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Planning Orthopedic Treatment for Patients with Occlusal-Articulation Disorders and Functional Disorders of the Dentofacial System or Pain Syndrome Associated with Temporomandibular Joint Dysfunction

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Abstract

The number of patients with temporomandibular joint (TMJ) dysfunction increases annually. This trend is largely attributed to the prolonged asymptomatic progression of these disorders and the absence of organic changes in the early stages of the disease, both clinically and radiographically. Scientific perspectives on the etiology and pathogenesis of TMJ dysfunctions remain significantly contradictory. This article highlights the following methodological approaches: Integration of modern diagnostic methods: utilization of cone-beam computed tomography to assess changes in the TMJ, synchrography to study the function of masticatory muscles and the imbalance in their activity depending on occlusal-articulatory relationships before and after prosthetic treatment; Personalized approaches: development of individual treatment protocols based on detailed multidimensional analysis and the creation of predictive models for treatment strategy selection during the preparatory and occlusal therapy stages (decision tree methodology). These protocols are adapted to the severity of disorders in patients and leverage modern digital technologies in dentistry, including the application of CAD/CAM technologies for creating permanent and temporary prosthetic constructions and Digital Smile Design methodology for harmonizing the aesthetic and functional aspects of treatment.

Keywords: temporomandibular disorders; cone-beam computed tomography of the temporomandibular joint; occlusion; occlusal therapy; orthopedic treatment.

Introduction. TMJ frequently comes into focus for dental practitioners. Due to its complex anatomical structure, this joint is prone to various pathologies, including dysfunction [1]. Over the past few decades, temporomandibular disorders (TMD) have become the second most common musculoskeletal conditions. According to some researchers, functional disorders of the TMJ account for 80% of all joint pathologies. The term "temporomandibular disorders" is a broad concept encompassing a group of conditions characterized by dysfunction of the TMJ and/or masticatory muscles. In their efforts to identify the etiology and pathogenesis of TMD, clinicians and researchers have studied occlusion for decades as one of the primary causes of TMD due to the anatomical relationship between tooth positioning and TMJ function [2].

Despite numerous studies on the diagnosis and treatment of TMJ disorders, they remain one of the most challenging and unresolved issues in orthopedic and surgical dentistry [3]. The relevance of this problem is underscored by the high prevalence of this pathology, the annual increase in patient visits, the variety of clinical manifestations, and the significant challenges in diagnosis and treatment, which necessitate a multidisciplinary approach.

Objective. To propose a personalized algorithm for orthopedic treatment of occlusal-articulatory disorders associated with TMJ dysfunction based on mathematical models of multidimensional machine learning analysis and to evaluate its effectiveness.

Materials and Methods. The study of patients with occlusal disorders and functional disturbances of the masticatory system involved an evaluation of the topography and localization of dental arch and crown defects, as well as an analysis of functional occlusion using the digital T-Scan NOVUS system (USA). Neuromuscular characteristics of the dentofacial system were assessed via synchrography using the Teethan XT4 device (Italy). Pain intensity was measured using a visual analog scale (VAS) [11], and intra-articular relationships were evaluated with CBCT of the TMJ, conducted on a MyRay Hyperion X9 PRO device.

A total of 150 patients aged 20 to 65 years were examined and treated. The orthopedic treatment plan for patients with occlusal-articulatory disorders accompanied by intra-articular disturbances, with or without pain syndrome, aimed to achieve harmonious TMJ and masticatory muscle function by repositioning the mandible and creating new, adapted occlusal-articulatory relationships.

Individual treatment protocols were developed based on the results of detailed uni- and multidimensional analysis and the creation of predictive models for pain syndrome development associated with TMJ dysfunction (random forest method) and treatment strategy selection during the preparatory and occlusal therapy stages (decision tree methodology). These protocols were adapted to the severity of patients' disorders and leveraged modern digital dental technologies, including CAD/CAM for fabricating permanent and temporary prosthetic constructions and Digital Smile Design for harmonizing aesthetic and functional treatment outcomes.

Statistical analysis was performed using the R statistical programming environment (r-project.org, version 4.0). The main methods used included univariate analysis (Chi-squared test, paired Student's t-test) and the development of a hierarchical classification model ("decision tree") to determine the necessity and type of therapeutic measures. The model demonstrated sensitivities of 79% for preparatory measures and 90% for occlusal therapy selection.

The study was conducted in compliance with ethical principles outlined in the Declaration of Helsinki (2000) and the Council of Europe Convention on Human Rights (1997). Patients provided informed voluntary consent to participate in the study.

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Results and Discussion. A stepwise algorithm for orthopedic treatment was developed, which included:

- Initial preparatory measures or their combination, depending on the clinical situation in the oral cavity and the chosen option for occlusal therapy of TMJ dysfunction at the first stage of orthopedic treatment.
- Personalized application of occlusal therapy for TMJ dysfunction.
- Establishment of the central jaw relation and interalveolar height, followed by creating a prototype of permanent restorations.
- Permanent prosthetics.

The selection of preparatory measures or their combinations depended on the feasibility of orthopedic treatment for TMJ dysfunction and existing issues in the oral cavity. The primary goal was to establish adequate support for removable or fixed orthopedic constructions needed for occlusal therapy. This stage included:

- Replacement of dental arch defects.
- Restoration of crown defects with temporary direct and indirect restorations.
- Elimination of inflammatory foci in the oral cavity.
- Tooth extraction where necessary.
- Selective grinding of supra-contacts.
- Removal of previous restorations with inadequately designed occlusal surfaces.

A multidimensional machine learning analysis—specifically, a decision tree algorithm—was applied to refine the orthopedic treatment algorithm (Figure 1). This mathematical model predicted the necessity and type of preparatory measures required, based on artificial intelligence. Prior to modeling, the most significant predictors were ranked using univariate analysis. The proposed decision tree model for preparatory measures comprised three levels and demonstrated a classification accuracy of 79%. At the top of the hierarchy, the presence of dentofacial deformities emerged as the most significant predictor. The terminal nodes (leaves) represented specific decisions, categorized as follows: No need for special preparatory measures; Selective grinding;

Restoration of crown defects or removal of previous restorations with inadequately designed occlusal surfaces. The branches of the tree consisted of nodes (subsets) where predictors were ranked according to their permutation importance—i.e., their contribution to the model's classification accuracy. Predictors at the second level included the presence of direct or indirect restorations with inadequately designed occlusal surfaces and multiple crown defects. At the third level, predictors included generalized or localized excessive wear of the occlusal surfaces. Considering the potential for tree development until reaching a homogeneous node (branch) based on the Gini index values for each branch, we opted to halt tree construction at the third level. This achieved a classification accuracy of 79% with Gini index values at the leaves ranging from 0.0 to 0.512.

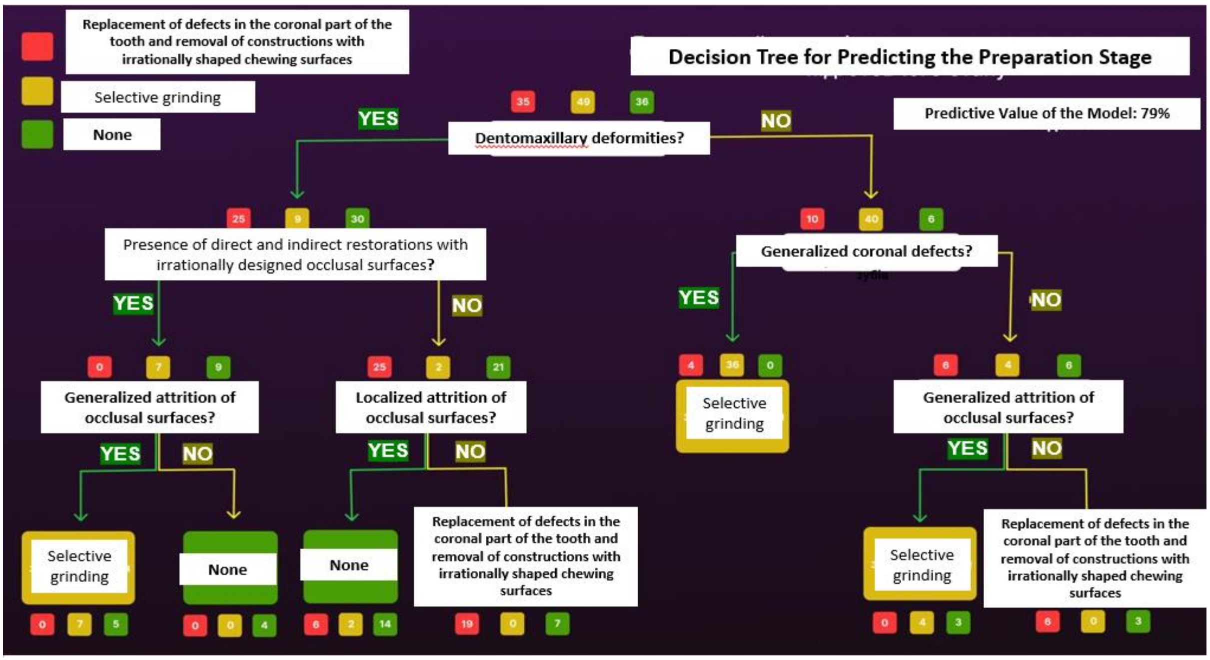

Figure 1. Predictive Model for Selecting the Option of Preparatory Measures, Developed Using a Machine Learning Method.

The next stage involved occlusal therapy, aimed at repositioning the joint heads within the articular fossae, stabilizing the mandible, and achieving relaxation and normalization of the masticatory muscles. This stage also facilitated the gradual formation of a physiological myotatic reflex and balanced, harmonious functioning of the TMJ and masticatory muscles. The therapy entailed the sequential modification and restoration of physiological mandibular movements through the creation of new occlusal-articulatory relationships. This was achieved by guiding mandibular movements along the inclined planes created on occlusal devices, with dynamic adjustments such as grinding and remodeling the occlusal surfaces of splints or Mock-up devices (altering centric and eccentric contacts between mandibular teeth and the splint or Mock-up). Similar to the preparatory stage, a predictive model for selecting the occlusal therapy method was developed using a machine learning algorithm—the decision tree method (Figure 2). The created model consisted of three levels and demonstrated a predictive power of 90%. The most significant predictor was pathological bite types. At the second level, predictors included restricted mouth opening and masticatory muscle hypertrophy. At the third level, predictors included persistent functional distal displacement of the mandible, pathological joint sounds, and pain syndrome duration exceeding six months. The terminal nodes (leaves) classified the treatment options into splint therapy and complete or partial Mock-up therapy.

Tree construction was finalized at the third level upon reaching a node homogeneity (Gini index) of 0.0 to 0.159 for the leaves.

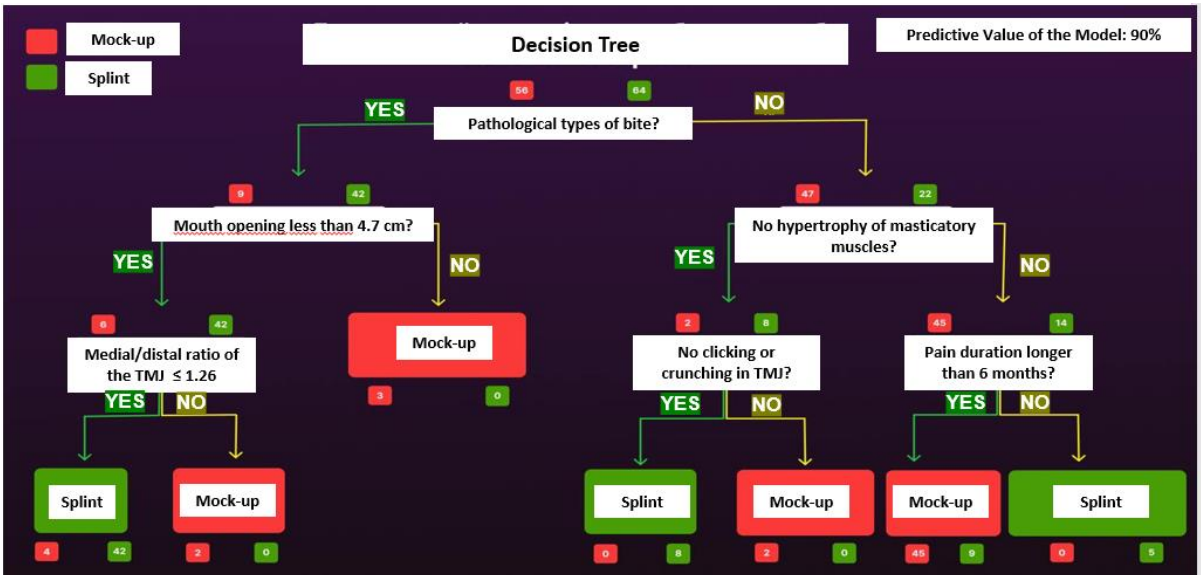

Figure 2. Predictive Model for Selecting the Occlusal Therapy Option, Developed Using a Machine Learning Method.

The next stage, depending on the clinical situation and the chosen occlusal design, involved the construction of temporary fixed restorations. These were made from aesthetic milled composite resins such as PPMA or through direct methods by taking impressions of printed models, filling them with Protemp 4, and construcating the restorations directly in the oral cavity. These temporary restorations were then adhered or temporarily fixed for a period ranging from 2 weeks to 2 months. The key criterion for the effective transfer of occlusal-articulatory relationships from 3D models to temporary restorations was the identical positioning of contact points on both the models and in the oral cavity.

The final stage involved definitive prosthetic treatment, which included either total or partial restorations. Materials used ranged from press ceramics to zirconium dioxide or combined approaches (direct and indirect restorations). Fixed aesthetic restorations were constructaed using digital techniques, except for direct restorations, while leveraging previously modeled designs in EXO-CAD. Comprehensive quality control was performed at this stage, including condylography, CBCT and synchrography to ensure optimal functional and aesthetic outcomes.

Results of Clinical Examination Following Orthopedic Treatment. During dental examinations conducted after orthopedic treatment, functional stable displacement of the mandible was detected in 76 patients (50.66%), which represents a 40% reduction compared to pre-treatment data ($p \leq 0.05$). Notably, significant displacement was not observed post-treatment. These findings were corroborated by CBCT evaluations. Specific metrics included the mesial/distal and lateral/medial joint space ratios for each joint, as well as the ratio of the superior joint space to the mean value of the mesial and distal spaces, which indirectly indicated deficits in interalveolar height. Key outcomes included: 1. Bilateral distal displacement of the mandibular condyles was observed in 76 patients (50.68%), a reduction of 18% from the baseline of 103 patients (68.67%). Furthermore, no significant mandibular displacement was present post-treatment compared to the 48.00% (72 observations) recorded prior to treatment; 2. Unilateral distal displacement of the mandibular condyles was noted in 4 patients (2.67%), which is three times lower than the pre-treatment rate of 32 patients (21.33%); 3. Reduction in interalveolar height in at least one TMJ was absent in all patients post-treatment, compared to 130 patients (86.67%) before treatment; 4. CBCT in coronal projection showed that absence of lateral displacement in any joint was confirmed in 114 patients (76.00%) post-treatment, compared to only 2 patients (1.33%) prior to treatment, of the 44 patients (29.33%) with corpus mandibular displacement to the right before treatment, only 17 patients (11.40%) retained this displacement post-treatment. Additionally, corpus displacement to the left was identified in only 1 patient (0.66%), residual unilateral lateral condylar displacement persisted in 18 patients (12.00%).

These results highlight significant improvements in mandibular and TMJ alignment and function, with a substantial reduction in pathological displacements and interalveolar height deficits following the implemented orthopedic treatment.

Analysis of Neuromuscular and Occlusal Characteristics. Using synchrography, the neuromuscular and occlusal characteristics of patients' dentofacial systems were analyzed. The asymmetry index of muscle pairs between the right and left sides showed statistically significant differences post-treatment: Right side asymmetry: 8.93, 95% CI [9.90–10.96]; Left side asymmetry: -7.46, 95% CI [-9.46 – -5.44]. The mean ASIM index values were 14.76 (post-treatment) compared to 23.69 (pre-treatment) on the right side and -10.97 (post-treatment) compared to -18.43 (pre-treatment) on the left side. The true mean difference between "pre-treatment" and "post-treatment" values lies within the range of -9.46 to -5.44 with 95% probability, indicating a significant reduction in asymmetry, particularly on the left side. Since the confidence interval lies entirely below zero, the findings confirm a substantial decrease in asymmetry after treatment. When compared to the reference values outlined in the device's manual (-10% < ASIM < 10%), the post-treatment mean values indicate a tendency toward normalization within the acceptable range. The rotational displacement index (TORS) of the mandible in the axial plane showed the following significant differences: Right side: 15.08, 95% CI [-16.99 – -13.17]; Left side: -8.32, 95% CI [-9.95 – -6.69]. The mean TORS index values were 83.29 (post-treatment) compared to 68.22 (pre-treatment) on the right side and 85.83 (post-treatment) compared to 77.52 (pre-treatment) on the left side. The confidence intervals for both sides lie below zero, confirming substantial improvements post-treatment. When compared to the reference values (90% < TORS < 100%), the post-treatment mean values show a tendency toward normalization. The overall neuromuscular balance index, which integrates data from all other indices and reflects the system's overall equilibrium, demonstrated significant improvement: Post-treatment: 80.69 ± 2.10; Pre-treatment: 68.81 ± 4.24.Compared to the reference values provided in the device's manual (fully balanced ≥ 83%, conditionally balanced 75–82%, unbalanced ≤ 74%), the post-treatment mean indicates conditional balance of the masticatory muscles due to the newly established occlusal relationships.

These results highlight the efficacy of the treatment in reducing asymmetry, correcting rotational displacement, and improving the overall neuromuscular balance of the dentofacial system.

Conclusions. The effectiveness of the proposed treatment approach at all stages was evaluated using clinical, functional, and radiographic parameters. Key indicators included:

- Clinical resolution of musculoskeletal symptoms.
- Restoration of coordinated masticatory muscle function, as evidenced by synchrography.
- Normalization of mandibular articulation.
- Reestablishment of the relatively centric position of the condylar head within the articular fossa, reflected in the symmetry of joint spaces in both temporomandibular joints (as confirmed by CBCT).

The results of this study demonstrate that the proposed treatment algorithm for managing patients with TMJ dysfunction and occlusal-articulatory disorders allows for stable and relatively rapid therapeutic outcomes, irrespective of the etiopathogenesis of the pathological process. This is attributed to the algorithm's systematic approach, which includes the correction of occlusal-articulatory disorders—a primary cause of TMJ dysfunction—at specific stages of treatment.

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