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ORIGINAL RESEARCH

CBCT-based osseous severity is associated with lower mandibular ramus height but not symptom burden in pediatric and adolescent TMJ degenerative joint disease

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Abstract

Background: In pediatric and adolescent temporomandibular joint (TMJ) degenerative joint disease (DJD), subjective symptoms may not reliably reflect imaging-defined structural involvement. This study examined whether cone-beam computed tomography (CBCT)-based osseous severity burden is associated with reduced mandibular ramus height (Co-Go) and whether pain, functional, and psychosocial measures are associated with CBCT-based osseous severity burden. **Methods**: This retrospective cross-sectional study included 83 patients aged 6–18 years with CBCT-confirmed unilateral or bilateral TMJ DJD. Right- and left-side osseous severity scores were summed to calculate a cumulative bilateral severity burden. Cephalometric, TMJ morphometric, clinical, functional, and psychosocial variables were analyzed using correlation and age- and sex-adjusted regression models. Sensitivity analyses additionally adjusted for the A point-nasion-B-point (ANB) angle and the Frankfort mandibular plane angle (FMA). **Results**: Higher CBCT-based DJD severity burden was inversely associated with right, left, and mean Co-Go ramus height. In the age- and sex-adjusted model, each one-point increase in severity burden was associated with a 1.209-mm lower mean Co-Go ramus height (95% confidence interval, −1.979 to −0.439; $p = 0.0025$). After additional adjustment for the ANB angle and FMA, the association was attenuated but remained nominally significant (B = −0.639 mm; 95% confidence interval, −1.261 to −0.017; $p = 0.0442$). Pain intensity, jaw functional limitation, perceived stress, somatic symptoms, depression, and anxiety were not significantly associated with CBCT-based osseous severity burden. **Conclusions**: Within this cohort, greater cumulative CBCT-based osseous severity burden was associated with lower Co-Go ramus height. Because Co-Go includes the condylar region, this finding should be interpreted as a structural association within the condyle-ramus unit rather than evidence of impaired mandibular growth. Symptom burden did not consistently correspond to imaging-defined structural involvement, supporting the complementary interpretation of clinical and imaging findings.

Keywords

Temporomandibular joint disorders; Degenerative joint disease; Osteoarthritis; Cone-beam computed tomography; Adolescent; Child; Mandibular ramus; Pain measurement; Psychosocial factors

1. Introduction

Temporomandibular disorders (TMDs) comprise a heterogeneous group of painful and non-painful conditions affecting the temporomandibular joint (TMJ), masticatory muscles, and related craniofacial structures. TMJ degenerative joint disease (DJD), also referred to as temporomandibular joint osteoarthritis, is characterized by progressive structural changes of the articular cartilage and subchondral bone and may present with pain, joint noise, limited mouth opening, or altered mandibular function [1–4].

In children and adolescents, TMJ DJD is clinically important because the mandibular condyle is not only an articular structure but also a growth-related site that contributes to mandibular ramus height, mandibular length, and lower facial symmetry [5, 6]. Degenerative or inflammatory involvement of the TMJ during growth may therefore be associated with mandibular retrusion, facial asymmetry, or occlusal change, although cross-sectional data cannot establish temporal sequence or causal growth effects.

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Pediatric TMJ osseous disease is often discussed in relation to juvenile idiopathic arthritis; however, structural TMJ degeneration and deformity may also be encountered among children and adolescents referred to oral medicine or TMD clinics. Prior studies have emphasized that TMJ involvement in growing patients may be clinically subtle and that imaging is important for characterizing joint disease and its skeletal sequelae [5, 6]. Cone-beam computed tomography (CBCT) is particularly useful for evaluating osseous TMJ morphology, including condylar flattening, erosion, osteophyte formation, subchondral sclerosis, subchondral cysts, deformity, condylar resorption, and other osseous alterations [7–11]. Magnetic resonance imaging (MRI) remains more suitable for evaluating active synovitis and soft-tissue inflammatory activity, whereas CBCT provides a high-resolution visualization of osseous changes that may reflect the cumulative structural burden of disease.

A major clinical challenge is that subjective symptoms may not reliably reflect imaging-defined osseous involvement. Some patients with substantial osseous alteration report limited pain, whereas others with prominent pain or psychosocial distress may not have severe osseous involvement. Recent CBCT-based studies have similarly emphasized that clinical signs and symptoms do not consistently correspond to radiographic TMJ DJD findings, supporting indication-driven imaging rather than reliance on symptoms alone [10, 12–14]. This discordance is particularly relevant during growth because symptom burden may not consistently correspond to structural involvement of the condyle-ramus unit [5, 6].

In a descriptive skeletal/occlusal assessment of the same cohort, patients with TMJ DJD showed diverse anteroposterior and vertical skeletal patterns. More severe osseous changes appeared to be associated with a tendency toward Class II skeletal features and increased overjet, although these findings were exploratory and were not considered primary outcomes in the present analysis. Prior studies have reported TMJ osteoarthrosis in dentofacial deformity populations [12], CBCT-based associations between degenerative alterations or condyle-fossa relationships and skeletal Class II morphology [15, 16], skeletal-pattern differences in adolescent condyle-fossa relationships [17], and occlusal characteristics across TMD diagnostic groups [18]. However, the clinically relevant question in growing patients with TMJ DJD is not only whether symptoms and imaging findings are discordant, but also whether cumulative osseous burden is associated with a skeletal marker after accounting for potential confounding by skeletal phenotype. Therefore, the present study integrated CBCT and cephalometric measurements with clinical, pain-related, functional, psychosocial, and medical history variables in pediatric and adolescent patients with TMJ DJD. We hypothesized that higher CBCT-based bilateral DJD severity burden would be associated with lower Co-Go ramus height, whereas pain-related, functional, and psychosocial measures would not be significantly associated with CBCT-based osseous severity burden in this cohort. Because Co-Go ramus height includes the condylar region, this outcome was interpreted as a structural marker of the condyle-ramus unit rather than as direct evidence of generalized mandibular growth impairment.

2. Materials and methods

2.1 Study design and ethical approval

This retrospective cross-sectional observational study was performed at the Department of Oral Medicine, Pusan National University Dental Hospital. The source cohort comprised pediatric and adolescent patients who presented to the department for TMD-related evaluation between October 2022 and November 2024. The study protocol was approved by the Institutional Review Board of Pusan National University Dental Hospital (approval no. PNUDH-2025-08-002). The requirement for informed consent was waived by the Institutional Review Board of Pusan National University Dental Hospital because this retrospective study used de-identified clinical records and pre-existing CBCT images obtained for clinical purposes. Study information was disclosed through institutional notices, and an opt-out procedure was provided in accordance with institutional requirements. The study was conducted in accordance with the principles of the Declaration of Helsinki.

2.2 Participants

Patients were eligible if they met all of the following criteria: (1) age 6–18 years at the time of examination; (2) presentation to the Department of Oral Medicine for TMD-related clinical evaluation; (3) clinical diagnosis of TMD with CBCT-confirmed unilateral or bilateral TMJ degenerative osseous change; (4) complete clinical records including symptoms and physical examination findings; and (5) high-quality CBCT scans suitable for cephalometric and TMJ morphometric analysis. For the present integrated analysis, available pain, functional, psychosocial, past medical history, and laboratory data were linked to imaging-derived variables using patient identification numbers.

Exclusion criteria were as follows: (1) history of TMJ trauma or surgery; (2) previously confirmed systemic rheumatic disease, including juvenile idiopathic arthritis; (3) craniofacial syndrome or congenital deformity such as cleft lip/palate; (4) previous orthognathic surgery; (5) TMJ surgery within the previous 6 months; and (6) incomplete clinical or imaging data.

Patients who underwent laboratory or clinical screening for possible inflammatory arthritis during the diagnostic work-up were not excluded unless a systemic rheumatic disease, including juvenile idiopathic arthritis, had been confirmed before or during the study period.

2.3 Clinical assessment

Clinical evaluation was performed by oral medicine specialists using the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [3, 19]. Pain-related variables included TMJ arthralgia during palpation or function, masticatory muscle pain involving the masseter, temporalis, and pterygoid muscles, and myofascial pain with referral. Functional variables included maximum unassisted mouth opening, TMJ noise such as clicking or crepitus, and limitation of mandibular movement. Associated diagnoses included disc displacement

with reduction, disc displacement without reduction, and osteoarthritis based on clinical and radiographic findings.

Clinical variables analyzed in the integrated dataset included the numerical rating scale (NRS) pain score, arthralgia, myalgia or myofascial pain, joint noise, closed locking, open locking, past medical history, medication and allergy history, and available laboratory results. Questionnaire-based variables included the Graded Chronic Pain Scale (GCPS) pain intensity and disability measures [20], the Jaw Functional Limitation Scale-20 (JFLS-20) total score [21], the Perceived Stress Scale (PSS) total score [22], the Patient Health Questionnaire-15 (PHQ-15) [23], Patient Health Questionnaire-9 (PHQ-9) [24], Generalized Anxiety Disorder-7 (GAD-7) [25], and Patient Health Questionnaire-4 (PHQ-4) [26]. These instruments were selected to capture pain intensity, pain-related disability, jaw functional limitation, perceived stress, somatic symptom burden, depressive symptoms, anxiety symptoms, and overall psychological distress.

2.4 CBCT imaging protocol

CBCT images were acquired using a DCT Pro dentofacial cone-beam CT system (Vatech Co., Ltd., Seoul, Republic of Korea). Imaging parameters were as follows: 90 kVp, 4–5 mA, an isotropic voxel size of 0.3 mm, and a field of view of 20 × 19 cm. Patients were positioned in a natural head position with the Frankfort horizontal plane parallel to the floor, and images were acquired in maximum intercuspation. Multiplanar reconstructed images were generated in the axial, sagittal, and coronal planes before analysis.

2.5 CBCT-based DJD grading and severity burden

TMJ degenerative osseous changes were evaluated on sagittal, coronal, and axial CBCT slices according to established TMJ image-analysis criteria, current imaging recommendations, and a recent CBCT study of TMJ osteoarthritis [7, 11, 27]. Assessed osseous abnormalities included erosion, osteophyte formation, subchondral sclerosis, cystic change, deformity, condylar resorption, and flattening when accompanied by other degenerative features or marked contour change. The appropriateness of CBCT for evaluating TMJ osseous abnormalities was further supported by published imaging recommendations for the TMJ [11].

Because no universally accepted CBCT-based ordinal severity grading system exists for pediatric and adolescent nonsystemic TMJ DJD, these findings were summarized using an investigator-defined 4-point ordinal osseous severity scale to quantify cumulative osseous burden in a clinically interpretable manner. The scale was developed from established image-analysis criteria and published CT/CBCT descriptions of TMJ osseous change, but it was operationalized for the present study and should not be interpreted as an externally validated pediatric severity index. The ordinal grades were intended to rank overall definite osseous abnormality burden rather than to assign equal biological or prognostic weight to each individual imaging feature. Importantly, because condylar cortical maturation may be incomplete in growing patients and flattening may represent adaptive remodeling, subtle cortical irregularity, incomplete cortication, or isolated mild flattening was not considered sufficient to define degenerative osseous disease. Grading emphasized definite destructive, proliferative, or deforming osseous abnormalities visible on multiplanar CBCT images.

Grade 0 indicated no definite degenerative osseous abnormality on CBCT, without erosion, osteophyte formation, subchondral cystic change, marked sclerosis, deformity, or condylar resorption. Grade I indicated mild osseous change, such as early subchondral sclerosis or subtle surface irregularity accompanied by other degenerative features; isolated mild flattening alone was regarded as possible remodeling and was not sufficient for DJD grading. Grade II indicated moderate disease with definite erosion, osteophyte formation, subchondral cystic change, condylar deformity, condylar resorption, or marked flattening accompanied by other degenerative features. Grade III indicated severe disease with extensive erosion, marked condylar resorption, large osteophytes, or advanced condylar deformity. Quantitative joint-space measurements were analyzed separately and were not used to calculate the CBCT-based DJD severity burden.

Representative CBCT examples of side-specific osseous severity grades are provided in **Supplementary Fig. 1** to illustrate the operational grading approach.

For the present analysis, the side-specific right and left DJD severity scores were summed to create the primary predictor, the CBCT-based DJD severity burden. The observed severity burden ranged from 1 to 6. This summed index was chosen to represent cumulative bilateral osseous burden, but it was not intended to replace side-specific interpretation and may obscure clinically important asymmetry. Therefore, side-specific and asymmetric findings were evaluated descriptively. Patients were also classified as having unilateral or bilateral DJD based on the presence of osseous disease on one or both sides. For sensitivity and descriptive phenotype analyses, high severity was defined as a severity burden score of 5–6 and low/moderate severity as a score of 1–4.

CBCT images were independently reviewed by two examiners (Soo-Min Ok and Jae Joon Hwang) for side-specific TMJ osseous severity grading. Inter-examiner agreement for ordinal radiographic grading was excellent (weighted kappa = 0.85). Discrepant ratings were resolved by consensus. Continuous morphometric measurements were performed by one trained examiner. To assess intra-examiner reliability of continuous morphometric measurements, 20 randomly selected patients were remeasured after a 2-week interval in the original imaging analysis, and intraclass correlation coefficients exceeded 0.85 for all measured variables, indicating excellent reproducibility.

2.6 Cephalometric and TMJ morphometric measurements

Cephalometric analysis was performed on CBCT-generated lateral scout images using ON3D software (version 1.0.0, 3D ONS, Inc., Seoul, Republic of Korea). The anteroposterior skeletal relationship was evaluated using sella-nasion-A point (SNA), sella-nasion-B point (SNB), and A point-nasion-B point (ANB) angles. Skeletal classification was defined as

Class I (1.5 degrees < ANB < 5 degrees), Class II (ANB ≥5 degrees), and Class III (ANB ≤1.5 degrees). The vertical skeletal pattern was evaluated using the mean of the right and left Frankfort mandibular plane angle (FMA) measurements and classified as high angle (FMA ≥30 degrees), normal angle (20 degrees < FMA < 30 degrees), or low angle (FMA ≤20 degrees). Occlusal variables included overjet and overbite, measured in millimeters.

TMJ joint spaces were measured at six standardized locations for each joint on multiplanar reconstructed CBCT images: lateral superior, central superior, medial superior, anterior, superior, and posterior joint spaces. Linear mandibular measurements included mandibular body length (Go-Me), total mandibular length (Co-Me), and mandibular ramus height (Co-Go), all of which were assessed bilaterally; Co-Go is referred to hereafter as Co-Go ramus height. Menton deviation was used as an indicator of facial asymmetry [28], with positive values indicating rightward deviation and negative values indicating leftward deviation. The primary outcome of the present study was mean Co-Go ramus height, calculated as the mean of the right and left Co-Go ramus heights, because it represents a clinically interpretable growth-related skeletal indicator in pediatric patients with TMJ DJD.

2.7 Statistical analysis

Continuous variables were summarized as means and standard deviations, and categorical variables as counts and percentages. Spearman correlation coefficients were calculated between CBCT-based DJD severity burden and skeletal, clinical, pain-related, functional, and psychosocial variables. To account for multiple comparisons in the exploratory correlation analyses, false discovery rate (FDR)-adjusted q-values were calculated.

The main model tested whether CBCT-based DJD severity burden was associated with mean Co-Go ramus height after adjustment for age and sex. Secondary age- and sex-adjusted linear regression models evaluated right Co-Go ramus height, left Co-Go ramus height, mean mandibular body length, mean Co-Me length, absolute menton deviation, and mean posterior joint space. Regression coefficients, 95% confidence intervals, standard errors, standardized beta coefficients, p-values, FDR q-values, and model R^2 values were reported. Low/moderate and high severity groups were compared using appropriate two-sample tests for continuous variables; because the high-severity subgroup was small, these subgroup comparisons were interpreted descriptively. Incremental explanatory models were fitted in the same complete-case dataset to allow fair comparison of R^2 values across age/sex, structural, clinical, and combined models (**Supplementary Table 1**). A two-sided p-value < 0.05 was considered nominally significant; FDR q-values were used to identify findings that remained significant after adjustment for multiple testing.

To address potential confounding by underlying skeletal phenotype, an additional sensitivity regression model was fitted by adding ANB and FMA as continuous covariates to the primary age- and sex-adjusted model. Continuous ANB and FMA values were used rather than categorical skeletal class and vertical pattern to reduce information loss and account for differences in anteroposterior and vertical skeletal morphology. Additional sensitivity models using the same covariate set were also fitted for secondary skeletal outcomes (**Supplementary Table 2**). Published normative and reference cephalometric datasets relevant to mandibular ramus height were reviewed and summarized for contextual interpretation; these datasets were not treated as formal external controls (**Supplementary Table 3**, Ref. [29–32]). To describe questionnaire missingness, patients with complete clinical-score data were compared with those with incomplete clinical-score data according to age, sex, CBCT severity burden, high-severity status, and mean Co-Go ramus height (**Supplementary Table 4**). To address side-specific clinical relevance, patients with asymmetric right-left severity scores were evaluated descriptively by comparing Co-Go ramus height on the more severely affected side with that on the less severely affected side (**Supplementary Table 5**). Signed menton deviation was explored descriptively only, because side-direction coding was not prespecified as a primary analysis. The overall analytic framework is shown in Fig. 1. Statistical analyses were performed using Python 3.11 with pandas, scipy, statsmodels, and matplotlib.

3. Results

3.1 Study population and data completeness

The final integrated dataset included 83 pediatric and adolescent patients with matched CBCT/cephalometric and clinical information. The mean age was 14.82 ± 2.82 years; 56 patients (67.5%) were female, and 27 (32.5%) were male. Bilateral DJD was present in 72 patients (86.7%), and unilateral DJD was present in 11 patients (13.3%). Clinical questionnaire availability varied by instrument (Table 1). The complete clinical-score dataset used in incremental models included 63 patients; 20 patients had incomplete clinical-score data. Although patients with complete and incomplete clinical-score data did not differ significantly in age, sex distribution, DJD severity burden, or high-severity status, the incomplete clinical-score group showed numerically higher DJD severity burden (3.55 ± 1.61 *vs.* 3.17 ± 1.37), a higher proportion of high-severity burden (35.0% *vs.* 15.9%; $p = 0.1079$). Mean Co-Go ramus height was significantly lower in the incomplete clinical-score group than in the complete clinical-score group (58.38 ± 7.16 *vs.* 63.37 ± 6.05 mm; $p = 0.0089$). These findings suggest that missingness may not have been completely random and that complete-case symptom analyses may have underrepresented patients with greater imaging-defined structural involvement (**Supplementary Table 4**).

Inter-examiner agreement for side-specific ordinal radiographic grading was excellent (weighted kappa = 0.85).

No patient had a confirmed diagnosis of juvenile idiopathic arthritis or another systemic rheumatic disease at the time of data extraction. Patients who had undergone laboratory screening for inflammatory arthritis but did not meet the criteria for a confirmed systemic rheumatic disease were retained in the analysis.

The cohort included diverse skeletal patterns: Class I, 43

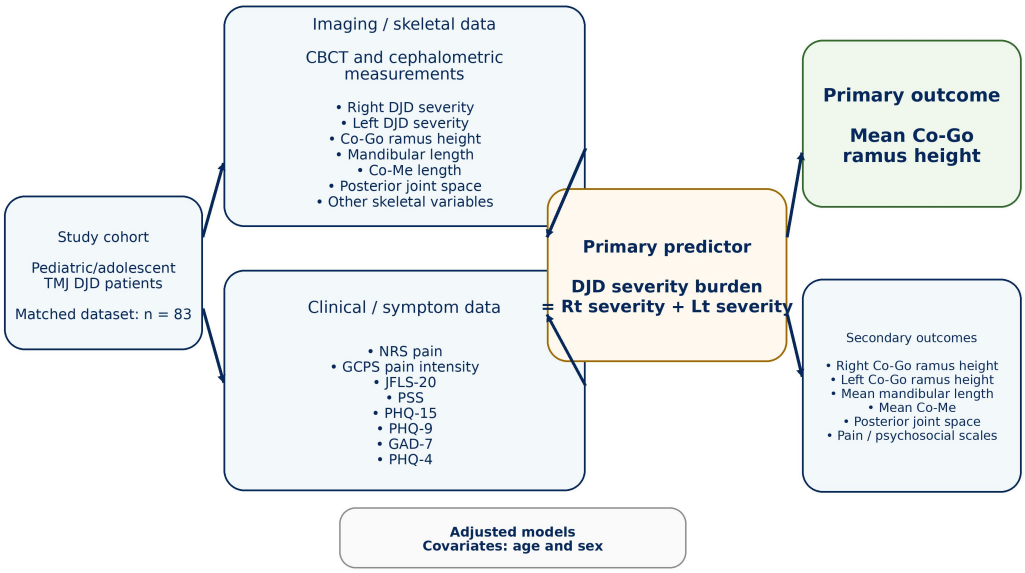


FIGURE 1. Analytic framework of the integrated pediatric/adolescent TMJ DJD study. CBCT-based right and left osseous severity scores were summed to create the DJD severity burden. The primary outcome was mean Co-Go ramus height; secondary outcomes included other skeletal and joint-space variables and pain/psychosocial questionnaire scores. CBCT, cone-beam computed tomography; DJD, degenerative joint disease; GAD-7, Generalized Anxiety Disorder-7; GCPS, Graded Chronic Pain Scale; JFLS-20, Jaw Functional Limitation Scale-20; NRS, numerical rating scale; PHQ, Patient Health Questionnaire; PSS, Perceived Stress Scale; TMJ, temporomandibular joint; Co-Go, mandibular ramus height; Co-Me, total mandibular length; Rt, right; Lt, left.

TABLE 1. Baseline characteristics and data availability.

Variable	n or value
Total patients with matched CBCT/clinical records	83
Age, yr	14.82 ± 2.82
Sex: female/male	56 (67.5%)/27 (32.5%)
DJD distribution: bilateral/unilateral	72 (86.7%)/11 (13.3%)
Maximum DJD grade: I/II/III	25 (30.1%)/36 (43.4%)/22 (26.5%)
DJD severity burden range	1–6
Low/moderate severity burden, score 1–4	66
High severity burden, score 5–6	17
Skeletal class: I/II/III	43 (51.8%)/27 (32.5%)/13 (15.7%)
Vertical skeletal pattern: high/normal/low angle	26 (31.3%)/51 (61.4%)/6 (7.2%)
SNA/SNB/ANB, degrees	81.22 ± 3.31/77.17 ± 4.31/4.04 ± 2.74
FMA, degrees	27.90 ± 6.61
Overjet/overbite, mm	4.20 ± 2.00/1.79 ± 2.86
NRS pain available	74
GCPS pain intensity data available	74
JFLS-20/PSS available	79/83
PHQ-15/PHQ-9/GAD-7/PHQ-4 available	82/82/82/79
Complete clinical-score dataset	63
Incomplete clinical-score data	20
Asymmetric right-left severity scores	46

Data are presented as n (%) or mean ± SD. ANB, A point-nasion-B point angle; CBCT, cone-beam computed tomography; DJD, degenerative joint disease; FMA, Frankfort mandibular plane angle; GAD-7, Generalized Anxiety Disorder-7; GCPS, Graded Chronic Pain Scale; JFLS-20, Jaw Functional Limitation Scale-20; NRS, numerical rating scale; PHQ, Patient Health Questionnaire; PSS, Perceived Stress Scale; SD, standard deviation; SNA, sella-nasion-A point angle; SNB, sella-nasion-B point angle.

patients (51.8%); Class II, 27 (32.5%); and Class III, 13 (15.7%). The vertical skeletal pattern was high angle in 26 patients (31.3%), normal-angle in 51 (61.4%), and low-angle in 6 (7.2%). Mean ANB was 4.04 ± 2.74 degrees, mean FMA was 27.90 ± 6.61 degrees, mean overjet was 4.20 ± 2.00 mm, and mean overbite was 1.79 ± 2.86 mm. The CBCT-based DJD severity burden ranged from 1 to 6; 17 patients had high severity burden scores (5–6), and 66 had low-to-moderate severity burden scores (1–4). Data availability for clinical questionnaires is shown in Table 1.

3.2 Primary skeletal association

CBCT-based DJD severity burden showed a significant inverse association with Co-Go ramus height (Table 2). In unadjusted Spearman correlation analysis, higher severity burden was associated with lower mean Co-Go ramus height (*rho* = −0.361, p = 0.0008, FDR q = 0.0087). Similar associations were observed for right Co-Go ramus height (*rho* = −0.366, p = 0.0007, FDR q = 0.0087) and left Co-Go ramus height (*rho* = −0.347, p = 0.0013, FDR q = 0.0096). Mean mandibular length and mean Co-Me length showed nominal inverse associations, but these did not remain significant after FDR correction. The association between DJD severity burden and mean Co-Go ramus height is illustrated in Fig. 2.

3.3 Age- and sex-adjusted primary model

In the main age- and sex-adjusted regression model, DJD severity burden was associated with mean Co-Go ramus height (Table 3). Each one-point increase in severity burden was associated with a 1.209-mm lower mean Co-Go ramus height (95% confidence interval (CI), −1.979 to −0.439; standard error (SE) = 0.387; standardized beta = −0.261; p = 0.0025; FDR q = 0.0104). The model explained 47.4% of the variance in mean Co-Go ramus height.

In the sensitivity model additionally adjusted for ANB and FMA, the association between DJD severity burden and mean Co-Go ramus height was attenuated but remained nominally significant. Each one-point increase in severity burden was associated with a 0.639-mm lower mean Co-Go ramus height (95% CI, −1.261 to −0.017; SE = 0.312; standardized beta = −0.138; p = 0.0442), and the model R^2 increased to 0.688. Sensitivity models for secondary skeletal outcomes are provided in **Supplementary Table 2**.

3.4 Secondary skeletal outcomes

Secondary age- and sex-adjusted models showed associations between severity burden and both right and left Co-Go ramus height. Each one-point increase in severity burden was associated with a 1.107-mm lower right Co-Go ramus height (95% CI, −1.860 to −0.354) and a 1.311-mm lower left Co-Go ramus height (95% CI, −2.175 to −0.448). Mean mandibular length and mean Co-Me length had negative coefficients, suggesting that mandibular dimensions tended to be smaller with increasing severity burden, but these associations did not remain statistically significant after FDR correction. Mean posterior joint space showed a positive adjusted association with severity burden (B = 0.132 mm per severity point; 95% CI, 0.025 to 0.239; p = 0.0166; FDR q = 0.0291). Additional ANB- and FMA-adjusted sensitivity models for secondary skeletal outcomes showed attenuation of the severity coefficients, while the direction of association for right and left Co-Go ramus height remained negative (**Supplementary Table 2**). In a descriptive side-asymmetry analysis, 46 patients had unequal right-left severity scores. In these patients, Co-Go ramus height on the more severely affected side was descriptively lower than that on the less severely affected side (62.68 ± 7.22 *vs.* 64.12 ± 6.65 mm; paired mean difference, −1.44 ± 3.27 mm). The more severely affected side was the shorter side in 30 of 46 patients (65.2%). Among unilateral DJD cases (n = 11), the same directional pattern was observed but was not statistically significant because of the small sample size (mean difference, −1.72 ± 3.70 mm; the affected side was shorter in 7 of 11 patients (63.6%)). Signed menton deviation did not show a consistent association with side-specific severity difference (**Supplementary Table 5**). Standardized effect estimates for age- and sex-adjusted skeletal models are shown in Fig. 3.

3.5 Pain, functional limitation, and psychosocial variables

In contrast to skeletal outcomes, pain intensity, jaw functional limitation, and psychosocial questionnaire scores were not significantly associated with CBCT-based DJD severity burden in this sample. NRS pain, GCPS pain intensity, JFLS-20, PSS, PHQ-15, PHQ-9, GAD-7, and PHQ-4 showed no statistically significant correlations with severity burden after FDR correction (Table 2). These non-significant findings should not be interpreted as evidence that symptoms are unrelated to TMJ disease activity or clinical need, particularly because some questionnaire data were incomplete and the study may have had limited power to detect associations.

3.6 High-severity phenotype and clinical-radiographic discordance

When patients were dichotomized into low/moderate and high severity groups, the high-severity group had numerically lower mean Co-Go ramus height and mean mandibular length. However, pain intensity, jaw functional limitation, perceived stress, somatic symptoms, depressive symptoms, and anxiety symptoms did not differ significantly between severity groups (Table 4). Because the high-severity subgroup included only 17 patients compared with 66 in the low/moderate group, these subgroup comparisons were underpowered and should be interpreted descriptively. The overall pattern supports a degree of clinical-radiographic discordance within this cohort: CBCT-defined osseous severity was linked to a skeletal structural measure, whereas subjective symptom burden did not show corresponding increases with CBCT-based osseous severity burden in the present sample. The overall pattern is summarized in Fig. 4.

3.7 Incremental explanatory value of severity burden

Incremental modeling was repeated in the same complete-case dataset (n = 63) to avoid comparing R^2 values across models

TABLE 2. Correlations between CBCT-based DJD severity burden and skeletal, pain, functional, and psychosocial variables.

Variable	n	Spearman *rho*	*p* value	FDR *q*
Right Co-Go ramus height	83	−0.366	0.0007	0.0087
Mean Co-Go ramus height	83	−0.361	0.0008	0.0087
Left Co-Go ramus height	83	−0.347	0.0013	0.0096
Mean mandibular length	83	−0.238	0.0305	0.1177
Mean Co-Me length	83	−0.235	0.0321	0.1177
Mean posterior joint space	83	0.183	0.0976	0.2386
NRS pain	74	−0.221	0.0589	0.1850
GCPS pain intensity mean	74	−0.076	0.5218	0.6869
JFLS-20 sum	79	0.059	0.6070	0.7419
PSS total	83	−0.070	0.5308	0.6869
PHQ-15 total	82	−0.140	0.2094	0.4189
PHQ-9 total	82	−0.120	0.2836	0.5199
GAD-7 total	82	0.004	0.9743	0.9743
PHQ-4 total	79	−0.031	0.7837	0.8621

CBCT, cone-beam computed tomography; Co-Me, total mandibular length; DJD, degenerative joint disease; FDR, false discovery rate; GAD-7, Generalized Anxiety Disorder-7; GCPS, Graded Chronic Pain Scale; JFLS-20, Jaw Functional Limitation Scale-20; NRS, numerical rating scale; PHQ, Patient Health Questionnaire; PSS, Perceived Stress Scale; Co-Go, mandibular ramus height. DJD severity burden was calculated as the sum of right- and left-side CBCT-based osseous severity scores. FDR $q < 0.05$ was considered statistically significant after correction for multiple comparisons.

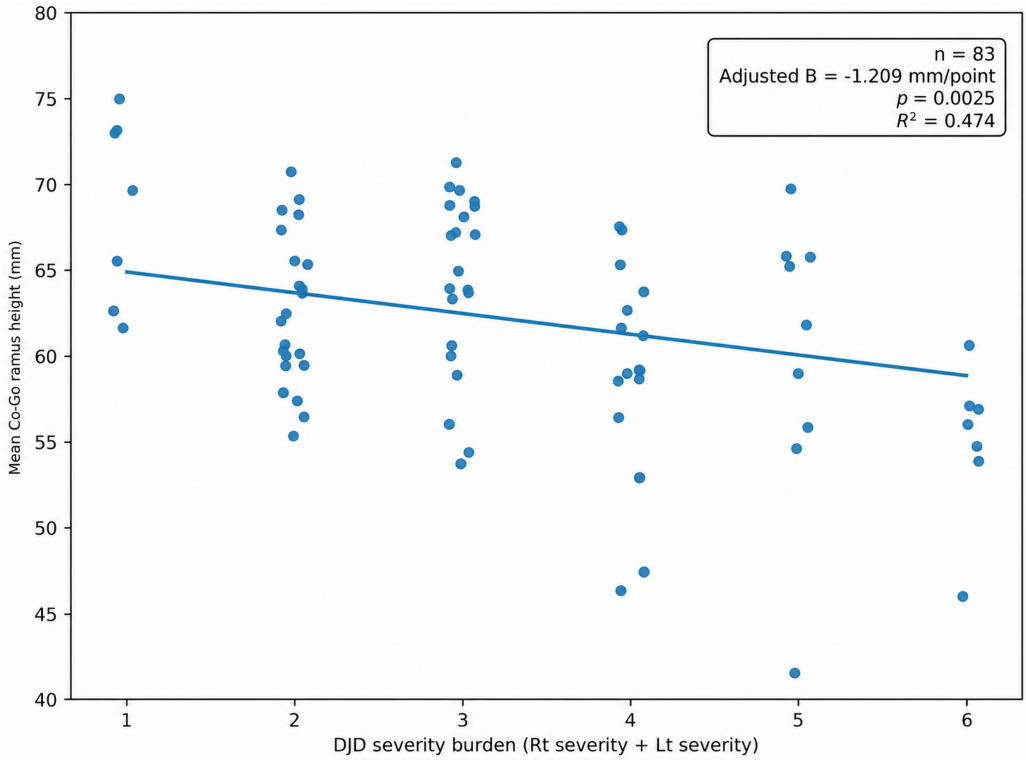


FIGURE 2. Scatterplot of CBCT-based DJD severity burden and mean Co-Go ramus height. Points indicate individual patients. The fitted line represents the age- and sex-adjusted linear model evaluated at mean covariate values. In this model, each one-point increase in severity burden was associated with a 1.209-mm lower mean Co-Go ramus height. The regression model included DJD severity burden, age, and sex. B, unstandardized regression coefficient; CBCT, cone-beam computed tomography; DJD, degenerative joint disease; Co-Go, mandibular ramus height; Rt, right; Lt, left.

TABLE 3. Age- and sex-adjusted regression models for skeletal outcomes.

Outcome	n	R^2	Adjusted R^2	Severity B (95% CI)	SE	Std beta	p value	FDR q
Mean Co-Go ramus height	83	0.474	0.454	−1.209 (−1.979 to −0.439)	0.387	−0.261	0.0025	0.0104
Right Co-Go ramus height	83	0.481	0.461	−1.107 (−1.860 to −0.354)	0.378	−0.243	0.0045	0.0104
Left Co-Go ramus height	83	0.423	0.401	−1.311 (−2.175 to −0.448)	0.434	−0.264	0.0034	0.0104
Mean Co-Me length	83	0.491	0.472	−0.760 (−1.664 to 0.145)	0.454	−0.137	0.0985	0.1150
Mean mandibular length	83	0.489	0.469	−0.790 (−1.704 to 0.123)	0.459	−0.142	0.0890	0.1150
Absolute menton deviation	83	0.017	−0.021	−0.189 (−0.572 to 0.195)	0.193	−0.112	0.3309	0.3309
Mean posterior joint space	83	0.071	0.036	0.132 (0.025 to 0.239)	0.054	0.271	0.0166	0.0291

Each model included DJD severity burden, age, and sex as independent variables. B indicates the unstandardized change in outcome per one-point increase in DJD severity burden. Values in parentheses indicate 95% confidence intervals for B. CI, confidence interval; Co-Me, total mandibular length; DJD, degenerative joint disease; FDR, false discovery rate; R^2, coefficient of determination; SE, standard error; Co-Go, mandibular ramus height.

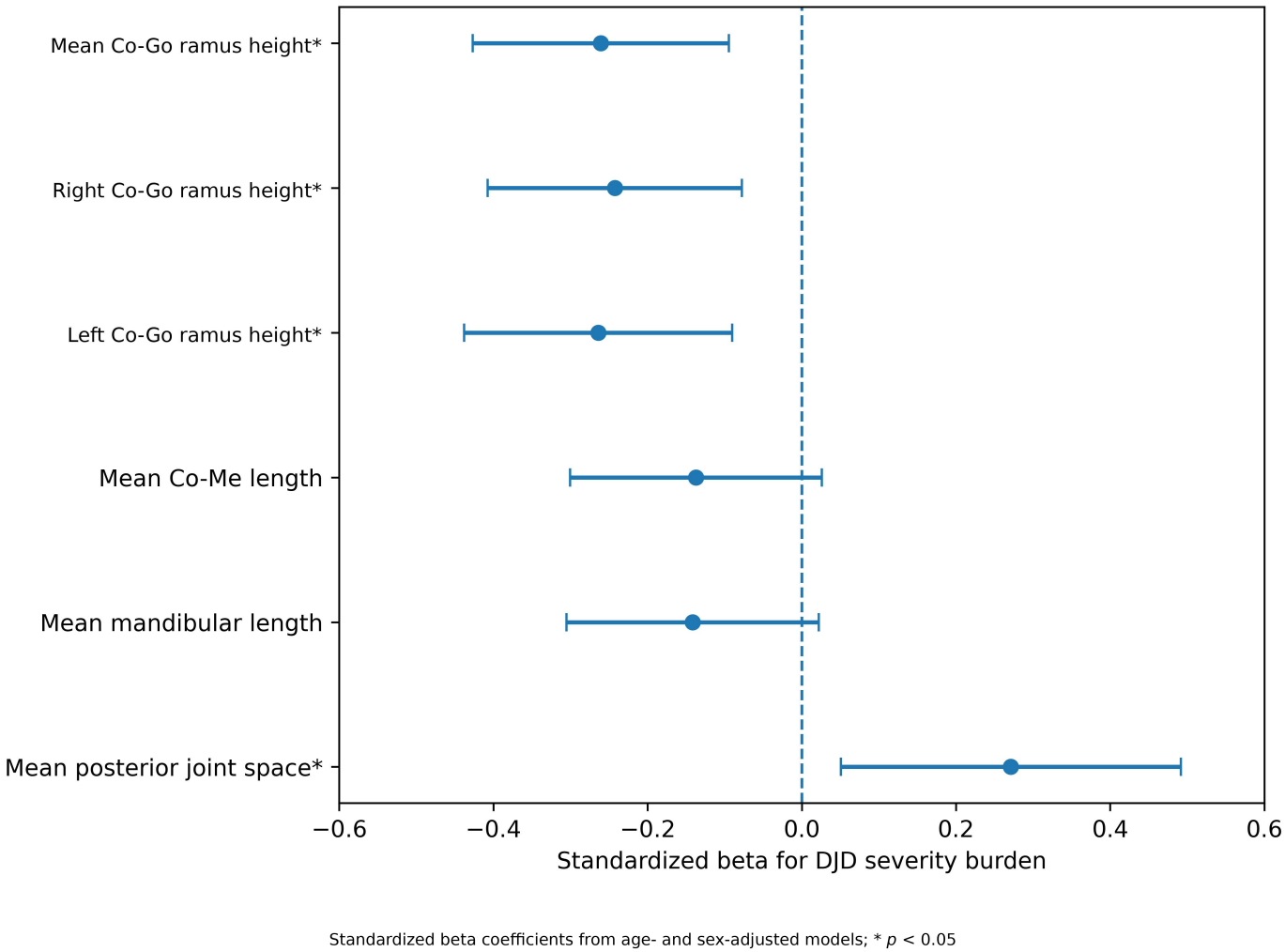


FIGURE 3. Coefficient plot of standardized beta coefficients for age- and sex-adjusted skeletal regression models. Points represent standardized beta coefficients for DJD severity burden, and horizontal bars represent 95% confidence intervals. Each model included DJD severity burden, age, and sex. The vertical reference line indicates zero. Asterisks indicate $p < 0.05$ for the severity-burden coefficient. DJD, degenerative joint disease; Co-Go, mandibular ramus height; Co-Me, total mandibular length.

TABLE 4. Comparison of low/moderate and high CBCT-based DJD severity groups.

Variable	Low/moderate n	Low/moderate mean ± SD	High n	High mean ± SD	*p* value
Age, yr	66	14.813 ± 2.719	17	14.637 ± 3.276	0.8402
Mean Co-Go ramus height	66	62.971 ± 5.798	17	59.040 ± 8.743	0.0944
Mean mandibular length	66	119.010 ± 7.305	17	115.022 ± 9.868	0.1339
NRS pain	60	3.083 ± 2.346	14	2.464 ± 2.530	0.4141
GCPS pain intensity mean	60	2.144 ± 2.019	14	1.845 ± 2.383	0.6690
JFLS-20 sum	63	24.492 ± 22.501	16	24.000 ± 23.953	0.9415
PSS total	66	16.848 ± 6.092	17	16.000 ± 7.185	0.6590
PHQ-15 total	65	4.615 ± 3.543	17	3.706 ± 3.549	0.3557
PHQ-9 total	65	4.646 ± 4.442	17	3.412 ± 4.124	0.2894
GAD-7 total	66	2.939 ± 3.157	16	3.500 ± 4.662	0.6535

High severity was defined as DJD severity burden score 5–6; low/moderate severity was defined as score 1–4. CBCT, cone-beam computed tomography; DJD, degenerative joint disease; GAD-7, Generalized Anxiety Disorder-7; GCPS, Graded Chronic Pain Scale; JFLS-20, Jaw Functional Limitation Scale-20; NRS, numerical rating scale; PHQ, Patient Health Questionnaire; PSS, Perceived Stress Scale; SD, standard deviation; Co-Go, mandibular ramus height.

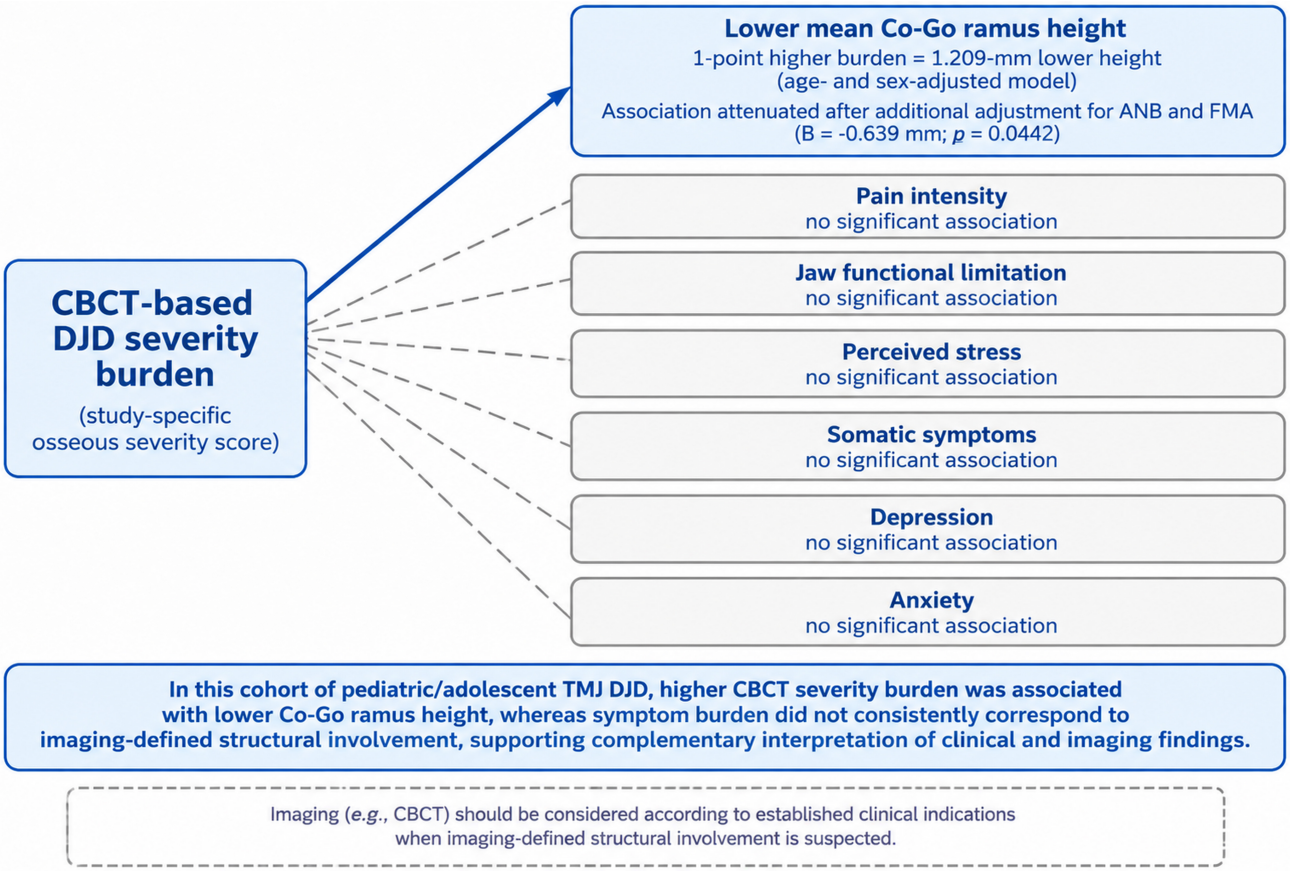


FIGURE 4. Schematic summary of clinical-radiographic discordance. In the age- and sex-adjusted model, each one-point increase in CBCT-based DJD severity burden was associated with a 1.209-mm lower mean Co-Go ramus height; this association was attenuated after additional adjustment for ANB and FMA (B = −0.639 mm; $p = 0.0442$). Pain intensity, jaw functional limitation, perceived stress, somatic symptoms, depression, and anxiety showed no significant association with severity burden in this sample. Solid arrow indicates the observed inverse association; dashed arrows indicate no significant association. Symptom burden did not consistently correspond to imaging-defined structural involvement in this cohort, supporting complementary interpretation of clinical and imaging findings. Imaging should be considered according to established clinical indications. CBCT, cone-beam computed tomography; DJD, degenerative joint disease; TMJ, temporomandibular joint; Co-Go, mandibular ramus height; ANB, A point-nasion-B point angle; FMA, Frankfort mandibular plane angle.

with different sample sizes (**Supplementary Table 1**). In this complete-case dataset, age and sex explained 39.9% of the variance in mean Co-Go ramus height. Adding DJD severity burden increased R^2 to 47.5%. The model including age, sex, and clinical scores explained 44.0% of the variance, whereas the combined model including age, sex, DJD severity burden, and clinical scores explained 49.8%. These findings support that CBCT-based severity burden may contribute additional explanatory information about Co-Go ramus height beyond age and sex, while indicating that pain/psychosocial scores alone did not adequately explain Co-Go ramus height variation in the complete-case sample.

4. Discussion

4.1 Principal findings

This integrated analysis of pediatric and adolescent TMD patients with CBCT-confirmed TMJ DJD showed clinical-radiographic discordance within the DJD cohort: cumulative CBCT-based osseous severity burden was quantitatively associated with lower Co-Go ramus height, with a 1.209-mm lower mean Co-Go ramus height for each one-point increase in severity burden, whereas patient-reported pain, functional limitation, and psychosocial questionnaire scores showed no corresponding association with CBCT-based osseous severity burden in this sample. The primary association was attenuated from −1.209 mm to −0.639 mm per severity point after additional adjustment for ANB and FMA, but it remained nominally significant. This attenuation is important because it indicates that underlying anteroposterior and vertical craniofacial morphology may partly explain the relationship between severity burden and Co-Go ramus height, although the association was not explained solely by ANB and FMA.

The main contribution of this study is therefore more specific than the general observation that symptoms and imaging findings may differ. Within a pediatric/adolescent TMJ DJD cohort, the bilateral CBCT-based osseous severity burden was linked to a measurable skeletal parameter of the condyle-ramus unit, while pain intensity, jaw functional limitation, perceived stress, somatic symptoms, depression, and anxiety did not show corresponding increases with CBCT-based osseous severity burden. This pattern suggests that a patient with relatively limited pain or psychosocial burden may still have imaging-defined structural involvement, while also emphasizing that patient-reported symptoms remain essential for symptom management and clinical care.

The magnitude of the age- and sex-adjusted association was clinically interpretable and readily communicable: one additional point in CBCT-based severity burden corresponded to approximately 1.2 mm less mean Co-Go ramus height. However, because ramus height was measured as Co-Go and therefore includes the condylar region, part of this association may reflect anatomical overlap between CBCT-defined condylar deformity/resorption and the cephalometric landmark used to calculate ramus height. This limitation is central to interpretation. The present findings support a structural association between cumulative osseous TMJ burden and the condyle-ramus skeletal unit in pediatric/adolescent DJD, but they do not establish that DJD severity caused impaired mandibular growth or that patients had an abnormal growth deficit relative to healthy peers.

External normative cephalometric datasets further support the view that ramus height is an age- and sex-dependent growth-related measurement. Still they do not remove the need for caution in the present study. Available datasets reporting Co-Go, condylion-gonion (Cd-Go), or mandibular growth percentiles differ from our cohort in ethnicity, occlusal criteria, imaging protocol, and landmark definitions; therefore, we reviewed and summarized them as contextual references rather than used them as formal controls (**Supplementary Table 3**) [29–32].

4.2 Interpretation in the context of pediatric TMJ DJD

The mandibular condyle contributes to vertical ramus growth and mandibular development [5, 6], while mandibular growth and facial asymmetry may also vary with underlying craniofacial phenotype [33, 34]. Therefore, osseous TMJ degeneration during growth may coexist with reduced ramus height, shortened mandibular length, mandibular asymmetry, altered joint-space relationships, or occlusal change [5, 6]. The present findings support the concept that Co-Go ramus height is a skeletal correlate of CBCT-based DJD severity in pediatric/adolescent patients, but do not provide evidence of longitudinal growth disturbance.

The descriptive skeletal/occlusal assessment of this cohort provides context for these findings. Patients with pediatric/adolescent TMJ DJD were distributed across diverse skeletal patterns, and exploratory observations suggested that more severe osseous changes may coexist with a Class II skeletal tendency and increased overjet. Because these skeletal/occlusal observations were not primary outcomes and were not designed to establish causality, they should be interpreted as contextual findings. Prior studies have reported TMJ osteoarthrosis in dentofacial deformity populations [12], associations between degenerative TMJ alterations and skeletal Class II morphology [15, 16], skeletal-pattern differences in condyle-fossa relationships in adolescents without TMD [17], and overjet/overbite characteristics across TMD diagnostic groups [18]. In the revised analysis, adjustment for ANB and FMA reduced the severity coefficient, reinforcing that craniofacial phenotype may contribute to the observed relationship and should be accounted for in future studies.

The absence of significant associations between CBCT-based structural severity and pain or psychosocial scores should not be interpreted as evidence that symptoms are unimportant or unrelated to TMJ disease activity. Rather, in the present sample, patient-reported symptom burden and CBCT-defined osseous burden appeared to capture different dimensions of pediatric/adolescent TMD. Pain may reflect active synovitis, disc displacement, masticatory muscle pain, central sensitization, psychosocial factors, or other mechanisms that are not directly captured by CBCT osseous morphology. Recent studies combining clinical TMD assessment with CBCT-based evaluation

have similarly reported limited or inconsistent associations between pain/clinical symptoms and radiographic DJD findings [10, 13, 14]. A recent retrospective CBCT study also evaluated clinical factors associated with radiographic severity of progressive TMJ osteoarthritis [35]. Thus, in growing TMJ DJD patients, patient-reported outcomes remain essential for symptom care, while imaging findings should be interpreted as complementary information when imaging is obtained according to established clinical indications.

4.3 Clinical implications

These findings suggest a practical evaluation framework for pediatric/adolescent TMJ DJD. Symptom assessment remains essential for pain management, functional care, and quality-of-life evaluation. At the same time, low pain or modest psychosocial burden should not be assumed to indicate a low imaging-defined osseous burden, particularly in patients with facial asymmetry, mandibular retrognathia, progressive occlusal change, persistent TMJ dysfunction, or skeletal patterns such as high-angle Class II morphology. Co-Go ramus height may serve as a clinically interpretable skeletal marker of the condyle-ramus unit in retrospective and longitudinal studies. This integrated approach is especially relevant for orofacial pain clinicians because it distinguishes patient-reported symptom management from the detection of imaging-defined structural involvement, while recognizing that a normative growth deficit cannot be established without an appropriate control or reference comparison.

The positive adjusted association between posterior joint space and severity burden was unexpected and should be interpreted cautiously. One possible explanation is that condylar deformity, resorption, or positional remodeling may alter the spatial relationship between the condyle and glenoid fossa, resulting in an apparent increase in posterior joint space on static CBCT images. Another possibility is that joint-space measurements reflect adaptive or positional changes rather than active disease severity. Because CBCT cannot evaluate disc position, joint loading, or active inflammatory status, this finding requires confirmation in studies combining CBCT and MRI.

The present cross-sectional findings do not establish a specific imaging-monitoring or surveillance strategy. Imaging should be considered according to established clinical indications and interpreted together with clinical diagnosis, symptom assessment, and psychosocial findings. Patients with prominent pain or psychosocial distress require appropriate symptom management even when CBCT-based osseous severity is not high, whereas low symptom burden should not be assumed to indicate low structural involvement.

4.4 Strengths and limitations

The strengths of this study include complete availability of matched CBCT/cephalometric and clinical datasets for 83 pediatric/adolescent patients, integration of skeletal, joint-space, pain-related, functional, psychosocial, medical history, and laboratory information, and use of an a priori primary model focusing on mean Co-Go ramus height. The manuscript also benefits from detailed CBCT acquisition parameters, predefined CBCT-based osseous severity criteria, DC/TMD-based clinical evaluation, independent radiographic interpretation by oral medicine and oral and maxillofacial radiology specialists with excellent inter-examiner agreement, and reliability information for continuous morphometric measurements from the original imaging analysis.

Several limitations should be acknowledged. First, the retrospective cross-sectional design precludes causal inference and cannot determine whether DJD preceded the observed reduction in Co-Go ramus height or whether pre-existing skeletal morphology influenced susceptibility to DJD. In addition, Co-Go ramus height includes the condylar region. Therefore, part of the observed association may reflect anatomical overlap between the predictor and outcome, particularly because CBCT-based severity grading includes condylar deformity, resorption, and flattening when accompanied by other degenerative features. To avoid overinterpretation, the association should be viewed as a structural relationship involving the condyle-ramus unit rather than direct evidence that TMJ DJD caused impaired mandibular growth.

Second, the cohort lacked a non-TMD control group or an internal age- and sex-matched normative cephalometric comparison. To address this issue, we reviewed published cephalometric normative and reference datasets reporting mandibular ramus height, Co-Go, or closely related condylion-gonion measurements in growing populations, and summarized relevant datasets in **Supplementary Table 3** [29–32]. These datasets include German normal-occlusion standards from 6 to 17 years of age, Filipino age- and sex-specific cephalometric norms including Cd-Go, a large Craniofacial Growth Consortium dataset providing sex-specific percentile curves including Co-Go, and mandibular growth curves for Anatolian Turkish children [29–32]. These studies support the interpretation of ramus height as an age- and sex-dependent, growth-related measurement. However, they differ from the present cohort in ethnicity, occlusal selection criteria, referral setting, imaging acquisition, and landmark definitions. Therefore, these literature-derived data were used only for contextual interpretation and were not treated as a formal external control group or used to classify individual patients as having normative growth deficits. Consequently, the present study cannot determine whether the observed ramus heights were below expected normative growth ranges, or whether DJD severity burden was associated with a clinically abnormal growth deficit rather than biological variation within a referred pediatric/adolescent TMD population. The results should therefore be interpreted as a within-DJD cohort association. Future studies should include age- and sex-matched controls, directly applicable normative cephalometric reference data, or longitudinal growth comparisons.

Third, although the primary model adjusted for age and sex and the revised analysis included additional adjustment for ANB and FMA, residual confounding by skeletal phenotype remains possible. The severity coefficient for mean Co-Go ramus height was attenuated after ANB/FMA adjustment, indicating that anteroposterior and vertical skeletal morphology may partly contribute to the observed association. Fourth, because the high-severity subgroup included only 17 patients and the unilateral DJD group included only 11 patients, sub-

group and side-pattern comparisons were underpowered and should be considered descriptive. Fifth, the summed bilateral severity-burden score captures cumulative osseous burden but may obscure clinically important asymmetry or side-specific relationships between the more affected joint and ipsilateral Co-Go ramus height. Sixth, CBCT is well suited for osseous assessment but cannot directly evaluate active synovitis, disc position, joint loading, or soft-tissue inflammatory activity; MRI would be required to assess active arthritis or internal derangement. Seventh, questionnaire data were not available for all variables in all patients. A complete-case comparison showed that patients with incomplete clinical-score data had lower mean Co-Go ramus height and numerically higher high-severity burden, suggesting that missingness was not completely random and that complete-case symptom analyses may have underrepresented patients with greater imaging-defined structural involvement. Eighth, although the ordinal CBCT-based DJD severity scale was derived from established image-analysis criteria and CT/CBCT descriptions of TMJ osseous change, it was operationalized for the present study and has not been externally validated as an independent pediatric severity index. The scale should therefore be interpreted as an investigator-defined ranking of osseous burden rather than a validated pediatric disease-severity score. In addition, condylar cortical maturation is age-dependent and may be incomplete in children and adolescents; therefore, subtle cortical irregularity or isolated mild flattening may reflect developmental variation or adaptive remodeling rather than degenerative erosion. To reduce this risk, the present grading emphasized definite osseous abnormalities, such as erosion, osteophyte formation, subchondral cystic change, deformity, marked sclerosis, and condylar resorption, rather than cortical continuity or flattening alone. Finally, because the study was conducted in a tertiary oral medicine setting, selection bias is possible, and generalizability to community populations may be limited.

Finally, the term “DJD severity burden” represents the summed CBCT-based osseous severity across both joints. This index captures bilateral structural burden but does not distinguish whether severity reflects active inflammatory arthritis, chronic osseous sequelae, mechanically driven degeneration, skeletal phenotype-related variation, or a combination of mechanisms. Although patients with confirmed systemic rheumatic disease, including juvenile idiopathic arthritis, were excluded from the primary analysis, CBCT cannot determine active synovitis or inflammatory disease activity. Therefore, subclinical inflammatory TMJ involvement cannot be completely ruled out. Future studies should incorporate MRI, rheumatologic assessment, and longitudinal follow-up to clarify disease activity and temporal sequence.

4.5 Future directions

Future studies should evaluate these relationships longitudinally to determine whether baseline CBCT severity, Co-Go ramus height, or Co-Go ramus height asymmetry predicts subsequent mandibular growth disturbance relative to age- and sex-matched normative data. Multimodal studies combining CBCT, MRI, standardized orofacial examination, orthodontic/cephalometric assessment, and inflammatory markers may help distinguish active inflammatory arthritis, chronic osseous sequelae, mechanically driven DJD, and skeletal phenotype-related variation. Larger multicenter pediatric cohorts would also enable the development of risk stratification models for identifying patients who may require closer clinical follow-up and, when clinically indicated, imaging assessment.

5. Conclusions

In pediatric and adolescent patients with TMJ DJD, each one-point increase in cumulative CBCT-based osseous severity burden was associated with a 1.209-mm lower mean Co-Go ramus height after adjustment for age and sex. This primary association was attenuated but remained nominally significant after additional adjustment for ANB and FMA, indicating that craniofacial skeletal phenotype may partly contribute to the observed relationship. In contrast, pain intensity, jaw functional limitation, perceived stress, somatic symptoms, depression, and anxiety were not significantly associated with CBCT-based osseous severity burden in this sample. These findings indicate that CBCT-based osseous severity and symptom burden represent related but non-interchangeable domains in pediatric and adolescent TMJ DJD. Because Co-Go ramus height includes the condylar region and no normative control group was included, the findings should be interpreted as a within-cohort structural association involving the condyle-ramus unit rather than definitive evidence of an abnormal mandibular growth deficit. In this cohort, symptom burden did not consistently correspond to imaging-defined structural involvement. Accordingly, patient-reported outcomes and CBCT-derived skeletal indicators, particularly Co-Go ramus height, should be interpreted as complementary clinical information.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy restrictions but may be obtained from the corresponding author upon reasonable request and with appropriate institutional approval.

AUTHOR CONTRIBUTIONS

JS and SMO—conceptualized the study. JS, SL, JJH and SMO—developed the methodology. JS and SL—curated the clinical and imaging datasets and prepared visual materials; drafted the original manuscript. JS—performed formal statistical analysis. JJH and SMO—independently reviewed CBCT images and performed radiographic validation, and critically reviewed and edited the manuscript. SMO—supervised the study, acquired funding, administered the project, and provided resources. All authors contributed to editorial changes, read and approved the final manuscript, and agreed to be accountable for all aspects of the work.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This retrospective study was approved by the Institutional Review Board of Pusan National University Dental Hospital (approval no. PNUDH-2025-08-002). The requirement for informed consent was waived by the Institutional Review Board of Pusan National University Dental Hospital because the study used de-identified retrospective clinical records and pre-existing CBCT images obtained for clinical purposes. Study information was provided through institutional notices, and an opt-out procedure was implemented in accordance with institutional requirements. The study was conducted in accordance with the principles of the Declaration of Helsinki.

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Not applicable.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://files.jofph.com/files/article/2120763863282401280/attachment/Supplementary%20material.docx.

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