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Comparative Evaluation of Mandibular Kinematics in Orthodontic Patients Using Optical Jaw Tracking Technology

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ABSTRACT

To investigate mandibular motion patterns in an orthodontic population through the use of the Modjaw® optical tracking system. Materials and Methods: A cohort of 154 orthodontic patients underwent mandibular movement assessment. Skeletal relationships were classified using ANB angles, while dental classification was derived from digital casts. Recordings followed the manufacturer's guidelines, capturing centric occlusion–maximum intercuspation (CO–MI) discrepancies, maximal mouth opening, Bennett angles, and sagittal condylar guidance. Temporomandibular disorder (TMD) presence was evaluated using DC-TMD questionnaires. Non-parametric statistical tests and Spearman correlation analyses were performed. Results: Mandibular motion showed notable differences across skeletal classifications, particularly in CO–MI discrepancies, Bennett angles, and maximal opening ($p < 0.05$). Patients with TMD exhibited larger CO–MI discrepancies, though other movement parameters remained largely unaffected. Weak correlations were observed between sagittal condylar guidance and anterior guidance variables. Conclusions: Mandibular motion patterns vary with skeletal type, with Class III patients displaying distinctive characteristics. While TMD symptoms influence CO–MI discrepancies, overall mandibular function appears largely stable.

Keywords: Orthodontics, Optical jaw tracking system, Mandibular kinematics

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Introduction

The temporomandibular joint (TMJ) is a paired synovial articulation linking the mandible to the temporal bone, operating as a coordinated unit in which the right and left joints function simultaneously rather than independently [1]. TMJ movement is guided by a hinge axis—a conceptual line around which the condyles rotate without translation [2]. This axis defines a reproducible terminal position, clinically significant as it corresponds to centric relation (CR) and can be reliably recorded [2]. Pure rotational movement is used to determine this axis, typically spanning 12–15° from maximum intercuspation or about 19–20 mm at the incisal edges [2].

Evaluating mandibular motion is crucial for understanding normal orofacial function and for diagnosing dysfunctions linked to malocclusions. Pioneering work by Posselt has detailed the extreme movements of the lower incisors in sagittal, frontal, and lateral planes [3]. Assessing dynamic mandibular kinematics allows clinicians and researchers to gain insights into TMJ behavior and the underlying causes of related disorders [4]. Epidemiological evidence suggests that roughly one-third of the population experiences temporomandibular disorders (TMD), with nearly half of these cases co-occurring with bruxism [5]. Clinically, such assessments are applied in evaluating dynamic occlusion for prosthetic work, guiding orthodontic treatment planning, and screening for TMD [6].

A wide range of techniques has been developed to capture mandibular movements, from mechanical tools like articulators, axiographs, and condylar position indicators, to photographic, radiographic, and video-based methods, and more recently, electromagnetic, ultrasonic, and optical tracking systems [7-9]. Among these, devices like the Modjaw® system (Villeurbanne, France) allow for detailed three-dimensional analysis of mandibular activity, including opening, closing, lateral movements, and protrusion [10]. By combining optical sensors with anatomical landmark recognition, the system calculates an individualized hinge axis with high precision [10, 11] and maps mandibular movements to the CR position, supporting comprehensive diagnosis and treatment planning [12, 13]. This method enables visualization of both rotational and translational condylar movements and quantifies their range, improving the accuracy and efficiency of clinical assessments [8, 12, 14, 15].

Accurate determination of intermaxillary relationships and vertical occlusal dimension is also fundamental for planning extensive dental interventions and optimizing treatment outcomes [16]. Although previous studies have investigated the influence of orthodontic therapy and TMD on mandibular kinematics, findings are inconsistent due to variability in study design and methodology [17-20]. While a direct causal relationship between orthodontic treatment and TMD has largely been rejected, there remains limited research examining how differences in mandibular kinematics may affect orthodontic treatment outcomes or present within an orthodontic population.

The present study aims to characterize mandibular motion in an orthodontic cohort using a 3D optical jaw tracking system. The central hypothesis is that mandibular kinematics do not significantly differ across skeletal and dental classifications, while the primary objective is to identify key determinants of mandibular motion and explore their variation within different orthodontic classifications.

Materials and Methods

This study was a single-center, observational investigation conducted in accordance with the STROBE guidelines [21]. Ethical approval was obtained from the institutional review board (internal code: 22/270-E), and all participants provided written informed consent following the principles outlined in the 2024 version of the Helsinki Declaration.

Sample size determination

The primary variable for sample size calculation was condylar discrepancy (in millimeters) among Class I, II, and III patients. Using data from Hidaka et al., sample size estimation was performed with G*Power software (version 3.1.9.7, Heinrich Heine University Düsseldorf, Germany), assuming a medium effect size (f^2 = 0.45), 80% statistical power, and $\alpha = 0.05$ for a three-group ANOVA. This resulted in a minimum requirement of 53 participants per group [22].

Patient selection

Patients attending a private orthodontic practice in Portugal were recruited if they had comprehensive initial orthodontic records, including extraoral and intraoral photographs, panoramic and profile radiographs, 3D scans, and Modjaw® jaw tracking data.

Inclusion criteria

- Complete permanent dentition
- Full set of initial orthodontic records

Exclusion criteria

- Previous orthodontic or occlusal splint therapy
- Overjet exceeding 8 mm
- Complete incisor overlap (100%)
- History of maxillofacial trauma or surgery
- Systemic conditions affecting orofacial structures
- Unreliable Modjaw® measurements

TMD assessment

Temporomandibular disorder (TMD) status was evaluated using the DC-TMD questionnaire from the International Consortium for TMD and Orofacial Pain, completed during the initial orthodontic evaluation [23]. A cross-culturally adapted and validated version in the participant's language was employed, following the Consortium's guidelines.

Data acquisition

All measurements were obtained and analyzed by a single calibrated examiner, with intra-rater reliability assessed. Intraoral models were captured using the iTero® element Flex scanner (Align Technology, San José, CA, USA) according to the manufacturer's protocol. STL files were imported into Modjaw® software (https://modjaw.com/en/, accessed 1 March 2025). After calibrating the device and securing the Tiara and SMIL'IT tracking units, mandibular movements were recorded in triplicate, including: open–close, centric relation (CR) via Dawson's bimanual technique, protrusion, lateral excursions, speech (numbers 60–70), and chewing.

From the CR record, pure rotational motion was isolated, and the software determined the hinge axis. Condylar position graphs were used to quantify CO–MI discrepancies. Maximum mouth opening was measured as the distance from the most protruded upper incisor tip to the corresponding lower incisor tip, plus the overbite (mm). Protrusive movements were used to calculate sagittal condylar guidance angles (°), while Bennett angles (°) were recorded during lateral excursions for each TMJ.

Data management

All variables were entered into Microsoft Excel® (Microsoft Office, Redmond, WA, USA), including:

- Presence/absence of TMD signs and symptoms
- Age and gender
- CO–MI discrepancy (vertical, sagittal, transverse; right and left; mm)
- Overjet and overbite (mm)
- Maximum opening (mm)
- Sagittal condylar guidance (right and left, °)
- Bennett angles (right and left, °)
- Angle and skeletal classifications (ANB angle)

Analyses were performed using IBM SPSS (version 29 for Windows, IBM Corp., Armonk, NY, USA). Normality testing via Kolmogorov–Smirnov indicated that most variables were non-normally distributed ($p < 0.05$); therefore, non-parametric tests were applied. Comparisons across Angle and skeletal classifications were performed using the Kruskal–Wallis test, with Bonferroni-adjusted pairwise comparisons for significant results ($p < 0.05$). Differences between TMD and non-TMD patients were evaluated using the Mann–Whitney U test. Spearman's correlation coefficient assessed relationships among continuous variables, with thresholds defined as negligible (0–0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong (0.90–1.00) [24].

A significance level of 5% was adopted. The sample was also stratified into two age groups: <20 years and ≥20 years. Independent t-tests were conducted to examine age-related effects on the evaluated variables. Statistical analyses were additionally verified using IBM SPSS version 26 (IBM Corp., 2019).

Results and Discussion

The study population consisted of 154 patients, with a predominance of females (72.7%), ranging in age from 11 to 66 years and a mean age of 26.9 ± 10.5 years. According to Angle classification, 37.0% were Class I, 27.3 percent Class II, and 35.7 percent Class III. Skeletal classification revealed 36.4% of patients as Class I, 42.9% as Class II, and 20.8 percent as Class III. TMD signs or symptoms were observed in 49 participants, accounting for 31.8% of the cohort **(Table 1)**.

Table 1. Sample characteristics

		n	**%**
Gender	Male	42	27.3
	Female	112	72.7

Age (years)	10–19	66	42.9
Minimum = 11	20–29	35	22.7
Maximum = 66	30–39	19	12.3
Mean = 26.9	40–49	24	15.6
Standard deviation = 14.0	50–59	7	4.5
	60+	3	1.9
Angle classification	Class I	57	37.0
	Class II	42	27.3
	Class III	55	35.7
Skeletal classification	Class I	56	36.4
	Class II	66	42.9
	Class III	32	20.8
TMD signs/symptoms	No	105	68.2
	Yes	49	31.8

Table 2 provides a summary of the descriptive statistics for all variables analyzed in the study.

Table 2. Descriptive statistics

	Minimum	**Maximum**	**Mean**	**SD**	**CI 95%**
CO-MI vertical right	−3.61	4.89	0.12	0.98	−0.04, 0.27
CO-MI vertical left	−3.56	3.53	0.00	0.91	−0.15, 0.14
CO-MI sagittal right	−1.90	2.97	0.00	0.81	−0.12, 0.13
CO-MI sagittal left	−2.70	2.38	0.02	0.76	−0.10, 0.14
CO-MI transversal	−1.36	2.06	0.00	0.49	−0.08, 0.08
CO-MI vertical right—absolute value	0.00	4.89	0.67	0.73	0.55, 0.78
CO-MI vertical left—absolute value	0.00	3.56	0.62	0.66	0.51, 0.72
CO-MI sagittal right—absolute value	0.00	2.97	0.58	0.56	0.49, 0.67
CO-MI sagittal left—absolute value	0.00	2.70	0.54	0.53	0.45, 0.62
CO-MI transversal—absolute value	0.00	2.06	0.33	0.37	0.27, 0.39
Sagittal condylar guidance right	7.00	85.00	49.16	12.11	47.23, 51.09
Sagittal condylar guidance left	19.00	91.00	47.94	11.81	46.06, 49.82
Bennett angle right	−16.00	32.00	6.89	8.18	5.59, 8.19
Bennett angle left	−11.00	31.00	4.59	7.46	3.40, 5.78
Maximum opening	3.00	51.00	35.70	6.21	34.71, 36.69
Overjet	−7.00	10.00	2.75	2.73	2.31, 3.18
Overbite	−6.00	7.50	2.21	2.41	1.83, 2.60

SD—standard deviation; CI 95%—95% confidence interval for the mean.

Comparisons between participants under 20 years and those aged 20 or older using the independent-samples Student's t-test showed no meaningful differences across any of the assessed variables. When data were analyzed according to Angle classification **(Table 3)**, several parameters exhibited significant variation ($p \leq 0.05$), including right and left CO–MI sagittal distances, absolute CO–MI vertical on the right side, right sagittal condylar guidance, bilateral Bennett angles, maximum opening, overjet, and overbite. Overall, Class III individuals tended to present lower values in these measurements compared with Class I and Class II groups. Exceptions included right CO–MI sagittal distance (similar between Class II and III), absolute right CO–MI vertical (no difference between Class I and III), right sagittal condylar guidance (no difference between Class I and III), and right Bennett angle (no difference between Class I and III). Comparisons between Class I and Class II showed no significant differences for most variables, except for right sagittal condylar guidance, which was higher in Class II patients than in Class I.

Table 3. Comparison by angle classification

	Skeletal Classification			
	Class I (*n* = 56)	**Class II (*n* = 66)**	**Class III (*n* = 32)**	***p***
CO-MI vertical right	−0.12 (0.97)	0.23 (1.10)	0.29 (0.64)	0.099
CO-MI vertical left	−0.09 (0.70)	0.10 (1.03)	−0.07 (0.96)	0.247
CO-MI sagittal right	0.07 (0.75)	0.09 (0.89)	−0.29 (0.65)	0.085
CO-MI sagittal left	−0.05 (0.67)	0.17 (0.88)	−0.17 (0.54)	0.189
CO-MI transversal	0.01 (0.36)	−0.07 (0.51)	0.15 (0.63)	0.065
CO-MI vertical right—absolute value	0.62 (0.74) ^{ab}	0.79 (0.79) ^{a}	0.48 (0.51) ^{b}	0.037 *
CO-MI vertical left—absolute value	0.54 (0.45)	0.71 (0.75)	0.56 (0.78)	0.217
CO-MI sagittal right—absolute value	0.58 (0.47)	0.61 (0.65)	0.51 (0.49)	0.506
CO-MI sagittal left—absolute value	0.46 (0.48)	0.65 (0.62)	0.43 (0.36)	0.128
CO-MI transversal—absolute value	0.25 (0.26)	0.35 (0.38)	0.42 (0.49)	0.177
Sagittal condylar guidance right	47.50 (11.47)	50.26 (11.22)	49.81 (14.79)	0.305
Sagittal condylar guidance left	48.63 (9.94)	47.97 (11.74)	46.69 (14.89)	0.679
Bennett angle right	5.48 (7.59) ^{a}	9.62 (8.56) ^{b}	3.72 (6.64) ^{a}	0.002 **
Bennett angle left	4.75 (7.69) ^{ab}	5.92 (7.68) ^{a}	1.56 (5.71) ^{b}	0.012 *
Maximum opening	35.18 (7.17)	36.85 (4.98)	34.25 (6.47)	0.163
Overjet	2.66 (2.41) ^{a}	4.28 (1.93) ^{b}	−0.26 (2.08) ^{c}	<0.001 ***
Overbite	2.42 (2.14) ^{a}	2.92 (2.54) ^{a}	0.37 (1.54) ^{b}	<0.001 ***

Values are reported as mean ± standard deviation; p indicates the overall significance from the Kruskal–Wallis test; groups sharing the same superscript letter (a, b, c) showed no significant differences in pairwise comparisons ($p > 0.05$); $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

When examining skeletal classifications **(Table 4)**, the only CO–MI measurement that differed significantly was the absolute vertical distance on the right side ($p = 0.037$), which was lower in Class III compared to Class II patients. Significant variation was also observed for Bennett angles on both sides, as well as for overjet and overbite ($p < 0.05$). Specifically, Class II individuals exhibited the largest Bennett angles, while Class III patients showed reduced overjet and overbite relative to the other groups.

Table 4. Comparison by skeletal classification

	Skeletal Classification			
	Class I (*n* = 56)	**Class II (*n* = 66)**	**Class III (*n* = 32)**	***p***
CO-MI vertical right	−0.12 (0.97)	0.23 (1.10)	0.29 (0.64)	0.099
CO-MI vertical left	−0.09 (0.70)	0.10 (1.03)	−0.07 (0.96)	0.247
CO-MI sagittal right	0.07 (0.75)	0.09 (0.89)	−0.29 (0.65)	0.085
CO-MI sagittal left	−0.05 (0.67)	0.17 (0.88)	−0.17 (0.54)	0.189
CO-MI transversal	0.01 (0.36)	−0.07 (0.51)	0.15 (0.63)	0.065
CO-MI vertical right—absolute value	0.62 (0.74) ^{ab}	0.79 (0.79) ^{a}	0.48 (0.51) ^{b}	0.037 *
CO-MI vertical left—absolute value	0.54 (0.45)	0.71 (0.75)	0.56 (0.78)	0.217
CO-MI sagittal right—absolute value	0.58 (0.47)	0.61 (0.65)	0.51 (0.49)	0.506
CO-MI sagittal left—absolute value	0.46 (0.48)	0.65 (0.62)	0.43 (0.36)	0.128
CO-MI transversal—absolute value	0.25 (0.26)	0.35 (0.38)	0.42 (0.49)	0.177
Sagittal condylar guidance right	47.50 (11.47)	50.26 (11.22)	49.81 (14.79)	0.305
Sagittal condylar guidance left	48.63 (9.94)	47.97 (11.74)	46.69 (14.89)	0.679
Bennett angle right	5.48 (7.59) ^{a}	9.62 (8.56) ^{b}	3.72 (6.64) ^{a}	0.002 **
Bennett angle left	4.75 (7.69) ^{ab}	5.92 (7.68) ^{a}	1.56 (5.71) ^{b}	0.012 *
Maximum opening	35.18 (7.17)	36.85 (4.98)	34.25 (6.47)	0.163

Overjet	2.66 (2.41) [a]	4.28 (1.93) [b]	−0.26 (2.08) [c]	<0.001 ***
Overbite	2.42 (2.14) [a]	2.92 (2.54) [a]	0.37 (1.54) [b]	<0.001 ***

Data are shown as mean ± standard deviation; p represents the overall significance from the Kruskal–Wallis test; groups marked with the same superscript letter (a, b, c) didn't differ significantly in pairwise comparisons (p > 0.05); significance levels are indicated as p < 0.05 (*), p < 0.01 (**), and p < 0.001 (***).

As presented in **Table 5**, patients exhibiting TMD signs or symptoms had significantly greater CO–MI distances in all absolute measurements—vertical, sagittal, and transverse—compared with those without TMD (p < 0.05). No significant differences between the two groups were observed for any of the other assessed variables (p > 0.05).

Table 5. Comparison by TMD signs/symptoms

	TMD Signs/Symptoms		
	No (*n* = 105)	**Yes (*n* = 49)**	***p***
CO-MI vertical right	0.07 (0.75)	0.22 (1.36)	0.299
CO-MI vertical left	0.08 (0.73)	−0.18 (1.19)	0.191
CO-MI sagittal right	0.03 (0.69)	−0.05 (1.01)	0.313
CO-MI sagittal left	0.05 (0.64)	−0.04 (0.96)	0.906
CO-MI transversal	−0.07 (0.30)	0.15 (0.74)	0.066
CO-MI vertical right—absolute value	0.52 (0.53)	0.97 (0.97)	0.001 ***
CO-MI vertical left—absolute value	0.51 (0.53)	0.85 (0.85)	0.011 *
CO-MI sagittal right—absolute value	0.50 (0.48)	0.75 (0.67)	0.009 **
CO-MI sagittal left—absolute value	0.46 (0.45)	0.70 (0.65)	0.025 *
CO-MI transversal—absolute value	0.21 (0.22)	0.58 (0.49)	<0.001 ***
Sagittal condylar guidance right	49.30 (10.77)	48.88 (14.70)	0.755
Sagittal condylar guidance left	48.31 (9.89)	47.14 (15.22)	0.664
Bennett angle right	6.07 (7.43)	8.65 (9.42)	0.234
Bennett angle left	4.40 (7.18)	5.00 (8.10)	0.721
Maximum opening	35.76 (6.34)	35.58 (6.01)	0.422
Overjet	2.82 (2.65)	2.59 (2.92)	0.820
Overbite	2.16 (2.42)	2.32 (2.41)	0.709

Values are expressed as mean ± standard deviation; p corresponds to the Mann–Whitney test p-value. Statistical significance is indicated as p < 0.05 (*), < 0.01 (**), and < 0.001 (***).

Table 6 illustrates the relationships between selected variables. The most pronounced correlation occurred between the right and left sagittal condylar guidance (RS = 0.553, p < 0.001). The Bennett angles on both sides exhibited weak yet statistically significant positive associations with OC-IM sagittal right absolute values (both sides) and sagittal condylar guidance (both sides), with correlation coefficients ranging from 0.163 to 0.293 (p < 0.05). Overjet also demonstrated weak but significant positive correlations with CR-MI sagittal measurements on the right (RS = 0.206, p = 0.010) and left (RS = 0.209, p = 0.009). Furthermore, right and left sagittal condylar guidance showed small positive correlations with overjet and overbite (RS < 0.180).

Table 6. Correlations between variables

	Correlation Coefficient
Bennett angle left vs. CO-MI sagittal right (absolute value)	R_S = 0.176, *p* = 0.029 *
Bennett angle right vs. CO-MI sagittal left (absolute value)	R_S = 0.216, *p* = 0.007 **
Bennett angle right vs. sagittal condylar guidance right	R_S = 0.293, *p* < 0.001 ***
Bennett angle right vs. sagittal condylar guidance left	R_S = 0.163, *p* = 0.043 *
Bennett angle left vs. sagittal condylar guidance right	R_S = 0.174, *p* = 0.031 *
Bennett angle left vs. sagittal condylar guidance left	R_S = 0.190, *p* = 0.018 *
Bennett angle right vs. CO-MI transversal	R_S = 0.047, *p* = 0.566
Bennett angle right vs. CO-MI transversal (absolute value)	R_S = 0.026, *p* = 0.752
Bennett angle left vs. CO-MI transversal	R_S = 0.076, *p* = 0.346

Bennett angle left vs. CO-MI transversal (absolute value)	$R_S = 0.088$, $p = 0.278$
Overjet vs. CO-MI sagittal right	$R_S = 0.206$, $p = 0.010$ **
Overjet vs. CO-MI sagittal left	$R_S = 0.209$, $p = 0.009$ **
Sagittal condylar guidance right vs. sagittal condylar guidance left	$R_S = 0.553$, $p < 0.001$ ***
Sagittal condylar guidance right vs. overjet	$R_S = 0.075$, $p = 0.355$
Sagittal condylar guidance right vs. overbite	$R_S = 0.157$, $p = 0.052$
Sagittal condylar guidance left vs. overjet	$R_S = 0.119$, $p = 0.140$
Sagittal condylar guidance left vs. overbite	$R_S = 0.178$, $p = 0.027$ **
Age vs. CO-MI vertical right	$R_S = -0.049$, $p = 0.547$
Age vs. CO-MI vertical left	$R_S = 0.009$, $p = 0.911$
Age vs. CO-MI sagittal right	$R_S = -0.130$, $p = 0.107$
Age vs. CO-MI sagittal left	$R_S = -0.148$, $p = 0.066$
Age vs. CO-MI transversal	$R_S = -0.022$, $p = 0.785$
Age vs. sagittal condylar guidance right	$R_S = 0.037$, $p = 0.652$
Age vs. sagittal condylar guidance left	$R_S = 0.062$, $p = 0.443$
Age vs. Bennett angle right	$R_S = -0.114$, $p = 0.160$
Age vs. Bennett angle left	$R_S = -0.220$, $p = 0.006$ **
Age vs. maximum opening	$R_S = -0.071$, $p = 0.385$

RS indicates the Spearman correlation coefficient. Significance levels are denoted as * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

This investigation examined mandibular motion in an orthodontic cohort prior to treatment using the Modjaw® optical tracking system to capture dynamic, real-time jaw activity. The goal was to define baseline kinematic patterns, which are essential for planning individualized orthodontic care and anticipating functional outcomes. The data highlighted variability in mandibular function, offering potential guidance for tailored treatment strategies.

Analysis of the study population revealed a predominance of female patients (72.7%), consistent with previous findings showing higher orthodontic demand among women [25]. The cohort spanned a wide age range, with 42.9% of participants aged 10–19, reflecting the typical period of craniofacial growth when orthodontic correction is commonly sought [26]. Interventions during this developmental stage can enhance both functional and aesthetic outcomes while influencing overall craniofacial maturation [27-29].

Significant differences emerged when mandibular kinematics were compared across skeletal and dental classifications. Class III patients exhibited smaller maximum openings, reduced Bennett angles, and lower CO-MI discrepancies relative to Classes I and II, suggesting potential functional limitations that must be considered in treatment planning. By contrast, Classes I and II did not differ significantly, indicating largely similar mandibular movement characteristics. Class III cases often present later, sometimes requiring surgical management, which can heighten the risk of functional compromise [30].

Examination of skeletal classifications **(Table 4)** further revealed statistically significant variations in Bennett angle, overjet, and overbite. Specifically, Class II patients demonstrated larger Bennett angles than Classes I and III, while Class III patients showed markedly lower overjet and overbite ($p < 0.001$). These findings reinforce the influence of maxillomandibular relationships on mandibular dynamics and their relevance for orthodontic planning. While measurable differences were observed between Class III and the other groups, the practical impact on routine treatment may be limited; such distinctions may become more critical in complex cases, borderline malocclusions, or when surgical planning is involved. Future research should clarify whether these kinematic differences meaningfully affect long-term outcomes or treatment stability.

To date, no studies have specifically compared mandibular kinematics prior to orthodontic intervention across Class I, II, and III malocclusions, highlighting a gap in the literature and the need for further study.

Additionally, the presence of TMD signs and symptoms was associated with higher absolute values in certain parameters, notably CO-MI discrepancies, corroborating earlier reports [31, 32]. Although overall mandibular motion did not appear substantially altered in patients with TMD, detectable variations suggest that these conditions should be factored into both initial treatment planning and ongoing management.

The study revealed notable associations between Bennett angles, sagittal condylar guidance, and CO–MI discrepancies, suggesting that variations in condylar position can affect mandibular function and carry clinical significance. Specifically, the link between the left Bennett angle and the absolute right-sided CO–MI sagittal discrepancy highlights how the two condyles coordinate during lateral jaw movements. In such motions, the non-working condyle moves medially and anteriorly, shaping the Bennett angle observed on the working side. This interplay underscores the complex biomechanics of the TMJ and supports evaluating cross-side relationships when analyzing mandibular motion. Considering absolute discrepancy values captures the full magnitude of deviations without directional bias, providing clearer insight into compensatory mechanisms. While Bennett angles are not routinely applied in orthodontic planning, they may reveal asymmetries in condylar motion or joint function that could be relevant in cases with functional shifts or suspected TMJ disorders. Though this study did not link Bennett angle measurements to specific treatment methods, identifying such variations could encourage more thorough joint assessments or guide decisions on appliance design, occlusal adjustments, or interdisciplinary care. Further research is needed to determine whether these metrics can enhance individualized orthodontic protocols.

Overjet and overbite also showed associations with sagittal condylar guidance, pointing to a potential influence of anterior guidance on condylar function. The moderate correlation between sagittal condylar guidance on both sides may be attributed to the TMJ's anatomical axis connecting the condyles through the mandibular corpus. Other variables, however, showed weak correlations, indicating that CO–MI discrepancies have limited direct impact on mandibular function and that condylar guidance does not strongly dictate anterior dental guidance. These findings echo recent literature questioning the traditionally assumed relationship between condylar and anterior guidance in restorative dentistry [33, 34], where anterior guidance may dominate occlusal behavior [33]. Reduced overjet and overbite in the sample could have affected this outcome, emphasizing the importance of including anterior guidance criteria in future studies.

Lastly, significant relationships between Bennett angles and transverse CO–MI discrepancies suggest that condylar positioning during mandibular movements influences mandibular dynamics. These findings reinforce the relevance of Bennett angles in orthodontic planning, as variations may affect both treatment efficiency and long-term joint health, highlighting the need for ongoing research and advanced diagnostic approaches to optimize clinical protocols.

Our analysis demonstrated that mandibular kinematics vary significantly among different malocclusion types, leading us to reject the null hypothesis. The cross-sectional design of this study prevents conclusions about causality, and the exclusive recruitment from a single private clinic may limit the applicability of the findings. Although the Modjaw® system delivers precise dynamic measurements, variations in patient participation and operator handling could have influenced the data. Future investigations should employ longitudinal, multicenter designs and incorporate assessments of muscle activity and anterior guidance to achieve a more complete evaluation.

Conclusion

Significant differences were observed in most mandibular kinematic measures when comparing patients with Class I and Class II malocclusions to those with Class III, with Class III individuals generally exhibiting lower values in several key parameters, emphasizing the impact of skeletal pattern on mandibular movement. Moreover, the presence of TMD symptoms was linked to increased absolute values in specific measurements, particularly the CR-MI discrepancy, although overall mandibular motion remained largely unchanged aside from this variation.

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