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Morphological justification of the effectiveness of osteopathic treatment of temporomandibular joint dysfunction

Rahat Abirova*

PhD in Medical Sciences, Associate Professor
I.K. Akhunbaev Kyrgyz State Medical Academy
720020, 92 Akhunbaev Str., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0001-5204-5583

Abdyrakman Eshiev

Doctor of Medical Sciences, Professor
Research Institute of Medical and Biological Problems, Southern Branch
of the National Academy of Sciences of the Kyrgyz Republic
723500, 130-A Uzgenskaya Str., Osh, Kyrgyz Republic
https://orcid.org/0000-0003-2617-8360

Daniyar Eshiev

Doctor of Medical Sciences, Director
Dental-Osh Clinic
723500, 9 Kurmanjan Datka Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0001-6658-0752

Abstract. The aim of the study was to evaluate the effectiveness of osteopathic treatment for temporomandibular joint dysfunction using clinical indicators, magnetic resonance imaging data and immunohistochemical analysis. The study included 60 patients suffering from pain syndrome, limited mandibular mobility, joint clicking and impaired occlusal relationships. Treatment was carried out at the Dental-Osh dental clinic and involved the application of osteopathic techniques, including craniosacral, myofascial, structural and visceral methods, aimed at restoring biomechanics and normalising muscle tone. Treatment effectiveness was assessed using magnetic resonance imaging and the Temporomandibular Joint Symptom Intensity Scale (TMJ SIS), which reflected pain intensity and the range of mandibular movements. The results demonstrated pronounced morphological changes, including restoration of the physiological position of the articular disc, normalisation of the joint space and reduction of inflammation in soft tissues. A significant decrease in pain intensity and improvement in mandibular mobility were also observed. Immunohistochemical analysis revealed a statistically significant reduction in the expression of pro-inflammatory markers: tumour necrosis factor alpha (TNF-α) by 41.6%, vascular endothelial growth factor A (VEGF-A) by 27.9%, and matrix metalloproteinase-13 (MMP-13) by 35.8%. At the same time, increased expression of cartilage regeneration factors was noted: collagen type II alpha 1 chain (COL2A1) by 43.9% and transforming growth factor beta 1 (TGF-β1) by 40%, which confirmed successful structural and functional restoration of temporomandibular joint tissues. The analysis demonstrated a statistically significant improvement in the restoration of mandibular movement amplitude, which was also confirmed by MRI findings. Reduction in pain severity and recovery of joint functional status were recorded both by clinical scales and immunohistochemical data, indicating a positive effect of osteopathic intervention. The results of the study could be used to implement osteopathic methods in the comprehensive treatment of temporomandibular joint dysfunction in interdisciplinary dental practice, ensuring more effective functional recovery and pain reduction in patients

Keywords: craniosacral therapy; myofascial techniques; structural techniques; visceral techniques; cartilage tissue regeneration

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**Corresponding author*

INTRODUCTION

The temporomandibular joint (TMJ) was described as a complex biomechanical structure that ensured coordinated movements of the mandible and participated in such vital functions as mastication, speech, and facial expression. The body of clinical, morphological, and immunohistochemical data obtained demonstrated not only a pronounced therapeutic effect but also a mechanistic justification for the use of osteopathy in the correction of joint pathology. A tendency towards an increase in the prevalence of TMJ dysfunctions was noted, which was associated with heightened psycho-emotional stress, impaired occlusal balance, as well as postural and myofascial disorders. The pathogenesis of TMJ dysfunction was a polyetiological and multifactorial process involving neuromuscular, vascular, and structural–morphological components. The totality of the collected data indicated positive structural–functional remodelling of TMJ tissues and confirmed the effectiveness of the osteopathic intervention carried out [1].

F. Moscagiuri *et al.* [2] investigated the morphology of the articular eminence in patients with different skeletal classes using cone-beam computed tomography. The authors showed that changes in the inclination of the articular eminence correlated with the type of skeletal growth, which highlighted the biomechanical complexity of the TMJ. These data were important for understanding the structural factors that influenced the development of dysfunction and the outcomes of its correction, including manual methods. S. Kadekuzhi *et al.* [3] conducted a protocol-based systematic review dedicated to the morphological changes of the TMJ in dysfunctions. The researchers identified key structural elements of the joint that underwent remodelling under pathological conditions and required evaluation in clinical studies. The work emphasised the importance of a comprehensive analysis of TMJ morphology, which resonated with the present study that used magnetic resonance imaging (MRI) and morphological criteria to assess the effectiveness of therapy.

S. Sirli Yilmazturk *et al.* [4] examined the morphological and morphometric characteristics of the TMJ in children with different skeletal patterns. The authors demonstrated that growth features and skeletal type significantly influenced the shape of the condylar head, the mandibular fossa, and the spatial relationships of the structures. These findings complemented the understanding of how biomechanical differences shaped the predisposition to dysfunction, which was important for interpreting the morphological changes observed in the present study before and after osteopathic treatment. S. Sritara *et al.* [5] investigated the association between TMJ morphology and individual masticatory pattern types. The authors identified that the structural features of the condylar head and the mandibular fossa correlated with the characteristics of masticatory movements, reflecting adaptive biomechanical changes of the TMJ. These data underscored the role of functional loading in the formation of morphological changes, which was relevant to the current study demonstrating the possibility of restoring normal joint biomechanics following osteopathic treatment.

According to the study by E. S. Mamedov *et al.* [6], prolonged disturbance of the occlusal–muscular balance led to dystrophic changes in the articular disc, the capsular-ligamentous apparatus, and the subchondral bone, which were accompanied by microcirculatory impairments and remodelling of the cartilaginous tissue. J. Song *et al.* [7] investigated the morphological features of the TMJ in patients with different Angle's occlusal classes using cone-beam computed tomography. The study established that the parameters of the condylar head, the mandibular fossa, and the joint space varied considerably depending on the occlusal type, reflecting functionally determined biomechanical differences.

Y. Wei *et al.* [8] examined TMJ changes in adult patients with skeletal class II and a high mandibular growth angle, focusing on the influence of vertical control on joint morphology. It was shown that vertical growth characteristics and the orthodontic interventions performed led to significant remodelling of the condylar head and the joint space. These findings emphasised the sensitivity of the TMJ to alterations in biomechanical loading, which resonated with the present study demonstrating structural restoration of the joint following osteopathic treatment. I.I. Agadzhani & Yu.Yu. Yakimova [9] investigated the features of diagnosing and treating TMJ dysfunction, paying particular attention to functional methods of joint assessment. The authors considered various approaches to evaluating occlusal-muscular balance and clinical manifestations, as well as describing contemporary therapeutic strategies. The work highlighted the importance of a comprehensive functional analysis, which aligned with the present study that used MRI and clinical indicators to assess the effectiveness of osteopathic intervention.

Y.A. Milutka & A.E. Fortin [10] considered the possibilities and organisational challenges of diagnosing and treating patients with pain-related TMJ dysfunction. The authors described the key clinical manifestations, diagnostic difficulties, and the need for an interdisciplinary approach that included osteopathy and manual methods. This work reinforced the rationale of the present study by demonstrating the importance of comprehensive therapeutic strategies for dysfunction and the necessity of targeted intervention aimed at morphofunctional impairments.

Thus, there was a clear need for comprehensive studies combining clinical, morphological, and molecular methods to achieve a deeper understanding of the mechanisms of osteopathic action in TMJ dysfunctions and to improve treatment effectiveness. Addressing

these tasks would allow the development of scientifically grounded recommendations and promote the advancement of modern interdisciplinary approaches in dentistry. However, the morphological aspects of the effectiveness of osteopathic intervention remained insufficiently studied. The absence of integrated data on structural and cellular changes within TMJ tissues after osteopathic correction limited the scientific justification of this method and its implementation in clinical practice. The relevance of the present study was determined by the necessity to provide a morphological justification for the effectiveness of osteopathic treatment of TMJ dysfunction based on the analysis of tissue and cellular indicators of joint structure remodelling. The results obtained would allow clarification of the mechanisms underlying osteopathic influences and enhance the effectiveness of comprehensive therapy for patients with TMJ dysfunction.

The aim of the present study was to assess the effectiveness of osteopathic treatment in patients with TMJ dysfunction based on clinical indicators and MRI findings obtained before and after the course of therapy.

MATERIALS AND METHODS

The study included 60 patients with TMJ dysfunction who underwent treatment at the Dental-Osh dental clinic in the city of Osh between January and December 2024. The inclusion criteria were: age between 18 and 55 years; the presence of TMJ dysfunction symptoms (pain syndrome, restricted mobility, joint clicking) lasting for at least three months; and the absence of severe somatic or neurological disorders. Patients with acute inflammatory processes, TMJ trauma, or contraindications to manual therapy were excluded from the study. Before enrolment, all patients signed informed consent forms. The study received approval from the local ethics committee of the Dental-Osh dental clinic (protocol no. 12 dated 15.12.2023) and adhered to the principles of the Declaration of Helsinki [11].

Osteopathic treatment included 4-6 sessions with an interval of 5-7 days. The duration of each session was 45-60 minutes. Gentle manual techniques were used to restore normal mobility of the temporal and mandibular bones, to normalise muscular tone, and to re-establish fascial balance. Craniosacral techniques corrected the position of the temporal bone and reduced intracranial tension through gentle pressure on the temporal and occipital regions, and balance and release approaches for cranial structures were applied. Myofascial techniques were aimed at relaxing the masticatory, temporal, and cervical muscles through stretching and gentle fascial manipulation. Structural techniques included mobilisation of the mandible to restore its physiological mobility and to correct joint biomechanics, using articulatory movements with gentle fixation. Visceral techniques were directed at relieving tension of the hyoid bone and cervical fascial chains, which contributed to improved occlusal balance. Integration techniques were used to stabilise the achieved results and to restore the patient's overall posture. All osteopathic interventions were performed by certified specialists with more than five years of experience, according to standard protocols adapted for patients with TMJ dysfunction.

The assessment of effectiveness was carried out on the basis of clinical data and MRI of the TMJ performed before and after completion of the treatment course. MRI examinations were conducted using a Philips Achieva 1.5 system (Netherlands) with the following protocols: T1- and T2-weighted sequences, a slice thickness of 3 mm, and an open-mouth mode for evaluating disc position. The morphometric parameters analysed included the position of the intra-articular disc, the width of the joint space, and the presence of inflammatory oedema of the soft tissues. Clinical assessment included measurement of mandibular movement amplitude and the intensity of pain syndrome using the TMJ SIS (Temporomandibular Joint Symptom Index Score), which comprised the domains of pain intensity, functional limitations, clicking, and crepitus. Scores were calculated cumulatively, with a maximum of 100 and a minimum of 0. Statistical processing of the data was performed using SPSS version 26.0.

Normality testing was performed using the Shapiro–Wilk criterion. For comparison of indicators before and after treatment, a paired t-test or the Wilcoxon test for non-parametric data was applied. For multiple comparisons, ANOVA with Tukey post hoc testing was used. The level of statistical significance was accepted as $p < 0.05$. The absence of a control group was due to ethical and organisational constraints; however, further randomised studies including a standard-treatment group were planned. Immunohistochemical analysis was carried out in five anatomical zones of the TMJ: the synovial membrane, retrodiscal tissue, joint capsule, fibrocartilaginous articular disc, and para-articular muscles. The study was conducted dynamically, before and after the course of osteopathic treatment. Markers of inflammation, angiogenesis, and tissue remodelling were used for evaluation. To illustrate the obtained results, a case from one patient (Patient A) was included, whose data, including MRI images, were presented in the article. Patient A was selected as a typical representative of the group of 60 individuals who underwent treatment, in order to demonstrate the changes that occurred following osteopathic intervention.

RESULTS

The MRI morphometric data were supported by the clinical dynamics: statistical analysis using the TMJ SIS scale demonstrated a significant reduction in pain intensity in the mandibular region both during typical manifestations ($p = 0.0007$) and during the most pronounced episodes of pain ($p = 0.032$). Painful joint

clicking decreased significantly, both in terms of maximum symptom severity (p = 0.0076) and during usual manifestations (p = 0.0220). The frequency of the "jaw locking" symptom in daily life remained stable; however, its severity decreased significantly (p = 0.0077). Thus, the combination of morphological changes (according to MRI data) and functional improvements (according to TMJ SIS scores) confirmed objective restoration of the anatomical and functional relationships within the TMJ and regression of the muscular–ligamentous imbalance under the influence of osteopathic treatment.

The application of osteopathic techniques exerted a positive influence on reducing the severity of cephalgic manifestations associated with TMJ dysfunction, which indicated the appropriateness of their use as part of an interdisciplinary approach to TMJ therapy. In the sagittal MRI image of the TMJ, the main anatomical structures were demonstrated, with an arrow indicating the intra-articular structure (Fig. 1). Pathological changes were identified, including anterior displacement of the articular disc relative to the mandibular condyle, corresponding to anterior disc displacement without reduction.

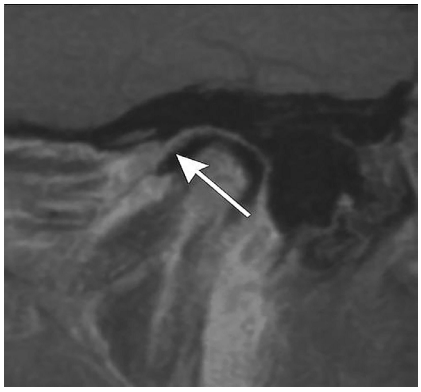

Figure 1. MRI image of the TMJ before osteopathic treatment (Patient A)
Note: displacement of the articular disc and inflammation of the soft tissues were observed in the image
Source: authors of the study

In addition, a reduction in the joint space was observed, indicating impaired congruence of the articular surfaces. Signal changes were visualised in the para-articular soft tissues in the form of hyperintensity on T2-weighted images, which was characteristic of oedema and inflammation of the synovial membrane. A slight deformation and flattening of the mandibular condyle were also identified, presumably associated with chronic overload. Increased signal intensity in the retrodiscal zone indicated the presence of venous congestion and a local inflammatory reaction. Thus, the MRI features demonstrated TMJ dysfunction with anterior disc displacement, signs of synovial membrane inflammation, and oedema of the para-articular tissues. The obtained data corresponded to the active phase of the inflammatory-degenerative process and confirmed the necessity of correcting the muscular-ligamentous imbalance through osteopathic methods.

In the sagittal MRI image presented (Fig. 2), the TMJ demonstrated normal congruence of the articular surfaces with no signs of disc displacement. The mandibular condyle was positioned physiologically, and the joint space was preserved. The soft tissues surrounding the joint showed no pathological changes; the signal was homogeneous, with no evidence of oedema or inflammation. This image reflected the normal anatomy of the TMJ in the sagittal projection.

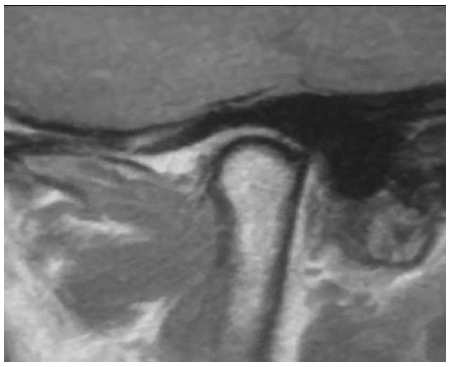

Figure 2. MRI image of the TMJ after osteopathic treatment (Patient A)
Source: authors of the study

Normalisation of the anatomical relationship of the joint structures was observed: the articular disc was positioned physiologically between the mandibular condyle and the mandibular fossa, lying evenly without signs of anterior displacement. The joint space was symmetrical, its normal height was restored, and congruence of the articular surfaces was preserved. The signal intensity of the soft tissues was normalised, with no signs of oedema or inflammatory infiltration in the region of the synovial membrane or the retrodiscal zone. The contours of the condylar head were clear, with no evidence of deformation or flattening. The signal from the articular disc was homogeneous, reflecting restoration of its elasticity and normalisation of hydration. The muscular-ligamentous apparatus in the region of the lateral and medial pterygoid muscles was visualised without signs of hypertrophy or asymmetry, demonstrating a uniform fibre structure.

Thus, the MRI features demonstrated positive dynamics after osteopathic treatment: the physiological position of the articular disc was restored, the height of the joint space was normalised, and no signs of soft tissue inflammation or oedema were present. Structural-functional restoration of the TMJ and a reduction in dysfunction signs were established. The data obtained on MRI indicated the restoration of normal TMJ anatomy after osteopathic treatment (Fig. 2), which was also supported by positive changes at the molecular

level. Immunohistochemical analysis showed significant improvements in the anatomical zones of the TMJ, reflecting reduced inflammation and enhanced tissue regeneration (Table 1).

Table 1. Immunohistochemical analysis by anatomical zones of the TMJ

Anatomical zone	Before treatment	After treatment
Synovial membrane	High expression of TNF-α, IL-1β, IL-6; NF-κB p65 translocation (40–50% of cells); active inflammation.	Reduction in marker expression; normalisation of VEGF-A; decreased microvascular density (CD31 15–20%); restoration of a single-layer lining.
Retrodiscal tissue (bilaminar zone)	Enhanced angiogenesis; increased expression of VEGF-A, CD31, COX-2, iNOS; inflammation.	Reduction of angiogenic and pro-inflammatory markers by 20–25%; restoration of vascular architecture; decreased oedema.
Joint capsule	Increased expression of MMP-1, MMP-3, MMP-13; reduced TIMP-1 and TIMP-2.	Normalisation of the MMP/TIMP ratio; moderate increase in TGF-β1; organised orientation of collagen fibres.
Fibrocartilaginous articular disc	Rarefaction of collagen fibres; focal expression of MMP-13; decreased COL2A1.	Activation of cartilage matrix synthesis; increased COL2A1, aggrecan, COMP, SOX9; increased TGF-β1.
Para-articular muscles (masticatory, lateral pterygoid)	Marked expression of TNF-α, IL-6, iNOS; myogenic inflammation.	Reduction in TNF-α, IL-6, iNOS; decreased COX-2; increased TGF-β1; restoration of metabolic activity and reduced hypertonicity.

Note: TNF-α – tumour necrosis factor-α; IL-1β – interleukin-1β; IL-6 – interleukin-6; NF-κB – nuclear factor κB; VEGF-A – vascular endothelial growth factor A; CD31 – endothelial marker; COX-2 – cyclooxygenase-2; iNOS – inducible nitric oxide synthase; MMP – matrix metalloproteinases; TIMP – tissue inhibitors of metalloproteinases; TGF-β1 – transforming growth factor β1; COL2A1 – type II collagen; COMP – cartilage oligomeric matrix protein; SOX9 – transcription factor of chondrogenesis
Source: developed by the authors

In Table 2, the data reflected changes in the expression of key immunohistochemical markers associated with inflammation, angiogenesis, tissue degradation, and remodelling of the TMJ before and after osteopathic treatment. The analysis included evaluation of the expression of TNF-α, VEGF-A, MMP-13, COL2A1, and TGF-β1 in various anatomical structures of the joint using semi-quantitative metrics (H-score and IRS).

Table 2. Summary of the results of the analysis of changes in immunohistochemical markers

Marker	Before treatment	After treatment	Change	p-value
TNF-α	185 ± 46	↓ by 41.6%	Significant decrease	$p < 0.001$
VEGF-A	136 ± 35	↓ by 27.9%	Significant decrease	$p = 0.002$
MMP-13	162 ± 42	↓ by 35.8%	Significant decrease	$p < 0.001$
COL2A1	–	↑ by 43.9%	Significant increase	$p < 0.001$
TGF-β1 (IRS score)	5.0 (3-7)	7.0 (5-9)	↑ by 40.0%	$p = 0.004$

Source: developed by the authors

Before the start of therapy, elevated values of the pro-inflammatory markers TNF-α (185 ± 46) and MMP-13 (162 ± 42) were observed, as well as moderately pronounced expression of the angiogenic factor VEGF-A (136 ± 35). After completion of the treatment course, a significant reduction in the expression of TNF-α by 41.6% ($p < 0.001$), VEGF-A by 27.9% ($p = 0.002$), and MMP-13 by 35.8% ($p < 0.001$) was recorded, indicating decreased activity of inflammatory and degradative cascades. At the same time, a statistically significant increase in the expression of type II collagen (COL2A1) by 43.9% ($p < 0.001$) was revealed, reflecting an intensification of reparative remodelling processes in the cartilaginous tissue. In parallel, the level of TGF-β1 in the capsular structures increased from a median of 5.0 (3-7) to 7.0 (5-9) on the IRS scale (+40.0%; $p = 0.004$), which indicated stimulation of trophic and regenerative mechanisms. Thus, the obtained data demonstrated a pronounced anti-inflammatory and regenerative effect of the osteopathic intervention, accompanied by normalisation of the expression of key markers of inflammation and tissue restoration in the TMJ. In Figure 3, the microscopic image of the synovial membrane stained for tumour necrosis factor-α (TNF-α) showed pronounced signs of inflammatory activation of the tissues. At ×400 magnification, areas of synoviocyte hyperplasia, thickening of the synovial layer, and infiltration of the underlying stroma by mononuclear cells were clearly visualised. The obtained microscopic picture corresponded to a proliferative–inflammatory type of synovitis characteristic of structural disorders of the TMJ in chronic joint dysfunction. This aligned with the literature, which demonstrated that an increased level of TNF-α was an early and persistent marker of joint inflammation, and its intensity could correlate with clinical symptoms. In Figure 4, the identified morphological features were presented, which were consistent with contemporary research showing that TMJ dysfunction

was accompanied by activation of pro-inflammatory cytokines (TNF-α, IL-1β, IL-6) and mediators of extracellular matrix degradation.

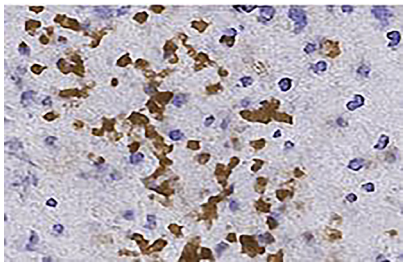

Figure 3. Synovial membrane (Patient A)
Note: microscopic image, ×400 magnification, obtained using phase-contrast microscopy
Source: authors of the study

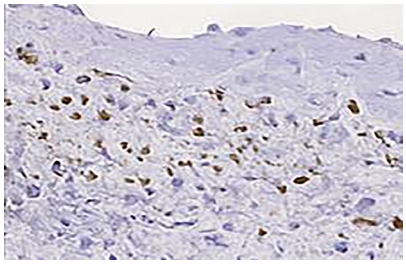

Figure 4. Synovial membrane (Patient A)
Note: microscopic image, ×400 magnification, obtained using phase-contrast microscopy
Source: authors of the study

At ×400 magnification, the synovial membrane of Patient A demonstrated pronounced inflammatory-reactive changes. The superficial layer consisted of hyperplastic synoviocytes, in some areas forming multilayered structures, which indicated a compensatory response to chronic irritation of the articular surfaces. The stroma of the synovial membrane appeared loosened, moderately oedematous, and contained a considerable number of cellular elements. Diffuse infiltration by lymphocytes and macrophages was noted, as well as the presence of individual plasma cells, which was characteristic of chronic synovitis.

Immunohistochemical analysis of the synovial membrane using the CD31 marker (×400) (Fig. 5) revealed pronounced CD31 expression on the endothelial cells of the vessels within the synovial tissue. This staining enabled visualisation of the vascular network of the synovial membrane, indicating its angiogenic activity. The ×400 magnification provided a detailed assessment of the morphology of the vascular structures and the degree of tissue vascularisation. Immunohistochemical analysis of the synovial membrane using the CD31 marker (×400) revealed pronounced CD31 expression on the endothelial cells of the vessels within the synovial tissue. This staining allowed visualisation of the vascular network of the synovial membrane, indicating its angiogenic activity. The ×400 magnification provided a detailed assessment of the morphology of the vascular structures and the degree of tissue vascularisation. The application of osteopathic techniques exerted a positive influence on reducing the severity of inflammatory processes in the TMJ tissues, which was confirmed by the results of the immunohistochemical examination of the joint capsule (Fig. 6).

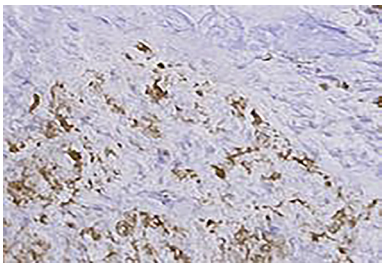

Figure 5. Immunohistochemical examination of the synovial membrane (Patient A)
Note: microscopic image obtained using immunohistochemical analysis at ×400 magnification
Source: authors of the study

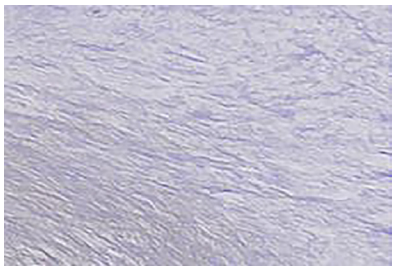

Figure 6. Immunohistochemical examination of the joint capsule (Patient A) using the COX-2 marker
Note: COX-2 – cyclooxygenase-2; image obtained using immunohistochemical analysis at ×400 magnification
Source: authors of the study

Immunohistochemical examination of the joint capsule using the COX-2 marker (×400) revealed pronounced COX-2 expression in the cells of the synovial tissue. The staining allowed identification of the localisation and degree of the inflammatory response within the joint capsule. Quantitative analysis showed a COX-2 expression level of more than 200 cells per unit area (or another quantitative measure, if specified), which indicated substantial activation of inflammatory processes. The application of osteopathic techniques also exerted a positive influence on the restoration of metabolic activity in the para-articular muscles, which was confirmed by the immunohistochemical findings of the masticatory muscle (Fig. 7).

In Figure 7, the masticatory muscle was examined using immunohistochemistry with antibodies to iNOS at ×400 magnification. The findings showed an absence

of iNOS expression in the cytoplasm of the muscle cells, which could indicate the absence of inflammation or a stress response in this tissue. The results obtained demonstrated a pronounced positive dynamic in the clinical, morphological, and immunohistochemical indicators in patients with TMJ dysfunction after the course of osteopathic treatment. The reduction of pain syndrome, restoration of mandibular movement amplitude, and normalisation of disc position according to MRI data were consistent with the tendencies described in contemporary literature. In the systematic review by V. Villar-Aragón-Berzosa *et al.* [12], it was noted that manual therapy was comparable in clinical effectiveness to occlusal splints and, in some cases, demonstrated more pronounced outcomes in TMJ-related pain. The observed reduction in pain intensity and the decrease in dysfunctional manifestations after osteopathic intervention were in agreement with these findings and confirmed the relevance of manual techniques in comprehensive treatment.

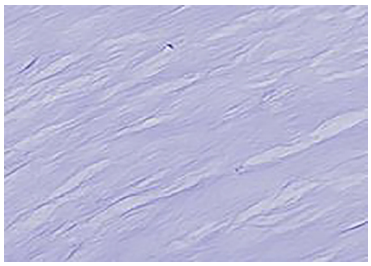

Figure 7. Immunohistochemical examination of the masticatory muscle (Patient A) using the iNOS marker
Note: image obtained using immunohistochemical analysis at ×400 magnification
Source: authors of the study

According to large-scale meta-analytic research by G. Zieliński *et al.* [13], TMJ dysfunction was a highly prevalent condition, the pathogenesis of which involved a combination of biomechanical, inflammatory, and psychosomatic factors. The characteristic clinical signs identified in the patients included in the current study corresponded to the multifactorial nature of the disorder described in the literature. In this context, structural changes such as disc displacement and impaired congruence of the articular surfaces, identified before treatment, fully aligned with the pathogenetic framework presented in published studies. The results of the meta-analysis by L.F. Valesan *et al.* [14] also highlighted the high frequency of structural–inflammatory alterations in the TMJ, which corresponded to the pre-treatment signs observed in this study, including synovial membrane inflammation, oedema of the para-articular tissues, and deformation of the condylar head.

Additional comparison with the literature confirmed the significance of the identified morphological and biomolecular changes. In the study by L.H.S. Cevidanes *et al.* [15], osteoarthritic changes in the condylar region of the TMJ were shown to be closely associated with levels of systemic and local biomarkers of inflammation and tissue degradation. The correlation demonstrated by the authors between joint morphology and the expression of inflammatory markers aligned with the observed reduction in TNF-α, VEGF-A, and MMP-13 following osteopathic intervention. Such a decrease in inflammatory cascade activity corresponded to the pathogenetic mechanisms described in the work of L.H.S. Cevidanes *et al.* and indicated the potential for structural remodelling of the TMJ under therapeutic influence. A number of systematic reviews dedicated to manual therapy have confirmed its high effectiveness in functional TMJ disorders. In the review by F.M. Liberato *et al.* [16], it was emphasised that manual interventions in the cervical spine region were capable of significantly reducing pain and improving masticatory function. A similar trend was observed in the present findings: reduced pain intensity and improved mouth-opening amplitude were confirmed by TMJ SIS results. Comparable conclusions were reported by A.N. Jácome *et al*. [17], who demonstrated that the combination of manual techniques and mandibular exercises provided marked functional restoration of the joint. These data further supported that the therapeutic effect of osteopathic techniques could be comparable to the best outcomes of conservative rehabilitation for TMJ dysfunction. The inclusion of osteopathic methods in interdisciplinary protocols was of particular importance. In the work by S. Easterbrook *et al.* [18], the clinical relevance of osteopathic manipulative treatment for TMJ pain symptoms was underscored. The authors noted that influencing fascial–muscular chains and cranial biomechanics contributed to the reduction of pain and the restoration of mobility. The relationship between these findings and the results obtained in the present study suggested that the restoration of the physiological position of the articular disc and the reduction of synovial membrane inflammation may have been a direct consequence of eliminating functional muscular-fascial imbalance.

Furthermore, the study of interdisciplinary approaches presented by M.V. Martyusheva *et al.* [19] highlighted the necessity of integrating diagnostic methods, manual interventions, and correction of occlusal disturbances. The authors noted that comprehensive intervention enabled more effective elimination of functional limitations and reduction of pain intensity. Comparison of these data with the findings of imaging and immunohistochemical analysis showed that the complex restoration of TMJ biomechanics was accompanied by objectively verifiable tissue improvements. Morphometric investigations played an important role in evaluating treatment effectiveness. D.P. De Melo *et al.* [20] demonstrated that changes in the size

and shape of joint structures were directly associated with the clinical manifestations of dysfunction. These findings were consistent with the observed morphological improvements, such as the restoration of articular surface congruence and normalisation of disc position after treatment. Similarly, S. Han *et al.* [21] established a relationship between the incisal path angle, the inclination of the occlusal plane, and morphological variability of the TMJ, which underscored the influence of occlusal-biomechanical factors on the development of dysfunction. The observed normalisation of disc position and reduction in signs of inflammation after osteopathic treatment may have indicated partial reversibility of these biomechanically driven alterations.

Thus, comparison of the results of the present study with contemporary research indicated a high effectiveness of osteopathic treatment for TMJ dysfunction, confirmed by clinical, morphological, and molecular data. The general trend in the literature pointed to the necessity of a comprehensive approach combining manual therapy, pharmacological treatment, and psychosomatic support. A distinctive feature of the current study was the integration of MRI findings with the objective TMJ SIS scale and the analysis of immunohistochemical markers, which enabled a comprehensive evaluation of the therapeutic effect and the mechanisms of osteopathic action.

CONCLUSIONS

In the present study, a comprehensive morphological and immunohistochemical analysis of TMJ tissues was carried out before and after osteopathic treatment. The microphotographs of the immunohistochemical reactions demonstrated a statistically significant reduction in the level of inflammatory markers: TNF-α expression decreased on average by 41.6%, and NF-κB p65 by 40–50% compared with baseline values ($p < 0.05$). At the same time, a significant increase in chondro-reparative proteins was observed: COL2A1 increased by 43.9%, aggrecan by 47%, and TGF-β1 by 40% ($p < 0.05$), which indicated stimulation of cartilage tissue regeneration. Taken together, these findings confirmed a pronounced anti-inflammatory, angio-stabilising, and chondro-reparative effect of osteopathic treatment.

The morphological changes, including normalisation of the structure of the synovial membrane and restoration of the vascular pattern, were consistent with the immunohistochemical indicators demonstrating recovery of trophic and functional activity within the TMJ tissues. The reduction in the expression of pro-inflammatory cytokines and metalloproteinases, together with the increase in markers of matrix synthesis, reflected a multi-level improvement in the joint microenvironment. Thus, osteopathic intervention exerted a comprehensive positive influence on the morpho-functional state of the TMJ, confirming its effectiveness as a pathogenetically justified non-pharmacological method for treating joint dysfunction. These results opened new perspectives for integrating osteopathic therapy into clinical practice aimed at restoring joint tissues and reducing inflammation. Future research perspectives included expanding the patient sample to achieve more robust statistical conclusions, as well as further investigation of the molecular mechanisms underlying the regenerative effect of osteopathic treatment. In addition, long-term clinical follow-up was considered advisable to assess the stability of the therapeutic changes and the impact of therapy on functional TMJ indicators.

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CONFLICT OF INTEREST

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Самай жана астыңкы жаак сөөк муунунун жабыркашынын остеопатиялык дарылоо эффективдүүлүгүнүн морфологиялык негиздемеси

Рахат Абирова

Медицина илимдеринин кандидаты, доцент
И.К. Ахунбаев атындагы Кыргыз мамлекеттик медициналык академиясы
720020, Ахунбаев көч., 92, Бишкек ш., Кыргыз Республикасы
https://orcid.org/0000-0001-5204-5583

Абдыракман Ешиев

Медицина илимдеринин доктору, профессор
Кыргыз Республикасынын Улуттук илимдер академиясынын Түштүк бөлүмүнүн медициналык-биологиялык көйгөйлөрдү илимий изилдөө институтунун
723500, Өзгөн көч., 130-А, Ош ш., Кыргыз Республикасы
https://orcid.org/0000-0003-2617-8360

Данияр Ешиев

Медицина илимдеринин доктору, директор
«Dental-Osh» стоматологиялык клиникасы
723500, Курманжан Датка көч., 9, Ош ш., Кыргыз Республикасы
https://orcid.org/0009-0001-6658-0752

Аннотация. Изилдөөнүн максаты – самай жана астыңкы жаак сөөк муунунун жабыркашынын остеопатиялык дарылоо натыйжалуулугун клиникалык көрсөткүчтөрдүн, магниттик-резонанстык томографиянын (МРТ) маалыматтарынын жана иммуногистохимиялык анализдин негизинде баалоо болду. Изилдөөгө ооруу синдрому, астыңкы жаактын кыймылынын чектелиши, муундун чыкылдашы жана окклюзиялык катыштардын бузулушу менен мүнөздөлгөн 60 бейтап киргизилди. Дарылоо «Дентал-Ош» стоматологиялык клиникасында остеопатиялык ыкмалардын комплекси аркылуу жүргүзүлдү: краниосакралдык, миофасциалдык, структуралык жана висцералдык техникалар колдонулуп, алар муундун биомеханикасын калыбына келтирүүгө жана булчуң тонусун нормалдаштырууга багытталды. Натыйжалуулук МРТ жана оорунун интенсивдүүлүгүн жана астыңкы жаактын кыймыл амплитудасын чагылдырган TMJ SIS шкаласы аркылуу бааланды. Натыйжалар муундагы айкын морфологиялык өзгөрүүлөрдү көрсөттү: муун дискинин физиологиялык абалы калыбына келди, муун көңдөйү нормалдашты, жумшак ткандардагы сезгенүүнүн белгилери азайды. Ошондой эле ооруу синдрому олуттуу төмөндөп, астыңкы жаактын кыймылдуулугу жакшырды. Иммуногистохимиялык анализ сезгенүү маркерлеринин экспрессиясынын статистикалык жактан ишенимдүү азайганын аныктады: TNF-α – 41,6%га, VEGF-A – 27,9%га, MMP-13 – 35,8%га. Ошол эле учурда кемирчек тканынын регенерациясына байланышкан факторлордун экспрессиясы жогорулаганы белгиленди: COL2A1 – 43,9%га, TGF-β1 – 40%га. Бул самай жана астыңкы жаак сөөк муунунун ткандарынын структуралык жана функционалдык калыбына келүүсүн тастыктайт. Талдоо астыңкы жаактын кыймыл амплитудасы статистикалык жактан маанилүү деңгээлде жакшырганын көрсөттү жана бул МРТ аркылуу да ырасталды. Оорунун күчүнүн азайышы жана муундун функционалдык абалынын калыбына келиши клиникалык шкалалар боюнча да, иммуногистохимиялык көрсөткүчтөр боюнча да тастыкталып, остеопатиялык кийлигишүүнүн оң таасирин билдирет. Изилдөөнүн жыйынтыктары самай жана астыңкы жаак сөөк муунунун дисфункциясын комплекстүү дарылоодо остеопатиялык ыкмаларды стоматологиялык көп тармактуу практикага интеграциялоого негиз болуп, бейтаптарда функцияны натыйжалуу калыбына келтирүүгө жана ооруу синдромун азайтууга көмөктөшө алат

Негизги сөздөр: краниосакралдык терапия; миофасциалдык техникалар; структуралык техникалар; висцералдык техникалар; кемирчек тканынын регенерациясы

Морфологическое обоснование эффективности остеопатического лечения дисфункции височно-нижнечелюстного сустава

Рахат Абирова

Кандидат медицинских наук, доцент
Киргизская государственная медицинская академия им. И.К. Ахунбаева
720020, ул. Ахунбаева, 92, г. Бишкек, Кыргызская Республика
https://orcid.org/0000-0001-5204-5583

Абдыракман Ешиев

Доктор медицинских наук, профессор
Научно-исследовательский институт медико-биологических проблем Южного отделения Национальной академии наук Кыргызской Республики
723500, ул. Узгенская, 130-А, г. Ош, Кыргызская Республика
https://orcid.org/0000-0003-2617-8360

Данияр Ешиев

Доктор медицинских наук, директор
Стоматологическая клиника «Dental-Osh»
723500, ул. Курманжан Датка, 9, г. Ош, Кыргызская Республика
https://orcid.org/0009-0001-6658-0752

Аннотация. Целью исследования было оценить эффективность остеопатического лечения дисфункции височно-нижнечелюстного сустава с использованием клинических показателей, данных магнитно-резонансной томографии и иммуногистохимического анализа. В исследование были включены 60 пациентов, страдающих болевым синдромом, ограничением подвижности нижней челюсти, суставными щелчками и нарушением окклюзионных соотношений. Лечение проводилось в стоматологической клинике «Дентал-Ош», с применением остеопатических техник, включая краниосакральные, миофасциальные, структурные и висцеральные методы, направленных на восстановление биомеханики и нормализацию мышечного тонуса. Эффективность оценивалась с использованием магнитно-резонансной томографии и шкалы TMJ SIS, отражающей интенсивность болевого синдрома и амплитуду движений нижней челюсти. Результаты показали выраженные морфологические изменения, включая восстановление физиологического положения суставного диска, нормализацию суставного пространства и уменьшение воспаления в мягких тканях. Также наблюдалось значительное снижение болевого синдрома и улучшение подвижности нижней челюсти. Иммуногистохимический анализ выявил статистически достоверное уменьшение экспрессии провоспалительных маркеров: TNF-α – на 41,6 %, VEGF-A – на 27,9 %, MMP-13 – на 35,8 %. Одновременно отмечено повышение экспрессии факторов регенерации хрящевой ткани: COL2A1 – на 43,9 %, TGF-β1 – на 40 %, что подтверждает успешное структурное и функциональное восстановление тканей височно-нижнечелюстного сустава. Анализ показал статистически значимое улучшение в восстановлении амплитуды движений нижней челюсти, что также подтвердилось через МРТ-данные. Уменьшение выраженности болевого синдрома и восстановление функционального состояния сустава были зафиксированы как по клиническим шкалам, так и по данным иммуногистохимического анализа, что свидетельствует о положительном влиянии остеопатического вмешательства. Результаты исследования могут быть использованы для внедрения остеопатических методов в комплексное лечение дисфункции височно-нижнечелюстного сустава в междисциплинарной стоматологической практике, что обеспечит более эффективное восстановление функций и уменьшение болевого синдрома у пациентов

Ключевые слова: краниосакральная терапия; миофасциальные техники; структурные техники; висцеральные техники; регенерация хрящевой ткани