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Mandibular bone apposition in relation to temporomandibular joint disorders: a radiographic and MRI study

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Abstract

Background This study investigated whether mandibular angle bone apposition (MABA) observed in temporomandibular disorder (TMD) patients reflects intrinsic joint pathology or represents a skeletal response to altered biomechanical loading related to occlusal and demographic factors.

Methods Panoramic radiographs and temporomandibular joint (TMJ) magnetic resonance imaging (MRI) scans from 282 patients with TMDss (564 TMJs) were retrospectively analyzed. Bone apposition was graded on panoramic images, while MRI findings (disc position, condylar morphology, effusion) were recorded. Demographic data and individual tooth loss patterns were evaluated. Statistical analyses included chi-square tests with Bonferroni-adjusted post hoc comparisons and ordinal logistic regression based on generalized estimating equations.

Results MABA showed no significant association with MRI-detected intra-articular TMJ abnormalities ($p > 0.05$). In univariate analyses, higher apposition levels were associated with increasing age, male sex, and greater numbers of missing maxillary and mandibular teeth ($p \leq 0.05$). Tooth-level analysis demonstrated a localized association involving the right maxillary second premolar ($p = 0.037$). In multivariable analysis using generalized estimating equations, male sex, right-side location, and higher grades of joint effusion remained significantly associated with bone apposition levels ($p \leq 0.05$).

Conclusions Although a causal relationship cannot be confirmed in this retrospective design, the observed associations suggest that MABA may be more closely related to functional and demographic factors than to intra-articular TMJ pathology. When MABA is detected on panoramic radiographs, assessment of occlusal stability may be considered, as functional loading patterns could play a role in mandibular remodeling.

Keywords Bone remodeling, Magnetic resonance imaging, Mandible, Radiography, panoramic radiography, Temporomandibular joint disorders

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Background

Temporomandibular disorders (TMD) are musculoskeletal conditions affecting the temporomandibular joint (TMJ) and its associated anatomical structures, typically characterized by pain, joint sounds, and restricted mandibular movement [1, 2]. TMD has a multifactorial etiology involving structural abnormalities, trauma, muscle dysfunction, psychological stress, and systemic conditions [3, 4]. Given the complex anatomy of the TMJ and the heterogeneity of symptoms, clinical examination alone is insufficient for accurate diagnosis; advanced imaging techniques are essential.

Cone-beam computed tomography (CBCT), magnetic resonance imaging (MRI), panoramic radiography, and ultrasonography (USG) are among the most commonly used diagnostic modalities for TMJ evaluation [5]. MRI is considered the gold standard for assessing TMD, as it provides detailed visualization of soft tissue structures such as the articular disc and joint effusion [6]. In contrast, although CBCT lacks soft tissue contrast, it remains valuable for high-resolution assessment of osseous components such as the condyle and mandibular angle [7, 8]. Despite its limitations in soft tissue evaluation, panoramic radiography is a practical and widely used method for detecting distinct osseous changes in the condyle and mandibular angle [9]. Since each modality contributes unique diagnostic information, the combined use of multiple imaging methods is often crucial.

Numerous studies have emphasized the diagnostic value of MRI, CBCT, and USG in detecting intra-articular derangements and degenerative changes of the TMJ [10–12]. Among radiographic findings associated with TMD [9, 13], mandibular angle bone apposition (MABA) is a frequent observation, particularly on panoramic radiographs. Previous reports have noted that MABA appears more common in patients with TMJ dysfunction and parafunctional habits [14, 15]. Such associations have led to a widespread clinical assumption that MABA may serve as an indirect indicator of underlying TMJ pathology or increased functional loading.

However, the exact nature of this relationship remains unclear. It has not been sufficiently investigated whether MABA and TMJ abnormalities share a direct causal link, or whether both may represent separate outcomes of a common etiologic factor—such as altered biomechanics resulting from posterior tooth loss and occlusal instability. Most previous studies have relied solely on panoramic imaging [14, 15] or on clinical TMD diagnosis [15], without clarifying whether MABA is specifically correlated with MRI-confirmed intra-articular structural abnormalities.

This study was designed to address this knowledge gap by determining whether mandibular angle bone apposition is associated with MRI-confirmed intra-articular temporomandibular joint abnormalities or with occlusal factors influencing mandibular biomechanical loading, particularly tooth loss. The null hypothesis of this study was that mandibular angle bone apposition would show no significant association with intra-articular TMJ pathology or dental factors influencing occlusal support.

Materials and methods

Patient selection and imaging protocol

Ethical approval for this study was obtained from the Karadeniz Technical University Faculty of Dentistry Scientific Research Ethics Committee (Decision No: 2025/16, 9 May 2025). Written informed consent was obtained from all participants. For those under the age of 16, informed consent to participate was obtained from their parents or legal guardians. Data were collected from 282 patients (200 females, 82 males; mean age 34.6 ± 15.7 years, ranging from 14 to 79 years) who presented to the Oral and Maxillofacial Surgery and Oral Diagnosis and Radiology clinics at Oral and Dental Health Hospital between March 2019 and December 2024, complaining of TMJ disorders.

These patients underwent clinical examination according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) Axis I protocol [16]. Based on this assessment, TMD diagnoses were classified as pain-related TMDs (myalgia and/or arthralgia) and/or intra-articular disorders, including disc displacement with or without reduction and degenerative joint disease. The clinical evaluation included assessment of jaw and joint pain, limitations of mandibular movement, pain provoked or increased by mandibular function, tenderness on palpation of the temporomandibular joint, evaluation of the masticatory muscles by palpation, and detection of joint sounds (clicking or crepitation).

For diagnostic confirmation and treatment planning, all patients underwent panoramic radiography and bilateral TMJ MRI. Panoramic radiographs were obtained using an Instrumentarium OP300 device (Instrumentarium Imaging Dental Inc., Milwaukee, WI, USA) with standardized exposure parameters (66 kVp, 8 mA, 12 s), positioning the Frankfurt horizontal plane parallel to the floor and the midsagittal plane vertically aligned.

Bilateral TMJ examinations were performed on a MAGNETOM Aera 1.5 T system (Siemens Healthineers, Erlangen, Germany). Oblique sagittal and oblique coronal T1-weighted, proton density–weighted (PDWI), and T2-weighted sequences were obtained in both closed-mouth and open-mouth positions. T1-weighted images were acquired with a gradient-echo/FLASH technique using a repetition time (TR) of 7–8.6 ms and an echo time (TE) of 2.95–4.0 ms. PDWI images were obtained with a turbo spin-echo sequence, with TR values of approximately 2000–3500 ms and TE values between 10

and 30 ms. For T2-weighted images, TR extended up to 3500 ms and TE reached 120 ms. Slice thickness ranged from 3 to 5 mm, and all acquisitions used a 512 × 512 matrix with a field of view (FOV) of 250–260 mm. The examinations were conducted using an UltraFlex Large 18-channel flexible coil on the 1.5 T platform, and no contrast material was administered.

MRI findings were evaluated in terms of disc position and morphology, joint effusion, and degenerative osseous changes, and interpreted in conjunction with the clinical DC/TMD diagnoses. In this study, the term "TMJ disease" refers to clinically established TMD diagnoses according to DC/TMD Axis I criteria together with MRI-detected intra-articular pathological findings.

A total of 564 TMJs from 282 individuals, whose TMJ disease was confirmed based on clinical and radiological findings, were included in the study. Their MRI and panoramic radiography images were independently reviewed three times by two oral and maxillofacial radiologists (with 8 and 5 years of clinical experience, respectively), with several weeks' interval between readings. Patients for whom the radiologists disagreed were excluded from the analysis.

Patients with systemic diseases that could affect bone metabolism (e.g., rheumatoid arthritis, systemic steroid use, Paget's disease of bone, hypoparathyroidism, hyperparathyroidism, osteomalacia, or renal osteodystrophy), a history of medication use affecting bone structure, or those undergoing orthodontic treatment were excluded from the study.

Magnetic Resonance Imaging (MRI) examination

TMJs were evaluated for disc configuration, internal disc status, condylar morphology, and effusion. Disc configuration was categorized on closed-mouth MRI scans according to Arayasantiparb et al. [17] as biconcave, concave, flattened, folded, amorphous or perforated disc (Figs. 1 and 2). Internal disc status was classified by examining both open- and closed-mouth MRI scans based on Koh et al. [18] as normal, disc displacement with reduction (DDWR), or disc displacement without reduction (DDWOR). Condylar morphology was categorized on closed-mouth T1WI MRI scans according to Roh et al. [19] as normal, osteophyte, flattening, sclerosis, subchondral bone cyst, or combined (any combination of these morphologies) (Fig. 3). Effusion was graded in four levels: Grade 0 indicated no bright T2 signal intensity within the joint space on T2WI; Grade 1 showed dot or linear bright and high signal intensity along the articular surface on T2WI; Grade 2 presented bands of bright high signal intensity on T2WI; and Grade 3 represented an accumulation of high signal intensity within the joint space on T2WI.

Bone apposition level and dental status on panoramic radiography

The morphology of the right and left mandibular angles on panoramic radiographs was classified into four distinct groups according to Türp et al. [14] for assessing bone apposition level. Grade 0 indicated a convex course of the basal cortex with no directional change and no bone apposition. Grade 1 showed a directional change from the convex course of the basal cortex, but no bone apposition. Grade 2 presented a directional change plus generalized bone apposition with an inhomogeneous surface. Grade 3 indicated a directional change plus localized bone apposition at one or more sites (Fig. 4). The dental status of the patients, including the presence or absence of prostheses and missing teeth, was recorded in detail by specifying tooth numbers.

Statistical analysis

The sample size for this study was calculated using G*Power statistical software (ver. 3.1.9.7). For a chi-square test (goodness-of-fit tests: contingency tables), a minimum sample size of 220 patients was determined with a statistical power of 0.95, an effect size of 0.5 (medium effect size), and a Type I error rate (α) of 0.05. To increase the robustness of the analysis, the sample size was expanded, and a total of 564 TMJs from 282 patients were included. The recalculated post hoc power for this sample size was 99% [20]. Intra- and interobserver reliability for panoramic radiograph and MRI evaluations were assessed using Cohen's kappa statistics.

Descriptive statistics for categorical variables are presented as frequency (n) and percentage (%). Associations

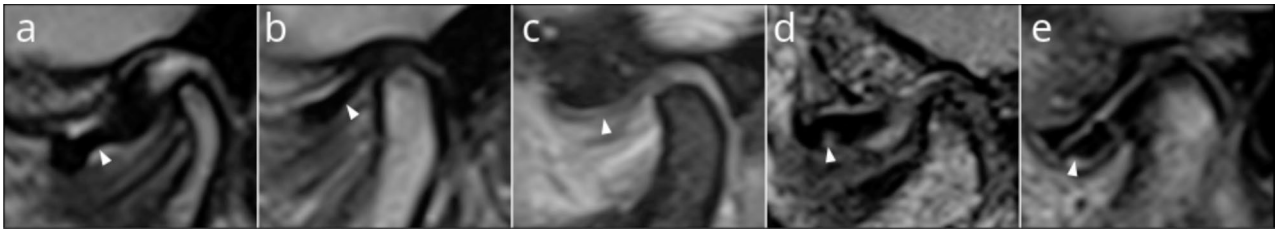


Fig. 1 Types of disc configuration on MR T2 images. (**a**) Biconcave, (**b**) Concave, (**c**) Flattened, (**d**) Folded, (**e**) Amorphous. Arrows indicate the articular disc morphology

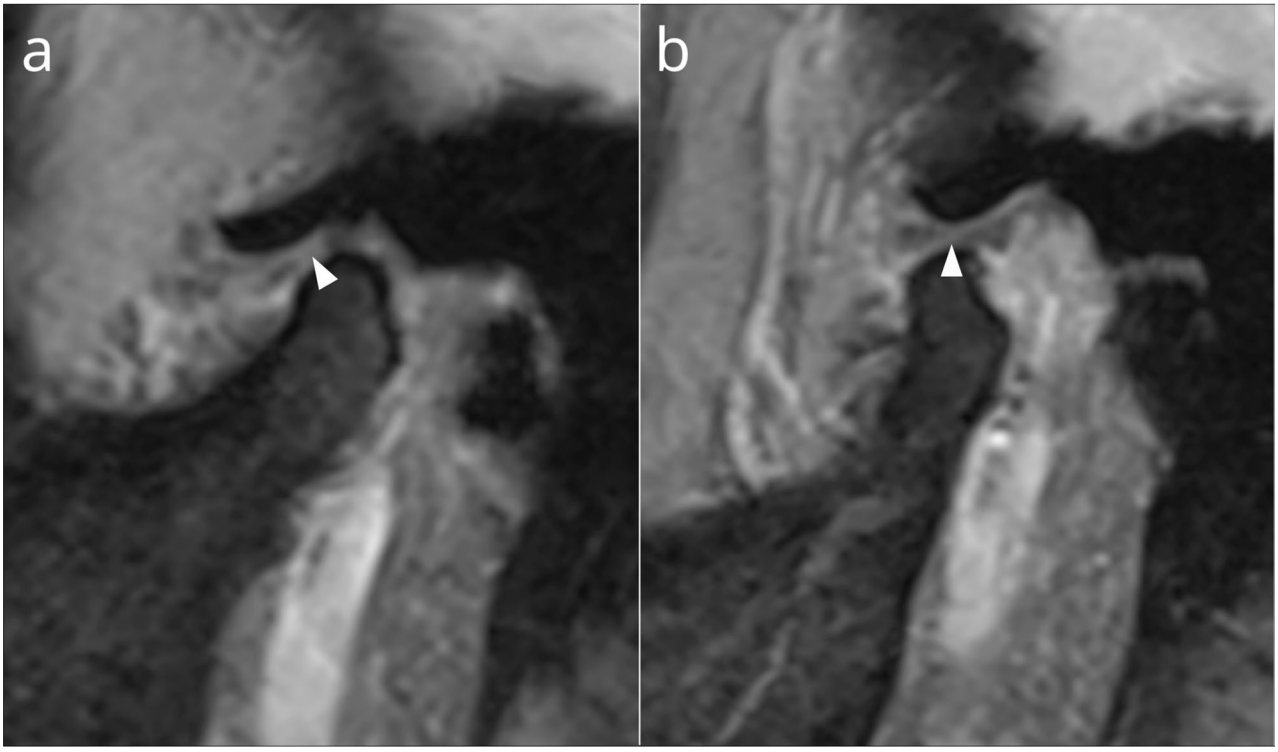


Fig. 2 T2-weighted MR images demonstrating perforated discs in a patient with normal disc-condyle relationship in both closed- and open-mouth positions. Disc perforation was defined by high signal intensity on fat-saturated T2WI in both positions. Arrowheads indicate the site of disc perforation. (**a**) Closed-mouth view: Grade 1 effusion in the anterior joint space and condylar flattening. (**b**) Open-mouth view

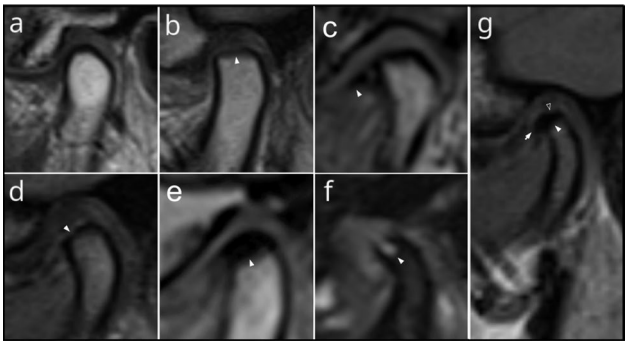


Fig. 3 T1-weighted MR images showing condylar morphology. (**a**) Normal condyle (no arrow). (**b**) Flattening, (**c**) Osteophyte, (**d**) Erosion, (**e**) Sclerosis, (**f**) Subchondral bone cyst, and (**g**) Combined findings (any combination of these morphological changes). Arrowheads in panels (**b**–**f**) indicate the corresponding osseous changes. In panel (**g**), the solid arrowhead indicates sclerosis, the hollow arrowhead indicates erosion, and the arrow indicates osteophyte formation

between categorical variables were analyzed using the Pearson chi-square test and Fisher's exact test with Monte Carlo correction. Post hoc multiple comparisons were performed using the Bonferroni-adjusted z test.

To account for the potential non-independence of bilateral TMJs within the same patient, the effects of independent variables on bone apposition level were analyzed using repeated ordinal logistic regression based on generalized estimating equations (GEE). Statistical analyses were performed using IBM SPSS Statistics (version 23; IBM Corp., Armonk, NY, USA). A p value < 0.05 was considered statistically significant.

Results

The weighted κ coefficient demonstrated good intraobserver agreement for both observers (Observer 1: κ = 0.71–0.78; Observer 2: κ = 0.65–0.73) and good interobserver agreement between the two observers (κ = 0.66–0.72) for both panoramic radiographs and MRI assessments [21].

A total of 282 panoramic radiographs and MRI scans from TMJ patients, spanning six age groups ranging from 14 to 79 years, were included in the analysis. Bone apposition levels at the mandibular angle and TMJ characteristics were examined for both the right and left sides independently. Among the 564 mandibular angles from these patients (200 females, mean age 33.7 ± 14.8 years; 82 males, mean age 36.8 ± 17.4 years), the presence of Grade 2 apposition was observed in 26.8% ($n = 151$), and Grade 3 apposition in 9.6% ($n = 54$) (Table 1).

Based on the MRI data for each patient's TMJ, no significant relationship was observed between bone apposition level and disc configuration, disc perforation, internal derangement, condylar morphology, or effusion ($p > 0.05$)

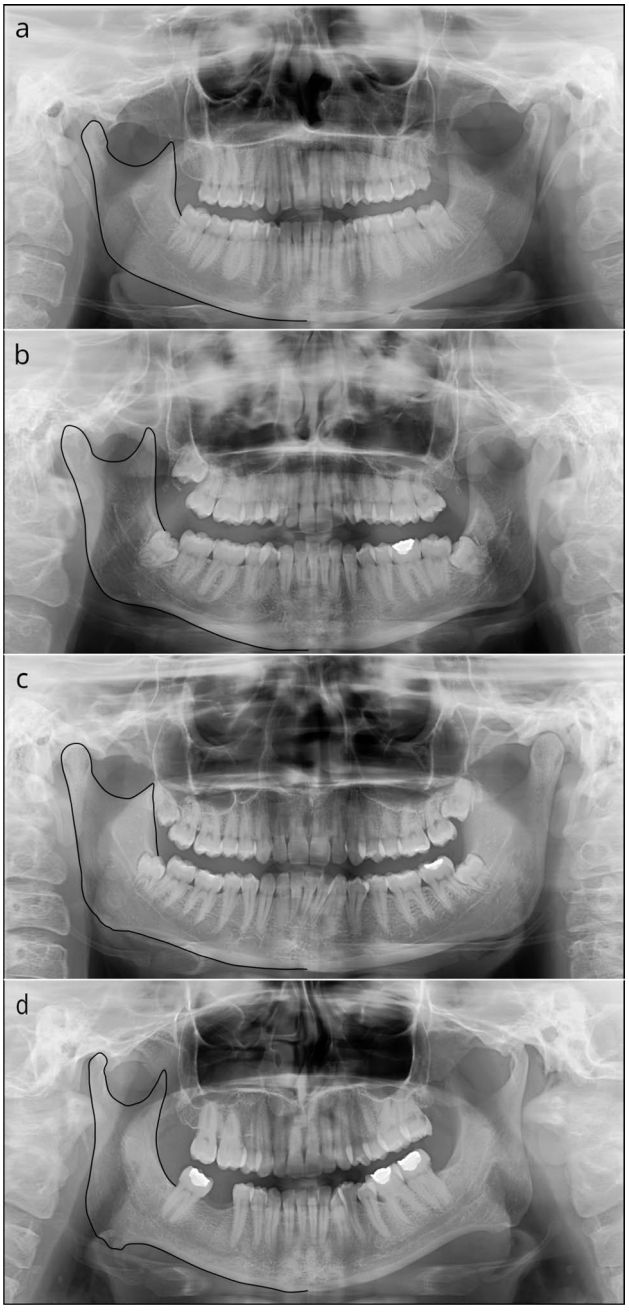


Fig. 4 Classification of mandibular angle bone apposition on panoramic radiographs: (**a**) Grade 0, (**b**) Grade 1, (**c**) Grade 2, and (**d**) Grade 3. A schematic hemimandible outline was added to the images to highlight the mandibular angle and clarify the grading patterns

(Table 1). However, a significant relationship was found between bone apposition level and gender, age, presence/absence of prostheses, and number of missing maxillary and mandibular teeth ($p \leq 0.05$) (Table 1). Representative panoramic and magnetic resonance images illustrating these concurrent changes are presented in Fig. 5.

Gender

Lower bone apposition levels (Grades 0 and 1) were more frequent in females (27.8% and 44.5%, respectively), whereas males showed clearly higher proportions in the higher bone apposition categories, Grades 2 and 3 (39.0% and 18.3% vs. 21.8% and 6.0% in females, respectively). This pattern indicates a tendency toward higher degrees of bone apposition in males ($p < 0.001$) (Table 1).

Presence or absence of prostheses

Individuals with prosthetic restorations exhibited higher rates of advanced bone apposition—Grade 2 (33.3%) and Grade 3 (19.6%)—compared with those without prostheses (26.1% and 8.6%, respectively) (Table 1). This finding suggests that the presence of prostheses may be associated with greater degrees of mandibular bone apposition ($p = 0.031$) (Table 1).

Age

Bone apposition levels varied significantly across age groups. Younger individuals (14–20 and 21–30 years) predominantly exhibited lower apposition grades ("0" and "1"), with minimal representation in the higher categories ("2" and "3"). As age increased (particularly within the 31–40, 41–50, 51–60, and 61+ groups), the proportion of patients showing higher bone apposition levels progressively rose. The oldest group (≥61 years) demonstrated the highest prevalence of Grades 2 (40.0%) and 3 (22.0%). These findings indicate a clear tendency for bone apposition degree to increase with advancing age ($p < 0.001$) (Table 1).

Number of missing mandibular teeth

The distribution of missing mandibular teeth differed significantly across bone apposition levels. Notably, all patients with five or six missing teeth (a small subgroup) exhibited higher apposition grades ("2" or "3"), whereas the majority of those with three missing teeth (37.5%) belonged to the lowest apposition category ("0"). Patients with a single missing tooth tended to show higher apposition levels, while those with three missing teeth demonstrated lower apposition levels (Table 1). This pattern suggests a complex relationship between the number of missing mandibular teeth and the degree of bone apposition ($p = 0.029$) (Table 1).

Number of missing maxillary teeth

The distribution of missing maxillary teeth showed a highly significant difference across bone apposition levels. Patients with four, five, or six missing teeth were predominantly clustered in the higher apposition categories ("2" and "3"), whereas those with no missing teeth mainly exhibited lower apposition levels ("0" and "1"). These results indicate a clear tendency for the degree of bone

Table 1 Association between MABA levels, MRI findings, and patient-related factors

	Bone apposition level				Test Statistics	*p*
	0	**1**	**2**	**3**		
Disc Configuration					15.099	.196[x]
Biconcave	78 (28)	104 (37.3)	72 (25.8)	25 (9)		
Concave	5 (21.7)	11 (47.8)	5 (21.7)	2 (8.7)		
Flattened	36 (19)	79 (41.8)	57 (30.2)	17 (9)		
Folded	11 (16.2)	33 (48.5)	15 (22.1)	9 (13.2)		
Amorphous	2 (40)	0 (0)	2 (40)	1 (20)		
Perforated Disc Presence						
Perforated	32 (24.8)	49 (38)	34 (26.4)	14 (10.9)	0.741	.860[x]
Non-perforated	100 (23)	178 (40.9)	117 (26.9)	40 (9.2)		
Internal derangement						
Normal	66 (24.4)	97 (35.8)	77 (28.4)	31 (11.4)	6.863	.323[x]
DDWOR	23 (19.8)	57 (49.1)	28 (24.1)	8 (6.9)		
DDWR	43 (24.3)	73 (41.2)	46 (26)	15 (8.5)		
Condylar morphology						
Normal	24 (30.4)	28 (35.4)	20 (25.3)	7 (8.9)	12.389	.630[x]
Erosion	5 (26.3)	8 (42.1)	5 (26.3)	1 (5.3)		
Flattening	34 (25.2)	53 (39.3)	39 (28.9)	9 (6.7)		
Osteophyte	8 (25.8)	9 (29)	11 (35.5)	3 (9.7)		
Sclerosis	3 (30)	2 (20)	3 (30)	2 (20)		
Subchondral bone cyst	0 (0)	1 (50)	0 (0)	1 (50)		
Combined (≥ 2)	58 (20)	127 (43.8)	73 (25.2)	32 (11)		
Effusions						
0	57 (29.8)	67 (35.1)	49 (25.7)	18 (9.4)	14.468	.099[x]
1	38 (25.9)	63 (42.9)	36 (24.5)	10 (6.8)		
2	30 (17.5)	73 (42.7)	48 (28.1)	20 (11.7)		
3	7 (12.7)	24 (43.6)	18 (32.7)	6 (10.9)		
Number of missing maxillary teeth						
0	89 (24.3)	159 (43.3)	91 (24.8)	28 (7.6)[a]	41.417	**< 0.001[x]**
1	17 (19.5)	36 (41.4)	28 (32.2)	6 (6.9)[a]		
2	17 (30.9)	17 (30.9)	10 (18.2)	11 (20)[ab]		
3	5 (21.7)	8 (34.8)	10 (43.5)	0 (0)[a]		
4	1 (12.5)	1 (12.5)	3 (37.5)	3 (37.5)[ab]		
5	2 (18.2)	1 (9.1)	5 (45.5)	3 (27.3)[ab]		
6	0 (0)	0 (0)	1 (33.3)	2 (66.7)[b]		
7	1 (10)	5 (50)	3 (30)	1 (10)[ab]		
Number of missing mandibular teeth						
0	81 (22.6)	163 (45.4)	86 (24)	29 (8,1)[a]	31.233	**0.029[x]**
1	32 (27.1)	35 (29.7)	38 (32.2)	13 (11)[a]		
2	5 (13.2)	15 (39.5)	13 (34.2)	5 (13.2)[a]		
3	9 (39.1)	6 (26.1)	7 (30.4)	1 (4.3)[a]		
4	3 (23.1)	4 (30.8)	4 (30.8)	2 (15.4)[ab]		
5	0 (0)	0 (0)	1 (100)	0 (0)[ab]		
6	0 (0)	0 (0)	0 (0)	2 (100)[b]		
7	2 (20)	4 (40)	2 (20)	2 (20)[ab]		
Presence of prosthesis						
Present	10 (19.6)	14 (27.5)	17 (33.3)	10 (19.6)[a]	8.745	**0.031[x]**
Absent	122 (23.8)	213 (41.5)	134 (26.1)	44 (8.6)[b]		
Sex						
Female	111 (27.8)[a]	178 (44.5)[a]	87 (21.8)[a]	24 (6)[a]	47.262	**< 0.001[x]**
Male	21 (12.8)[b]	49 (29.9)[b]	64 (39)[b]	30 (18.3)[b]		
Side						

Table 1 (continued)

	Bone apposition level				Test Statistics	*p*
	0	**1**	**2**	**3**		
Right	62 (22)	111 (39.4)	77 (27.3)	32 (11.3)	2.506	.474[y]
Left	70 (24.8)	116 (41.1)	74 (26.2)	22 (7.8)		
Age category						
14–20	27 (27)	59 (59)[a]	13 (13)[a]	1 (1)[a]	60.677	**< 0.001[x]**
21–30	45 (23.7)	85 (44.7)[ab]	46 (24.2)[ab]	14 (7.4)[ab]		
31–40	26 (23.6)	34 (30.9)[bc]	36 (32.7)[b]	14 (12.7)[bc]		
41–50	11 (16.2)	27 (39.7)[ab]	20 (29.4)[ab]	10 (14.7)[bc]		
51–60	11 (23.9)	15 (32.6)[bc]	16 (34.8)[b]	4 (8.7)[abc]		
61+	12 (24)	7 (14)[c]	20 (40)[b]	11 (22)[c]		

x Fisher's Exact Test with Monte Carlo correction; y Pearson Chi-square test; values are presented as frequency (percentage); a–c groups sharing the same superscript letter are not significantly different

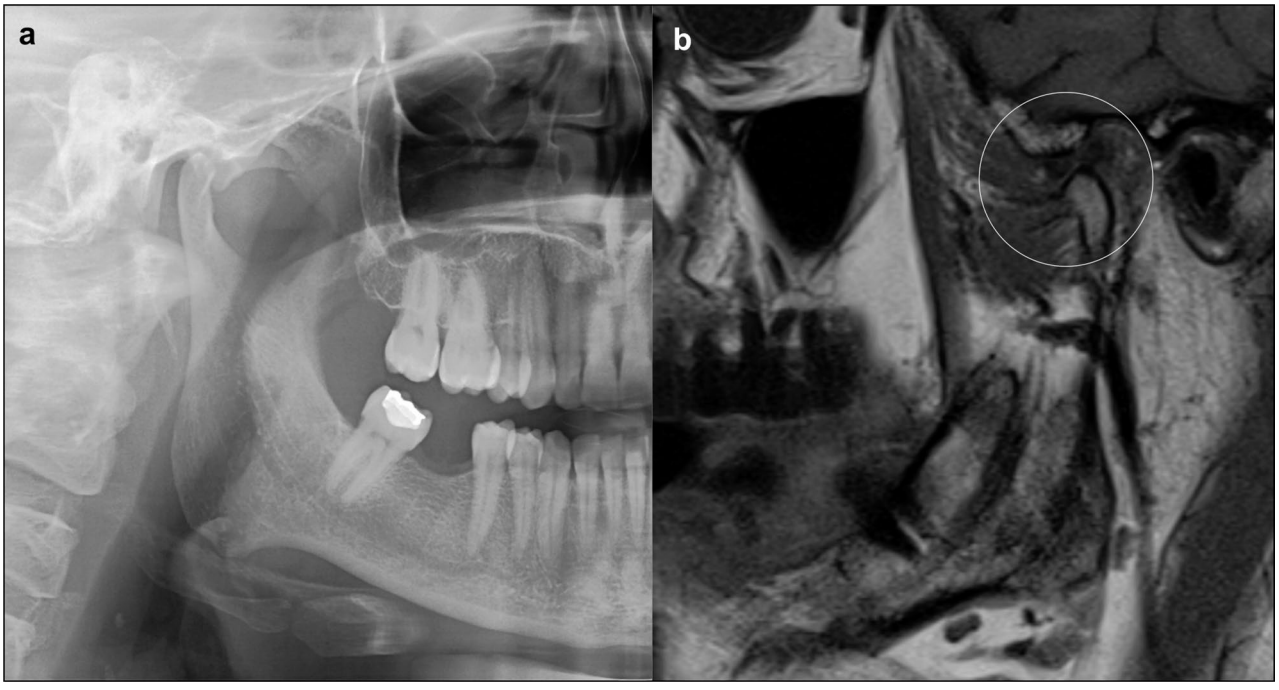


Fig. 5 Right-sided findings in the same patient: (**a**) Panoramic radiograph showing Grade 3 bone apposition at the mandibular angle, (**b**) Open-mouth sagittal T1-weighted MR image demonstrating condylar surface flattening and a biconcave disc configuration on the right temporomandibular joint (Shown in circle)

apposition to increase in parallel with the number of missing maxillary teeth ($p < 0.001$) (Table 1).

A tooth-specific analysis was performed to further evaluate the relationship between bone apposition levels and individual tooth loss. A statistically significant association was observed only for the maxillary second premolar (#15) ($p = 0.037$), whereas no significant associations were detected for the remaining teeth. Given the multiple comparisons performed, this isolated finding should be interpreted with caution (Table 2).

To further evaluate independent predictors of mandibular angle bone apposition, an ordinal logistic regression analysis based on generalized estimating equations (GEE) was performed to account for the non-independence of bilateral TMJs within the same patient. The analysis demonstrated that male sex (OR = 0.277, $p < 0.001$) and right-side location (OR = 1.287, $p = 0.020$) were significantly associated with higher bone apposition levels. In addition, moderate and severe joint effusion (grades 2 and 3) were significantly associated with bone apposition ($p = 0.011$ and $p = 0.044$, respectively). Compared with the reference group (≥ 61 years), younger individuals—particularly those aged 14–20 years—showed significantly lower odds of higher bone apposition levels (OR = 0.245, $p = 0.005$). Variables such as disc configuration, internal derangement, condylar morphology, number of missing teeth, and prosthesis presence were not identified

Table 2 Tooth-level analysis of the association between bone apposition level and tooth loss

	Bone apposition level				Test Statistics	p^x
	0	1	2	3		
Maxillary teeth						
11	1 (2.3)	4 (5.9)	3 (5)	4 (15.4)	59.809	**0.037**
12	2 (4.7)	8 (11.8)	2 (3.3)	5 (19.2)		
13	4 (9.3)	8 (11.8)	2 (3.3)	2 (7.7)		
14	9 (20.9)	7 (10.3)	10 (16.7)	8 (30.8)		
15	8 (18.6)[ab]	8 (11.8)[a]	15 (25)[ab]	10 (38.5)[b]		
16	14 (32.6)	25 (36.8)	13 (21.7)	6 (23.1)		
17	6 (14)	8 (11.8)	6 (10)	7 (26.9)		
21	0 (0)	6 (8.8)	5 (8.3)	1 (3.8)		
22	1 (2.3)	5 (7.4)	7 (11.7)	1 (3.8)		
23	6 (14)	5 (7.4)	9 (15)	4 (15.4)		
24	7 (16.3)	9 (13.2)	16 (26.7)	5 (19.2)		
25	11 (25.6)	15 (22.1)	18 (30)	6 (23.1)		
26	12 (27.9)	17 (25)	20 (33.3)	8 (30.8)		
27	6 (14)	13 (19.1)	16 (26.7)	7 (26.9)		
Mandibular teeth						
31	1 (2)	3 (4.7)	2 (3.1)	2 (8)	39.417	0.585
32	1 (2)	2 (3.1)	2 (3.1)	2 (8)		
33	2 (3.9)	2 (3.1)	3 (4.6)	1 (4)		
34	2 (3.9)	4 (6.3)	7 (10.8)	3 (12)		
35	7 (13.7)	8 (12.5)	10 (15.4)	1 (4)		
36	22 (43.1)	30 (46.9)	30 (46.2)	7 (28)		
37	9 (17.6)	11 (17.2)	14 (21.5)	4 (16)		
41	2 (3.9)	4 (6.3)	0 (0)	3 (12)		
42	2 (3.9)	4 (6.3)	1 (1.5)	3 (12)		
43	3 (5.9)	2 (3.1)	0 (0)	2 (8)		
44	4 (7.8)	5 (7.8)	7 (10.8)	4 (16)		
45	9 (17.6)	10 (15.6)	9 (13.8)	8 (32)		
46	21 (41.2)	26 (40.6)	25 (38.5)	14 (56)		
47	10 (19.6)	16 (25)	10 (15.4)	6 (24)		
Overall						
11	1 (1.1)	4 (3)	3 (2.4)	4 (7.8)		
12	2 (2.1)	8 (6.1)	2 (1.6)	5 (9.8)		
13	4 (4.3)	8 (6.1)	2 (1.6)	2 (3.9)		
14	9 (9.6)	7 (5.3)	10 (8)	8 (15.7)		
15	8 (8.5)	8 (6.1)	15 (12)	10 (19.6)		
16	14 (14.9)	25 (18.9)	13 (10.4)	6 (11.8)		
17	6 (6.4)	8 (6.1)	6 (4.8)	7 (13.7)		
21	0 (0)	6 (4.5)	5 (4)	1 (2)		
22	1 (1.1)	5 (3.8)	7 (5.6)	1 (2)		
23	6 (6.4)	5 (3.8)	9 (7.2)	4 (7.8)	92.155	0.254
24	7 (7.4)	9 (6.8)	16 (12.8)	5 (9.8)		
25	11 (11.7)	15 (11.4)	18 (14.4)	6 (11.8)		
26	12 (12.8)	17 (12.9)	20 (16)	8 (15.7)		
27	6 (6.4)	13 (9.8)	16 (12.8)	7 (13.7)		
31	1 (1.1)	3 (2.3)	2 (1.6)	2 (3.9)		
32	1 (1.1)	2 (1.5)	2 (1.6)	2 (3.9)		
33	2 (2.1)	2 (1.5)	3 (2.4)	1 (2)		
34	2 (2.1)	4 (3)	7 (5.6)	3 (5.9)		
35	7 (7.4)	8 (6.1)	10 (8)	1 (2)		
36	22 (23.4)	30 (22.7)	30 (24)	7 (13.7)		
37	9 (9.6)	11 (8.3)	14 (11.2)	4 (7.8)		

Table 2 (continued)

	Bone apposition level				Test Statistics	p^x
	0	**1**	**2**	**3**		
41	2 (2.1)	4 (3)	0 (0)	3 (5.9)		
42	2 (2.1)	4 (3)	1 (0.8)	3 (5.9)		
43	3 (3.2)	2 (1.5)	0 (0)	2 (3.9)		
44	4 (4.3)	5 (3.8)	7 (5.6)	4 (7.8)		
45	9 (9.6)	10 (7.6)	9 (7.2)	8 (15.7)		
46	21 (22.3)	26 (19.7)	25 (20)	14 (27.5)		
47	10 (10.6)	16 (12.1)	10 (8)	6 (11.8)		

x Pearson Chi-square test; values are presented as frequency (percentage); a–b groups sharing the same superscript letter are not significantly different

Table 3 Ordinal logistic regression analysis of factors associated with bone apposition levels

	β	SE	OR (95% CI)	*p*
Threshold				
Bone apposition level (Reference = 3)				
0	-2.472	0.593	0.084 (0.026: 0.27)	**< 0.001**
1	− 0.492	0.558	0.611 (0.205: 1.826)	0.378
2	1.424	0.555	4.154 (1.399: 12.317)	**0.010**
Location				
Sex (Female)	-1.284	0.230	0.277 (0.177: 0.435)	**< 0.001**
Side (Right)	0.252	0.108	1.287 (1.041: 1.59)	**0.020**
Disc configuration (Reference= Biconcave)				
Amorphous	0.378	1.275	1.459 (0.12: 17.743)	0.767
Biconcave (perforation)	-0.220	0.332	0.803 (0.419: 1.539)	0.508
Concave	0.254	0.436	1.289 (0.549: 3.031)	0.560
Flattened	0.342	0.225	1.408 (0.907: 2.186)	0.127
Flattened (perforation)	0.054	0.299	1.055 (0.587: 1.898)	0.855
Folded	0.144	0.288	1.155 (0.657: 2.03)	0.617
Folded (perforation)	0.376	1.993	1.456 (0.029: 72.385)	0.850
Internal derangement (Reference=Normal)				
DDWOR	-0.306	0.288	0.736 (0.419: 1.296)	0.288
DDWR	-0.212	0.225	0.809 (0.52: 1.257)	0.346
Condylar morphology (Reference= Normal)				
Erosion	0.168	0.517	1.183 (0.43: 3.258)	0.745
Flattening	0.110	0.291	1.116 (0.631: 1.976)	0.707
Osteophyte	0.270	0.437	1.31 (0.557: 3.083)	0.536
Sclerosis	0.238	0.713	1.269 (0.314: 5.124)	0.739
Combined (≥ 2)	0.331	0.272	1.392 (0.817: 2.373)	0.223
Effusions (Reference = 0)				
1	-0.057	0.209	0.945 (0.628: 1.422)	0.784
2	0.568	0.223	1.765 (1.14: 2.729)	**0.011**
3	0.646	0.321	1.908 (1.017: 3.579)	**0.044**
Age (Reference = ≥ 61 years)				
14–20	-1.407	0.507	0.245 (0.091: 0.661)	**0.005**
21–30	-0.813	0.486	0.444 (0.171: 1.15)	0.094
31–40	-0.413	0.478	0.662 (0.259: 1.687)	0.387
41–50	-0.353	0.506	0.703 (0.261: 1.893)	0.485
51–60	-0.601	0.468	0.548 (0.219: 1.37)	0.199
Number of missing maxillary teeth	0.144	0.089	1.155 (0.969: 1.376)	0.107
Number of missing mandibular teeth	-0.172	0.100	0.842 (0.691: 1.025)	0.087
Presence of prosthesis (Yes)	-0.057	0.311	0.945 (0.514: 1.737)	0.855

*β*regression coefficient, *SE* standard error, *OR* odds ratio, *CI* confidence interval

as independent predictors in the multivariable model (Table 3).

Discussion

In the present study, MABA was identified in more than one-third of patients with TMD, confirming its relatively high prevalence. This finding is consistent with previous reports suggesting that bone apposition represents an adaptive remodeling response [14, 22, 23]. Some authors have also proposed MABA as a radiographic marker of bruxism, a parafunctional habit associated with repetitive mechanical stress on the mandible [15, 16]. Given that bruxism has been linked to advanced TMJ changes such as disc displacement and condylar remodeling [24, 25], a correlation between MABA and TMD might be expected. Yet, our MRI-based analysis found no such association.

No significant relationship was observed between MABA and MRI-detected intra-articular abnormalities—including disc displacement and condylar morphology changes—suggesting that MABA may not represent a direct consequence of internal derangement. Instead, it appears to reflect a long-term biomechanical adaptation of the mandibular angle to redistributed occlusal forces, rather than a direct manifestation of intra-articular pathology [26].

A significant association was observed between MABA and the number of missing teeth. In particular, the number of missing maxillary teeth showed a stronger relationship with increasing bone apposition levels, whereas a weaker but still significant association was also observed for missing mandibular teeth. These findings suggest that reduction of occlusal support, especially in the maxillary arch, may contribute to altered load transmission across the mandible. Loss of posterior occlusal support has been shown to modify the distribution of masticatory forces and alter mandibular loading patterns [15]. From a biomechanical perspective, this interpretation is consistent with the well-established principle that bone tissue adapts to long-term mechanical loading through structural remodeling [26]. In addition, tooth-level analysis demonstrated a significant association between bone apposition level and the distribution of missing teeth in the maxillary arch. Among individual teeth, the maxillary second premolar (#15) showed a noticeable difference in distribution across bone apposition levels. Because this observation derives from multiple tooth-level comparisons, it should be interpreted cautiously and may reflect localized changes in occlusal support rather than a consistent tooth-specific effect. Notably, this finding was observed in the right maxillary arch, which may partly correspond with the slightly higher frequency of bone apposition detected on the right side. However, due to the retrospective design of the study, functional factors such as chewing side preference or occlusal contact patterns could not be evaluated.

In addition, multivariable analysis showed an association between higher grades of joint effusion and mandibular angle bone apposition. Although joint effusion is often interpreted as a sign of intra-articular inflammation, it may also reflect altered mechanical loading within the joint. Previous studies have suggested that increased functional loading or occlusal imbalance can modify joint stress and contribute to synovial reactions detectable as effusion on MRI [19, 27]. Therefore, the observed association may represent parallel adaptive responses of both osseous and intra-articular structures to altered mechanical loading rather than direct evidence of intrinsic TMJ pathology.

While changes in occlusal loading may explain much of this phenomenon, bone apposition was more frequent in males—despite the higher prevalence of TMD and bruxism in females [1, 24]. This suggests that sex-related physiological factors such as greater bite force, muscle mass, or masticatory efficiency may enhance the adaptive response of mandibular bone [26]. Increased muscle mass and contractile force may enlarge the functional load transmitted to the cortical bone surface, potentially promoting localized appositional remodeling of the mandibular angle. Similarly, older individuals, who often experience reduced occlusal stability and cumulative loading, also exhibited higher rates of apposition. Collectively, these demographic patterns reinforce the interpretation of MABA as a load-dependent remodeling phenomenon rather than a disease marker [14, 26].

From a clinical perspective, therefore, the presence of mandibular angle bone apposition on panoramic radiographs should be interpreted as a potential indicator of altered functional loading rather than as a direct sign of intra-articular TMJ pathology. Accordingly, clinicians should consider evaluating occlusal stability, prosthetic adequacy, and posterior tooth support when this radiographic feature is observed. Such an approach may assist in identifying functional imbalance and guiding individualized treatment planning rather than focusing solely on joint-centered diagnostics.

Although CBCT remains the gold standard for evaluating osseous structures, MRI allowed simultaneous assessment of both soft and hard tissues without radiation exposure. The lack of correlation between MRI findings and MABA thus provides robust evidence that these two processes evolve through distinct mechanisms—one intra-articular, the other biomechanical [25, 28]. The originality of this study lies in directly testing the relationship between mandibular angle bone apposition and MRI-confirmed TMJ findings, thereby allowing differentiation between joint-related pathology and extra-articular biomechanical adaptation.

Despite its strengths, this study has several limitations that should be acknowledged. Its retrospective design restricted standardization and prevented comprehensive evaluation of functional habits. Bone apposition was assessed solely on panoramic radiographs without CBCT or histologic validation, which may have affected diagnostic precision. Bruxism was not systematically evaluated, so its independent contribution cannot be excluded. In addition, limitations related to MRI evaluation should be considered. Although imaging was performed in both sagittal and coronal planes, the number and coverage of coronal sections available for analysis were limited in some cases, which may have restricted comprehensive three-dimensional assessment of disc position and morphology. Despite these limitations, the observed association between MABA and tooth loss supports the interpretation of this finding as a possible adaptive skeletal response to altered occlusal loading. Future prospective, multicenter studies incorporating multimodal imaging and longitudinal follow-up are warranted to further validate these findings.

Conclusion

Mandibular angle bone apposition was not associated with MRI-detected intra-articular temporomandibular joint pathology. Instead, it was more closely related to demographic and functional factors, suggesting that this radiographic finding may reflect adaptive skeletal remodeling rather than a manifestation of TMJ disease. Recognition of this feature on panoramic radiographs may prompt evaluation of occlusal stability and posterior occlusal support.

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Authors' contributions
SAK, AAS, TU performed the data collection. SAK and DNG participated in the writing and analysis of the article. SAK, AAS, TU and DNG planned the study.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the Karadeniz Technical University Faculty of Dentistry Scientific Research Ethics Committee (Decision No: 2025/16, 9 May 2025). The study was conducted in accordance with the Declaration of Helsinki of 1975, as revised in 2013. Written informed consent to participate was obtained from all participants. For those under the age of 16, informed consent to participate was obtained from their parents or legal guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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