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CLINICAL, IMAGING AND FUNCTIONAL FEATURES OF CONDYLAR MALPOSITION IN PATIENTS WITH TEMPOROMANDIBULAR DISORDERS

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CONTENTS

1. CONCEPTUAL CHARACTERISTICS OF THE RESEARCH

Temporomandibular disorders (TMDs) represent a heterogeneous group of disorders of the masticatory system, involving the temporomandibular joints (TMJs), the masticatory muscles and associated structures, with variable clinical manifestations: orofacial pain, joint noises, limitation or deviation of mandibular movements and different degrees of functional impairment [36, 50]. In contemporary literature, TMDs are no longer interpreted as simple consequences of an occlusal disorder or an isolated change in condylar position, but as multifactorial musculoskeletal and pain disorders, in which structural, neuromuscular, behavioral and psychosocial components interact [7, 30, 36]. This change requires the evaluation of the condyle–fossa relationship, occlusal status and skeletal particularities in relation to the patient's symptomatology, mandibular function and pain profile.

The relevance of the problem is supported by the high prevalence of TMD signs and symptoms and their impact on the quality of life. Epidemiological estimates vary depending on the case definition, the population examined and the diagnostic criteria, but recent analyses indicate that TMD is one of the most common non-dental orofacial conditions, predominantly affecting women and young or middle-aged adults [7]. The clinical relevance derives not only from its frequency, but also from its potential for chronicity and its association with headache, neck pain, sleep disorders, anxiety, depression and limitations in mastication, speech or opening the oral cavity [36, 50]. In the pathogenesis of TMD, occlusal imbalances, skeletal peculiarities, parafunctions and the individual capacity for functional adaptation must be considered as interdependent elements of the stomatognathic system [8, 10-13, 20-21, 39, 48, 56-57]. Thus, the morphofunctional assessment must correlate the intermaxillary relationships, occlusal contacts, muscle response and pain expression in an integrated diagnostic model [9, 39, 58], extended by functional, gnathological and algic markers capable of better explaining the heterogeneity of the clinical picture [8, 39-40, 58].

In this framework, the position of the mandibular condyle in the glenoid fossa represents an important component of the structural evaluation of the TMJ. Operationally, condylar malposition describes the deviation of the condyle from a position considered centric or balanced in relation to the articular fossa, in the sagittal, vertical and/or transverse plane. The clinical significance of this deviation remains incompletely elucidated, since posterior, anterior or asymmetric condylar positions have been reported both in symptomatic patients and in situations without obvious clinical expression [34, 44]. Therefore, condylar malposition should not be treated as an autonomous diagnosis or as a unique explanation of TMD, but as a structural element that requires correlation with pain, mandibular mobility, muscle status, joint changes and functional paths of the condyles. The relationship between condylar position and craniofacial morphology becomes more informative when analyzed together with the inclination of the occlusal planes, skeletal class and vertical or transverse peculiarities of the maxillomandibular complex [10-13, 20-21, 56].

Advances in three-dimensional imaging allow for a more precise analysis of the condyle–fossa relationship. CBCT offers the possibility of evaluating the morphology of the mandibular condyle, glenoid fossa, articular eminence, and anterior, superior, posterior, medial, and lateral joint spaces [5, 27-28]. At the same time, standardization of section orientation, anatomical landmarks, section thickness, and interpretation indicators is essential, as methodological variations can modify the results of measurements [5]. The Pullinger–Hollender indicators and the Ikeda–Kawamura landmarks can objectify the distribution of joint spaces, but their clinical value is greater when integrated into a complex protocol, uniformly applied, and correlated with the patient's clinical data [27, 44]. Another relevant dimension is the relationship between condylar position, occlusal plane, and dentoskeletal morphology. Cephalometric and orthodontic studies have shown that the inclination of the occlusal plane, especially the posterior maxillary occlusal plane, can be associated with mandibular position and the development of dentoskeletal patterns [55]. These relationships should not be interpreted mechanistically, but justify the analysis of occlusal planes and skeletal classes in patients with TMD and condylar malposition, in order to understand mandibular adaptations, functional asymmetries and the influence of dento-alveolar relationships on the position of the mandible in intercuspation and movement. In orthodontic and gnatho-functional practice, this correlation can contribute to the differentiation of structural peculiarities with adaptive potential from those associated with clinical dysfunction.

Static assessment of the condyle is not sufficient for understanding joint function. The TMJ is a dynamic biomechanical structure, and the clinical expression of TMD depends not only on the position of the condyle at rest or in intercuspation, but also on its displacement in opening, protrusion and lateral movements. Condylography and computerized axiography allow three-dimensional recording of condylar trajectories and analysis of the amplitude of movement, sagittal condylar inclination, transverse component, bilateral symmetry and regularity of the trajectory [1]. These data may reveal functional impairments that cannot be deduced from clinical examination or static CBCT images alone.

Therefore, the investigation of condylar malposition in patients with TMD requires an integrated approach, as clinical, imaging, cephalometric and kinematic aspects are frequently studied separately. The DC/TMD protocol provides a standardized clinical framework for the diagnosis of pain and dysfunction, including Axis I and Axis II assessment, and CBCT, cephalometry and condylography complement the analysis with objective structural and functional data [1, 5, 50].

In this context, the premise of the research is that investigating the relationship between the clinical picture, condylar position, dentoskeletal morphology and mandibular kinematics can contribute to the delineation of more precise diagnostic patterns and the individualization of therapeutic management in patients with TMD and condylar malposition.

Thus, to test this hypothesis, the following **aim of the study** was formulated: to characterize the clinical, functional, imaging-structural and kinematic expression in patients with temporomandibular disorders and condylar malposition, in order to identify specific characteristics.

To achieve the aim, the following **study objectives** were set:

1. Evaluation of the clinical and functional picture of patients with TMD and condylar malposition based on the DC/TMD protocol, regarding the distribution of orofacial pain, the degree of functional limitation, the intensity and chronicity of pain and indicators of psycho-emotional impairment.
2. Qualitative and quantitative imaging examination of the morphology of the condyle, glenoid fossa and articular eminence, as well as the distribution of sagittal and coronal joint spaces in patients with TMD and condylar malposition.
3. Highlighting the cephalometric particularities of the investigated group, based on the distribution of skeletal classes and analyses by authors (Downs-Graber, Sato, Slavicek, Kim).
4. Three-dimensional assessment of mandibular kinematics in opening, protrusion and mediotrusion by condylography, using both standard indices (X, Y, Z displacements, SCI, TCI) and derived parameters, to assess the organization of condylar movements.
5. Integrated analysis of clinical, imaging and functional data in patients with temporomandibular disorders and condylar malpositions.

The working hypothesis claims that, in patients with TMD and condylar malposition, supplementing the DC/TMD protocol with standardized CBCT assessment of the condyle–fossa relationship and three-dimensional condylographic analysis highlights reproducible patterns of malposition and functional asymmetry, not deducible from clinical examination alone and useful for personalizing the diagnosis and therapeutic strategy.

Synthesis of scientific research methodology and justification of research methods

The research complied with the rules of biomedical ethics. The scientific project was examined by the Research Ethics Committee of the "Nicolae Testemițanu" State University of Medicine and Pharmacy in the meeting of July 1, 2020 and declared compliant with ethical requirements. The favorable opinion was issued on 22.09.2020, no. 1, upon request no. 64 of 18.06.2020. The research was conducted within the "Nicolae Testemițanu" State University of Medicine and Pharmacy, with the informed consent of the participants.

The study was designed as a cross-sectional observational research on a group of 75 patients with TMD and condylar malpositions, clinically examined according to DC/TMD (Axis I and Axis II). The protocol allowed the integration of somatic and psychosocial dimensions, by assessing orofacial pain, movement limitations, joint noises and by indices such as JFLS-8, CPI, GAD-7 and PHQ-9, used to quantify functional limitations, pain intensity and anxiety-depressive symptoms. The choice of these instruments aimed at describing the patient not only through articular signs, but also through the functional and psycho-emotional consequences of pain.

The structural analysis was based on CBCT, with measurements of the glenoid fossa, articular eminence, mandibular condyle and sagittal, vertical and coronal joint spaces. Linear indices and derived parameters were calculated, including condylar position indices according to Kamelchuk–Ikeda, to characterize the condyle–fossa relationship and the distribution of joint spaces. The dynamic function of the TMJ was assessed by computerized condylography, with three-dimensional recording of the trajectories in opening, protrusion and laterotrusion. Parameters included linear coordinates, sagittal and transverse angles, and curvature indices for the balancing condyle and the working-side condyle.

The data were processed using descriptive indicators (mean, median, interquartile range, standard deviation) and nonparametric inferential tests. For comparisons with reference values or expected distributions, the Wilcoxon one-sample test and the binomial test were used, and the relationships between clinical, imaging, and functional parameters were explored using Spearman correlations. Asymmetry indices and derived indicators of condylar position were calculated to examine the relationship between structural malposition and the clinical and functional expression of TMD.

The main limitations of the study derive from the cross-sectional observational design, the unicentric nature of the research, and the absence of a parallel healthy control group, aspects that limit the causal interpretation of the relationships between clinical, imaging, and functional parameters.

Scientific novelty and originality. The research integrates, on the same group of patients, CBCT assessment of the condyle–fossa relationship, condylar dynamics recorded condylographically, and the clinical-psychobehavioral picture characterized by DC/TMD and Axis II instruments. Thus, condylar malposition is analyzed as a structural link in a numerically documented functional and psychosocial context, which allows for a more nuanced description of the phenomenon in patients with TMD.

CBCT results revealed variability in the dimensions of the glenoid fossa, articular eminence, condyle and joint spaces, with linear and composite indices, including D_{Ikeda}, frequently deviating from the thresholds conventionally considered "centric". This dispersion shows that condylar malposition cannot be reduced to a single sagittal scheme, but must be analyzed as a continuum of joint positions and spaces, with different combinations of narrowing or widening in various planes. In this way, imaging results can be interpreted more cautiously, avoiding the automatic attribution of symptoms to a single condylar position. Another original contribution is the 3D condylographic characterization through amplitude, orientation and curvature indices for the balancing condyle and the working-side condyle. Correlation matrices revealed stable groups of variables in the sagittal and transverse planes (SCI–SagAng, TCI–TransAng), the distinct role of the balancing condyle, and the utility of a reduced set of non-redundant parameters for describing condylar kinetics in patients with condylar malposition.

The study documents concomitantly high pain and functional burden, with pain on two or more mandibular movements in almost all patients, mobility limitations, extensive muscle tenderness, and elevated GAD-7 and PHQ-9 scores. The integration of these dimensions supports the interpretation of condylar malposition as an element of a multifactorial picture of chronic pain, in which structural changes, neuromuscular dysfunction, and psychological vulnerability intersect.

Practical importance. The results indicate the need to interpret condylar malposition in the context of a complete DC/TMD examination and functional and psychological assessment, not just based on CBCT appearance. Changes in joint spaces and condylar position indices should be correlated with pain, muscle tenderness, and functional response before therapeutic decisions are made, including in the case of repositioning devices.

Condylographic analysis provides additional data on the predominant directions of movement and on trajectories with pronounced curvature or unstable orientation. These data can be used in the planning of functional therapy, for example by adjusting lateral guidance or occlusal splint design, and in monitoring changes in condylar kinematics during treatment. Separating the role of the balancing condyle from that of the working-side condyle may provide additional information on the organization of lateral movements.

Documenting the severity of pain burden, functional limitations, and anxiety-depressive symptoms supports the need for a multidisciplinary approach, in which interventions on the stomatognathic system are correlated with psychological or psychiatric evaluation when necessary. This perspective may reduce the risk of over-emphasizing strictly structural components and invasive treatments based solely on the imaging aspect of TMJ.

Applicative value. By configuring a unified protocol, combining DC/TMD (Axis I and Axis II), additional clinical indices, CBCT assessment of the condyle–fossa relationship and three-dimensional condylographic analysis, the study provides a practical framework that can be taken up in clinical centers interested in diagnosing and monitoring patients with TMD and condylar malposition. The described parameters can be integrated into standardized examination sheets and follow-up protocols, facilitating longitudinal comparison of cases and objective assessment of treatment response. The sets of CBCT and condylographic indices identified as informative for describing condylar position and dynamics can be used as benchmarks to optimize imaging and functional interpretation in current practice, especially in situations where a condylar repositioning guided by occlusal splints or other devices is considered. Also, data on psychological burden and functional limitations can guide the development of referral pathways to specialists in orofacial pain, psychology, or rehabilitation medicine, which increases the chances of truly interdisciplinary management of these patients.

Approval of scientific results. The scientific results of the research were validated and disseminated through 10 scientific articles (including 1 article in the European Journal of Orthodontics, internationally indexed, and 1 article in a peer-reviewed foreign journal), complemented by 8 publications in accredited national journals and in the process of accreditation. The results were additionally presented through 10 abstracts published in conference proceedings. The approval by the scientific community is supported by 14 active participations with communications at scientific forums, including presentations at major international events: European Orthodontic Society (EOS) – Nice, France (2019), Limassol, Cyprus (2022), Verona, Italy (2024); VieSID Summer School/International Conference on Occlusion and Function in Dentistry – Vienna, Austria (2015; 2022). Participation in regional and national forums with relevant visibility was also recorded (BAOS and thematic congresses in Iași, Romania, respectively national conferences with international participation in Chișinău). The innovation component was confirmed by participation in international invention salons, with distinctions: Salon International des Inventions, Geneva, Switzerland (2025) – gold medal, respectively INNOVA, Brussels, Belgium (2015) – gold medal. The results were also consolidated by 5 innovator certificates (methods/indicators for assessing condylar position and kinematics).

Thesis volume. The thesis is presented on 129 pages of basic text and includes an introduction, 4 chapters, general conclusions and practical recommendations. The bibliography includes 293 sources. The work is completed with annexes, a list of publications and participation in scientific forums, a statement on assuming personal responsibility, annotations in Romanian/English and the author's CV. The basic text is illustrated with

24 tables, 2 figures and 13 formulas. **Keywords:** temporomandibular disorders, condylar malposition, interdisciplinary dentistry, condylography, cephalometry, functional diagnosis, DC/TMD, CBCT, temporomandibular joint, condyle–fossa relationship.

2. MATERIAL AND METHODS

2.1. Characteristics of the research sample

The study had a single-center cross-sectional observational design, through which clinical and imaging data were collected and analyzed from patients with temporomandibular disorders and condylar malpositions, who presented consecutively to the university clinical base of the Department of Interdisciplinary Dentistry and Oral Rehabilitation of the USMF "Nicolae Testemițanu" - Fala Dental Clinic during the period 2019–2022. All patients were evaluated according to the DC/TMD criteria, using Axis I for the clinical diagnosis of TMD and, where appropriate, Axis II for the assessment of psychosocial factors. The version of the instruments from the DC/TMD protocol available at the start of the study was used. Patients who met the inclusion criteria and agreed to participate were subsequently investigated based on the clinical and imaging examination protocol, with data being collected securely for subsequent statistical processing.

Based on the analysis of studies in the field, the inclusion and exclusion criteria for the research were compiled, in order to ensure the relative homogeneity of the group from a diagnostic point of view, but at the same time to reflect the clinical reality.

Inclusion criteria: patients with a confirmed clinical diagnosis of TMD established according to the DC/TMD protocol available at the time of study initiation; patients who expressed their informed consent to participate in the study and to undergo CBCT examination of the TMJ; patients aged approximately between 18 and 45 years (in the final sample 19–43 years), an interval that corresponds to the period of maximum prevalence of TMD and in which the prevalence of severe degenerative changes is less frequent; patients in whom, following clinical-functional examination (symptoms, palpation, condylar trajectories during mandibular movements, intercuspid relationship), condylar malposition was identified and confirmed (obvious deviations of the condyle from the center of the glenoid fossa in the sagittal and/or vertical plane); patients in whom this suspicion could be subsequently documented by CBCT imaging; patients with sufficiently complete dentition and stable occlusion, to ensure reliable positioning in maximum intercuspidation during scanning and interpretable functional recording.

The exclusion criteria aimed at eliminating systemic or local factors that could independently influence the position of the condyle or the quality of the imaging information. Patients with systemic conditions with known effects on joint structures (inflammatory or generalized degenerative rheumatological diseases, metabolic arthropathies, severe osteoporosis with specific treatment in the medical history, etc.) were excluded, as were patients with other forms of nonspecific or neuropathic orofacial pain; congenital malformations or marked developmental disorders of the stomatognathic system; a history of major trauma or surgery in the TMJ region or masticatory muscles; acute inflammatory processes in the maxillofacial region at the time of examination; CBCT volumes with pronounced artifacts, insufficient resolution or loss of maximum intercuspation during acquisition – situations that would have compromised the correct assessment of joint spaces and condylar position.

In the final sample, 75 patients were included, which corresponds to 150 analyzed temporomandibular joints (each patient contributing two TMJs). The subjects' age ranged between 19 and 43 years, with a mean of 28.36 ± 5.42 years, a median of 29 years and an interquartile range of 8 years, indicating a concentration of cases around the third decade of life. The group included both women and men, without gender restrictions; gender distribution was used in descriptive and exploratory analyses but did not constitute a stratification criterion for inclusion. At the level of imaging analyses, the unit of observation was the joint (TMJ), which allowed both the evaluation of each TMJ separately and right–left paired analyses in the same patient. The minimum required sample size (number of patients/TMJs) was estimated before the start of the study, the number of patients required for the research was determined using the following formula:

$$n = \frac{1}{(1-f)} \times \frac{2\left(Z_\alpha + Z_\beta\right)^2 \times P(1-P)}{D^2} \qquad (1)$$

where:

P(1-P) – the variance estimated based on literature data, for an anticipated proportion of approximately 3% (P = 0.03) of the form of temporomandibular disorder of the disc displacement with reduction and intermittent locking (with condylar malposition), according to the reported incidence of approximately 3% in studies that applied the DC/TMD diagnostic criteria [26, 54];

Z_α – tabular value. When the statistical significance is 95.0%, then the coefficient $Z\alpha = 1.96$;

Z_β – tabular value. When the statistical power of the comparison is 80.0%, then the coefficient $Z\beta = 0.84$;

D – the minimum difference considered clinically relevant between proportions (effect size), set at 11.2% (D = 0.112);

f – the rate of participants who are assumed to be likely to leave the study – estimated at 10.0% (f = 0.1).

By entering the data into the formula, we obtained:

$$n = \frac{1}{(1-0.1)} \times \frac{2(1.96+0.84)^2 \times 0.0291}{(0.112)^2} = 40.42 \qquad (2)$$

Therefore, the research groups will include at least 41 patients with condylar malpositions, who will be investigated according to the study objectives.

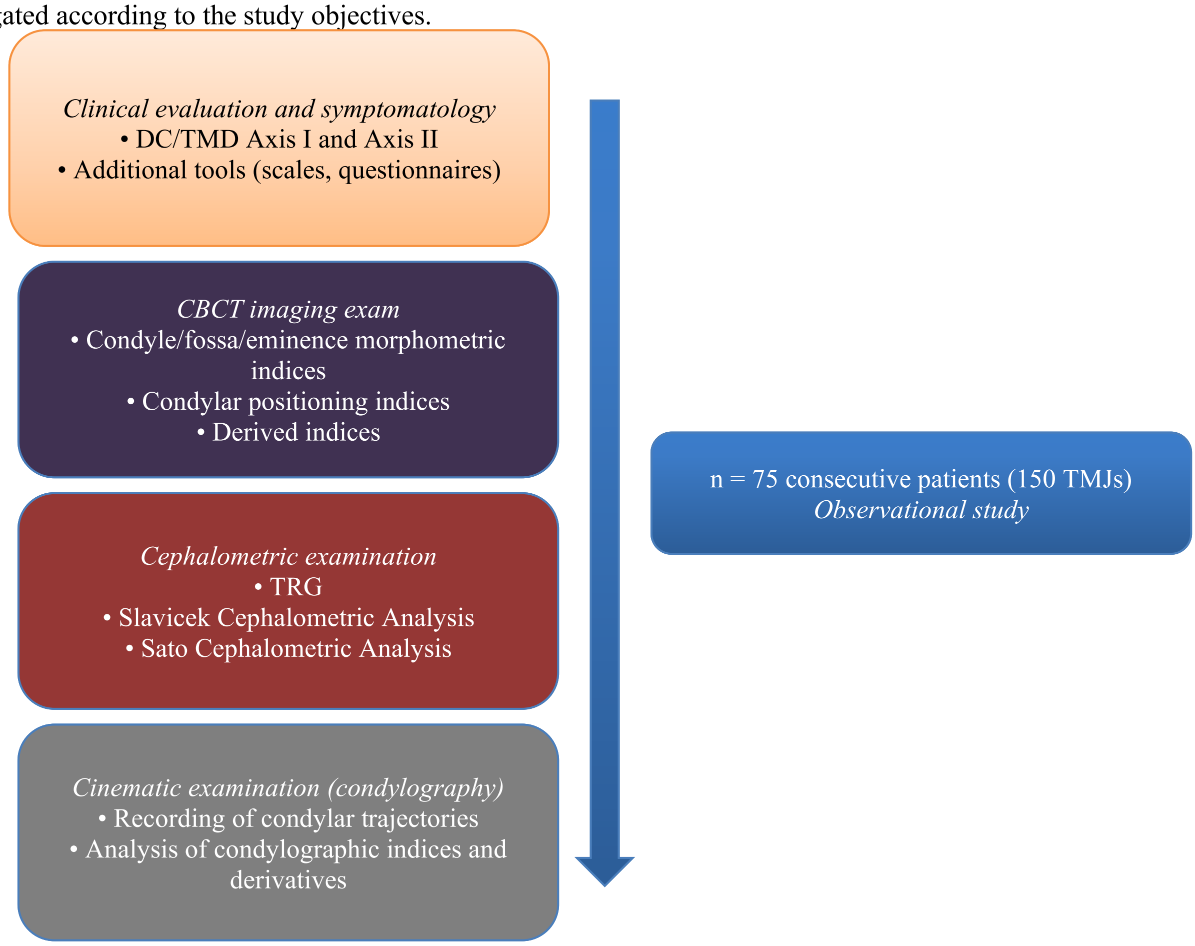

Figure 1. Clinical and imaging study design

Although the main objective of the present study was not to compare two independent groups, but to analyze condylar position and its relationships with other indices in a single group of patients with TMD, this calculation scheme was kept as a conservative benchmark for the minimum sample size, considering that in secondary analyses comparisons between subgroups (according to different categorical factors) might be necessary. From this point of view, the inclusion of 75 patients (equivalent to 150 TMJs) exceeds the theoretical minimum threshold and ensures adequate statistical power for the non-parametric tests actually used (Wilcoxon one-sample and Wilcoxon paired tests for imaging indices, binomial test for categorical variables, Spearman correlations). Thus, the size of the group can be considered sufficient to obtain stable estimates of the distributions and to detect effects of at least moderate magnitude, in line with current good practices in observational clinical research. Based on the above, a study design scheme was developed, consisting of performing a series of clinical and imaging investigations (Figure 1).

2.2. Methodology for the clinical assessment of temporomandibular disorder symptoms

DC/TMD Protocol – Axis I. In the clinical study on 75 patients with temporomandibular disorders (TMD), symptomatology was assessed according to the DC/TMD clinical criteria (Diagnostic Criteria for TMD, 2014), using validated instruments for quantifying mandibular mobility, severity of dysfunction, pain intensity, functional limitation and psycho-emotional comorbidities. Clinical and additional instruments were applied: Mandibular Mobility Index (MMI), Helkimo Index – clinical component Di and Temporomandibular Index (TMI). From Axis II DC/TMD, the JFLS-8, Characteristic Pain Intensity (CPI) from the Graded Chronic Pain Scale – 1-month version, validated by Sharma et al., GAD-7 for anxiety and PHQ-9 for depression were used. The clinical examination followed the standard DC/TMD steps, including measuring mandibular movements with a millimeter ruler, standardized palpation of the masticatory muscles and temporomandibular joints, and recording data in the standardized DC/TMD form, FDI format [6, 18-19, 46, 50]. The instruments used are internationally validated and allow for the complementary assessment of different dimensions of TMD symptomatology [50].

The first stage consisted of a detailed history of pain and headache in the last 30 days. The localization of symptoms was recorded according to the DC/TMD topography: temporal muscle, masseter, other masticatory muscles, temporomandibular joint, non-masticatory structures, and for headache – temporal region or other cranial areas. Thus, the pain analysis was reported at a uniform interval of 30 days and included both spontaneous pain and pain triggered or exacerbated by the functions of the stomatognathic system. The functional component was assessed by analyzing mandibular opening, noting the rectilinear or deviated trajectory, the correctable or persistent nature of the deviation, the direction, amplitude, and the time of occurrence during the opening–closing movement. Pain, joint noises, and episodes of joint locking were recorded [50]. To determine the total range of motion (ROM), maximum opening, right/left laterotrusion, and protrusion were measured, indicating for each movement the presence of pain, familiar pain, or familiar headache in the temporalis muscle, masseter, temporomandibular joint, other masticatory muscles, or non-masticatory structures [50]. Mandibular opening was determined according to the DC/TMD under three conditions: maximum opening without pain, maximum opening unassisted, and maximum opening assisted by the examiner. The values were measured between the incisal edges of the upper and lower central incisors, with adjustment for vertical overbite or vertical open bite. Assisted opening was performed using standardized manual traction until ligamentous-articular resistance was felt. The difference between the active and assisted values allowed the assessment of the predominant muscular or articular substrate of the limitation [50].

Muscle and joint pain was assessed by standardized palpation. The temporomandibular joint was palpated with approximately 0.5 kgf at the lateral pole and 1 kgf periarticularly, using Palpeter devices to apply reproducible pressure. For each site examined, the presence/absence of pain and its correspondence with the familiar pain described by the patient were recorded.

Additional Axis I indices from the DC/TMD protocol. The Mandibular Mobility Index (MMI) quantifies the limitation of mandibular movements, including mouth opening, laterotrusion, and protrusion [25]. The MMI calculation was based on data collected through the DC/TMD protocol, using the maximum interincisal distance, with adjustments for over-/under-occlusion, and the amplitudes of eccentric movements measured with a millimeter ruler. The values were classified into mobility categories: for centric movements, 0 points ≥40 mm, 1 point 30–40 mm, 5 points <30 mm; for eccentric movements, 0 points >7 mm, 1 point 4–7 mm, 5 points <4 mm [25]. The total MMI score objectively reflects the biomechanical restriction of the mandible [25]. Although not included in the DC/TMD protocol, MMI remains frequently used in the literature as a clinical marker for quantifying functional impairment and post-treatment evaluation [45]. The severity of TMD was assessed using the Helkimo Index – the clinical component Di, a classic instrument introduced by Martti Helkimo in 1974. Since DC/TMD does not include a specific instrument for the global severity of the pathology, the Helkimo index is frequently used together with DC/TMD in clinical research [16]. The index includes five subscales: limitation of mandibular movements expressed by IMM, pain on mandibular movements, joint pain, changes in TMJ function – noises, blockages, deviations, dislocation – and pain on palpation of the masticatory muscles [59]. Each component is scored ordinally with 0, 1 or 5 points, according to the original methodology [45, 59]. The total score, between 0 and 25, is interpreted as follows: 0 – absence of dysfunction, 1–4 – mild dysfunction, 5–9 – moderate dysfunction, ≥10 – severe dysfunction, with severe subgroups [46]. The Helkimo index provides a global clinical assessment, integrating mobility, pain and joint function into a single severity score [6]. Recent validations confirm its usefulness, with Alonso-Royo et al. (2021) reporting a sensitivity of approximately 87% for the detection of TMD and a specificity of approximately 68% compared to DC/TMD [6]. Thus, the index remains applicable for screening and quantification of global severity [6]. The data for calculating the Di index came from the DC/TMD protocol: accurate measurement of mandibular movements, including correction for incisal overlap, and standardized palpation of the temporalis, masseter and TMJ muscles. Palpation was performed with 1 kgf for 2 seconds for the muscles and 0.5 kgf for the TMJ, with extension at 5 seconds to identify the extent of pain or referred pain [50]. Palpation force was calibrated with the Wagner FDX-10 algometer and 0.5 kgf/1 kgf Palpeter devices, both with an active area of 1 cm² [19]. This method increases the reproducibility of pain assessment, including myofascial pain. The Helkimo index was used to establish the initial severity of TMD and monitor clinical evolution.

Temporomandibular Index (TMI) is a composite index developed by Pehling et al. in 2002 at the University of Minnesota, intended to assess the symptomatic burden in TMD [42]. TMI integrates clinical findings of RDC/TMD into a single score [18] and represents a modernization of the Craniomandibular Index proposed by Fricton and Schiffman in 1986 [42]. Its structure includes three subindices: Function Index (FI), with 12 items regarding mobility, pain and deviations on opening; Muscle Index (MI), with 20 muscle palpation sites; and Joint Index (JI), which assesses TMJ pain on palpation and joint sounds bilaterally. Each item is scored 0 if absent and 1 if present, and the score of each subindex represents the proportion of positive items. The total TMI score is obtained by averaging the three subindices and ranges from 0 to 1, where 1 indicates maximum dysfunction. The TMI is compatible with the RDC/TMD and implicitly with the DC/TMD, has high validity and reliability, excellent inter-examiner consistency, and strong correlations with the RDC/TMD diagnosis and other severity scales [42]. Because it is not significantly influenced by age or sex, unlike some range-of-motion indices, the TMI is suitable for primary clinical diagnosis and monitoring of progress under treatment [42, 52].

Instruments from Axis II of DC/TMD. The subjective impact of TMD on mandibular function was assessed by the Jaw Functional Limitation Scale, the short version JFLS-8. The JFLS scale was developed and validated by Ohrbach et al. in 2008, as part of the DC/TMD psycho-functional instruments [38]. The instrument assesses three domains of orofacial function: mastication, general mandibular mobility, and verbal/emotional expression [38]. The full version JFLS-20 has excellent psychometric properties, and the JFLS-8, derived by Rasch analysis, includes 8 items that globally cover these domains and provides a unidimensional score of functional limitation [38]. Each item is rated by the patient on a Likert scale from 0 – not at all difficult to 10 – impossible to achieve. The total score can be calculated by averaging the responses or by summing, with a range of 0–80 [38]. Higher values indicate a more pronounced functional limitation. The JFLS-8 is a valid screening tool for orofacial functional disability and differentiates patients with TMD from asymptomatic subjects [38]. In our study, the JFLS-8 complemented the objective assessment by IMM and Helkimo, providing the patient's perspective on the impact of TMD on daily activities. Being sensitive to change, the tool can also be used in repeated assessments to assess functional improvement. The Characteristic Pain Intensity (CPI) is a 0–100 numerical index derived from the Graded Chronic Pain Scale (GCPS), which describes the severity of chronic orofacial pain. The GCPS was developed by Von Korff et al. in 1992 for chronic musculoskeletal pain, including TMD, and includes pain intensity and functional disability/interference [51]. Although the original version used a 6-month interval, Sharma et al. (2021) validated the 1-month version in 521 patients with TMD, demonstrating comparable psychometric properties for most parameters, with a Cronbach α of 0.87 for pain intensity and an ICC of 0.91 for the CPI [51]. The CPI is calculated as the mean of three items regarding current, maximum and average pain during the reference period, initially expressed on a 0–10 scale and multiplied by 10 for a 0–100 score. In the current study, only the CPI score was used, without the interference with daily activities section, because Sharma et al. showed that, in the 1-month version, pain intensity is more reliable than short-term disability indicators [51]. The anxiety component was assessed by the GAD-7, given the association between anxiety, chronic pain and TMD, as well as its influence on pain perception and treatment compliance [47]. The GAD-7 is a short questionnaire developed by Spitzer et al. in 2006 for screening and quantifying symptoms of generalized anxiety [49]. The scale includes 7 items corresponding to DSM criteria, with the patient reporting the frequency of symptoms in the last 2 weeks on a scale of 0–3. The total score ranges from 0 to 21, with the usual interpretive thresholds: 5 – mild anxiety, 10 – moderate anxiety, 15 or more – severe anxiety. Validations have demonstrated excellent internal consistency, Cronbach α approximately 0.89, and good agreement with the specialized clinical interview [49]. The GAD-7 is self-administered, rapid, and useful for both screening and assessing the severity of anxiety, and the decrease in score under treatment correlates with the improvement of chronic pain and quality of life [49]. The depressive component was assessed by the PHQ-9, given the documented association between chronic pain and depression [47]. The PHQ-9, derived from the Patient Health Questionnaire, includes 9 items corresponding to the DSM-IV criteria for major depressive episode and was developed by Kroenke, Spitzer and Williams, and was validated in 2001 in primary care and outpatient settings [32]. The patient rates the frequency of depressive symptoms in the last 2 weeks on a scale of 0–3, and the total score ranges from 0 to 27 [32]. The PHQ-9 can indicate both a probable diagnosis of major depression, when at least 5 out of 9 symptoms are present at the level of "more than half the days" or more often, including necessarily depressed mood or anhedonia, and the severity of the symptoms: 0–4 – absence of clinical depression, 5–9 – mild depression, 10–14 – moderate, 15–19 – moderate-severe, ≥20 – severe [32].

2.3. Imaging evaluation of the stomatognathic system in patients with temporomandibular disorders

In this study, the imaging evaluation of the temporomandibular joints (TMJ) was based on a set of basic morphometric parameters, taken and adapted from the literature, to which were added a series of derived indices intended to characterize more extensively the condylar malposition in the sagittal, vertical and coronal planes. The measurements were performed on CBCT images, using a positioning and reconstruction scheme previously described for previous studies of our group, including the orientation of the palatal plane as true horizontal line (THL) and the selection of the sagittal section passing through the greatest mediolateral width of the condyle. The CBCT images were obtained using the Visio G7 system (Planmeca, Finland), using the following exposure parameters: tube voltage of 120 kVp, current of 11 mA, exposure time of 8.4 s, field of view of 170 x 150 mm and voxel size of 150 μm. Further processing of the imaging data was performed in the Romexis software, version 6.2.1 (Planmeca, Finland), following the manufacturer's recommendations regarding calibration and measurement procedures. The study group included 75 CBCT examinations, corresponding to 150 temporomandibular joints, from patients diagnosed with temporomandibular disorders. For each patient, both the right and left side images were evaluated, analyzing the main joint structures – the mandibular condyle, the glenoid fossa and the articular eminence. CBCT volumes with unsatisfactory imaging quality, with artifacts or acquisition errors, as well as cases in which the maximum intercuspation was not maintained during the scan, were not admitted. The selection of radiological parameters of interest was based on a critical analysis of the specialized literature, and indices frequently used in imaging studies in patients with TMD were chosen. The methodology used for imaging evaluation aligns with common practices reported in CBCT studies of TMJ morphology, where high reproducibility of head position and reference planes is aimed for [2].

Basic morphometric parameters. The vertical height of the glenoid fossa (VHF) was defined as the linear distance from the most superior point of the glenoid fossa to the reference plane drawn through the lowest point of the articular tubercle and the lowest point of the external auditory meatus. This measurement describes the depth of the fossa and contributes to the understanding of the architecture of the compartment in which the condyle is positioned. For the articular eminence, two parameters were analyzed – the articular eminence height (AEH) and the articular eminence inclination (AEI). AEH was measured as the distance between the THL (palatal plane) and a line parallel to it that reaches the most prominent point of the eminence; AEI represents the angle formed between a line parallel to the THL and the tangent of the slope of the articular eminence. Similar parameters have been reported in CBCT studies of condylar-fossa morphology, in which the slope and height of the eminence were associated with condylar mobility patterns and malocclusion types. The morphology of the mandibular condyle was described based on 3 basic parameters – condylar length (CoW), condylar width (CoL), and condylar height (CoH). Condylar length was measured in the sagittal plane, between the most anterior and posterior points of the condylar head; condylar width was defined in the coronal plane as the distance between the medial and lateral poles; condylar height was assessed as the perpendicular distance from the most superior condylar point to a line drawn from the sigmoid notch, perpendicular to the tangent applied to the posterior aspect of the mandibular ramus. Analog measurements have been used in CBCT studies that described variations in condylar volume, height, and length in asymptomatic or TMD populations, confirming the validity of these landmarks as a basic structural description of the condyle [2]. The superior joint space (SJS), anterior joint space (AJS), and posterior joint space (PJS) were measured using the metric methodology originally proposed by Kamelchuk et al. and later adapted for CBCT by Ikeda and Kawamura and Al-Koshab et al. [2]. Thus, tangents are drawn to the anterior and posterior slopes of the glenoid fossa, converging at its deepest point; AJS and PJS represent the minimum perpendicular distances from the most prominent anterior and posterior points of the condyle to these tangents, and SJS is the distance between the superior condylar point and the most cranial point of the fossa. This type of measurement allows a standardized quantification of the condyle–fossa relationship in the sagittal plane and is used extensively in studies comparing asymptomatic joints with joints with displaced discs or degenerative degeneration [17]. Ikeda and Kawamura demonstrated, in a group of young, asymptomatic subjects with normal disc position, an average ratio of the anterosuperior–posterior sagittal spaces of approximately 1:1.9:1.6, with mean values around 1.3 mm (AJS), 2.5 mm (SJS), and 2.1 mm (PJS), thus proposing a model of optimal condyle position in the glenoid fossa [17, 27-28].

In the coronal plane, the medial joint space (MJS) and lateral joint space (LJS) were measured by drawing tangents to the medial and lateral slopes of the glenoid fossa and calculating the perpendicular distances from the corresponding most prominent condylar points [37]. Similar parameters are used in CBCT studies to characterize the mediolateral position of the condyle and any displacement towards the medial or lateral wall, both in patients with TMD and in asymptomatic controls. All morphometric and joint space parameters were determined separately for the right and left TMJ, allowing both the assessment of the absolute position of the condyle in each joint and the analysis of right–left asymmetry.

Composite/derived imaging indices

To describe the position of the condyle in the glenoid fossa in the sagittal plane, we calculated for each joint a condylar position index (sagittal condylar position) according to the formula proposed by Pullinger and Hollender and adopted in numerous CBCT-based studies [17]:

$$SCP = \frac{P-A}{P+A} \times 100 \tag{3}$$

The resulting values between −12% and +12% are considered to correspond to an approximately concentric position of the condyle; values less than −12% indicate a predominantly posterior positioning (narrow posterior space, wide anterior space), and values greater than +12% indicate an anterior position of the condyle. These thresholds were initially proposed based on the analysis of the distribution of condylar positions in subjects without obvious dysfunction and were subsequently taken as a standard in multiple studies on the relationship between condylar position and DTM [31]. In addition to the SCP, we calculated the anterior/posterior ratio (AP = AJS/PJS) and its logarithmic transformation – ln(PJS/AJS), used in some recent works as continuous variables for comparative analyses or regression models, because the logarithmic transformation reduces the asymmetry of the distribution and attenuates the influence of extreme values [22, 60]. In interpretation, AP values ≈1 would indicate an approximately concentric condyle; AP values > 1 or ln(P/A) < 0 indicate a more posterior position of the condyle, while AP < 1 or ln(P/A) > 0 correspond to a more anterior position. To evaluate the position of the condyle in the superior–inferior direction within the fossa, we introduced a vertical index (VI) defined as the ratio between the superior space and the sum of the sagittal spaces, according to the formula:

$$VI = \frac{S}{A+S+P} \tag{4}$$

This dimensionless index expresses the proportion of the superior space within the total "sagittal envelope" of the joint. The reasoning derives from the observation of Ikeda and Kawamura that the ratio A:S:P ≈ 1:1.9:1.6 characterizes joints with optimal function, which is reflected by an SJS that represents approximately 40–45% of the sum of the three spaces. Also, in the specialized literature, it is mentioned that an SJS with values of 2–4 mm would be considered "normal", with variability depending on the examined population and the measurement technique [35]. Thus, we used VI as a continuous indicator, where lower values indicate a condyle located more superiorly (relatively small superior space compared to AJS and PJS), while increased values indicate a condyle located lower in the fossa (with a relatively large SJS). Being a newly derived composite index, there are no thresholds for VI; therefore, interpretation is done comparatively between groups and in correlation with other clinical and imaging manifestations of TMD.

To describe the mediolateral position of the condyle, we derived two simple indices based on the coronal joint spaces MJS and LJS.

1) *Coronal centricity index* (CCI), coronal analogue of the sagittal concentricity index according to Pullinger-Hollander, with the following formula:

$$CCI = \frac{M-L}{M+L} \times 100 \quad (5)$$

Values close to 0% reflect a condyle approximately centered between the medial and lateral walls of the fossa. Positive values indicate that MJS > LJS, so the condyle is closer to the lateral wall; negative values indicate a condyle located more medially. In the literature, mean values of MJS and LJS and differences between them are frequently reported, but less often a symmetrical ratio-type index, so the CCI was designed as a normalization tool for the fossa size in this study. The reasoning is analogous to the Pullinger–Hollender formula, allowing comparability between joints with different fossa sizes. However, it is worth noting that, according to some normative data, the condyle tends to be slightly closer to the lateral wall, i.e. the MJS would be slightly larger than the LJS (which could reflect a slightly positive CCI trend) [29].

2) *Medial/lateral ratio* (ML = MJS/LJS), which summarizes in a single value the relationship between the medial and lateral joint spaces. In studies on asymptomatic TMJs, a slightly larger MJS than LJS is frequently described, which corresponds to ML values > 1 (condyle slightly closer to the lateral wall). Some normative data from the specialized literature (such as Ikeda/Al-Rawi) indicate a "reference" interval for the medial/lateral spaces in healthy individuals (medial ≈ 2.4 mm vs. lateral ≈ 1.8 mm), thus the medial/lateral ratio (ML) would have values of ≈ 1.3, but nevertheless the authors proposing norms mention that the exact values depend a lot on the measurement technique used and the population investigated [3, 27, 29]. In the present research, ML is used as a continuous variable; there are no well-established normative thresholds, therefore the interpretation is made relatively (comparison of means between groups, correlations with clinical signs and other indices).

The right/left differences for homologous parameters were also calculated by simple arithmetic difference ($\Delta_Q = Q_D - Q_S$). Given that condylar malposition often has an asymmetric character, we defined percentage asymmetry indices for multiple imaging parameters (AJS, PJS, SJS, LJS, MJS, etc.), according to the general formula:

$$Asym_Q = \frac{Q_D - Q_S}{(Q_D + Q_S)/2} \times 100 \quad (6)$$

This type of calculation (the difference reported to the mean of the two values) is frequently used in craniofacial morphometry to assess the degree of asymmetry in relative terms, independent of the absolute size of the structure. In the present context, a high value of $Asym_Q$ indicates a significant difference between the position of the right and left condyle for that parameter, which can be correlated with other clinical or imaging indicators.

We developed a composite index derived from the norms originally proposed by Ikeda (the A:S:P ratio) for asymptomatic joints, with a disc in normal position, which would allow an assessment not only of the absolute spaces, but also of the relative distribution of the condyle in the glenoid fossa. Based on the Ikeda ratio, the "optimal" values are approximately AJS ≈ 1.3 mm, SJS ≈ 2.5 mm, PJS ≈ 2.1 mm, with an A:S:P ratio ≈ 1:1.9:1.6 [27, 29].

Thus we can define indices of deviation from the norms according to Ikeda:

- A/S ratio (R_{AS} = A/S), with normative $R_{AS}^{norm} = 1/1.9 = 0.53$;
- P/S ratio (R_{PS} = P/S), with normative $R_{PS}^{norm} = 1.6/1.9 = 0.84$;
- A/P ratio (R_{AP} = A/P), with normative $R_{AP}^{norm} = 1/1.6 = 0.63$.

To quantify in a single parameter the individual deviation from this model, we defined a general deviation index according to Ikeda (D_{Ikeda}), with the following formula:

$$D_{Ikeda} = \sqrt{(R_{AS} - R_{AS}^{norm})^2 + (R_{PS} - R_{PS}^{norm})^2} \quad (7)$$

This index represents the Euclidean distance, in the (R_{AS}, R_{PS}) plane, between the position of a condyle and the "optimal point" described by Ikeda. Low D_{Ikeda} values indicate a distribution of sagittal spaces close to the pattern considered optimal, while high values indicate an abnormal distribution of anterior, superior and posterior spaces. Although A:S:P ratios are well documented in the literature, a composite D_{Ikeda}-type index is not, to our knowledge, standardized in other studies and is introduced here as an original methodological proposal, to allow quantitative analyses and easy comparison between joints. The index is calculated separately for the right and left TMJ. Lower values would reflect a condyle close to the optimal A-S-P values; and higher values a more marked malposition in the sagittal plane. Conventionally, we separated three categories of values for the interpretation of this index: close to the norm according to Ikeda ($D_{Ikeda} \leq 0.3$), moderate deviation (D_{Ikeda} with values between 0.3–0.6) and marked deviation ($D_{Ikeda} > 0.6$). These thresholds are not derived from a published standard, but were chosen to delimit, in a practical way, joints with sagittal space distribution very close, moderately deviated or obviously different from the Ikeda model, thus allowing clearer comparative analyses within the study.

2.4. Cephalometric analysis of lateral cephalograms (CADIAS)

Profile lateral cephalogram (TRG) was performed in all patients included in the study, after the condylographic examination. Before image acquisition, three radiopaque metallic markers were placed on the skin, corresponding to the axis orbitalis plane used in condylography: one ball at the level of the terminal axis of right/left rotation and an additional ball at the Orbital point. The patient was positioned with the dental arches in maximum stable intercuspation, with the lips in light contact and the head oriented so that the axis orbitalis plane defined by the markers could be recognized and subsequently used as a reference plane. Only digital images with clear visibility of the markers, without motion artifacts, with correct superposition of bilateral structures (mandibular rami, orbits, skull base) and with clear delineation of the bone contours necessary for cephalometric tracing were accepted; images that did not meet these quality criteria were repeated or excluded from the analysis. Cephalometric analysis was performed by digital tracing in CADIAS software (Gamma Dental), which allows image orientation according to the axis orbitalis plane defined by radiopaque markers and subsequent integration with condylographic data. For each patient, the Sato cephalometric methodology was applied, using the standard modules implemented in CADIAS. Thus, the parameters included in Sato Analysis were calculated, organized into four main groups: Denture Frame analysis (angles and distances between the Frankfort plane, palatal plane, occlusal plane, mandibular plane and A–B, A'–P' ratios, etc.), upper occlusal plane analysis (maxillary and FH plane ratios to the anterior and posterior occlusal planes), Kim analysis (ODI, APDI and combination factor) and Downs–Graber analysis (facial angles, profile convexity, position of points A and B to the facial plane, facial height, Y-axis, interincisal angles, position and inclination of the incisors, gonial angle, ramus inclination, etc.). For each parameter, the software recorded the numerical value and displayed the corresponding norm, as well as the deviation trend (Trend column). In parallel, for the same TRG images, cephalometric analysis according to Slavicek was also applied, also in CADIAS software (Gamma Dental, Austria). This included several categories of parameters: skeletal measurements (e.g. facial axis, facial depth, mandibular plane, mandibular arch, jaw position, convexity and lower facial height), dental measurements (interincisive angle, position and inclination of upper and lower incisors, position of upper molar, etc.), occlusal plane parameters (occlusal plane ratios to the axis orbitalis plane and to the Slavicek orbital axis, DPO distance, radius of Spee's curve) and functional measurements (in particular right/left sagittal condylar inclination angles and relative condylar inclination angles, as well as anterior guidance parameters). The aesthetic relationship of the upper lip to the position of the incisors (aesthetic plane) was also assessed, according to the aesthetic module included in the Slavicek analysis. For each parameter, the software provided the measured value, the reference norm, and the direction of deviation, thus allowing an integrated assessment of skeletal, dental, occlusal, and functional relationships in relation to condyle position and condylographic data.

2.5. Kinematic analysis and derived indices

Condylar kinematic data were obtained with a Cadiax® 4 axiographic system (Gamma Dental, Klosterneuburg, Austria), which records the three-dimensional translation of each condyle in a coordinate system based on the axis orbitalis plane (terminal hinge axis – Orbital point) during standardized mandibular movements. For each movement and each temporomandibular joint (TMJ), the system exported the translation components along three orthogonal axes (X, Y, Z; in millimeters), the sagittal and transverse condylar inclinations (SCI – sagittal condylar inclination; TCI – transverse condylar inclination; in degrees) and the total length of the condylar trajectory (S; in millimeters). The X axis corresponds to the anteroposterior direction (positive anterior), the Y axis to the mediolateral direction (positive to the patient's right), and the Z axis to the vertical direction (positive inferior), as defined in the reference plane used in the CADIAX system based on the hinge axis and the Orbital point. The data obtained were evaluated within the descriptive statistical evaluation, as well as the inter-relationships between the parameters, depending on the laterality of the TMJ (right/left), and were used to calculate new derived indices.

The parameters collected were [23, 33]: Anteroposterior translation (X, mm); Lateral/medial displacement (Y, mm), with positive values to the right and negative to the left; Vertical displacement (Z, mm), with positive values inferiorly); SCI (sagittal condylar inclination) defined as the angle formed between the protrusive condylar path and a horizontal reference plane (the axis-orbitalis plane), thus representing the angle of the path in sagittal projection [15]; TCI (transverse condylar inclination), also called the Bennett angle, defined as the angle between the sagittal plane and the condylar path in the horizontal plane for the non-working-side condyle during lateral movements [4]; S (Path Length) – the total distance that the condyle traverses during the recorded movement.

Derived kinematic indices

Planar amplitude indices. To obtain a compact description of the magnitude of condylar translation, we calculated for each part/movement a new parameter – the three-dimensional amplitude (Amp) as the Euclidean norm of the translational components, according to the formula:

$$Amp = \sqrt{X^2 + Y^2 + Z^2} \quad (8)$$

The parameter follows the standard three-dimensional (3D) kinematics of rigid bodies, where the magnitude of the displacement is given by the square root of the sum of the square components along the orthogonal axes. In the literature on the biomechanics/kinematics of the locomotor system, displacement is defined as the straight-line distance between the start and end points, the magnitude being given by the Euclidean norm of the components [24]. Also, in studies of 3D kinematic evaluation of movement, the mandibular body (as any bony element) is considered a rigid body, and in the case of the mandible it is characterized by 3 rotational components and 3 translational components. The translations of the condylar markers/endpoint are calculated in mm for the X, Y, Z axes as the basic data for the kinematic analysis. These translations are exactly the components whose resulting magnitude is calculated as the Euclidean norm [14]. For each condyle, the CADIAX system exports the translational displacement components along three orthogonal axes in a hinge-orbital coordinate system: X (anteroposterior direction); Y (mediolateral direction); Z (vertical direction). Thus, the net displacement vector of a condyle from the beginning to the end of a movement is: $\vec{d} = (X, Y, Z)$. The formula for magnitude is a three-dimensional extension of the Pythagorean theorem applicable to a 3D vector.

Also, the following parameters were calculated, namely the planar amplitudes in the sagittal (AmpSag) and horizontal (AmpHor) projections, according to the following formulas:

$$AmpSag = \sqrt{X^2 + Z^2} \quad (9)$$

$$AmpHor = \sqrt{X^2 + Y^2} \quad (10)$$

These parameters represent, respectively, the condylar excursion in the sagittal (anterior-inferior) and horizontal (anterior-mediolateral) planes and are analogous to the projected lengths of the condylar trajectory commonly evaluated in axiographic and kinematic recording studies of mandibular movements.

Thus, the calculated parameters are defined: Amp – the total three-dimensional excursion of each condyle (right/left) within the functional movement performed (opening-closing; protrusion-retrusion; right mediotrusion; left mediotrusion), representing the description of the straight-line displacement vector (beginning-end, in mm); AmpSag – the excursion in the sagittal plane (anterior-inferior, X-Z) of each condyle (right/left); AmpHor – the excursion in the horizontal plane (anterior-mediolateral, X-Y) of each condyle (right/left).

The clinical reasoning of these indices of condylar range of motion is related to the potential interpretation of the amplitude values, such that low values would indicate restricted translational capacity of the condyle. For opening movement, this could reflect capsular limitation, the presence of adhesions, early disc displacement without complete reduction, or the protective splinting mechanism against pain. In protrusion or mediotrusion, low values would indicate a flattened, reduced excursion towards the articular eminence, or functional avoidance of this direction. High values would indicate a wide translational range, potentially characteristic of hypermobility, increased ligament laxity, or peculiarities of eminence morphology (permissive).

The statistical evaluation of these parameters was based on the following reasoning:

- Comparison within the subject between different movements could highlight cases where the condyle is consistently limited in all movements (global restriction) or only in a specific trajectory (e.g.: restricted mediotrusion, but opening is normal).
- Comparison according to laterality, where marked differences between sides (right/left) could highlight unilateral restriction or functional shift;
- Monitoring these parameters over time could allow the evaluation of the effectiveness of the primary treatment of TMD (reversible occlusal therapy with occlusal splints/kinesitherapy), by highlighting the freedom/restriction in translation pre-/post-treatment.

Angular indices of condylar movement trajectory

To characterize the general direction of net condylar displacement, we defined separate sagittal and transverse trajectory angles from the beginning to the end of each recorded movement. In the sagittal plane (X-Z), the separate condylar trajectory angle (SagAng) was calculated as the angle between the projection of d ⃗ on this plane and the positive X-axis. Thus, the value of this angle in degrees, we determined using the two-argument arctangent, according to the formula:

$$SagAng = \frac{180}{\pi} atan2(Z, X), \text{ unde:}$$

atan2(Z,X) returns the signed angle (in radians) between the vector (X,Z) and the positive X axis, taking into account the correct quadrant.

In the horizontal plane (X-Y), the separate angle of the condylar trajectory (TransAng) was defined as the angle between the projection of $\vec{d}$ on this plane and the positive X axis. Thus, the value of this angle in degrees, we determined using the arctangent with two arguments, according to the formula:

$$TransAng = \frac{180}{\pi} atan2(Y, X), \text{ where:}$$

atan2(Y,X) returns the signed angle (in radians) between the vector (X,Y) and the positive X axis, in the horizontal plane (X-Y), taking into account the correct quadrant.

The angles were initially obtained in radians using the two-argument arctangent function (atan2) and then converted to degrees by multiplying by 180/π.

These 2 parameters (SagAng, TransAng) are therefore simple geometric descriptors of the general direction of condylar displacement in the sagittal and horizontal planes, respectively. They are expressed in degrees, like SCI and TCI, but are calculated directly from the net start-end translation, rather than from an adjusted trajectory segment. These geometric definitions reflect the conceptual definition of sagittal condylar inclination and Bennett angle (transverse) used in both the geometric theory underlying articulator construction and the reasoning of axiographic/CBCT studies, where SCI is the angle between the protrusive trajectory and a horizontal reference in the sagittal plane, and Bennett angle is the angle between the sagittal plane and the mediotrusive trajectory of the non-functional condyle in the horizontal plane. Unlike software-calculated SCI and TCI, which are typically derived from an optimal fit of the entire trajectory or a defined segment, SagAng and TransAng capture the net start-end direction of motion and have been used as auxiliary geometric descriptors, rather than substitutes for SCI/TCI. Thus, the calculated parameters are defined as: SagAng – angle of net condylar displacement in the sagittal plane (in degrees) per TMJ (left/right); TransAng – the angle of net condylar displacement in the horizontal plane (in degrees) per TMJ (left/right). These parameters are additional to the SCI/TCI angles, being consistent with their value, so in case of steep values of SagAng/SCI, this would be reflected in a more marked displacement of the condyle during forward translation. Clinical situations in which such values could be encountered would be cases with high cusps and rapid disocclusion of posterior teeth during mandibular excursions. They could also be characteristic in deep occlusions, certain patterns observable in skeletal Class II or in case of articular eminences that are not flattened. Low values of SagAng/SCI reflect a more superficial condylar guidance. Characteristic clinical situations could be a reduced vertical separation of the posterior teeth during mandibular excursions, which would be reflected in the need for an occlusal design with flatter cusps to avoid interference. It could also reflect clinical situations of remodeling/flattening of the mandibular condyle, as well as the consequences of long-term sustained parafunctional activity. It could also be characteristic of certain skeletal patterns. High positive values of the TransAng parameter for the balancing condyle, during lateral movements, would reflect a pronounced deviation of the trajectory towards the medial, a progressively increased Bennett angle, or a masticatory pattern with a pronounced lateral component. Low values of TransAng would reflect a more linear trajectory, with a reduced medial component, which would correspond to situations with restriction of lateral movements. A negative value of this index on the working side would indicate an outward displacement of the condyle (a side shift), which could be associated with the presence of interferences on the working side.

Curvature index of the condylar trajectory. To quantify the degree of linearity/curvature of the condylar trajectory, we compared the total length of the S-trajectory exported by CADIAX (i.e. the length of the recorded 3D curve) with the linear amplitude Amp. For each part we defined a curvature index (Curvature) as:

$$Curvature = \frac{|S|}{Amp} \tag{11}$$

where |S| represents the absolute length of the trajectory.

The proposed index is a reflection of the concept of Path Length Ratio (PLR), proposed by Pierrynowski (2009) [43], used in gait analysis, balance analysis and upper limb kinematics, where the efficiency of a movement is quantified by comparing the actual length of a marker's trajectory with the straight-line distance between its start and end positions. In these models, perfectly straight movement gives a ratio of 1, while more wavy or irregular trajectories produce higher values. Thus, clinically, values close to 1 of the Curvature parameter reflect a smooth and rectilinear movement of the condyle, characteristic of well-coordinated movements. While values significantly higher than 1 would reflect a complex or chaotic condyle trajectory, which could denote certain clinical situations of mechanical irregularity (disc displacements with reduction, abrupt eminences) or a possible neuromuscular adaptation (such as protective splinting). Also, the parameter could be used for potential monitoring of treatment efficacy, with the change in the degree of curvature of the condylar trajectory pre-/post-treatment.

Asymmetry indices. Given the clinical interest in left-right differences observed in studies in the literature, we systematically expressed lateral asymmetries for key variables (Amp, SCI, TCI and |S|) using both raw differences and normalized asymmetry indices. For a generic bilateral variable V (e.g., Amp value on right and left), the raw difference was defined as:

$$\delta_V = V_{dreapta} - V_{stânga} \tag{12}$$

To consider the scale of the measurements and allow comparison between variables, we calculated a Habets-type asymmetry index (AI) (expressed in percentages):

$$IA_V = \frac{V_{dreapta} - V_{stânga}}{\left(\frac{V_{dreapta} + V_{stânga}}{2}\right)} \times 100\% \tag{13}$$

This form, or close to the original formula $|R–L|/(R+L)×100$, which is widely used to quantify mandibular and condylar asymmetry on panoramic radiographs and CBCT, including condylar and ramus height differences [41, 53]. Habets et al. originally proposed a percentage calculation formula – $|R-L|/(R+L)\times100\%$ as an index of vertical condylar and ramus asymmetry, and subsequent studies have applied the same formula, often using a threshold of ~6% to distinguish symmetric from asymmetric cases [41, 53]. In the present work, we retained the signed version of IA (positive values indicating higher values on the right side, and negative values indicating higher values on the left side) and also analyzed the absolute value $|IA_V|$, when the magnitude of the asymmetry, rather than its direction, was of interest.

For the path length S, asymmetry indices were calculated from the absolute values $|S_{Right}|$ and $|S_{Left}|$ to reflect differences in distance traveled, independent of the direction of the sign (negative/positive).

The assessment of the degree of symmetry of the amplitude of movement could allow the clinical highlighting of situations with bilateral symmetry of the condylar range of motion (in case of reduced values), or in case of significant differences reflecting structural limitations (related to the capsule, disc, eminence shape) or functional avoidance/neuromuscular inhibition of the range of motion. If the asymmetry occurs in a single movement, it could reflect specific directional restriction or the effect of an occlusal interference. SCI asymmetry could reflect the fact that the sagittal guidance is steeper/flatter on one of the sides (right/left), which could be caused either by anatomical differences (asymmetrical eminences, consequences of trauma, remodeling); with the potential effect of asymmetric disocclusion, occlusal interferences on one side, functional mandibular displacements. However, such asymmetry justifies the application of individualized settings per TMJ within the programming of fully adjustable articulators. TCI asymmetry reflects unequal Bennett angles, so that one of the condyles moves more medially in lateral excursions than the other. This may influence the pattern of functional occlusal schemes (canine guidance, group function, or mediotrusive contacts). It may also reflect the patient's tendency to prefer unilateral mastication or instability of the occlusal scheme. In the case of unilateral TMD, slight SCI/TCI asymmetries may be observed, however, it is not clear whether this phenomenon is a cause of TMD or a consequence of it. On a practical level, high values of SCI/TCI asymmetries indicate that in the planning of the patient's functional rehabilitation, it is necessary to avoid setting the articulator according to average/symmetrical parameters. However, it is not clear whether marked SCI/TCI asymmetries would be characteristic of certain subtypes of TMD, as well as the degree of association of these asymmetries with morphological changes within the TMJ structures or with effects at the occlusal level.

Comparing the degree of asymmetry of amplitude (Amp) with that of the actual path length (S) could reflect several clinical situations. In case of discordance (high values of asymmetry S and low values of asymmetry Amp) this would reflect situations where the final position of the condyles is similar, but one of the condyles moves on a longer circuit to the final position. This would reflect possible changes in neuromuscular recruitment or mechanical disorders (such as crackle or the presence of a disc recapture point, causing bypass), but which do not essentially change the net condylar displacement. Also, if both Amp and S are reduced on one side, this would reflect a potential limitation of the unilateral range of motion. However, these additional kinematic parameters are descriptive of the recorded kinematic paths. When evaluating them for each clinical case, it is necessary to consider the present symptomatology, the diagnostic confirmation of DTM (based on DC/TMD), the present occlusal scheme, the results of the imaging evaluation (CBCT/MRI). All derived variables (Amp, AmpSag, AmpHor, SagAng, TransAng, Curvature, Diff and IA asymmetry indices for Amp, SCI, TCI and |S|) were calculated in Excel software from the Microsoft Office suite (Microsoft, USA), using formulas inserted into cells.

These new derived indices do not introduce new assumptions beyond standard 3D rigid body kinematics and established asymmetry metrics, but rather provide a more compact and easier to interpret description of condylar motion, which can be directly linked to the existing literature on condylar guidance angles, trajectory shapes and mandibular asymmetry. The proposed composite and derived indices were registered at the “Nicolae Testemițanu” State University of Medicine and Pharmacy, obtaining innovator certificates.

2.6. Mathematical and statistical data processing methods

Statistical-mathematical analysis was performed in R/RStudio 2025.05.1 Build 513 (Posit Software, USA). For continuous variables, mean, standard deviation, median, IQR, minimum and maximum were calculated. Normality was checked by Shapiro–Wilk and, when necessary, by histograms/boxplots; the frequently asymmetric distributions of joint spaces, derived and cephalometric indices justified non-parametric tests. Pairwise right–left differences were evaluated by Wilcoxon signed-rank, and comparison of a continuous index with a theoretical/normative value by one-sample Wilcoxon. Categorical variables were reported as n, proportions and percentages; for dichotomous variables the binomial test with confidence intervals and p-values was applied. In the condylographic analysis, differences by sex were tested by Mann–Whitney U, and intra-patient comparisons between conditions/movements by Friedman, followed by post-hoc Durbin–Conover. Associations between indices and other quantitative variables were assessed by Spearman rho, reporting the coefficient and p. The significance threshold was $p < 0.05$.

3. CLINICAL AND RADIOLOGICAL CHARACTERISTICS OF PATIENTS WITH TEMPOROMANDIBULAR DISORDERS AND CONDYLAR MALPOSITIONS

3.1. Results of the clinical examination based on the DC/TMD protocol and additional instruments

The study group included 75 adult subjects (age range 19-43 years, mean age 28.4±5.4 years; median – 29 years; of which 76.0% were women – n = 57 with mean age 28.2±5.5 years; men – n = 18 – 24%, with mean age 28.9±5.4 years, without significant differences by age according to gender – p = 0.638), clinically examined according to the standardized DC/TMD protocol (Axis I and Axis II). For the general characterization of the group, descriptive indicators were calculated (mean, median, IQR, minimum and maximum values, standard deviation and standard error) and one-sample inferential tests were applied (Wilcoxon test for continuous variables and binomial test for categorical variables), in order to assess whether the observed distribution differs significantly from the reference values corresponding to a "no DTM" situation or a uniform distribution.

Results of applying Axis I instruments of the DC/TMD protocol

The duration of symptoms and the evolutionary phase of TMD were analyzed based on the data reported by the participants. The duration of symptoms had a mean of 17.520 months, a median of 12 months, an IQR of 16.000 months, a range of 4–108 months, a SD of 16.263 and an ES of 1.878 months. The Wilcoxon one-sample test indicated a significant deviation from the reference value (W = 2850; p < 0.001), with a mean difference of 14.500 months and a maximum effect (r = 1.00), which shows the prolonged nature of the symptoms in almost the entire group. By binomial test, acute forms (<6 months) were identified in 14 patients (18.7%; p < 0.001; 95% CI: 0.106–0.293), and chronic forms (≥6 months) in 61 patients (81.3%; p < 0.001; 95% CI: 0.707–0.894). The group was thus dominated by chronic TMD, with acute cases representing a minority. Occlusal parameters showed significant deviations from the reference. Overjet had a mean of 2.633 mm, median 2.50 mm, IQR 1.00 mm, range 0.5–9.0 mm, SD 1.295 and ES 0.15 (W = 2850; p < 0.001; DM = 2.50; r = 1.00). Overbite had a mean of 4.74 mm, median of 5.00 mm, IQR of 3.00 mm, range of 1.0–11.0 mm, SD of 2.37 and ES of 0.27 (W ≈ 2850; p < 0.001; DM = 4.50; r = 1.00), indicating marked vertical coverage. Midline deviation had a mean of 0.98 mm, median of 1.00 mm, IQR of 1.00 mm, range of 0–3.0 mm, SD of 0.78 and ES of 0.09 (W = 1830; p < 0.001; DM = 1.25; r = 1.00). Overall, the group was characterized by moderate overjet, relatively marked overbite and discrete but systematic midline deviation. The direction of deviation at mandibular opening showed no deviation in 15 patients (20.0%; p < 0.001; 95% CI: 0.116–0.308), deviation to the right in 21 (28.0%; p < 0.001; 95% CI: 0.182–0.396) and deviation to the left in 39 (52.0%; p = 0.818; 95% CI: 0.402–0.637). Thus, most patients presented functional asymmetry of the opening, with a predominance to the left. The opening pattern was rectilinear in 12 patients (16.0%; p < 0.001; 95% CI: 0.085–0.263), and the corrected deviation during movement was the dominant form, being present in 55 patients (73.3%; p < 0.001; 95% CI: 0.619–0.829). Uncorrected deviations were rare: right in 3 patients (4.0%; p < 0.001; 95% CI: 0.008–0.113) and left in 5 patients (6.7%; p < 0.001; 95% CI: 0.022–0.149). This profile indicates impaired, but frequently functionally compensated, movements rather than fixed deviations or mandibular locks.

Table 1. Amplitude of centric and eccentric functional movements collected based on the examination sheet from the DC/TMD protocol

	Mean	Median	IQR	Minimum	Maximum	SD	SE	W	*p*	MD	Effect size
Non-painful opening (mm)	34,253	34	14	17	55	10,028	1,158	2850	<.001	34	1
Maximum assisted opening (mm)	46,24	45	8,5	32	60	6,728	0,777	2850	<.001	46	1
Maximum unassisted opening (mm)	50,187	50	10	37	62	6,533	0,754	2850	<.001	50,25	1
Right laterotrusion (mm)	10,833	11	3	5	21	3,158	0,365	2850	<.001	11	1
Left laterotrusion (mm)	10,12	10	2,75	4	15	2,325	0,268	2850	<.001	10	1
Protrusion (mm)	7,607	7,5	3	2	15	2,29	0,265	2850	<.001	7,5	1

Note: IQR – interquartile range; SD – standard deviation; SE – standard error; W – Wilcoxon statistical test (one sample test); MD – mean difference.

Opening amplitudes followed a clear hierarchy: non-painful opening was smaller than maximum passive opening and maximum active opening, suggesting the existence of a functional reserve above the symptom-free threshold. Interindividual variability was significant, but without obvious separation into distinct subgroups. Right/left laterotrusions had similar amplitudes, indicating functional symmetry, while protrusion had lower mean values, with moderate variability. In habitual opening, temporal and masseter pain was relatively balanced bilaterally: right/left temporal 54.7% and 44.0% painful cases ($p = 0.489$; $p = 0.356$), right/left masseter 38.7% and 44.0% ($p = 0.064$; $p = 0.356$). For "other masticatory muscles" the absence of pain prevailed, with pain only in 20.0% right and 17.3% left ($p < 0.001$). TMJ pain was present in approximately one third of patients, 34.7% right and 36.0% left, and non-masticatory structures were predominantly non-painful bilaterally ($p < 0.001$). At maximum passive opening, temporal pain was rare: 9.3% right and 6.7% left ($p < 0.001$). The masseters showed higher frequencies, but without a clear statistical predominance: 40.0% right and 46.7% left ($p = 0.105$; $p = 0.644$). "Other masticatory muscles" were painful in 34.7% on the right, with the predominance of pain absence ($p = 0.011$), and almost equally distributed on the left (49.3% pain; $p = 1.000$). The right and left TMJ were painful in 17.3% of patients each, and the non-masticatory structures rarely remained symptomatic: 8.0% right and 14.7% left ($p < 0.001$). At maximum active opening, the movement was interrupted by pain in 22 patients (29.3%), while 53 (70.7%) completed the movement ($p < 0.001$). Pain was rare in the temporals and TMJ: right/left temporal 13.3% and 12.0%, right/left TMJ 13.3% and 14.7% ($p < 0.001$). The right masseter had an almost balanced distribution (48.0% pain; $p = 0.818$), and the left masseter was painful in 36.0% ($p = 0.020$). "Other masticatory muscles" were symptomatic in approximately one third of patients, 34.7% right and 33.3% left, and non-masticatory structures were rarely involved, 5.3% right and 4.0% left. Pain on active opening was associated mostly with the masseters, then with other masticatory muscles and TMJ.

Laterotrusion to the right was generally well tolerated. On the right side, the temporalis and TMJ were almost consistently asymptomatic (approximately 97% and 95% pain-free; $p < 0.001$), and the masseter and "other masticatory muscles" were the focus of pain, with approximately 15% of cases being symptomatic. The right non-masticatory structures were completely non-painful. On the left side, the absence of pain prevailed at all sites, but the masseter and "other masticatory muscles" had higher pain rates, approximately 24% and 19%; the left TMJ was non-painful in approximately 93% and the non-masticatory structures in 96% ($p < 0.001$). Laterotrusion to the left had a similar profile. On the right, temporal and non-masticatory pain was limited to 1.3% of cases, and pain-freeness was prevalent in the masseter (81.3%), "other masticatory muscles" (89.3%), and TMJ (82.7%; $p < 0.001$). On the left, pain-free cases represented 94.7% for the temporal, 86.7% for the masseter, 94.7% for "other masticatory muscles," 93.3% for the TMJ, and 96.0% for non-masticatory structures ($p < 0.001$). When pain occurred, it was more frequently localized to the masseter and right TMJ. In protrusion, pain was rare in the bilateral temporals (4.0%; $p < 0.001$), in the TMJ (4.0–5.3%), and almost absent in non-masticatory structures (1.3% right, absent left). The masseters were the main source of discomfort: 17.3% right and 6.7% left, and "other masticatory muscles" were painful in 14.7% right and 16.0% left. The protrusion was therefore well tolerated by the majority, with a symptomatic muscular component in a subgroup.

Click-like joint sounds were absent in most patients. On the right, the lack of click was observed in 73.3% on opening and 84.0% on closing, and the click in 26.7% and 16.0% ($p < 0.001$). Self-report was consistent with clinical examination, and pain associated with the right click was present in only 6.7%. On the left, the absence of click was 80.0% on opening and 77.3% on closing, with click in 20.0% and 22.7%; the patient perceived a left click in 29.3% of cases, and the associated pain was 8.0%. In eccentric movements, the right click was present in 17.3% and the left in 21.3%, with agreement between the patient and the examiner; the associated pain remained rare, 2.7% right and 9.3% left. Therefore, the click was relatively rare and predominantly painless. Palpation sensitivity was unevenly distributed. In the temporalis muscle, the posterior pars was rarely sensitive: 12.0% right and 16.0% left ($p < 0.001$). The pars media had more balanced values, 30.7% sensitivity right ($p = 0.001$) and 49.3% left ($p = 1.000$), and the anterior pars became predominantly sensitive bilaterally: 61.3% right and 57.3% left. For the masseter, sensitivity was increased, especially on the left: at origin 52.0% right and 69.3% left, at body 81.3% right and 93.3% left, and at insertion 73.3% right and 77.3% left ($p < 0.001$ for body and insertion). At the articular level, the lateral pole of the TMJ was predominantly painless: 74.7% right and 81.3% left without sensitivity ($p < 0.001$), but the adjacent periarticular area was frequently sensitive: 84.0% right and 89.3% left ($p < 0.001$). Tenderness was very common in the retromandibular (92.0–93.3%), submandibular (65.3% right; 64.0% left), lateral pterygoid (90.7–92.0%) and temporalis tendon regions, which were tender bilaterally in 97.3% of patients. Consequently, the painful load on palpation was concentrated in the masseter, deep periarticular structures, retromandibular region, lateral pterygoid and temporalis tendon.

The Mandibular Mobility Index (MMI) revealed a predominant impairment of vertical opening. For MMI.A, normal mobility was present in 22 patients (29.3%; 95% CI: 0.194–0.410), mild limitation in 30 (40.0%; 95% CI: 0.289–0.520), and severe limitation in 23 (30.7%; 95% CI: 0.205–0.424). For right laterotrusion MMI.B, 66 patients had normal mobility (88.0%; 95% CI: 0.784–0.944), and 9 had mild limitation (12.0%). For left IMM.C laterotrusion, 70 patients had normal mobility (93.3%; 95% CI: 0.851–0.978), and 5 had mild limitation (6.7%). For IMM.D protrusion, 54 patients were normal (72.0%), 19 had mild limitation (25.3%), and 2 had severe limitation (2.7%). The total IMM score ranged from 0 to 7 points, with a mean of 2.507, median 1, IQR 4.000, SD 2.356, and ES 0.272 ($W = 1711$; $p < 0.001$; DM = 3.500; $r = 1.00$), confirming the general but variable functional impairment of mandibular mobility. The Helkimo index confirmed the high clinical severity. The mobility subscale indicated normality in 17 patients (22.7%), mild limitation in 33 (44.0%), and severe limitation in 25 (33.3%). Pain on movement was absent in only 3 patients (4.0%), present with a single movement in 5 (6.7%), and with two or more movements in 67 (89.3%; $p < 0.001$). TMJ pain on palpation was absent in 18 patients (24.0%), strictly capsular in 2 (2.7%), and located posterior to the capsule in 55 (73.3%). TMJ function was relatively smooth, with deviation <2 mm, in 39 patients (52.0%), and uni-/bilateral crackles with deviation ≥2 mm were present in 35 (46.7%); blockage/dislocation occurred in only one patient (1.3%). Muscle tenderness was widespread, with 70 patients (93.3%) having tenderness in at least four sites. The Helkimo total score had a mean of 15.600, median of 17, IQR of 8.500, range 2–21, SD of 4.716, and ES of 0.545 ($W = 2850$; $p < 0.001$; DM = 16.000; $r = 1.00$), reflecting pronounced severity of TMD. The TMI index described a moderate to severe symptom burden, dominated by the muscle component. The muscle scale had the highest values: mean 0.683, median 0.750, IQR 0.300, range 0.2–1.000, SD 0.202 and ES 0.023 ($W = 2850$; $p < 0.001$; DM = 0.700; $r = 1.00$). The functional scale was intermediate, with mean 0.382, median 0.333, IQR 0.250, range 0.083–0.750, SD 0.177 and ES 0.02 ($W = 2850$; $p < 0.001$; DM = 0.375; $r = 1.00$). The joint scale had a mean of 0.375, median of 0.250, IQR of 0.250, range of 0–1.000, SD of 0.267, and ES of 0.031 ($W = 2080$; $p < 0.001$; DM = 0.437; $r = 1.00$), with greater variability. The total TMI score had a mean of 0.480, median of 0.497, IQR of 0.206, range of 0.094–0.817, SD of 0.163, and ES of 0.019 ($W = 2850$; $p < 0.001$; DM = 0.481; $r = 1.00$).

Results of the application of Axis II instruments of the DC/TMD protocol

Axis II assessed self-perception of mandibular function limitation by JFLS-8, pain intensity by CPI from GCPS – 1-month version, as well as anxiety and depressive symptomatology by GAD-7 and PHQ-9. The JFLS-8 score had a mean of 1.462, median of 0.750, IQR of 2.125, range of 0.000–7.125, SD of 1.597 and ES of 0.184 ($W = 2080$; $p < 0.001$; DM = 1.562; $r = 1.00$), indicating quantifiable but variable orofacial functional limitation. The CPI score had a mean of 42.444, median of 40.000, IQR of 26.667, range of 0.000–90.000, SD of 20.382 and ES of 2.353 ($W = 2775$; $p < 0.001$; DM = 43.333; $r = 1.00$), indicating marked perceived pain intensity, ranging from no pain to very high values. For the GAD-7, the mean was 7.493, median of 6, IQR of 7.000, range of 1–21, SD of 4.732 and ES of 0.546 ($W = 2850$; $p < 0.001$; DM = 7.000; $r = 1.00$), suggesting frequent but variable anxiety symptomatology. PHQ-9 had a mean of 6.893, median of 7, IQR of 6.000, range of 1–24, SD of 4.507 and ES of 0.52 ($W = 2850$; $p < 0.001$; DM = 6.500; $r = 1.00$), indicating depressive burden present in a significant segment of the group. Overall, Axis II indicators outlined a profile characterized by functional limitation, increased perceived pain and psycho-emotional symptomatology significantly deviated from reference levels. Although individual values were heterogeneous, the general trend was oriented towards increased scores. Since the main objective of the study did not aim at an in-depth analysis of these dimensions, only the total scores of the instruments were interpreted, without analysis per item or the inclusion of similar additional scales.

3.2. CBCT imaging analysis of the condyle–fossa relationship in patients with temporomandibular disorders

CBCT imaging evaluation of the TMJ allowed standardized measurement of the morphology of the glenoid fossa, articular eminence and mandibular condyle, as well as the afferent joint spaces. The indices obtained describe the condyle–fossa relationship in the sagittal, vertical and coronal planes in the patients included in the study. In the analyzed group, the basic morphometric parameters of the glenoid fossa and mandibular condyle showed relatively moderate variability and a distribution generally close to normal, in contrast to the much more pronounced dispersion observed at the level of the joint spaces and the derived indices. The vertical height of the glenoid fossa (VHF), the inclination and height of the articular eminence (AEI/AEH), as well as the length, width and height of the mandibular condyle (CoL, CoW, CoH), bilaterally, showed close means and medians, low standard deviations and narrow interquartile ranges. This profile indicates a relatively homogeneous morphological pattern of the bone components in patients with TMD and condylar malposition. The Shapiro–Wilk test did not reveal significant deviations from normality for most of these variables, especially on the right side, and on the left, only some distributions, such as condylar width and VHF, significantly deviated from the Gaussian model, probably due to the presence of isolated extreme values. In contrast, the sagittal and coronal joint spaces presented a much more heterogeneous profile. Although the means of the superior, anterior and posterior, bilateral spaces were relatively close, suggesting an average condylar positioning without massive displacements in a single direction, the standard deviations, interquartile ranges and extreme values indicated a significant variability between joints. In some cases, the joint spaces were much larger than the rest of the group. This dispersion is also supported by the Shapiro–Wilk test, significant for most sagittal (SJS, AJS, PJS) and coronal (MJS, LJS) joint spaces, indicating asymmetric distributions, influenced by extreme values. Thus, although the average suggests a relatively balanced condyle–fossa relationship, the results highlight the existence of a significant number of joints with marked spatial alterations, compatible with a wide spectrum of condylar malpositions. The sagittal condylar position index (SCP) indicates, in general, a slight tendency towards anterior positions of the condyle, more evident on the right side, but with very high variability. The positive means of the bilateral SCP suggest that the posterior space generally tends to be larger than the anterior one. However, the high standard deviations, the extended interquartile ranges and the simultaneous presence of significant negative values, corresponding to posterior condylar positions, and very large positive values, suggestive of marked anteriorizations, show that opposing condylar patterns coexist in the same group. A similar profile is observed for the A/P ratio and the logarithmic transformation ln(P/A), where the central values suggest a slight preponderance of anterior positioning of the condyle in the glenoid fossa, but the distributions are influenced by extreme values and deviate from normality for some variables.

The vertical index (VI) showed a more moderate distribution, with close means bilaterally and small differences between the mean and median, suggesting a relatively stable and comparable superior–inferior positioning between the two sides, expressed as a proportion of the total sagittal spaces. In contrast, the coronal indices, CCI and ML ratio, had positive means bilaterally, indicating that the medial space is generally larger than the lateral one, and the condyle tends to be positioned slightly closer to the lateral wall of the fossa. However, the large standard deviations, wide amplitudes and negative values, corresponding to medial displacements, indicate the existence of a subset of joints with pronounced coronal malpositions in both directions. The non-normal distributions of the ML ratio confirm the need for cautious interpretation, taking into account asymmetry and extreme values.

The analysis of the right–left asymmetry indices (for SCP, VI, CCI, SJS, MJS, LJS) highlights a particular phenomenon: for most variables, the medians are close to zero, suggesting the absence of a systematic imbalance between the two sides at the level of the average patient. However, high standard deviations, very wide interquartile ranges and extreme values, sometimes of the order of tens or hundreds of percent, indicate the existence of patients with marked condylar asymmetries. The profoundly non-normal distributions confirm that severe asymmetries are rare, but very pronounced when they occur, substantially influencing the distribution at the group level. Therefore, reporting the mean and standard deviation alone is not sufficient to characterize this dimension of condylar malposition, and the analysis of extreme values is also necessary, possibly through subgroups defined on the basis of asymmetry thresholds. The indices derived from the A/S and P/S ratios (R_{AS}, R_{PS}), as well as the composite index of deviation from the theoretical model of the distribution of sagittal spaces (D_{Ikeda}), confirm the inhomogeneous nature of the condylo-fossa relationship. The means and medians of R_{AS} and R_{PS} are relatively close between the right and left, indicating a similar overall distribution of the anterior and posterior spaces relative to the superior space. However, the wide dispersion, the large amplitude of the values and the significance of the normality tests show that these ratios are strongly influenced by individual variability. The D_{Ikeda} index, calculated bilaterally, had means around 0.55, slightly lower medians, but large standard deviations and maximum values of 2.5–2.9, suggesting that a considerable proportion of joints deviate substantially from the idealized pattern of sagittal spaces. Thus, in addition to a core of joints with reduced deviation, there is a significant segment of the group with complex malposition, in which the entire balance of the condylo-fossa spaces is affected, not just a single direction of movement.

Table 2. Comparison of right/left values of basic and derived imaging indices in patients with temporomandibular disorders and condylar malpositions

		W	*p*	MD	SED	Effect size
$\mathbf{VHF}_{Right}$	$\mathbf{VHF}_{Left}$	1906[a]	<.001	0,4	0,102	0,45
$\mathbf{AEI}_{Right}$	$\mathbf{AEI}_{Left}$	1914[b]	0,005	2,05	0,681	0,379
$\mathbf{AEH}_{Right}$	$\mathbf{AEH}_{Left}$	1143[d]	0,356	0,15	0,102	0,134
$\mathbf{CoW}_{Right}$	$\mathbf{CoW}_{Left}$	1334[a]	0,913	8,38×10^-5	0,219	0,015
$\mathbf{CoL}_{Right}$	$\mathbf{CoL}_{Left}$	859[e]	0,225	-0,15	0,109	-0,175
$\mathbf{CoH}_{Right}$	$\mathbf{CoH}_{Left}$	868[b]	0,005	-0,7	0,238	-0,375
$\mathbf{SJS}_{Right}$	$\mathbf{SJS}_{Left}$	1218[f]	0,886	-3,22×10^-5	0,116	-0,02
$\mathbf{AJS}_{Right}$	$\mathbf{AJS}_{Left}$	1090[g]	0,762	-0,05	0,107	-0,043
$\mathbf{PJS}_{Right}$	$\mathbf{PJS}_{Left}$	970[h]	0,257	0,15	0,096	0,173
$\mathbf{MJS}_{Right}$	$\mathbf{MJS}_{Left}$	841[i]	0,742	-2,49×10^-5	0,091	-0,05
$\mathbf{LJS}_{Right}$	$\mathbf{LJS}_{Left}$	747[j]	0,432	3,42×10^-5	0,094	0,127
$\mathbf{SCP}_{Right}$	$\mathbf{SCP}_{Left}$	1389[k]	0,527	2,022	2,533	0,087
$\mathbf{AP}_{Right}$	$\mathbf{AP}_{Left}$	1218[k]	0,733	-0,015	0,043	-0,047
$\mathbf{LN\text{-}PA}_{Right}$	$\mathbf{LN\text{-}PA}_{Left}$	1397[k]	0,497	0,045	0,058	0,093
$\mathbf{VI}_{Right}$	$\mathbf{VI}_{Left}$	1416	0,964	-4,85×10^-4	0,01	-0,006
$\mathbf{CCI}_{Right}$	$\mathbf{CCI}_{Left}$	949[l]	0,422	-2,275	2,109	-0,115
$\mathbf{ML}_{Right}$	$\mathbf{ML}_{Left}$	927[l]	0,343	-0,081	0,078	-0,136
$\mathbf{R}_{ASRight}$	$\mathbf{R}_{ASLeft}$	1305	0,528	-0,035	0,057	-0,084
$\mathbf{R}_{PSRight}$	$\mathbf{R}_{PSLeft}$	1453[m]	0,575	0,029	0,051	0,076
$\mathbf{D}_{IkedaRight}$	$\mathbf{D}_{IkedaLeft}$	1291	0,481	-0,032	0,06	-0,094

Note: W – value of the nonparametric Wilcoxon test (paired); MD – mean difference; SED – standard error of the difference.

The right-left comparative analysis (Table 2) shows that, despite the clinical picture of TMD and condylar malpositions, most imaging parameters do not present significant systematic differences between the two TMJs of the same patient. For most basic and derived indices, the Wilcoxon test revealed compatible values with very small effects and insignificant p-values, indicating a relative global symmetry of the condyle position in the glenoid fossa. In other words, although patients present TMD and condylar malpositions, these are not expressed, on average, by a constant lateral imbalance of the main condylar position indices. Against the background of this relative functional symmetry, a core of morphological asymmetry is nevertheless outlined at the level of some bone structures. The vertical height of the glenoid fossa (VHF) is significantly greater on the right side, with a medium-sized effect, suggesting a slightly deeper fossa. Also on the right, the inclination of the articular eminence (AEI) is more pronounced, the difference being significant and associated with a moderate effect. In contrast, the height of the mandibular condyle (CoH) is lower on the right than on the left, indicating a slightly shorter condyle in the context of a higher fossa and a steeper articular eminence. The longitudinal and transverse dimensions of the condyle (CoL, CoW), as well as the height of the articular eminence (AEH), do not differ significantly between the sides, suggesting that the observed asymmetry is mainly related to the local fossa–condyle configuration, and not to the overall condylar volume. Regarding the sagittal and coronal joint spaces, the results indicate a remarkable bilateral stability. The superior, anterior and posterior spaces (SJS, AJS, PJS), as well as the medial and lateral spaces (MJS, LJS), do not show significant differences between the right and left, and the estimated effects are very small. Thus, despite the morphological asymmetries of the fossa and condyle, the condyle appears to occupy a comparable position bilaterally with respect to the fossa walls. In practice, the joint play expressed by these distances does not indicate the predominance of one side, supporting the idea of a relative bilateral functional balance in the way the glenoid fossae are occupied. The same relative symmetry is maintained for the derived indices of condylar position. The Pullinger–Hollender index (SCP), the A/P ratio and the ln(P/A) transformation do not differ significantly between the right and left sides, and the effects are small, indicating a bilaterally comparable tendency towards anterior or posterior positions. The vertical index (VI) is practically identical between the sides, confirming the symmetry of the condylar position in the superior–inferior direction. In the coronal plane, the centricity index (CCI) and the ML ratio also present insignificant differences and small effects, which shows that there is no constant mediolateral shift of the condyle towards one of the sides.

The A/S and P/S ratios, as well as the D_{Ikeda} composite index, which summarizes the deviation from the theoretical model of the distribution of sagittal spaces, did not reveal significant differences between the right and left sides. The low values of the effects indicate that, although many patients deviate from the idealized Ikeda pattern, this deviation manifests itself relatively similarly bilaterally. Synthetically, the bone morphology presents certain structural asymmetries, namely a deeper fossa, a more inclined eminence and a shorter condyle on the right, but the condylar position indices and the distribution of the joint spaces remain, in general, balanced bilaterally. This profile suggests a possible functional adaptation that compensates for the underlying morphological differences and maintains, at the group level, a relatively symmetrical spatial organization of the condyles in the glenoid fossae. The classification of the Pullinger–Hollender index into categories of sagittal position of the condyle more clearly highlights the tendency towards anteriorization, which in the continuous analysis appeared only as a slightly positive average against a background of high variability. On the right side, 36 joints, respectively 48.0%, were classified as anterior, 31, respectively 41.3%, as centered, and 8, respectively 10.7%, as posterior. On the left side, the distribution was similar: 34 condyles, respectively 45.3%, were anteriorized, 32, respectively 42.7%, as centered, and 9, respectively 12.0%, as posteriorized. These proportions show that almost half of the joints fall into the anterior position category according to the ±12% threshold, while only about two-fifths can be considered relatively centered, and the posteriorized condyles represent a minority. Compared to the continuous analysis of SCP, the categorical classification transforms the heterogeneity of the distribution into a more clinically explicit prevalence: anterior malposition is not a marginal phenomenon, but characterizes almost half of the joints investigated, while the centered condylar position appears rather as a less frequent situation than as the dominant norm.

From the perspective of vertical position, the categorization of the superior joint space (SJS) confirms the impression of global stability with peripheral deviations, indicated by the VI and the continuous distributions of SJS. On the right side, 66 joints (88.0%) fall within the range considered within limits, and 9 (12.0%) present a widened superior space, interpreted as an inferior condylar position; on the left side, the proportions are similar, with 62 joints (82.7%) within limits and 13 (17.3%) with an inferiorly positioned condyle. In the investigated sample, no cases with an superiorly positioned condyle (very small superior space) were identified, which confirms that, in this group, the relevant vertical malpositions are mainly inferior displacements, and severe superior compression of the joint is absent. Compared to the results from the continuous analysis (where VI had close means between right and left and moderate variability), these frequencies show that although the vertical position is, on average, relatively stable, there is still a non-negligible subgroup – approximately one sixth of the joints – in which the condyle is in a clear inferior position, with potential functional impact.

The D_{Ikeda} classification provides additional insight into how much the condyle–fossa relationship deviates, in terms of A–S–P distribution, from the optimal theoretical model proposed by Ikeda et al. [27]. On the right side, only 27 joints (36.0%) can be considered close to the Ikeda norm, while 19 (25.3%) show moderate deviation and at least 29 (38.7%) fall into the marked deviation category. On the left side, the situation is practically identical, with 24 joints (32.0%) close to the norm, 21 (28.0%) with moderate deviation and 30 (40.0%) with marked deviation. If in the continuous analysis, the D_{Ikeda} parameter had means around 0.5, somewhat lower medians and large standard deviations, indicating the existence of a core of joints with low deviation and a significant number of TMJs with high deviation, following this analysis it is very clear that approximately two thirds of the joints clearly deviate from the idealized A:S:P ratio (present moderate or marked deviations), and the categories with marked deviation represent the only majority class. Thus, the deviations previously identified as extreme values (outliers) in the continuous distribution are not just isolated episodes but define a frequent pattern in this group. For the sample examined, the summation of these results reveals that the evaluation of categorical variables completes and nuances what emerged from the analysis of continuous variables. While the means and standard deviations indicated a slight overall trend towards anterior positions, a relative stability of the vertical position and a large heterogeneity in relation to the Ikeda model, the clinical grading shows that: almost half of the condyles are already anteriorized according to the Pullinger–Hollender criterion, and posteriorized condyles are rare; the vast majority of joints with superior space in the range considered physiological, but there is a constant subgroup of inferiorly positioned condyles; only about a third of the joints approach the Ikeda model, while the rest are in the area of moderate or marked deviations.

Thus, the transition from the strict analysis of continuous variables to categorical ones not only confirms the trends observed previously, but reflects them in concrete clinical proportions, revealing that condylar malposition, especially in the form of anteriorized positions and complex deviations from the ideal A–S–P distribution, seems to be a predominant characteristic of this sample, even if the continuous numerical parameters may indicate, at first glance, the presence of a relatively balanced average.

3.3. Cephalometric evaluation of patients with temporomandibular disorders and condylar malpositions

Subsequently, we evaluated the sample by performing cephalometric analysis of lateral cephalogram (TRG), following functional condylography. Based on condylography, the landmarks for the terminal hinge axis and the Orbital point were determined; these formed the reference plane, the axis orbitalis plane. The determining points of the plane were marked with metal balls placed on the facial skin, and the patient was subsequently subjected to the TRG radiological investigation. The digital image of the TRG was subsequently processed using the CADIAS software module of Gamma Dental Software (Gamma Dental, Austria). The analyses included in the examination methodology according to Sadao Sato (which also includes the Downs-Graber, Kim analysis) and that of Prof. Rudolf Slavicek were applied. The data are presented descriptively and comparatively (right vs. left) per group of cephalometric parameters specific to the analyses according to the authors. Based on the cephalometric analysis according to Downs Graber, at the level of mandibular morphology, the inclination of the mandibular ramus presents similar mean values bilaterally (≈14.6° right and 15.1° left), with relatively large standard deviations (≈5–6°) and very wide variation ranges (from very low values, even negative on the left, to almost 30°), which indicates a marked heterogeneity of the vertical patterns in this group. The right–left difference is not statistically significant (p=0.652), which indicates that, despite individual variability, the mandibular ramus does not present a clear systematic asymmetry. In contrast, for the gonial angle, the mean is slightly higher on the left (127.4° vs. 125.7°), and the Wilcoxon test indicates a significant difference (p=0.019), with an effect of small–moderate magnitude ($r_{bis} \approx -0.31$). This indicates a trend towards a more open gonial angle on the left side, compatible with a discrete vertical and morphological mandibular asymmetry within the group, but without being directly attributable to condylar malposition in the absence of a control group. The maxillomandibular sagittal skeletal relationships are characterized by mean values of SNA around 82° and SNB around 78–79°, with a mean ANB of ≈3.5° on both sides. The ANB distribution on the right-side deviates significantly from normality (Shapiro–Wilk test p=0.029), with a very wide range of variation (from negative Class III values to high positive values, associated with a Class II pattern). This dispersion confirms the existence of a very wide spectrum of sagittal relationships within the same group with TMD and condylar malposition, rather than a single dominant craniofacial type. For SNB, the right side shows a markedly non-normal distribution (p<0.001), while on the left the distribution is much more homogeneous (p=0.716). The convexity parameters and the AB–FP angle have negative means, with wide intervals, which again indicates a large variability of the sagittal profile (from more concave to more convex configurations), without a clear, unidirectional shift of the entire batch.

The parameters describing the position and inclination of the upper and lower incisors outline a relatively balanced dentoalveolar pattern, but with variable compensations between subjects. The U1–SN and U1–FH angles have almost identical mean values bilaterally (≈99° and ≈106°), with standard deviations of 7–10° and wide ranges (from marked values of retroclination to pronounced proclination). Similarly, the U1–A–Pog ratio centers around 4 mm, with variation between subjects, but without significant right–left differences (p=0.48–0.53). In the lower incisors, the L1–MP angle is, on average, around 96–98°, but here a statistically significant bilateral difference is observed (DM≈1.5°, p=0.003, r_{bis}≈0.39), with the incisors on the right side being slightly more proclined (or those on the left slightly more retroclined). The interincisive angle, with an average of ≈134–135°, shows a distribution moderately deviating from normality (p≈0.02 for the right), with wide variations (over 50° between minimum and maximum), which reflects multiple levels of dental compensation within the heterogeneous skeletal relationships described previously.

Regarding the orientation of the reference planes and the arches, the FH–SN angle has a median value of ≈7° on both sides, but with a significantly abnormal distribution on the right (p<0.001) due to some extreme values (up to 28°). This indicates the existence of subgroups with a pronounced inclination of the anterior skull base. The relationship between the occlusal plane and the Frankfort plane (FH–OP) is, on average, ≈8–9°, with moderate variations and no significant right–left differences. More importantly, the FH–MP angle, a classic indicator of vertical divergence, has an average of ≈21° on the right and ≈22° on the left, with a wide range (2.4–41°), indicating a combination of hypodivergent and hyperdivergent patterns in the group. The right–left difference is significant (p=0.005, DM≈1.1°, r_{bis}≈-0.37), indicating a slightly different inclination of the mandibular plane between the two hemifacial groups, compatible with a component of vertical asymmetry at the level of the mandible.

The general indicators of the facial profile – the facial angle and the facial Y-axis – have close mean values between the two parts (facial angle ≈87°, Y-axis ≈58°), with small standard deviations and distributions close to normality. This indicates that, at the level of the facial ensemble, the general growth direction and the anteroposterior profile of the face are relatively stable and symmetrical, despite local variations at the mandibular and dentoalveolar levels. The convexity parameters and the AB–FP angle present, as mentioned, negative mean values, with high dispersion, which reflects the coexistence of some subjects with a more convex profile and others with a straighter or even concave profile, characteristic of a heterogeneous clinical group.

Statistically, the results of the Shapiro–Wilk tests show that most cephalometric variables approach a normal distribution, but for a significant subset (right ANB, right SNB, right FH–SN, right AB–FP angle, right interincisive angle) the distribution is significantly non-normal, with the presence of extreme values and elongated tails. This justifies the use of non-parametric tests for right–left comparisons (Wilcoxon test) and indicates the existence of distinct clinical subgroups within the group (patients with marked Class II relationships or, conversely, with Class III patterns). Within the studied group, the distribution of classes is according to the following hierarchy – Class 1 (n = 33, 44%) > Class 2 (n = 32, 42.7%) > Class 3 (n = 10, 13.3%).

Thus, based on the Downs–Graber analysis, it can be concluded that in the investigated sample of patients with temporomandibular disorders and condylar malposition, a "unique craniofacial type" is not identified, but an extremely heterogeneous ensemble of sagittal and vertical patterns, with a relatively low level of systematic asymmetry between right and left. The statistically significant asymmetries (gonial angle, L1–MP, FH–MP) are of small amplitude, but coherent, indicating a discrete mandibular and dentoalveolar asymmetry that could have functional relevance in the context of condylar malposition and TMD.

The cephalometric evaluation according to Kim reveals that the CF parameter presents very close mean values between the two sides: 157.56 ± 7.72 on the right and 157.28 ± 8.35 on the left, with medians of 159.0 and 157.9, respectively, and quite wide ranges (approximately 139–174° on the right, 138–173° on the left). The distributions respect the hypothesis of normality (Shapiro–Wilk, p > 0.23), which indicates a physiological dispersion of the values, without extreme groups or obvious multimodality. This data structure indicates that, in general, the combination factor (which reflects the integrated skeletal and dento–alveolar relationships) is relatively stable within the group, with moderate variability, compatible with different phenotypes, but without major general deviations. The APDI index has means of 79.65 ± 6.66 on the right and 80.17 ± 6.67 on the left, with medians very close to 78.8–78.7, and the range of variation is from approximately 67 to 100–96. The distributions are also compatible with normality (p = 0.078–0.108). This configuration indicates a relatively wide sagittal spectrum, from situations with more pronounced anteroposterior discrepancies to cases with relationships close to equilibrium, but without concentration of the group in an extreme area (pure Class II or pure Class III). Basically, Kim's analysis confirms that, in this sample of patients with TMD and condylar malposition, the sagittal relationships are heterogeneous, but statistically centered in the area of intermediate values, which supports the idea that temporomandibular disorder is not necessarily associated with a single dominant sagittal skeletal type. The ODI index shows means of 77.72 ± 8.49 on the right and 76.93 ± 7.91 on the left, with medians of 77.6 and 76.7, respectively, and approximate ranges between 57–97 on the right and 61–95 on the left. Again, the Shapiro–Wilk test indicates approximately normal distributions (p = 0.90 and 0.40, respectively). These results indicate that, from the perspective of vertical control and overbite relationships, the group includes both patients with more pronounced overbite and with reduced values, but without highlighting a unique pattern at the group level. Verticality is therefore variable, but statistically centered in a moderate area, which is consistent with the finding, from other analyses, of the coexistence of brachyfacial and dolichofacial patterns within the same patients with TMD.

The right–left comparison using the Wilcoxon test does not reveal significant differences for any of the three Kim parameters: for CF, p = 0.915; for APDI, p = 0.235; for ODI, p = 0.428. The mean differences (MD) are very small (≈ +0.10 for CF, – 0.55 for APDI and +0.55 for ODI), and the effect sizes (rank biserial correlation) are low (< 0.17), which indicates a good overall morphological symmetry between the right and left hemifaces. Thus, although the condyles are malpositioned and DTM is present, the Kim index does not reveal a systematic displacement of the sagittal or vertical components previewerially on one side, but rather a functional impairment on a relatively symmetrical structural background.

Together with the detailed cephalometric analysis (Downs–Graber), the Kim analysis confirms that the group cannot be reduced to a single facial type or malocclusion type, but represents a mixture of sagittal and vertical patterns, with a general tendency towards moderate values and with good right–left symmetry of the composite indices. For the interpretation of the relationship between TMD/condylar malposition and craniofacial morphology, these results are important because they indicate that, in this sample, joint dysfunction is not necessarily associated with extreme abnormalities of the Kim indices, but occurs on a varied, but on average relatively balanced, cephalometric background. This supports the hypothesis that the role of functional factors (condylar position, muscle adaptations, parafunctions, occlusal history) is at least as important as the general sagittal and vertical morphology in determining the clinical picture of TMD, and subsequent analyses using condylography and assessment of the position of the condyles in the glenoid fossa become useful to identify subgroups with particular behavior.

We then applied the actual analysis according to Sato. The posterior occlusal plane (OPP) has close mean values on the two sides (13.8° right and 14.2° left), with medians of 14.7° and 14.5° respectively, and interquartile ranges of about 6–7°. This describes a moderate inclination of the posterior occlusal plane, with no statistically significant differences between right and left ($p=0.506$). However, the Shapiro–Wilk test indicates a deviation from normality ($p<0.05$), with extreme values from – 4.4° to 36.3°, indicating the presence of cases with very flat or very pronounced occlusal slopes within the same group. For the anterior occlusal plane (FH–OPA), the means are approximately 10.6° on the right and 11.4° on the left, with standard deviations of approximately 5° and distribution compatible with normality ($p=0.402$ and $p=0.117$). The Mx–OPP and Mx–OPA ratios (75–76° and 78–79° on both sides, respectively) show very close means and medians, with moderate dispersion and no significant lateral differences ($p>0.6$), which shows a stable and symmetrical relationship between the maxilla and the anterior/posterior occlusal planes. The FH–PP angle is, on average, very close to 0° (–0.65° right, –0.17° left), indicating a relatively good parallelism between the palatal plane and the Frankfort plane, again without significant asymmetry. In general, the maxillary skeletal components and the orientation of the occlusal planes are relatively well centered and balanced bilaterally, even in the presence of TMD and condylar malposition. The intermolar angle has large medians (≈174° on both sides), indicating, on average, relatively parallel molar axes. However, the very high standard deviations (≈28° right, 20° left) and the ranges from <1° to almost 180° generate a strongly non-normal distribution ($p<0.001$), with extremely divergent or convergent cases. However, the Wilcoxon analysis does not reveal a significant right–left difference ($p=0.311$, small effect), so the variation is large, but not systematized in a clear lateral direction. At the level of the lower incisors, the L1–AB distance is, on average, small and similar bilaterally (≈2.2–2.5 mm), indicating an anteroposterior position relatively close to the AB reference line. The distribution is normal on the right, but markedly non-normal on the left ($p<0.001$) due to some extreme values (up to 30 mm), indicating a restricted subgroup of patients with excessively vestibular positioning or with accentuated dentoalveolar peculiarities. The L1–AB angles (≈21–22°) also show very high variability (SD ≈20°, range 1–180°) and non-normal distribution, reflecting a pronounced heterogeneity of the inclination of the lower incisors, but without significant lateral differences ($p=0.882$ for distance, $p=0.742$ for angle). In contrast, the upper incisors have a much more homogeneous profile, with the U1–AB distance (2) around 5.6 mm and the U1–AB angle around 26° on both sides, with moderate standard deviations, relatively narrow interquartile ranges and distributions compatible with normality. Comparison tests show the absence of any significant asymmetry for these parameters ($p>0.6$). This indicates that, in the analyzed group, dentoalveolar compensations are more variable and disorganized at the level of the lower incisors, while the upper front is aligned and inclined in a more coherent way between patients and between hemiarches. The relationships of the upper molar with the A–P line (A′–6′/A′–P′) and with the A point (A′–6′) highlight one of the few consistent asymmetries in the Sato analysis. The A′–6′/A′–P′ value is, on average, 46.5 on the right and 44.8 on the left, and A′–6′ is 22.3 mm right versus 21.3 mm left. The differences of approximately 1–2 mm between the sides are statistically highly significant ($p<0.001$ for both), with rank biserial correlation coefficients in the range of 0.47–0.51, thus with a medium to large effect. This indicates a systematic sagittal asymmetry in the position of the upper molar: the ratio to the skeletal landmarks A and the A–P line is consistently higher on the right, indicating a discrepancy in molar positioning between the hemiarches, not just random variation. In contrast, the position of point A relative to the A–P line (A–P) has almost identical mean values (≈47.6 for both sides), and the right–left difference is not significant ($p=0.352$). Thus, the maxillary skeletal base appears generally symmetrical in the sagittal plane, and the asymmetry is predominantly manifested at the posterior dentoalveolar level (molar position), not at the level of the positioning of point A. From the perspective of the group with TMD and condylar malposition, this indicates that part of the lateral occlusal imbalances may be related to the different migration/positioning of the molars on the two sides, in conditions of a relatively symmetrical maxillary bone support. The AB–MP angle shows averages of 78.4°

on the right and 77.1° on the left, with standard deviations of approximately 8° and distributions compatible with normality. The difference of ≈1° is nevertheless statistically significant ($p=0.029$), with a small–medium intensity effect ($r≈0.29$), indicating a slight asymmetry of the relationship between the mandibular alveolar base and the mandibular plane, with somewhat higher values on the right. The OP–MP/PP–MP ratio shows mean values of 56.7 on the right and 94.0 on the left, with a relatively modest dispersion on the right (SD≈17.4) and extremely high on the left (SD≈208.6, with values up to over 1400). The distribution on the left is deeply non-normal, and the Wilcoxon test indicates a significant difference between the sides ($p=0.048$, effect $r≈–0.26$). This combination of statistical significance and the presence of extreme values (outliers) indicates that, although most patients present similar ratios on the two sides, there is a small subgroup with very high values on the left, which modify the mean upwards and define a pronounced vertical/occlusal asymmetry in some cases.

The OP–MP angle has a mean of 12.4° on the right and 18.0° on the left; although the mean difference is approximately 1° after rank correction (DM≈–1.0), the very small p-value (0.005) and the moderate effect (r≈–0.37) show that, across ranks, the occlusal plane is systematically steeper than the mandibular plane on the left side. The FH–MP angle confirms this trend: the mean is 21.0° right and 22.3° left, with a similar difference (DM≈–1.1, $p=0.005$, $r≈–0.37$), indicating a slight increase in mandibular divergence compared to Frankfort on the left. In contrast, the PP–MP angle is very close between the sides (≈21.6° vs. 22.4°) and does not differ significantly ($p=0.123$). Overall, these data outline a discrete but constant vertical asymmetry, such that the left hemimandible tends to be slightly more open (more divergent) with respect to the occlusal plane and the Frankfort plane, without a comparable change with respect to the palatal plane.

Overall, Sato's analysis shows that, in the patients with TMD and condylar malposition in this study, the maxillary skeletal structure and the orientation of the basic planes (FH, PP, MP) are largely symmetrical and approximately normally distributed. The major heterogeneity occurs especially at the dentoalveolar level (position and inclination of the lower incisors, intermolar angle, molar ratio to the A–P line) and at the interface between the occlusal plane and the mandibular plane, where both extreme values and small but systematic asymmetries in favor of the left hemipart are highlighted. Compared to other cephalometric analyses applied to the same group, Sato brings to the fore the way in which occlusal planes and tooth positions relate to the skeletal bases, highlighting the fact that, in this group with TMD and condylar malposition, the imbalances are not reflected by large frontal skeletal deviations, but rather by dento-alveolar asymmetries (especially in the upper 6th molar) and by vertical rotation discrepancies between the two hemiarches. These findings support the idea that in the evaluation and treatment planning of patients with TMD and condylar malposition, not only the position of the condyles and the craniofacial biotype must be taken into account, but also the fine distribution of occlusal loads and the position of the dento-alveolar segments on each side, as emerges from Sato's analysis.

The Slavicek cephalometric analysis generally describes a relatively balanced skeletal and dentoalveolar pattern, with important individual variations and some consistent asymmetries in the vertical plane. Most parameters present close mean values between the right and left sides, and the Shapiro–Wilk test indicates, for most variables, a distribution close to normal ($W \approx 0.97–0.99$, $p>0.05$), which supports the general homogeneity of the sample. From the perspective of aesthetic relations and the occlusal plane, the aesthetic plane presents slightly negative mean values bilaterally (≈ – 1.6 mm), which indicates a discretely retrusive perioral positioning, with a relatively large dispersion (DS ≈ 3 mm), reflecting the heterogeneity of the integumentary profile of the group. The lip embrasure is also slightly negative, around – 1.0 mm on both sides, without significant right–left differences, which indicates a general balance between the position of the lips and the reference plane. The distance of the occlusal plane from Xi and from the axis remains, on average, symmetrical (approximately – 1.5 – 1.9 mm from Xi and ≈ 33 mm from the axis), but the variable distance of the occlusal plane from the axis on the right side presents a significant deviation from normality and a very wide range (up to ≈ 95 mm), which indicates the presence of cases with marked morphological particularities or possible recording artifacts. In the idealized occlusal plane – axis-orbital plane relationship, the left side appears relatively compact (≈ 11.8° ± 3.25), while on the right side, the dispersion is much greater (DS ≈ 13.35°, with extreme values up to ≈ 121.8°), indicating that the accentuated deviations of the idealized plane are more frequent or more pronounced on this hemiarche. The analysis of the Von Spee curve highlights an average radius of ≈ 80.3 mm on the right and 77.4 mm on the left, the difference being statistically significant (DM ≈ 2.7 mm, $p=0.042$, $r_{biserial} \approx 0.27$). This indicates a Von Spee curve that is discretely flatter on the right side and somewhat more pronounced on the left side, without the difference reaching very large magnitudes, but indicating a tendency for functional asymmetry in the sagittal plane. The position of the upper molar (≈ 17.5 mm bilaterally) and the occlusal plane – axis-orbitalis plane relationship (≈ 11° on both sides) remain generally symmetrical and without significant right-left differences, which indicates a relatively balanced vertical framing of the lateral sector in relation to the condylar reference system. In the anterior sector, the position and inclination of the incisors are part of a picture of dentoalveolar balance, without extreme compensations. The inclination of the lower incisors has similar average values right-left (≈ 23.4–23.6°), with a reduced protrusion (≈ 0.8 mm), and the upper incisors present an average inclination of ≈ 21.7° and a protrusion of ≈ 4 mm, relatively symmetrical bilaterally. The interincisive angle is around 134–135°, which corresponds to a moderate anterosuperior relationship, without extreme proclinations or retroclinations of the frontal sector. Although for the vertical position of the upper incisors and for the interincisive angle on the right the normality test highlights deviations ($p<0.05$), the differences between the sides are not statistically significant, and the size effects are minor, which supports a clinically acceptable symmetry of the dental front.

The skeletal parameters specific to the Slavicek analysis – convexity, jaw position, mandibular arch, facial conicity, mandibular plane, depth and facial axis – outline a relatively balanced overall facial pattern. The average convexity is ≈ 2.2° bilaterally, and the jaw position is around 64.5–65.4°, without significant differences between the sides, indicating a moderately convex sagittal relationship, without major maxillomandibular discrepancies. The mandibular arch has average values of ≈ 36.1–36.2°, and facial depth ≈ 87.3–87.4°, with moderate dispersion and generally normal distributions. The facial axis is around 91.5° on the right and 90.8° on the left, indicating a general balance between the vertical and sagittal components of the facial skeleton; The distribution of the facial axis on the left deviates from normality, reflecting the presence of some cases with extreme patterns, which is predictable for a group of patients with TMD and condylar malposition.

Right–left comparisons highlight several clinically relevant vertical asymmetries. The height of the lower floor to point D is greater on the left side by ≈ 1.5 mm (DM ≈ – 1.5 mm, $p<0.001$, $r_{biserial} \approx -0.52$), and the same difference of ≈ 1.5 mm is also found for the overall height of the lower floor ($p<0.001$, $r_{biserial} \approx -0.53$). These moderate-sized effects indicate a consistent predominance of vertical dimensions on the left hemipart – which may correspond to a slight rotation or tilt of the mandible and/or of the occlusal plane in the frontal plane. At the same time, the facial conicity is slightly greater on the right (DM ≈ 1.05°, $p=0.006$, $r_{biserial} \approx 0.37$), and the mandibular plane is more open on the left (DM ≈ – 1.1°, $p=0.002$, $r_{biserial} \approx -0.40$). Together, these results describe a pattern of asymmetry in which the left hemicranium presents a greater vertical opening (more inclined mandibular plane and higher lower floor), while on the right side a somewhat narrower pattern and a flatter Von Spee curve are outlined. These particularities are compatible with morpho-functional adaptations to the condylar malposition and asymmetric loads characteristic of patients with TMD, indicating that the condylar changes are reflected not only at the articular level, but also in the dento-facial architecture and in the configuration of the occlusion planes.

3.4. Three-dimensional condylographic analysis of mandibular kinematics in patients with temporomandibular disorders and condylar malposition

The three-dimensional condylographic analysis aimed to characterize the mandibular kinematics in the standardized movements of opening–closing, protrusion–retrusion and bilateral mediotrusion. For each movement, the standard parameters provided by the CADIAX® 4 system (X, Y, Z, SCI, TCI, S) were evaluated, as well as the derived indices of the amplitude, direction and curvature of the trajectory (Amp, AmpSag, AmpHor, SagAng, TransAng, Curvature). The normality of the distributions was verified by the Shapiro–Wilk test, and the heterogeneous nature of several variables, with asymmetries and extreme values, justified the predominant use of non-parametric tests in the right–left comparisons and in the analysis of asymmetry indices.

3.4.1. Condylar kinematics during mandibular opening

During mandibular opening, the anteroposterior and mediolateral translations of the condyles were, on average, relatively balanced. The X coordinate had close values bilaterally, 10.47 ± 5.05 mm for the right condyle and 10.31 ± 5.40 mm for the left condyle, and the Y coordinate was close to zero on both sides (0.11 ± 0.64 mm vs. – 0.08 ± 0.74 mm), with no systematic tendency for lateral deviation. However, a discrete difference was outlined in the vertical direction, with the left condyle having a slightly greater inferior translation than the right one (7.92 ± 3.10 mm vs. 7.32 ± 2.48 mm). The same pattern was found in the path length and three-dimensional amplitude: |S| was 13.13 ± 4.64 mm on the right and 13.65 ± 4.60 mm on the left, and Amp was 13.26 ± 4.40 mm and 13.67 ± 4.60 mm, respectively. Therefore, the opening was achieved by a relatively symmetrical inferior–anterior translation in the horizontal plane, with a slight predominance of sagittal descent and excursion on the left side. Angular parameters indicated a comparable sagittal and transverse condylar guidance between the sides, but with significant interindividual variability. SCI had close mean values (38.88° ± 17.43° right; 37.31° ± 26.31° left), and TCI showed a descriptive trend towards more positive values on the right (1.18° ± 5.69° vs. – 1.64° ± 11.26°), without a constant lateral pattern. The geometric angles SagAng and TransAng confirmed a general infero-anterior direction, approximately 50° in the sagittal plane, and a horizontal orientation almost perpendicular to the anteroposterior axis. The curvature index was very close to 1 bilaterally, indicating generally rectilinear trajectories; however, the greater dispersion on the right suggests the existence of cases with more curved paths or individual movement peculiarities.

The right–left pairwise comparison (Table 3) confirmed the lack of significant differences for the X and Y components, supporting the overall symmetry of the opening in the horizontal plane. In contrast, Z was significantly greater on the left (mean right–left difference = – 0.475 mm; $W = 910$; $p = 0.007$; $r = -0.36$). Significant, but small-amplitude differences were also observed for |S|, Amp, and AmpSag, all suggesting a slightly larger excursion of the left condyle (≈0.4–0.5 mm). AmpHor did not differ significantly between sides. No robust differences were found for SCI and TCI, although TCI had a nearly significant trend toward higher values on the right ($p = 0.051$). SagAng was slightly larger on the right (≈1.5°; $p = 0.042$), and the statistical difference for Curvature, although present ($p = 0.047$), has a very small numerical amplitude and probably limited clinical relevance. Derived asymmetry indices show that the differences in amplitude and path length at opening are modest but consistent. ΔAmp and ΔSabs had median values of approximately – 0.42 mm, indicating a slightly larger excursion of the left condyle; the absolute relative indices IA_{Amp} and IA_S had medians of approximately 0.08–0.09, corresponding to a typical asymmetry of 8–9% between the condyles. Sagittal guidance showed a relative asymmetry of similar order, with a slight trend towards a larger SCI on the left when expressed normalized, but with gross differences in widely dispersed degrees. For TCI, the normalized indices were numerically unstable, as values close to zero for the sum of angles can generate disproportionate ratios; therefore, clinical interpretation should be based primarily on ΔTCI and non-normalized trajectories. Overall, mandibular opening shows a slight to moderate kinematic asymmetry, predominantly vertical/sagittal, with the left condyle slightly favored in amplitude and trajectory length.

Table 3. Evaluation of right-left differences in standard and derived condylographic indices for mandibular opening movement in patients with temporomandibular disorders and condylar malposition

Indices (Right vs. Left)		W	*p*	MD	SED	Effect size
X*Right*	**X***Left*	1303[a]	0,649	-0,1	0,286	-0,061
Y*Right*	**Y***Left*	1604[a]	0,245	0,175	0,151	0,156
Z*Right*	**Z***Left*	910	**0,007**	-0,475	0,251	-0,362
SCI*Right*	**SCI***Left*	1170	0,242	-0,885	2,816	-0,157
TCI*Right*	**TCI***Left*	1751[a]	0,051	1,77	1,552	0,262
S*Right*	**S***Left*	1015[a]	**0,045**	-0,41	0,29	-0,269
Amp*Right*	**Amp***Left*	1030	**0,037**	-0,409	0,253	-0,277
AmpSag*Right*	**AmpSag***Left*	1035	**0,04**	-0,403	0,254	-0,274
AmpHor*Right*	**AmpHor***Left*	1324	0,596	-0,11	0,268	-0,071
SagAng*Right*	**SagAng***Left*	1810	**0,042**	1,53	1,254	0,27
TransAng*Right*	**TransAng***Left*	1102[a]	0,125	-1,445	4,091	-0,206
Curvature*Right*	***Curvature****Left*	1801	0,047	1,95×10^-4	0,013	0,264

Note: W – value of the nonparametric Wilcoxon test (paired); p – probability; MD – mean difference; SED – standard error of the difference.

3.4.2. Condylar kinematics during protrusion

During mandibular protrusion, condylographic parameters described an almost symmetrical movement bilaterally. The X coordinate was practically identical between the condyles (6.16 ± 2.16 mm right; 6.15 ± 2.54 mm left), and the Y coordinate indicated only a minimal, insignificant lateral deviation (0.14 ± 0.83 mm vs. – 0.03 ± 0.69 mm).

The same symmetry was maintained in the vertical direction, with Z of 6.52 ± 1.81 mm on the right and 6.56 ± 2.10 mm on the left. The path length (9.13 ± 2.20 mm vs. 9.19 ± 2.66 mm), three-dimensional amplitude (9.17 ± 2.19 mm vs. 9.23 ± 2.64 mm), sagittal and horizontal amplitude were also very close, with no leading condyle as the average amplitude or direction of movement. The SCI and TCI angles did not reveal significant differences.

The SCI was 47.21° ± 11.33° on the right and 47.53° ± 12.30° on the left, and the TCI showed only a descriptive trend towards more positive values on the right (1.66° ± 7.86° vs. – 1.21° ± 10.16°). SagAng and TransAng confirmed the same geometric symmetry, and Curvature was very close to 1 bilaterally (0.995 vs. 0.993), indicating rectilinear and well-coordinated protrusive trajectories, without systematic irregularities. The Wilcoxon paired tests (table 4) confirmed the descriptive impression: neither the X, Y and Z coordinates, nor |S|, Amp, AmpSag, AmpHor, SCI, TCI, SagAng, TransAng or Curvature showed significant right–left differences. The mean differences were very small, of the order of hundredths of a millimeter for translations and below 2° for most angles, and the effects remained small. Therefore, protrusion represents in this group the most symmetrical of the movements analyzed, with bilaterally coordinated antero-inferior translation.

The asymmetry indices for protrusion confirm the lack of a stable directional bias. ΔAmp, $IA_{Amp\pm}$, ΔSCI, $IA_{SCI\pm}$, ΔSabs, and $IA_{S\pm}$ were centered around zero and did not indicate systematic dominance of one side. However, the absolute indices were significantly greater than zero: IA_{Amp} and IA_S had medians of approximately 0.09, and IA_{SCI} approximately 0.07, indicating that there is a relative individual asymmetry of 7–10%, even if its direction varies between patients.

For TCI, ΔTCI was not significant, and the $IA_{TCI\pm}$ and IA_{TCI} indices showed numerical instability through extreme values produced by small denominators; these indices should be considered exploratory and interpreted with caution. Thus, protrusion is globally symmetrical, but not completely free of moderate individual differences between condyles.

Table 4. Evaluation of right-left differences in standard and derived condylographic indices for protrusion movement in patients with temporomandibular disorders and condylar malposition

		W	*p*	MD	SED	Effect size
$\mathbf{X}_{Right}$	$\mathbf{X}_{Left}$	1368	0,763	-0,045	0,148	-0,04
$\mathbf{Y}_{Right}$	$\mathbf{Y}_{Left}$	1614[a]	0,149	0,19	0,16	0,195
$\mathbf{Z}_{Right}$	$\mathbf{Z}_{Left}$	1364	0,749	-0,035	0,14	-0,043
$\mathbf{SCI}_{Right}$	$\mathbf{SCI}_{Left}$	1174	0,185	-0,738	0,733	-0,176
$\mathbf{TCI}_{Right}$	$\mathbf{TCI}_{Left}$	1662[b]	0,14	1,92	1,969	0,198
$\mathbf{S}_{Right}$	$\mathbf{S}_{Left}$	1264[b]	0,508	-0,085	0,178	-0,089
$\mathbf{Amp}_{Right}$	$\mathbf{Amp}_{Left}$	1308	0,538	-0,075	0,174	-0,082
$\mathbf{AmpSag}_{Right}$	$\mathbf{AmpSag}_{Left}$	1299	0,508	-0,082	0,178	-0,088
$\mathbf{AmpHor}_{Right}$	$\mathbf{AmpHor}_{Left}$	1397	0,885	-0,024	0,144	-0,02
$\mathbf{SagAng}_{Right}$	$\mathbf{SagAng}_{Left}$	1678	0,182	0,739	0,731	0,177
$\mathbf{TransAng}_{Right}$	$\mathbf{TransAng}_{Left}$	1134[b]	0,173	-1,907	2,072	-0,183
***Curvature**$_{Right}$*	***Curvature**$_{Left}$*	1767	0,071	3,54×10^-4	0,003	0,24

Note: W – value of the nonparametric Wilcoxon test (paired); p – probability; MD – mean difference; SED – standard error of the difference.

3.4.3. Condylar kinematics during left mediotrusion

In left mediotrusion, defined by the displacement of the mandible to the right, the left condyle functions as mediotrusive/swinging, and the right condyle as laterotrusive/working side. The biomechanical pattern is clearly differentiated: the right condyle has reduced translations, and the left condyle presents ample antero-inferior and medial excursions. Thus, X was only 0.37 ± 1.77 mm on the right, but 6.73 ± 2.97 mm on the left; Y was – 0.65 ± 0.72 mm on the right and 1.62 ± 1.09 mm on the left; Z was 0.95 ± 1.47 mm on the right and 7.02 ± 3.18 mm on the left. These values correspond to the classical model in which the balancing condyle slides forward, medially and inferiorly, and the working side condyle remains relatively stable, with predominantly rotational movement. The differentiation of roles is even more evident by the trajectory length and three-dimensional amplitude: |S| was 1.97 ± 1.56 mm for the right condyle and 10.01 ± 3.65 mm for the left condyle, and Amp was 2.23 ± 1.50 mm and 10.18 ± 3.68 mm, respectively. AmpSag and AmpHor reproduced the same contrast, showing that both the sagittal and mediolateral components contribute to the major excursion of the left condyle. In terms of angles, the balancing condyle had a more stable and physiological sagittal guidance (SCI_{Left} 46.10° ± 13.29°) compared to the working side, where SCI_{Right} was very dispersed (12.71° ± 40.84°). TCI, SagAng and TransAng showed the same difference in interpretability: the angles of the balancing condyle are more consistent, while the angles of the working side are destabilized by the reduced amplitude of movement. The curvature was closer to 1 in the left condyle (0.976 ± 0.062) than in the right condyle (0.856 ± 0.190), indicating a more rectilinear path of the mediotrusive condyle and a more arcuate trajectory of the working side condyle.

Table 5. Evaluation of right-left differences in standard and derived condylographic indices for left mandibular mediotrusion movement in patients with temporomandibular disorders and condylar malposition

		W	*p*	MD	SED	Effect size
X_{Right}	X_{Left}	48	<.001	-6,331	0,42	-0,966
Y_{Right}	Y_{Left}	67	<.001	-2,245	0,189	-0,953
Z_{Right}	Z_{Left}	82	<.001	-6,255	0,468	-0,943
SCI_{Right}	SCI_{Left}	574	<.001	-30,827	5,466	-0,597
TCI_{Right}	TCI_{Left}	1347	0,682	-1,952	4,486	-0,055
S_{Right}	S_{Left}	72	<.001	-8,25	0,5	-0,95
Amp_{Right}	Amp_{Left}	65	<.001	-8,121	0,49	-0,954
$AmpSag_{Right}$	$AmpSag_{Left}$	72	<.001	-8,216	0,499	-0,95
$AmpHor_{Right}$	$AmpHor_{Left}$	52	<.001	-5,292	0,342	-0,964
$SagAng_{Right}$	$SagAng_{Left}$	138	<.001	-69,479	7,958	-0,903
$TransAng_{Right}$	$TransAng_{Left}$	545	<.001	-90,763	14,392	-0,618
Curvature$_{Right}$	*Curvature$_{Left}$*	280	<.001	-0,077	0,023	-0,803

Note: W – value of the nonparametric Wilcoxon test (paired); p – probability; MD – mean difference; SED – standard error of the difference.

Wilcoxon analysis (table 5) confirmed a very pronounced asymmetry between the working and balancing condyle. The differences were major for X (right–left = – 6.33 mm; p < 0.001; r ≈ – 0.97), Y (–2.25 mm; p < 0.001; r ≈ – 0.95) and Z (–6.07 mm; p < 0.001; r ≈ – 0.94). In the same sense, |S| and Amp were approximately 8 mm higher on the left side, and AmpSag and AmpHor confirmed the predominance of translation of the mediotrusive condyle. The geometric angles SagAng and TransAng revealed very large differences, but these must be interpreted in the context of the reduced amplitude of the working-side condyle, which makes the angular calculation unstable. The curvature was significantly closer to the rectilinear path on the mediotrusive side, confirming the difference in pattern between the sliding of the balancing condyle and the short, more arcuate movement of the working-side condyle.

The derived indices of asymmetry summarize this functional contrast. ΔAmp was approximately –8 mm, and $IA_{Amp\pm}$ had large negative values, indicating that Amp_{Left} systematically exceeds Amp_{Right}; IA_{Amp} had a median of approximately 1.39, which corresponds to a relative asymmetry of over 100%. ΔSabs and IA_S showed the same profile, with the trajectory of the balancing condyle much longer than that of the working-side condyle. For SCI, ΔSCI indicated a steeper sagittal guidance on the mediotrusive side, although the normalized indices were influenced by extreme values. For TCI, the raw difference was not significant, and the normalized indices were highly numerically unstable; therefore, the transverse interpretation should be more cautiously related to ΔTCI and to individual inspection of the trajectories. Overall, left mediotrusive describes a major kinematic dissociation between the swinging and working-side condyles, much more evident than in opening and protrusion.

3.4.4. Condylar kinematics during right mediotrusion

In right mediotrusion, defined by the displacement of the mandible to the left, the right condyle is mediotrusive/swinging, and the left condyle is on the working side. The observed pattern mirrors the left mediotrusion: the right condyle shows large translations, and the left condyle has small excursions. The X coordinate was 7.00 ± 2.82 mm on the right and 0.35 ± 1.46 mm on the left, Y 1.09 ± 0.92 mm vs. – 1.14 ± 0.88 mm, and Z 6.59 ± 2.56 mm vs. 0.56 ± 1.57 mm. Thus, the mediotrusive condyle moves forward, medially, and inferiorly, while the working-side condyle remains relatively fixed, with limited translation and a predominantly rotational role.

The path length and three-dimensional amplitude confirmed the same dissociation: right-side S was 9.85 ± 3.16 mm, compared to 1.64 ± 1.51 mm on the left, and Amp was 9.94 ± 3.17 mm vs. 2.20 ± 1.49 mm. AmpSag and AmpHor indicated the simultaneous contribution of the anteroposterior, vertical, and mediolateral components to the major excursion of the right condyle. SCI_{Right} was more stable and physiological (42.55° ± 13.55°) than SCI_{Left} (26.52° ± 38.70°), and TCI was much more dispersed on the working side. SagAng and TransAng confirmed the clear orientation of the balancing condyle, while the condylar angles on the working side were difficult to interpret due to the short displacement vector. The curvature was almost rectilinear at the right condyle (0.987 ± 0.037), but less so at the left condyle (0.725 ± 0.256), suggesting a more arcuate trajectory of the working-side condyle.

Table 6. Evaluation of right-left differences in standard and derived condylographic indices for right mandibular mediotrusion movement in patients with temporomandibular disorders and condylar malposition

		W	*p*	MD	SED	Effect size
X_{Right}	X_{Left}	2800	<.001	6,4	0,381	0,965
Y_{Right}	Y_{Left}	2794	<.001	2,165	0,189	0,961
Z_{Right}	Z_{Left}	2785	<.001	6,123	0,416	0,954
SCI_{Right}	SCI_{Left}	1719	0,121	7,773	5,022	0,206
TCI_{Right}	TCI_{Left}	1203	0,242	-6,908	5,78	-0,156
S_{Right}	S_{Left}	2790	<.001	8,219	0,444	0,958
Amp_{Right}	Amp_{Left}	2789	<.001	7,754	0,418	0,957
$AmpSag_{Right}$	$AmpSag_{Left}$	2790	<.001	8,205	0,444	0,958
$AmpHor_{Right}$	$AmpHor_{Left}$	2818	<.001	5,277	0,309	0,978
$SagAng_{Right}$	$SagAng_{Left}$	2725	<.001	89,605	9,361	0,912
$TransAng_{Right}$	$TransAng_{Left}$	2312	<.001	96,81	16,106	0,622
Curvature$_{Right}$	*Curvature*$_{Left}$	2799	<.001	0,242	0,03	0,964

Note: W – value of the nonparametric Wilcoxon test (paired); MD – mean difference; SED – standard error of the difference.

Paired tests (Table 6) revealed a very large amplitude asymmetry, mirroring the left mediotrusion. The right condyle had significantly greater translations for X (+6.40 mm; W = 2800; p < 0.001; r = 0.97), Y (+2.17 mm; p < 0.001; r = 0.96), and Z (+6.12 mm; p < 0.001; r = 0.95). Path length and amplitudes were also significantly greater on the right side: |S| differed by +8.22 mm, Amp by +7.75 mm, AmpSag by +8.21 mm, and AmpHor by +5.28 mm, all with p < 0.001 and very large effects. The raw SCI and TCI did not differ significantly, due to the pronounced dispersion of angles on the working side, but SagAng, TransAng and Curvature clearly separated the two functional roles: the balancing condyle has a well-defined anteroinferior and mediotrusive direction, and the working-side condyle presents a more variable and curved pattern. The asymmetry indices for right mediotrusion describe a pattern consistent with the functional roles of the condyles. ΔAmp was approximately +7.75 mm, and $IA_{Amp\pm}$ had large positive values, indicating that the amplitude of the right balancing condyle is systematically greater than that of the working-side condyle. For the path length, ΔSabs was approximately +8.21 mm, and IA_S sgn and IA_S confirmed a very high relative asymmetry, with the right condyle practically taking over the translation of the movement. For SCI, the raw differences and the signed index did not indicate a robust directional bias, but IA_{SCI} confirmed the frequent presence of differences between condyles. For TCI, normalized indices suggested a relatively more pronounced transverse inclination of the working-side condyle, although clinical interpretation must take into account the sensitivity of TCI to small amplitudes and the ratio of rotation to translation. Therefore, lateral movements are the most informative for characterizing condylar asymmetries in patients with TMD. In contrast to opening and protrusion, where differences are small to moderate, mediotrusions highlight a clear functional dissociation between the balancing condyle, with large excursion and relatively rectilinear trajectory, and the working-side condyle, with short, predominantly rotational and more geometrically variable movement.

Synthesis of condylographic results and clinical implications. Three-dimensional condylographic analysis showed that, in the group of patients with TMD and condylar malposition, the opening and protrusion movements maintain relatively good bilateral symmetry for the anteroposterior and mediolateral components. The significant differences identified by Wilcoxon are, in these movements, of small absolute amplitude, of the submillimeter or several degrees order, with small to moderate effects. However, a discrete tendency of predominance of the left condyle in opening is outlined, especially for vertical descent, path length and three-dimensional amplitude, with typical relative asymmetries of approximately 8–12%. In mediotrusion, the picture is different and much more biomechanically expressive. The mediotrusive/balancing condyle, regardless of the side, describes ample anteroinferior and medial paths, with amplitudes and path lengths approximately four–five times greater than the condyle on the working side. The latter has short displacements, a predominantly rotational role, more unstable angles and more curved trajectories. The very large effects for the translation and curvature parameters confirm that this dissociation is not a marginal phenomenon, but the main feature of condylar kinematics in lateral movements. Particular attention should be paid to the interpretation of the normalized indices for TCI and, in some situations, for SCI. When the angular values are small, of opposite sign or obtained from very short displacement vectors, reduced denominators can generate disproportionate normalized values and strongly asymmetric distributions. For this reason, the IA_{TCI} indices should be treated mainly as exploratory parameters, and the clinical interpretation should be supported by the raw values, the differences in degrees and the analysis of individual trajectories. Overall, the results outline a picture in which patients with TMD and condylar malposition frequently present a certain degree of kinematic asymmetry, but this does not organize into a single uniform pattern. Rather, a spectrum of individual patterns is observed, in which the ratio of amplitude, path length, guidance angles, and curvature varies from one patient to another. Three-dimensional condylography thus provides a sensitive tool for quantifying TMJ function, but the interpretation of indices should be made in an integrated manner, together with symptomatology, clinical DC/TMD examination, and imaging data, not as isolated markers of the severity or type of dysfunction.

3.5. Analysis of the clinical, radiological and cephalometric profile according to skeletal class

Based on the results obtained, we performed a multivariate data exploration procedure to characterize clinical, radiological and cephalometric variables in relation to skeletal class membership. The grouping variable was represented by the skeletal class, structured into three clusters corresponding to classes I, II and III. The procedure was based on the catdes function from the FactoMineR package, applied in R-Studio. This procedure does not aim to build a predictive model nor demonstrate a causal relationship, but to identify variables that statistically characterize each subpopulation, by relating the values observed within each class to the general distribution of the entire batch.

For quantitative variables, the analysis includes two successive levels. The first level assesses the global link between the grouping variable and each quantitative parameter, expressed by the square correlation coefficient, which indicates the proportion of the indicator's variability that can be associated with skeletal class membership. The second level describes each class separately: the mean of the variable in the analyzed category is compared with the general mean of the group, and the deviation is expressed by the v-test. The interpretation of the v-test was carried out according to the sign, amplitude and the associated p-value. A positive v-test indicates that the mean of the parameter in the respective class is higher than the general mean of the group, while a negative v-test indicates a lower mean value. Absolute values close to or higher than 2, associated with $p < 0.05$, were considered suggestive of a statistically significant characterization of the class. However, these results should be interpreted descriptively-exploratory, the v-test does not express the clinical severity of an anomaly and should not be confused with the deviation from the orthodontic norm, but only indicates the extent to which an indicator is over- or underexpressed in a class compared to the entire sample. For categorical variables, the global relationship with skeletal class was verified by the χ^2 test, and the description of each class was achieved by identifying over- or underrepresented categories. Cla/Mod indicates the proportion of individuals belonging to the analyzed class among all individuals presenting the respective modality, Mod/Cla expresses the proportion of individuals in the analyzed class presenting that modality, and Global represents the frequency of that modality in the entire group. For cephalometric parameters, the statistical interpretation was completed by the orthodontic assessment of the deviation from the norm based on the existing norms for these parameters according to skeletal class.

3.5.1. Multivariate exploration of clinical indicators

Clinical indicators had a smaller and more fragmentary relationship with skeletal class than other parameters. In the global analysis of categorical variables, the clustering was significant for GAD-7 Item 2 Anxiety ($p = 0.015$) and CPI Pain Intensity Level ($p = 0.022$), suggesting that some components of anxiety symptomatology and pain grading vary between skeletal classes. However, the small number of global associations indicates that the DTM clinical picture is not directly and uniformly determined by skeletal class. In class I, the clinical profile is limited to a few point signals: GCPS item 2 Maximum pain intensity = 7/10 and JFLS-8 item 7 Phonation = 3/10 are over-represented, while GCPS item 3 Average pain = 6/10 is under-represented. This picture does not define a homogeneous clinical burden, but rather isolated features of pain or functional limitation within the group. In class II, the categories item 3 of PHQ-9 Sleep disorders (difficulty falling asleep, interrupted or prolonged sleep) =2 (more than a week) and item 6 of JFLS-8 Limitation on wide opening of the oral cavity (yawning) =1 were over-represented. These results may suggest the presence of a psycho-functional component in some of the patients with class II, but do not support a clinical profile robust enough to globally characterize this class by the severity of TMD. In class III, the clinical profile is more consistent. GAD-7 item 2 Anxiety = 2 (more than a week), Helkimo index Subclass A (IMM – mandibular mobility) = 5 (severely limited), JFLS-8 item 5 (swallowing) = 1, GCPS item 1 Current pain = 6/10, IMMA subclass (maximum opening of the oral cavity) = 5 (severely limited); JFLS-8 item 4 Wide opening of the oral cavity = 2/10 and PHQ-9 item 4 Fatigue/Lack of energy = 1 were over-represented. This profile suggests that, in the analyzed group, class III concentrates more signals of mandibular functional impairment and psycho-functional load, especially through the Helkimo/IMM, JFLS, GCPS and GAD indicators. Overall, the clinical indicators do not separate the skeletal classes with the same clarity as other indices. The relationship between skeletal class and clinical expression of TMD seems indirect and incomplete, which supports the multifactorial interpretation of temporomandibular symptomatology.

3.5.2. Multivariate exploration of CBCT radiological indicators of the condyle–fossa relationship

CBCT radiological indicators of the TMJ showed a weak association with skeletal class. In the global analysis of quantitative variables, the only parameter that reached statistical significance was the left condyle length (CoL), with a coefficient of determination of 0.088 and $p = 0.036$. This result indicates a statistical link present, but of low intensity, with skeletal class explaining only a small proportion of the variability in left condylar length. In class I, lower values of condylar length were observed bilaterally – CoL on the right (v-test = – 2.09; category mean = 6.258; global mean = 6.609; $p = 0.037$) and CoL on the left (v-test = – 2.38; category mean = 6.285; global mean = 6.785; $p = 0.017$). This finding can be interpreted as a point morphometric signal, not as a complex CBCT profile of class I. In class II, no significant quantitative radiological variables were identified in the description of the cluster. This is an important observation, as it shows that although class II is very well defined cephalometrically, it does not automatically translate into a specific pattern of CBCT condylar position or morphology in this group. In class III, increased values were identified for the value of the posterior joint space on the left PJS_{Left} (v-test = 2.18; $p = 0.029$), the logarithmic posterior-anterior ratio on the left (v-test = 2.05; $p = 0.041$) and the position of the condyle on the left (v-test = 1.96; $p = 0.049$). These results suggest some left peculiarities of the condyle-fossa relationship, related to the posterior space, the logarithmic P/A ratio and the condylar position. However, the signals are small, close to the threshold of significance, and predominantly unilateral. Therefore, CBCT parameters of the condyle–fossa relationship appear to have little dependence on skeletal class. Condylar malposition and joint space organization should be interpreted individually, in relation to clinical and functional data, not mechanically deduced from class I, II, or III.

3.5.3. Cephalometric indicators

The cephalometric analysis according to Downs-Graber highlights the strongest relationship between skeletal class and sagittal parameters of the maxillomandibular relationship. The highest values of the coefficient of determination were observed for ANB_{Left} (0.579), $Convexity_{Left}$ (0.559), AB–Facial plane $angle_{Left}$ (0.528), $Convexity_{Right}$ (0.495), ANB_{Right} (0.478) and AB–Facial plane $angle_{Right}$ (0.315), all with $p < 0.001$. Thus, the skeletal class is differentiated primarily by the sagittal intermaxillary ratio and the convexity of the profile. In class I, the only significant variables were $FH.SN_{Right}$ and $FH.SN_{Left}$, both with negative v-test and which from the point of view of orthodontic interpretation, are within the norm for this class. This indicates that, in relation to the global average, class I has slightly lower values of FH.SN, but without a clinically relevant deviation from the norm. Therefore, class I appears as a relatively balanced reference profile. In class II, ANB_{Left} and ANB_{Right} are strongly increased compared to the global average, confirming the sagittal relationship specific to class II. U1.Facial $plane_{Left}$ and U1.Facial $plane_{Right}$ are also statistically increased, but with significant orthodontic deviation, which supports the involvement of the dentoalveolar component. FH.SN bilaterally is increased and deviated from the norm, and $L1.MP_{Left}$ is statistically increased, but remains within the norm. In the opposite direction, U1.FH bilateral, L1.OP bilateral, U1.SN bilateral, SNB_{Left}, AB–Facial plane angle bilateral and Convexity bilateral are reduced compared to the global average. Among these, U1.SN, AB–Facial plane angle and Convexity are clinically relevant by deviation from the norm, confirming the association of class II with sagittal and dentoalveolar changes. In class III, the opposite profile is observed. ANB_{Right} and ANB_{Left} are strongly reduced, with very high deviation from the norm, which reflects the sagittal relationship specific to class III. In the same cluster, Convexity bilateral, AB–Facial plane angle bilateral, L1.OP bilateral, Facial angle bilateral, SNB_{Left}, U1.SN bilateral and U1.FH bilateral are increased compared to the global average, while $Yaxis_{Right}$, $FH.OP_{Right}$, L1.MP bilateral and U1.Facial plane bilateral are reduced. The most marked deviations occur for ANB and U1.Facial plane, which indicates not only the modification of the skeletal base, but also important dentoalveolar compensations.

In the cephalometric analysis according to Kim, all four evaluated variables were significantly associated with skeletal class: $APDI_{Left}$, $APDI_{Right}$, ODI_{Right} and ODI_{Left}. APDI had the highest differentiation power, especially for separating class III from the other classes. In class II, ODI_{Left} and ODI_{Right} are increased compared to the global average, while $APDI_{Left}$ and $APDI_{Right}$ are reduced. All these variables are statistically significant, but marked as falling within the norm in the orthodontic interpretation. They characterize class II within the group, without necessarily indicating major deviations from external norms. In class III, $APDI_{Left}$ and $APDI_{Right}$ are significantly increased, and in the orthodontic interpretation they are marked with deviation from the norm. At the same time, ODI_{Left} and ODI_{Right} are reduced compared to the global average. This configuration supports the differentiation of class III through a distinct sagittal profile, APDI being one of the clearest indicators of class III membership in the analyzed set.

Cephalometric analysis according to Sato completes the interpretation by integrating skeletal relationships, occlusal planes and dentoalveolar components. The overall association with skeletal class is significant for AB.MP bilateral, $A.6_{Left}$, A.P bilateral, $OP.MP.PP.MP_{Right}$, $A'–6'.A.P_{Left}$, $A.6_{Right}$, OPP_{Left}, $FH.OPA_{Right}$ and $Mx.OPA_{Right}$. In class I, $OP.MP.PP.MP_{Right}$ and $Mx.OPA_{Right}$ are increased compared to the global average, but both are marked as being within the norm. These results have internal statistical differentiation value, not clinical deviation. In class II, AB.MP bilateral, A.P bilateral, A.6 bilateral and $FH.OPA_{Right}$ are increased compared to the global average, and $Mx.OPA_{Right}$ and $OP.MP.PP.MP_{Right}$ are reduced. Among them, $FH.OPA_{Right}$ is marked with deviation from the norm, which indicates the involvement of the occlusal plane in the class II profile. The other variables are mostly within the norm, but remain statistically relevant for the description of the cluster. In class III, the Sato profile is more complex. $Mx.OPP_{Left}$ is increased, but within the norm. In contrast, $FH.PP_{Right}$ is reduced and marked with significant deviation, and the indicators $U1.AB_{Left}$ and $U1.AB_{Right}$ are reduced with extreme deviation from the norm. $U1.AB_{Left}$ and $U1.AB_{Right}$ are also reduced and marked with deviation. In addition, $FH.OPA_{Right}$, $A.6_{Right}$, OPP_{Left}, $A'–6'.A.P_{Left}$, $A.6_{Left}$ and AB.MP bilateral are reduced compared to the global average. This profile shows that in class III skeletal changes, changes in occlusal planes and significant dentoalveolar compensations are combined, especially at the level of the upper incisors.

Cephalometric analysis according to Slavicek confirms the importance of convexity parameters and dentoalveolar indicators. The strongest links with skeletal class were observed for $Convexity_{Left}$ and $Convexity_{Right}$, followed by Lip embrasure, Facial depth, Upper incisor vertical and Facial axis. In class I, Lip $embrasure_{Right}$ and Upper incisor $vertical_{Right}$ are reduced compared to the global average, but with low clinical relevance or inapplicability in orthodontic interpretation. Thus, these results should be considered statistical signals, not defining elements of an anomaly. In class II, $Convexity_{Left}$ and $Convexity_{Right}$ are significantly increased and marked with significant deviation, confirming the convex character of the class II profile. Bilateral lip embrasure and bilateral upper vertical incisor are also increased, and left facial axis is reduced, but within the norm. This ensemble supports the association of class II with convexity changes and vertical dentoalveolar adaptations. In class III, left facial depth and right facial depth are increased, indicating a more anterior facial profile. In contrast, left upper vertical incisor, left lip embrasure and bilateral convexity are reduced. Right convexity and left convexity have very marked negative v-test and very marked deviation, confirming the inversion of the convexity profile compared to class II. This result is consistent with the changes observed by Downs-Graber and Kim.

Synthesis of the results of the multivariate exploration of the collected data. The evaluation results show a clear hierarchy of the discriminatory capacity of the analyzed variables. Cephalometric parameters differentiate the skeletal classes most robustly, clinical indicators have a weaker and more fragmentary association, and CBCT radiological parameters of the TMJ present only point signals. Class I has the most discrete differential profile. It is characterized by a few isolated clinical signals, by slightly reduced condylar length bilaterally and by minor cephalometric differences, generally within the norm. This class can be interpreted as a relatively balanced group, without major morphological deviations. Class II is defined mainly cephalometrically, by increased ANB, modification of convexity and AB–FP ratios, as well as by dento-alveolar adaptations of the incisors and modifications of the occlusal planes. Clinically and radiologically, class II does not present an equally distinct profile. Class III has the most complex profile. Cephalometrically, it is characterized by reduced or negative ANB, increased APDI, changes in SNB/Facial angle/Facial depth, reduction of some indicators of occlusal planes and important dentoalveolar deviations, especially of the upper incisors. Clinically, class III concentrates more signals of functional limitation and psycho-functional load, and radiologically presents some peculiarities of the condyle-fossa ratio on the left side. Consequently, the skeletal class provides an essential morphological framework for interpreting the patient, but does not fully explain the TMD picture. Cephalometric parameters describe the craniofacial architecture and dentoalveolar compensations, while clinical parameters and CBCT show that the expression of temporomandibular dysfunction remains influenced by functional, muscular, articular and psycho-behavioral factors. Therefore, the final interpretation must be integrative, by correlating the skeletal class with DC/TMD data, functional assessment, pain indicators, psycho-emotional status and individualized analysis of the TMJ.

GENERAL CONCLUSIONS

1. Patients with TMD and condylar malposition present a complex clinical and functional picture, dominated by the myofascial component and moderate impairment of the stomatognathic system function. Standardized palpation frequently revealed tenderness in the masseter, retromandibular region and periarticular areas, while spontaneous pain in eccentric movements was rarer, being reported in approximately 15–24% of patients, with significant differences compared to the absence of pain ($p < 0.001$). The mean values of the clinical indices indicated moderate functional and pain severity (TMI = 0.48, JFLS-8 = 1.46 and CPI = 42.44), associated with a tendency to increase levels of anxiety and depression.
2. CBCT evaluation demonstrated an increased frequency of sagittal condylar malposition, predominantly anterior, against the background of a bone structural asymmetry. According to the Pullinger–Hollender index, 48.0% of the right condyles and 45.3% of the left condyles were anteriorly displaced, 41.3–42.7% were centered, and 10.7–12.0% were posteriorly displaced. The vertical position was relatively stable, with over 80% of the joints having superior space within physiological limits, although 12–17% had inferiorly displaced condyles. The D_{Ikeda} index showed that only 32–36% of the joints approached the theoretical model, while 25–28% had moderate deviations and 38–40% had marked deviations. Right–$_{Left}$ differences were significant for glenoid fossa depth (VHF, W = 1906, $p < 0.001$), articular eminence slope (AEI, W = 1914, $p = 0.005$), and condyle height (CoH, W = 868, $p = 0.005$), indicating a deeper fossa and a more sloped eminence on the right, associated with a shorter condyle.
3. Cephalometric evaluation based on Downs-Graber, Sato, Slavicek and Kim analyses revealed the predominance of skeletal classes I and II, with a low frequency of class III (10.33%), without identifying a unique or dominant craniofacial pattern for patients with TMD and condylar malposition. The group presented dentoskeletal heterogeneity, with the association of hypo- and hyperdivergent patterns, dental compensations of variable intensity and discrete mandibular and dentoalveolar asymmetries. The statistically significant differences for the gonial angle, L1–MP, FH–MP and the position of point A relative to the A–P line had reduced amplitude, but suggested the existence of lateral imbalances with possible functional relevance in the context of TMD and condylar malposition.
4. Three-dimensional condylography showed that the kinematic expression depends on the type of movement tested. Opening and protrusion showed relatively good bilateral synchronization, with minimal or no clinically significant differences: in protrusion, SagAng was similar between sides (42.78° ± 11.33° right vs. 42.46° ± 12.28° left; W = 1678, $p = 0.182$), and the curvature index was almost identical (0.995 vs. 0.993; W = 1767, $p = 0.071$). In contrast, mediotrusions revealed marked kinematic dissociation between the balancing condyle and the working-side condyle, with mean differences of 6–8 mm for X, Y, and Z translations and very large effects ($|r| > 0.9$). The asymmetry indices IA_{Amp}, IA_{SCI} and IA_{TCI} were significantly increased in mediotrusion ($p < 0.001$), and IA_{Amp} and IA_{SCI} differed significantly from 0 (W = 2850, $p < 0.001$, $r = 1.00$), confirming the major role of lateral movements in highlighting condylar dysfunction.
5. The integration of clinical, imaging, cephalometric and condylographic data confirms that condylar malposition in patients with TMD cannot be interpreted in isolation, based only on symptomatology or a single investigation. The DC/TMD protocol highlighted the pain, functional and psycho-emotional burden; CBCT documented the prevalence of previous malpositions, deviations from the Ikeda model and morphological asymmetries; and condylography demonstrated functional dissociation of lateral movements. These results support the hypothesis that condylar malposition represents a relevant structural-functional component of TMD, the interpretation of which requires the correlation of clinical, imaging and functional data in the individual context of the patient.

PRACTICAL RECOMMENDATIONS

1. Given the significantly elevated scores on JFLS-8, CPI, GAD-7 and PHQ-9, it is recommended that the evaluation of patients with TMD consistently include both the assessment of pain and functional limitations, as well as the screening of anxiety and depression. Early recognition of these components allows orientation towards interdisciplinary interventions (psychology, pain medicine), reducing the risk of chronicity and failure of strictly occlusal or orthopedic treatments.
2. The high prevalence of anteriorized condyles and moderate or marked deviations from the Ikeda model

indicate that condylar malposition is frequent in this group of patients. The interpretation of these results should be made in the context of clinical symptoms and other indices, avoiding overdiagnosis or invasive interventions based exclusively on the apparently eccentric position of the condyle. It is recommended to consistently use the same indices (Pullinger–Hollander, D_{Ikeda}, vertical and coronal indices) and report them in a comparable manner, to facilitate monitoring over time and comparison with other studies.

3. The very large differences in translation and curvature between the working and balancing condyle in mediotrusions show that an important part of the joint load is related to the specific way in which the joint is used in lateral movements. 3D condylography allows the identification of these functional dissociations and provides useful information for the design and validation of repositioning devices, for occlusal adjustments and for the planning of orthodontic and prosthetic interventions. The use of standardized asymmetry indices (IA_{Amp}, IA_{SCI}, IA_{TCI}) and curvature-derived parameters is recommended in the clinical interpretation of condylar kinematics.

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LIST OF PUBLICATIONS AND PARTICIPATIONS IN SCIENTIFIC FORUMS

of Mr. Cazacu Igor, made for the doctoral thesis in medical sciences,
on the topic "Clinical, imaging and functional features of condylar malposition in patients with temporomandibular disorders",
Doctoral program 323.01 – Dentistry,
doctoral supervisor Valeriu Fala, dr. hab. şt. med., prof. univ., m.c. AŞM

SCIENTIFIC PAPERS

- **rticles in scientific journals abroad:**
  - ✓ **articles in ISI, SCOPUS journals and other international databases recognized by ANACEC**
    1. **Cazacu I.**, Zumbreanu I. Correlation of temporomandibular joint disorders with inclination of the upper posterior occlusal plane in class II patients. In: *European Journal of Orthodontics*. 2019, 41(5):e48. ISSN 1460-2210. https://www.ovid.com/journals/ejort/abstract/00003681-201910000-00119 (**IF: 2.7**)
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2. Fala V., Gribenco V., Pintea V., **Cazacu I.**, Nistor L., Bolun R., Forna N. Directed rehabilitation of patients with signs of tooth wear. In: *Romanian Journal of Oral Rehabilitation*. 2015, 7(1): 15-27. ISSN 2066-7000. https://ibn.idsi.md/sites/default/files/imag_file/DIRECTED-REHABILITATION-OF-PATIENTS-WITH-SIGNS-OF-TOOTH-WEAR.pdf

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- **Articles in journals in the accreditation process**

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26. Tighineanu M., **Cazacu I.**, Bordeniuc G., Fala V. Implicații gnatologice în tratamentul ortodontic la pacienții cu disfuncții temporomandibulare. *Congresul de Medicină Dentară „Impactul tehnologiilor digitale în stomatologia contemporană”*, 14-16 martie 2024, Iași, România
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✓ **national**

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✓ **Innovator certificates:**

37. Fala V., **Cazacu I.**, Tighineanu M. Metoda de evaluare a indicelui vertical de poziție a condilului mandibular la pacienți cu dereglări temporomandibulare. Certificat de inovator nr. 6431 (data eliberării 19.01.2026)
38. Fala V., **Cazacu I.** Metoda de evaluare a centricității în plan coronal a condilului mandibular la pacienți cu dereglări temporomandibulare. Certificat de inovator nr. 6433 (data eliberării 20.01.2026)
39. Fala V., **Cazacu I.** Metoda de evaluare a raportului mediolateral în plan coronal a condilului mandibular la pacienți cu dereglări temporomandibulare. Certificat de inovator nr. 6434 (data eliberării 20.01.2026)
40. Fala V., **Cazacu I.** Metoda de evaluare a devierii în plan sagital a condilului mandibular la pacienți cu dereglări temporomandibulare. Certificat de inovator nr. 6435 (data eliberării 20.01.2026)
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LIST OF ABBREVIATIONS

A′–6′ – linear distance between A′ and landmark 6′;
A′–6′/A′–P′ – maxillary molar position ratio;
AEH – articular eminence height;
AEI – articular eminence inclination;
AJS – anterior joint space;
Amp – net three-dimensional amplitude of condylar displacement;
AmpHor – amplitude of condylar trajectory in horizontal projection;
AmpSag – amplitude of condylar trajectory in sagittal projection;
ANB – angle between NA and NB;
AP – anterior/posterior ratio AJS/PJS;
APDI – Anteroposterior Dysplasia Indicator;
CADIAS – Computer Aided Diagnosis in Axiography and Cephalometry;
CBCT – cone beam computed tomography;
CCI – coronal centricity index;
CF – Combination Factor;
CoH – mandibular condyle height;
CoL – mandibular condyle width;
CoW – mandibular condyle length;
CPI – Characteristic Pain Intensity;
DC/TMD – Diagnostic Criteria for Temporomandibular Disorders;
Di – Clinical Dysfunction Index component of the Helkimo index;
D_{Ikeda} – Ikeda Deviation Index;
FH – Frankfort Plane;
GAD-7 – Generalized Anxiety Disorder-7 – 7-item questionnaire for generalized anxiety;
GCPS – Graded Chronic Pain Scale;
IA – Asymmetry Index;
IQR – interquartile range;
JFLS-8 – Jaw Functional Limitation Scale – 8-item short version;
L1 – lower central incisor;
LC – lateral cephalogram;
LJS – lateral joint space;
MD – mean difference;
MJS – medial joint space;
ML – medial/lateral MJS/LJS ratio;
MMI – Mandibular Mobility Index;
MP – mandibular plane;
MRI – magnetic resonance imaging;
ODI – Overbite Depth Indicator;
OP – occlusal plane;
PHQ-9 – Patient Health Questionnaire-9 – 9-item depression questionnaire;
PJS – posterior joint space;
PP – palatal plane;
$r_{biserial}$ – rank biserial correlation;
S – total length of the condylar trajectory;
SagAng – angle of general direction of condylar trajectory in sagittal plane;
SCI – sagittal condylar inclination – sagittal condylar guidance angle;
SCP – sagittal condylar position – index of condylar position in sagittal plane;
SD – standard deviation;
SE – standard error of the mean;
SJS – superior joint space;
SN – Sella–Nasion line;
SNA – Sella–Nasion angle–point A;
SNB – Sella–Nasion angle–point B;
TCI – transverse condylar inclination / Bennett guidance angle;
TMD – temporomandibular disorders;
TMI – Temporomandibular Index;
TMJ – temporomandibular joint;
TransAng – angle of general direction of condylar trajectory in horizontal plane;
U1 – upper central incisor;
VHF – vertical height of the glenoid fossa;
X – anteroposterior coordinate;
Y – mediolateral coordinate;
Z – vertical coordinate;
ΔAmp – difference between the 3D amplitudes of the two condyles, in mm;
ΔSabs – difference between the absolute lengths of the condylar trajectories, in mm;
ΔSCI – difference between the sagittal guidance angles, in degrees;
ΔTCI – difference between the transverse guidance angles, in degrees.

ANNOTATION

Cazacu Igor

"CLINICAL, IMAGING AND FUNCTIONAL FEATURES OF CONDYLAR MALPOSITION IN PATIENTS WITH TEMPOROMANDIBULAR DISORDERS"

Doctoral thesis in medical sciences, Chisinau, 2026

Thesis volume. The thesis is presented on 129 pages of basic text and includes an introduction, 4 chapters, general conclusions and practical recommendations. The bibliography includes 293 sources. The work is completed with annexes, a list of publications and participation in scientific forums, a statement on assuming personal responsibility, annotation in Romanian/English and the author's CV. The basic text is illustrated with 24 tables, 2 figures and 13 formulas.

Field of study: 323.01 – Dentistry

Aim of the thesis: characterization of the clinical, functional, imaging-structural and kinematic expression in patients with temporomandibular disorders and condylar malposition, in order to identify specific characteristics.

Study objectives: 1. Evaluation of the clinical picture and functionality of patients with TMD and condylar malposition based on the DC/TMD protocol, regarding the distribution of orofacial pain, the degree of functional limitation, the intensity and chronicity of pain and indicators of psycho-emotional impairment. 2. Qualitative and quantitative imaging examination of the morphology of the condyle, glenoid fossa and articular eminence, as well as the distribution of sagittal and coronal joint spaces in patients with TMD and condylar malposition. 3. Highlighting the cephalometric particularities of the investigated group, based on the distribution of skeletal classes and analyses by authors (Downs-Graber, Sato, Slavicek, Kim). 4. Three-dimensional assessment of mandibular kinematics in opening, protrusion and mediotrusion by condylography, using both standard indices (X, Y, Z displacements, SCI, TCI) and derived parameters, to assess the organization of condylar movements. 5. Integrated analysis of clinical, imaging and functional data in patients with temporomandibular disorders and condylar malpositions.

Scientific novelty and originality: An element of novelty consists in the integrated evaluation, on the same group of patients with TMD and condylar malpositions, of the condyle–fossa relationship by CBCT, condylar kinematics by 3D condylography, and the clinical, functional and psychobehavioral profile by DC/TMD and Axis II instruments. Morphometric variations of the glenoid fossa, articular eminence, condyle and joint spaces were identified, with deviations of linear and composite indices, including D_{Ikeda}, from conventionally centric reference values, revealing the multidimensional expression of condylar malposition in the sagittal, vertical and coronal planes. The originality of the study is supported by the definition and application of derived condylographic indices of amplitude, orientation and curvature, calculated separately for the balancing condyle and the working-side condyle. Stable groups of sagittal and transverse variables were identified, including the SCI–SagAng and TCI–TransAng pairs, as well as kinematic differences between the balancing and working-side condyles, the latter showing greater numerical variability during movements with reduced excursion. The study also reveals the association of condylar malposition with high pain and functional burden, mobility limitations, extensive muscle tenderness and increased GAD-7/PHQ-9 scores, outlining a complex clinical-imaging and psychobehavioral profile.

Applicative value. By configuring a unified protocol combining DC/TMD Axis I and Axis II, additional clinical indices, CBCT assessment of the condyle–fossa relationship and 3D condylography, the study provides a clinically applicable framework for diagnosing and monitoring patients with TMD and condylar malposition. The described parameters can be integrated into standardized examination forms and follow-up protocols, facilitating longitudinal comparison of cases and objective assessment of treatment response. CBCT and condylographic indices may serve as references for imaging and functional interpretation, including in cases of condylar repositioning guided by splints or other devices. Data on psychological burden and functional limitations may guide referral to specialists in orofacial pain, psychology or rehabilitation medicine, supporting interdisciplinary management of these patients.

Implementation of results: The results were consolidated through 5 innovator certificates (methods/indicators for assessing condylar position and kinematics) and implemented in the clinical activity of the "OrtoClinic" SRL Dental Clinic and the Department of Interdisciplinary Dentistry and Oral Rehabilitation of Nicolae Testemitanu State University of Medicine and Pharmacy.

Keywords: temporomandibular disorders, condylar malposition, interdisciplinary dentistry, condylography, cephalometry, functional diagnosis, DC/TMD, CBCT, temporomandibular joint, condyle–fossa relationship.

CAZACU IGOR

CLINICAL, IMAGING AND FUNCTIONAL FEATURES OF CONDYLAR MALPOSITION IN PATIENTS WITH TEMPOROMANDIBULAR DISORDERS

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