), with Classes II and III exhibiting greater dimensions than Class I. However, oropharyngeal dimensions showed no statistically significant differences ($p = 0.549$). The findings indicate that TMJ superior and posterior joint spaces and nasopharyngeal airway width vary according to skeletal class. However, these cross-sectional measurements do not establish a direct association between TMJ spaces and airway dimensions or indicate functional impairment.***

Keywords: cone-beam computed tomography; temporomandibular joint; joint space; pharyngeal airway; skeletal malocclusion

1. Introduction

The temporomandibular joint (TMJ) is anatomically and functionally integrated with the dentofacial skeleton. On sagittal cone-beam computed tomographic (CBCT) sections, the anterior, superior, and posterior joint spaces describe the spatial relationship between the mandibular condyle and the articular fossa.[1] These distances are accessible structural observations, but they are not interchangeable with disc position, joint loading, pain, or temporomandibular disorder diagnoses. Condylar-fossa relationships may vary with occlusal and skeletal configuration even in individuals without symptoms.[2]

Sagittal skeletal discrepancies may be accompanied by differences in mandibular position, growth rotation, articular morphology, or adaptive remodeling.[3] Previous tomographic investigations have explored condylar location and TMJ features in Class II and Class III malocclusions, with results influenced by anatomical definitions and sampled populations.[4] A comparison of joint spaces across skeletal classes may therefore describe morphological differences without establishing that malocclusion caused joint remodeling.[5]

The pharyngeal airway is another structure closely related to craniofacial form.[6] Its observed dimensions depend on skeletal relationships, tongue and soft-palate posture, head position, respiratory phase, and imaging posture.[7] CBCT has enabled three-dimensional airway measurements and has shown differences in airway morphology across certain skeletal and vertical patterns. Nevertheless, volumetric measurements, minimum cross-sectional areas, and linear anteroposterior widths represent distinct outcome variables and should not be interpreted as equivalent measures.[10]

Two investigations are particularly relevant. Alhammadi and colleagues examined 120 adults in skeletal Class I and II subgroups with average or increased vertical facial height and reported regional three-dimensional airway differences rather than a single uniform effect of skeletal class.[8] Oğuz and colleagues evaluated 93 skeletal Class I participants with different vertical growth patterns using AI-assisted segmentation and observed smaller mean airway and condylar volumes in the hyperdivergent group, although airway and condylar volumes were not significantly correlated within those groups.[9] These findings suggest that skeletal growth pattern and measurement technique may complicate comparisons across studies.[10]

Existing research has often emphasized either joint morphology or airway dimensions, and cross-study

comparison is limited by heterogeneous imaging protocols, landmark definitions, and outcome metrics.[10] Simultaneous documentation of TMJ joint-space dimensions and linear pharyngeal airway dimensions within a single archived CBCT cohort can clarify how each set of measurements varies by sagittal skeletal classification. However, such a design does not, by itself, test a direct TMJ-airway association.[8]

The objective of this retrospective cross-sectional study was to compare left-sided anterior, superior, and posterior TMJ joint spaces and nasopharyngeal and oropharyngeal anteroposterior dimensions among adults with skeletal Class I, II, and III relationships. The null hypothesis was that these measured dimensions would not differ across skeletal classes.[8]

This retrospective cross-sectional study evaluated archived cone-beam computed tomography (CBCT) records obtained for clinical purposes. Institutional ethics approval was obtained, and the participants had provided consent for the use of their clinical and radiographic data for research. No additional radiographic examinations were performed solely for the study.

A total of 200 archived CBCT records were screened, of which 60 records met the eligibility criteria and were included in the analysis. The study included 20 participants in each skeletal Class I, II, and III group, aged 18–30 years. The final sample consisted of 30 women and 30 men. Group-wise demographic characteristics are presented in Table 1.

2. Eligibility and skeletal classification

Included records had sufficient field of view and image quality to assess the left TMJ and the relevant upper-airway anatomy. Participants were adults with a skeletal Class I, II, or III relationship and no history of orthodontic treatment or orthognathic surgery, craniofacial syndromes, or known respiratory tract pathology affecting the measurement region. Records with artifacts preventing reliable landmark identification, incomplete anatomical coverage, marked facial asymmetry, or conditions affecting TMJ or airway anatomy were excluded.

Sagittal skeletal relationships were classified primarily by the ANB angle, with Wits appraisal used as a complementary linear assessment of the maxillomandibular relationship. The ANB criteria applied were 2°–4° for skeletal Class I, >4° for skeletal Class II, and <0° (negative ANB) for skeletal Class III. For Wits appraisal, the Class I reference values considered were approximately −1 mm in males and 0 mm in females; positive values were characteristic of skeletal Class II and negative values of skeletal Class III. Both measurements were considered in the cephalometric evaluation of the selected records.

3. CBCT acquisition and orientation

CBCT imaging was performed using a Carestream CS 9600 unit (Carestream Dental). The available acquisition-protocol photographs documented a field-of-view selection of 16 cm diameter × 6 cm height for the TMJ region and 16 cm diameter × 17 cm height for the skull and pharyngeal-airway region. For the displayed 16 × 17-cm skull protocol, the parameters were 120 kV, 5.0 mA, 24-second exposure time, a 0.7-mm copper filter, and a voxel size of 300 µm (0.3 mm). These values describe the documented skull-protocol display; the TMJ-protocol exposure parameters were not provided.

Acquired CBCT datasets were exported in Digital Imaging and Communications in Medicine (DICOM) format and imported into Carestream imaging software. The scans were oriented relative to the Frankfort horizontal plane before measurement to maintain consistent multiplanar alignment.

4. TMJ joint-space measurements

The left TMJ was evaluated on sagittal CBCT reconstructions passing through the center of the left mandibular condyle. Superior joint space (SS) was defined as the shortest distance between the superior condylar surface and the roof of the articular fossa. Anterior joint space (AS) and posterior joint space (PS) were measured between the corresponding condylar surfaces and the anterior and posterior walls of the articular fossa (Figure 1). A representative measurement is illustrated in Figure 2.

All anterior, superior, and posterior joint-space measurements were obtained from the left TMJ only using the linear measurement tools of Carestream imaging software and recorded in millimeters. The right TMJ was not measured for this analysis, and right- and left-sided values were neither combined nor averaged. Each participant contributed one left-sided value for each joint-space parameter.

5. Pharyngeal airway measurements

Pharyngeal airway dimensions were assessed on standardized sagittal CBCT sections using linear measurement tools. The nasopharyngeal region was defined between the anterior nasal spine–posterior nasal spine reference plane and the first cervical vertebral level (CV1). The oropharyngeal region extended from CV1 to the second cervical vertebral level (CV2). The narrowest anteroposterior distance within each region was recorded in millimeters (Figures 3 and 4).

Airway outcomes were linear sagittal measurements rather than volumetric measurements or cross-sectional areas. The study did not evaluate airflow, sleep-related respiratory function, or temporomandibular joint symptoms.

6. Statistical analysis

Continuous variables were summarized as means and standard deviations (SD). Normality was assessed using the Shapiro–Wilk test within each skeletal group. Left-sided anterior, superior, and posterior TMJ joint spaces were compared across skeletal classes using Welch's one-way analysis of variance, followed by Games–Howell post hoc comparisons. Nasopharyngeal and oropharyngeal dimensions were compared using the Kruskal–Wallis test because at least one group for each parameter showed evidence of non-normality; pairwise comparisons used Dunn's test with Bonferroni adjustment. Statistical significance was set at $p <$

0.05. The analysis was conducted using JASP statistical software.

7. Results

1) Study Population

Of the 350 archived CBCT examinations screened, 60 were included in the final analysis, with 20 participants in each skeletal class. Class I comprised 10 women and 10 men (mean age, 21.3 ± 2.8 years); Class II comprised 11 women and 9 men (20.9 ± 3.1 years); and Class III comprised 9 women and 11 men (21.7 ± 2.9 years). The overall mean age was 21.3 ± 2.9 years (Table 1).

2) TMJ joint-space comparisons

Left anterior joint-space (AS) means were 2.71 ± 0.45, 2.72 ± 0.34, and 2.38 ± 0.65 mm for skeletal Class I, II, and III, respectively. The overall group difference was not significant (Welch $F(2, 35.94) = 2.255$; $p = 0.120$), and no Games–Howell pairwise comparison was significant (Tables 2 and 3).

Left superior joint-space (SS) means were 3.53 ± 0.46 mm (Class I), 2.92 ± 0.75 mm (Class II), and 3.87 ± 0.71 mm (Class III). The overall group difference was significant (Welch $F(2, 36.05) = 8.586$; $p < 0.001$). Games–Howell tests showed significant differences between Class I and Class II (adjusted $p = 0.011$) and between Class II and Class III (adjusted $p < 0.001$), but not between Class I and Class III (adjusted $p = 0.186$) (Tables 2 and 3).

Left posterior joint-space (PS) means were 3.09 ± 0.28, 2.42 ± 0.54, and 3.22 ± 0.69 mm in Class I, II, and III, respectively. The overall difference was significant (Welch $F(2, 32.80) = 13.22$; $p < 0.001$). The Class II group differed from both Class I and Class III (both Games–Howell adjusted $p < 0.001$), whereas Class I and Class III did not differ significantly (adjusted $p = 0.719$) (Tables 2 and 3).

3) Pharyngeal airway comparisons

Nasopharyngeal (NP) mean dimensions were 20.42 ± 5.50 mm in Class I, 28.64 ± 5.46 mm in Class II, and 28.62 ± 6.31 mm in Class III. The Kruskal–Wallis test was significant ($H(2) = 21.777$, $p < 0.001$). Dunn's post hoc tests with Bonferroni adjustment identified differences between Class I and Class II and between Class I and Class III (both adjusted $p < 0.001$); Class II and Class III did not differ (adjusted $p = 1.000$). Normality tests and group comparisons are presented in Tables 2 and 4–6.

Mean oropharyngeal (OP) dimensions were 30.41 ± 4.92, 28.11 ± 5.92, and 29.04 ± 7.02 mm in Classes I, II, and III, respectively. The overall Kruskal–Wallis result was not significant ($H(2) = 1.199$, $p = 0.549$); none of the Dunn–Bonferroni pairwise tests was significant (Tables 2, 4–6).

The study compared TMJ and airway measurements by skeletal class. A direct correlation between joint-space dimensions and airway measurements was not assessed.

8. Discussion

In this sample, superior and posterior joint spaces measured at the left TMJ and nasopharyngeal airway dimensions differed significantly across sagittal skeletal classes, whereas left anterior joint space and oropharyngeal airway dimensions did not. The lowest mean superior and posterior joint spaces were observed in skeletal Class II, and the lowest mean nasopharyngeal dimension in skeletal Class I. These differences were specific to the anatomical measurements rather than uniform across the TMJ and airway. Previous tomographic studies have also described differences in condyle–fossa relationships across sagittal skeletal patterns.[3]

The mean left anterior joint space was numerically smallest in skeletal Class III, but the overall Welch ANOVA and all Games–Howell pairwise comparisons were nonsignificant. The descriptive difference should not be interpreted as evidence of condylar displacement. Arieta-Miranda and colleagues evaluated condylar position in different sagittal skeletal relationships using CBCT, illustrating the need for consistent anatomical definitions when interpreting joint-space measurements.[4]

Left superior and posterior joint spaces were significantly smaller in skeletal Class II than in Classes I and III, whereas Classes I and III did not differ significantly. Rodrigues and colleagues investigated condylar symmetry and condyle–fossa relationships in skeletal Class II Division 1 and Class III malocclusions by computed tomography.[3] Katsavrias and Halazonetis described condylar and fossa morphology in different skeletal patterns.[11] Park and colleagues examined condylar position and morphology in relation to vertical skeletal pattern.[5] Differences in anatomical endpoints, joint laterality, acquisition methods, and skeletal classification limit direct comparison with these investigations.[4]

The nasopharyngeal airway dimension was significantly smaller in skeletal Class I than in Classes II and III, while the latter groups had comparable measurements. Grauer and colleagues described variation in three-dimensional pharyngeal airway volume and shape in relation to facial morphology.[6] The present findings concern a single linear measurement and cannot be equated with total airway volume or minimum cross-sectional area. Likewise, a difference in sagittal airway width does not establish airway obstruction or abnormal respiratory function.[10]

Alhammadi and colleagues assessed regional pharyngeal airway volumes and minimum constricted areas in 120 adults with different sagittal and vertical skeletal patterns.[8] Their findings differed across airway compartments and facial-height groups. Oğuz and colleagues studied 93 skeletal Class I patients across vertical growth patterns and found reduced airway and condylar volumes in hyperdivergent individuals without a significant within-group correlation between these volumes.[9] The present study differs from both investigations because it compares three sagittal skeletal classes using linear TMJ joint-space and airway measurements.[6]

Tseng and colleagues evaluated volumetric airway compartments and minimum cross-sectional areas in different dentofacial skeletal patterns and reported group-specific volumetric differences.[12] Muto and colleagues examined the relationship between pharyngeal airway dimensions and craniofacial morphology while accounting for head posture.[13] De Freitas and colleagues compared upper and lower

pharyngeal airway widths in Class I and Class II malocclusions with differing growth patterns.[14] These studies emphasize the influence of skeletal pattern and measurement protocol on the interpretation of airway dimensions.[10]

The lack of a significant oropharyngeal difference in the present sample suggests that variation in airway dimensions may not occur uniformly across anatomical regions. Previous research has examined differences in pharyngeal dimensions among vertical growth patterns.[7] The absence of a significant difference, however, does not establish anatomical equivalence, particularly in a study with 20 individuals per group.[15]

The retrospective study design and inclusion of 60 records from 350 archived examinations may limit generalizability. Only the left TMJ was measured; right-sided joint spaces and bilateral asymmetry were not evaluated. In addition, the analyses did not adjust for potentially relevant variables such as vertical skeletal pattern, body mass index, tongue posture, or respiratory status. The cross-sectional design does not establish whether skeletal class contributed to the measured anatomical differences. Pharyngeal airway dimensions have also been reported to differ among vertical skeletal patterns.[7]

TMJ joint-space distances describe the relationship between the condylar surface and the articular fossa on selected images, but do not establish articular disc position or clinical joint dysfunction. Similarly, static airway measurements cannot determine respiratory resistance, sleep quality, or obstructive sleep apnea. These distinctions are particularly important when interpreting statistically significant differences of uncertain clinical magnitude. In a CBCT investigation of symptom-free joints, disc status was assessed separately by magnetic resonance imaging.[2]

Welch's ANOVA with Games–Howell comparisons was used for TMJ measurements with unequal group variances, while Kruskal–Wallis and Dunn–Bonferroni tests provided rank-based comparisons for airway measurements. These tests describe between-group differences but do not establish their clinical importance. Effect sizes and confidence intervals would provide further information about the magnitude and precision of the findings.[15]

The study did not test a direct association between TMJ joint spaces and airway dimensions. Both sets of measurements were compared with sagittal skeletal classification, but no within-participant correlation or regression analysis linked the joint-space measurements to the airway measurements. Therefore, the findings should not be interpreted as evidence that condylar position causes variation in pharyngeal airway size, or vice versa. In a separate skeletal Class I cohort, Oğuz and colleagues reported no significant correlation between condylar and airway volumes within the vertical-growth groups.[9]

CBCT may contribute useful anatomical information when obtained for an appropriate clinical indication; its use should remain justified by diagnostic need. Three-dimensional airway assessment methods have been evaluated for accuracy and reliability, supporting careful selection of measurement protocols.[10] Further studies with larger samples, standardized imaging and measurement procedures, documented measurement repeatability, and relevant clinical outcomes are required to determine the clinical significance of these anatomical differences.[10]

9. Conclusion

In this retrospective CBCT study of 60 adults, left superior and posterior TMJ joint spaces and nasopharyngeal airway dimensions differed significantly across skeletal Class I, II, and III groups. Left superior and posterior joint spaces were smallest in skeletal Class II, while nasopharyngeal airway dimensions were smaller in Class I than in Classes II and III. Left anterior joint space and oropharyngeal airway dimensions did not differ significantly. These findings describe group-level anatomical differences; they do not demonstrate a direct TMJ–airway relationship or establish clinical joint or respiratory dysfunction.

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Figure legends

Figure 1: Representative sagittal CBCT image illustrating the landmarks used to measure superior (A–B), anterior (C–D), and posterior (E–F) TMJ joint spaces. The study measurements were performed on the left TMJ only.

Figure 2: Representative sagittal CBCT illustration of linear TMJ joint-space measurements: anterior joint space, 3.9 mm; superior joint space, 5.5 mm; and posterior joint space, 3.6 mm. The study measurements were obtained from the left TMJ only.

Figure 3: CBCT views illustrating the pharyngeal airway measurement region and anatomical reference structures.

Figure 4: Midsagittal CBCT image illustrating linear airway measurements at the nasopharyngeal and oropharyngeal levels.

Tables

Table 1: Demographic characteristics by sagittal skeletal class

Skeletal group	n	Female, n	Male, n	Age, years (mean ± SD)
Class I	20	10	10	21.3 ± 2.8
Class II	20	11	9	20.9 ± 3.1
Class III	20	9	11	21.7 ± 2.9
Overall	60	30	30	21.3 ± 2.9

Values are expressed as the number of participants or mean ± standard deviation (SD), as appropriate.

Table 2: Descriptive statistics and overall comparisons of left TMJ joint spaces and pharyngeal airway dimensions

Parameter	Class I Mean ± SD (mm)	Class II Mean ± SD (mm)	Class III Mean ± SD (mm)	Overall test	Statistic (df)	p-value
Anterior joint space (AS)	2.71 ± 0.45	2.72 ± 0.34	2.38 ± 0.65	Welch ANOVA	F(2, 35.94) = 2.255	0.120
Superior joint space (SS)	3.53 ± 0.46	2.92 ± 0.75	3.87 ± 0.71	Welch ANOVA	F(2, 36.05) = 8.586	<0.001
Posterior joint space (PS)	3.09 ± 0.28	2.42 ± 0.54	3.22 ± 0.69	Welch ANOVA	F(2, 32.80) = 13.22	<0.001
Nasopharyngeal airway (NP)	20.42 ± 5.50	28.64 ± 5.46	28.62 ± 6.31	Kruskal–Wallis	H(2) = 21.777	<0.001
Oropharyngeal airway (OP)	30.41 ± 4.92	28.11 ± 5.92	29.04 ± 7.02	Kruskal–Wallis	H(2) = 1.199	0.549

Abbreviations: TMJ, temporomandibular joint; AS, anterior joint space; SS, superior joint space; PS, posterior joint space; NP, nasopharyngeal airway; OP, oropharyngeal airway; SD, standard deviation.

Table 3: Games–Howell post hoc comparisons of left TMJ joint spaces

Parameter	Pairwise comparison	Mean difference (mm)	Adjusted p-value	Interpretation
AS	Class I vs Class II	−0.01	0.997	Not significant
AS	Class I vs Class III	0.33	0.164	Not significant
AS	Class II vs Class III	0.34	0.112	Not significant
SS	Class I vs Class II	0.61	0.011	Significant
SS	Class I vs Class III	−0.34	0.186	Not significant
SS	Class II vs Class III	−0.95	<0.001	Significant
PS	Class I vs Class II	0.67	<0.001	Significant
PS	Class I vs Class III	−0.13	0.719	Not significant
PS	Class II vs Class III	−0.80	<0.001	Significant

Note: Mean differences are calculated as the first listed group minus the second group.

Table 4: Descriptive statistics and Shapiro–Wilk normality tests for pharyngeal airway measurements

Parameter	Group	n	Mean ± SD (mm)	Shapiro–Wilk W	p-value
Nasopharyngeal (NP)	Class I	20	20.42 ± 5.50	0.775	<0.001
Nasopharyngeal (NP)	Class II	20	28.64 ± 5.46	0.923	0.114
Nasopharyngeal (NP)	Class III	20	28.62 ± 6.31	0.927	0.135
Oropharyngeal (OP)	Class I	20	30.41 ± 4.92	0.927	0.137
Oropharyngeal (OP)	Class II	20	28.11 ± 5.92	0.895	0.033
Oropharyngeal (OP)	Class III	20	29.04 ± 7.02	0.868	0.011

Note: Shapiro–Wilk $p < 0.05$ indicates evidence against normality. NP Class I and OP Classes II and III had significant Shapiro–Wilk tests.

Table 5: Overall nonparametric comparisons for pharyngeal airway measurements

Parameter	Test	Statistic	df	p-value	Interpretation
Nasopharyngeal (NP)	Kruskal–Wallis	H = 21.777	2	<0.001	Significant
Oropharyngeal (OP)	Kruskal–Wallis	H = 1.199	2	0.549	Not significant

Table 6: Airway Dunn post-hoc comparisons with Bonferroni adjustment

Parameter	Pairwise comparison	z-value	Unadjusted p-value	Adjusted p-value	Interpretation
NP	Class I vs Class II	−4.025	<0.001	<0.001	Significant
NP	Class I vs Class III	−4.057	<0.001	<0.001	Significant
NP	Class II vs Class III	−0.032	0.975	1.000	Not significant
OP	Class I vs Class II	1.088	0.277	0.830	Not significant
OP	Class I vs Class III	0.435	0.663	1.000	Not significant
OP	Class II vs Class III	−0.653	0.514	1.000	Not significant

Figure

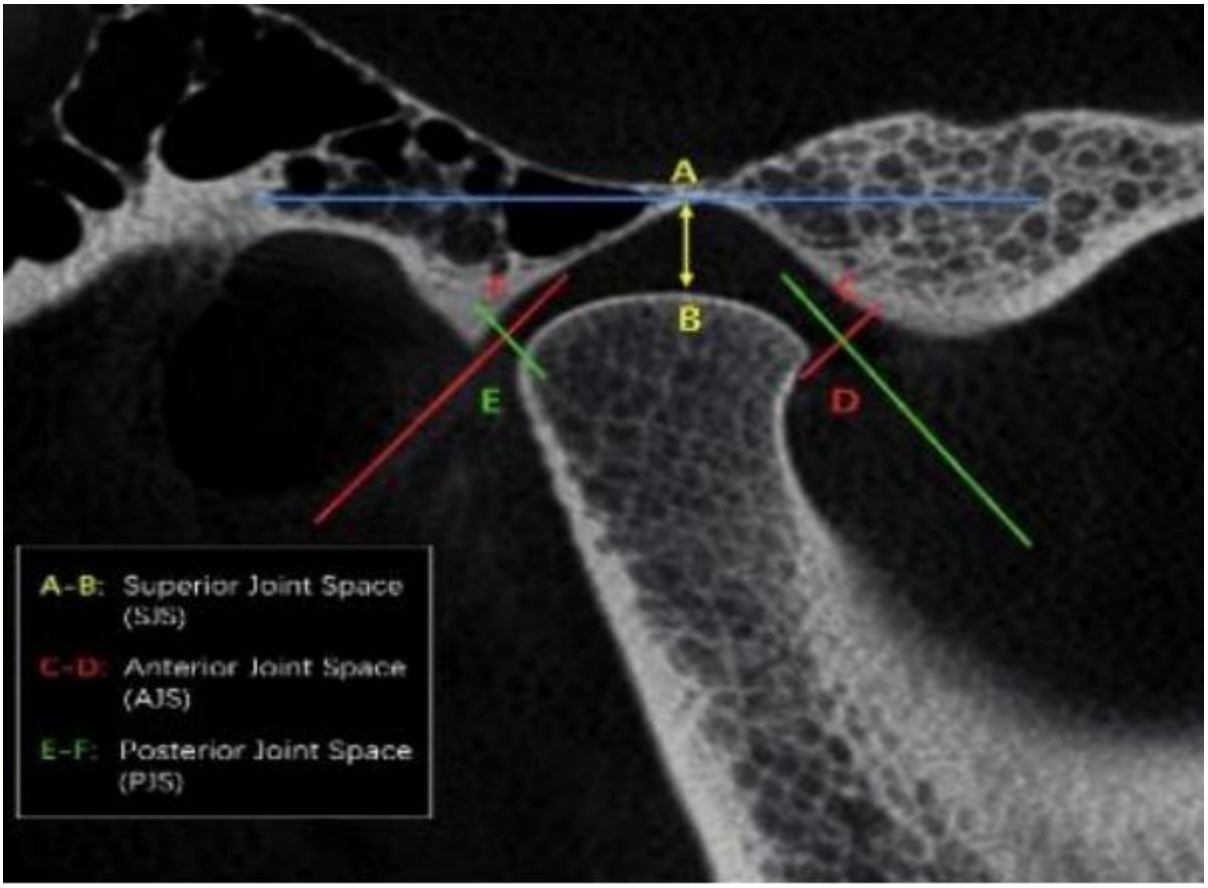


Figure 1

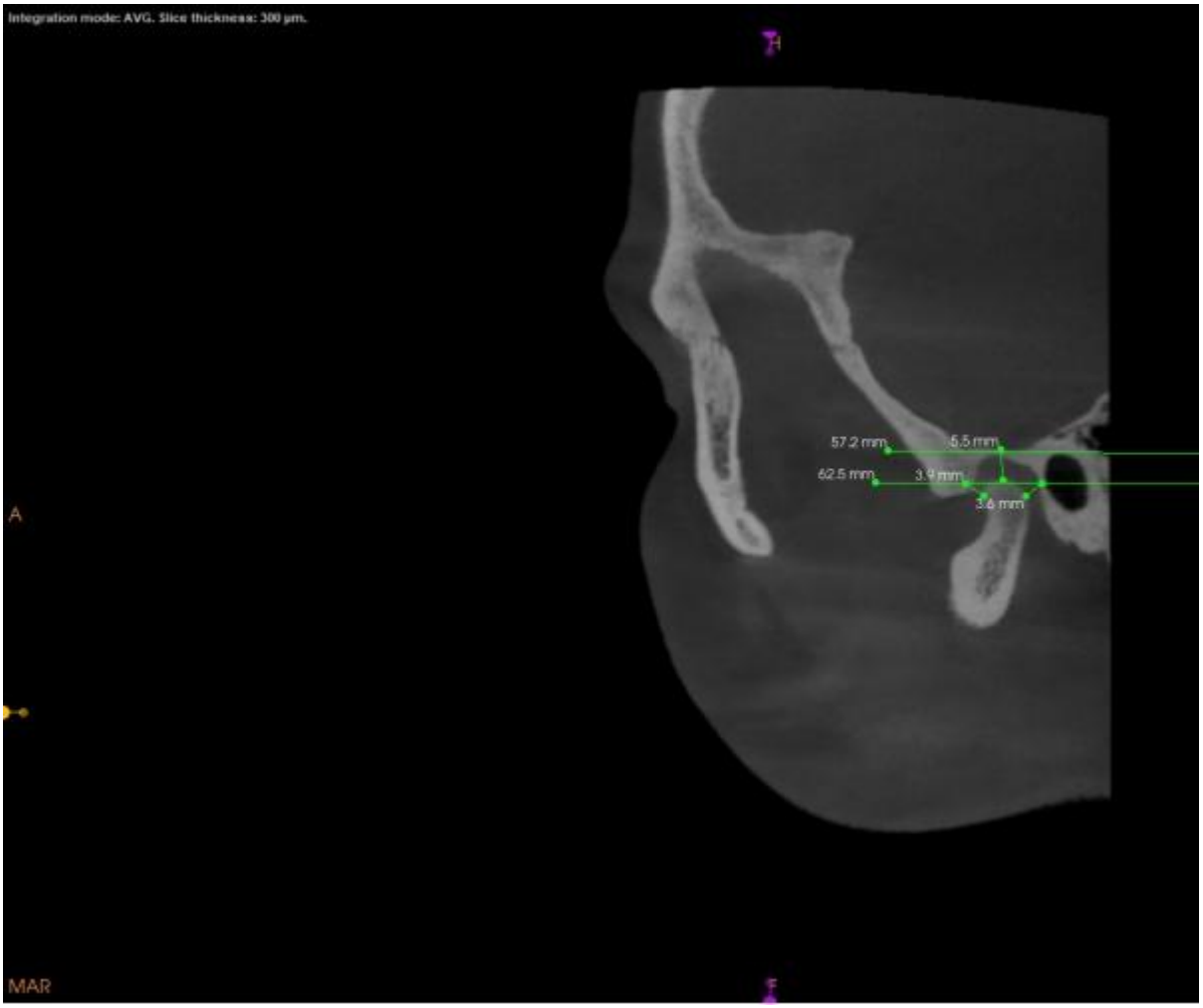


Figure 2

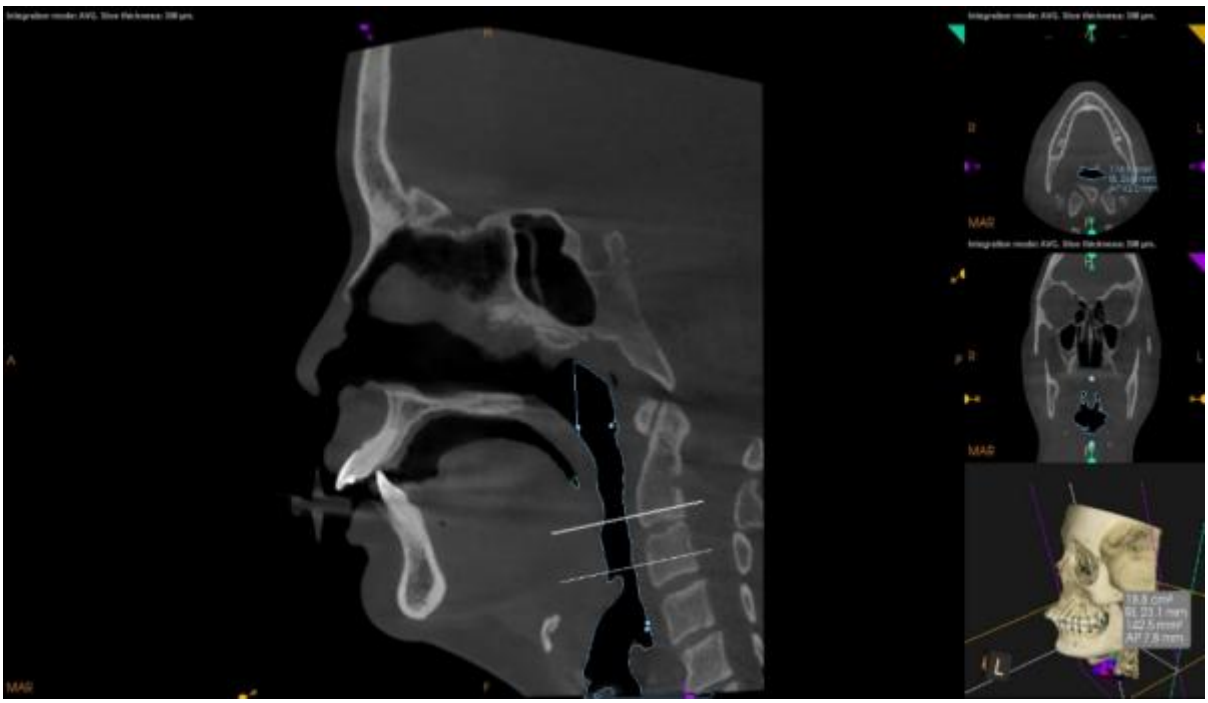


Figure 3

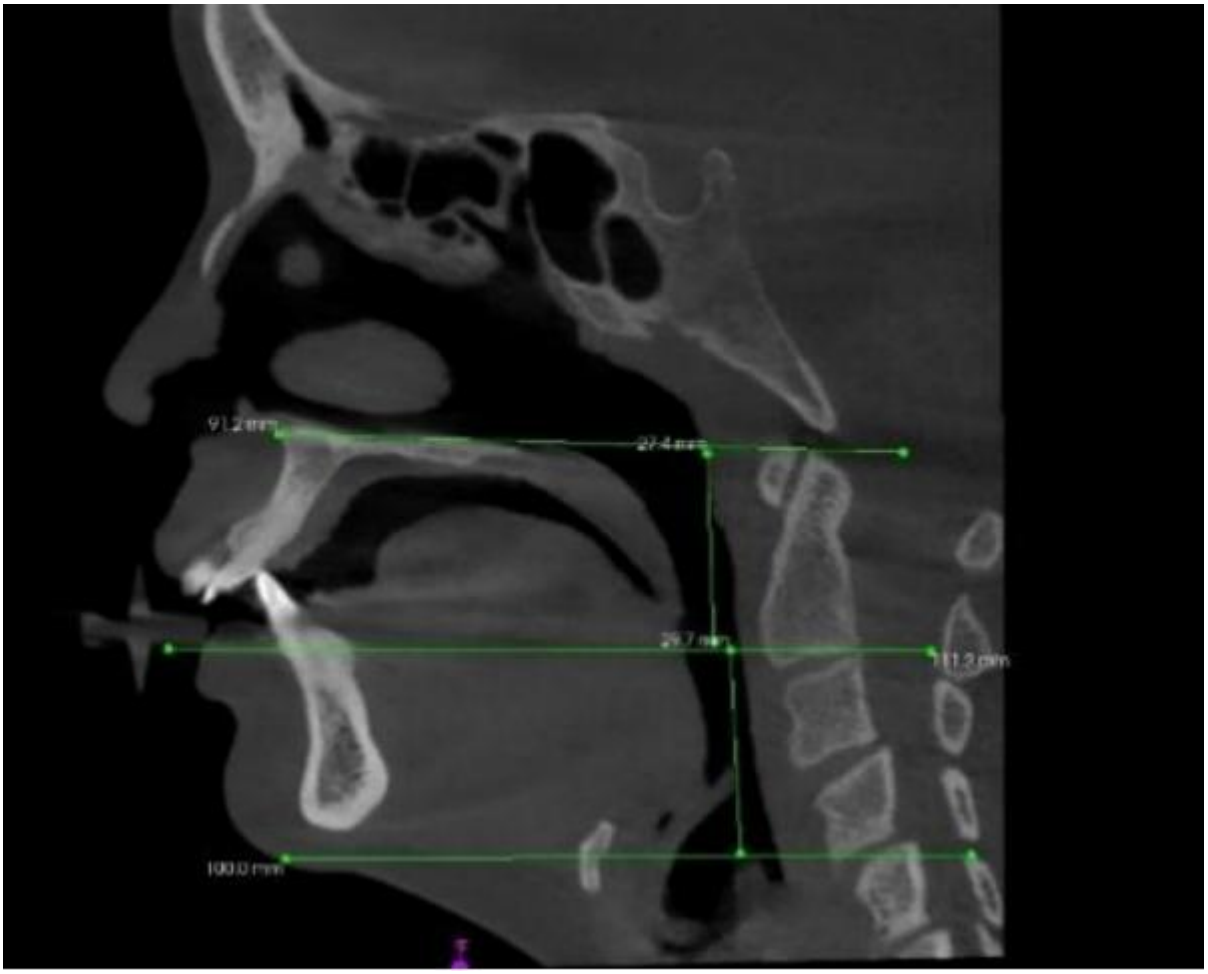


Figure 4