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RESEARCH ARTICLE

Biomechanical Stress Analysis in Retrodiscal Tissues of Temporomandibular Joint with Unilateral Disc Displacement Without Reduction: A Finite Element Study

Tek Taraflı Temporomandibular Eklem Redüksüyonsuz Disk Deplasmanında Retrodiskal Dokulara Gelen Stresin Biyomekanik Analizi: Sonlu Elemanlar Çalışması

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ABSTRACT

Objective: This study aimed to evaluate stress changes in retrodiscal tissues during mandibular movements in temporomandibular joints (TMJ) with unilateral disc displacement without reduction (DDwoR) using finite element analysis (FEA).

Materials and Methods: Geometric models were created using CT scan data from two patients: one with bilaterally normal disc positioning and another with DDwoR. DICOM files were segmented, and 3D models were reconstructed and converted into mathematical models following a standardized methodology. Two models were analyzed: a control model with bilaterally normal discs and a DDwoR model, with separate evaluations of the left (normal) and right (DDwoR) joints. TMJ movements during mouth opening and closing were simulated, and stress distribution patterns in the retrodiscal tissues were analyzed. Von Mises stress values were measured and compared between the DDwoR and healthy sides.

Results: Both the normal and DDwoR sides demonstrated altered stress patterns compared to the healthy control. The DDwoR side consistently exhibited elevated stress in the superior region during mouth opening, underscoring its mechanical vulnerability. The normal side, while less affected than the DDwoR side, displayed compensatory stress increases, particularly in the intermediate region during mouth opening.

Conclusion: These findings underscore the vulnerability of the retrodiscal tissues, especially the superior region, to mechanical stress in the presence of DDwoR. This study highlights the importance of clinical strategies aimed at preserving retrodiscal tissue integrity to prevent progressive joint damage.

Keywords: Disc displacement without reduction, finite element analysis, retrodiscal tissue, stress distribution, temporomandibular joint

ÖZET

Amaç: Bu çalışmanın amacı, unilateral redüksiyonsuz disk deplasmanı (DDwoR) bulunan temporomandibular eklemlerde (TME) mandibular hareketler sırasında retrodiskal dokulardaki stres değişimlerini sonlu elemanlar analizi (FEA) kullanarak değerlendirmektir.

Gereç ve Yöntemler: Geometrik modeller, biri bilateral olarak normal disk pozisyonuna sahip, diğeri ise unilateral DDwoRlu iki hastanın BT (Bilgisayarlı Tomografi) tarama verileri kullanılarak oluşturulmuştur. DICOM dosyaları segmentlere ayrılmış, 3D modeller yeniden yapılandırılmış ve standart bir metodoloji izlenerek matematiksel modellere dönüştürülmüştür. İki model analiz edilmiştir: bilateral olarak normal disk pozisyonuna sahip kontrol modeli ve unilateral DDwoR modeli. Bu modellerde sol (normal) ve sağ (DDwoR) eklemler ayrı ayrı değerlendirilmiştir. Ağız açma ve kapama hareketleri simüle edilerek retrodiskal dokulardaki stres dağılımı analiz edilmiştir. Von Mises stres değerleri ölçülerek DDwoR tarafı ile sağlıklı taraf karşılaştırılmıştır.

Bulgular: Hem normal hem de DDwoR tarafları, sağlıklı kontrole kıyasla değişen stres paternleri göstermiştir. DDwoR tarafı, ağız açma sırasında üst bölgede artmış stres seviyeleri sergileyerek mekanik açıdan daha hassas olduğunu ortaya koymuştur. Normal taraf, DDwoR tarafına kıyasla daha az etkilenmiş olsa da özellikle ağız açma sırasında orta bölgede telafi edici stres artışları göstermiştir.

Sonuç: Bu bulgular, DDwoR varlığında özellikle retrodiskal dokuların üst bölgesinin mekanik strese karşı savunmasız olduğunu vurgulamaktadır. Çalışma, ilerleyici eklem hasarını önlemek için retrodiskal doku bütünlüğünün korunmasına yönelik klinik stratejilerin önemini ortaya koymaktadır.

Anahtar Kelimeler: Redüksiyonsuz disk deplasmanı, retrodiskal doku, sonlu eleman analizi, stres, temporomandibular eklem

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INTRODUCTION

The temporomandibular joint (TMJ) is one of the most complex joints in the human body, both morphologically and functionally.[1] Mandibular function relies on the synchronized activity of both TMJs, as their movements are inherently interconnected.[2] Temporomandibular disorders (TMD) refer to a group of conditions affecting the TMJ, the muscles of mastication, and associated structures. Among these, disc displacement without reduction (DDwoR) is one of the most frequently encountered internal derangements, characterized by the articular disc's permanent anterior or anteromedial displacement. This displacement disrupts the normal condyle-disc relationship, resulting in mechanical imbalance, joint dysfunction, and often pain.[3] Unilateral DD has been shown to alter chewing patterns compared to healthy controls.[4] It has been demonstrated that the stress distribution on TMJ structures changes following DD. However, no studies have been found that investigate how the loading on the healthy, non-displaced joint is affected.

The retrodiscal tissue, located posterior to the articular disc, serves as a highly vascularized and innervated structure that contributes to joint stability and function.[3,5] It is susceptible to mechanical stress and deformation, especially in cases of DDwoR where the displaced disc fails to return to its normal position, exposing the retrodiscal tissue to abnormal loading conditions.[6,7] Prolonged mechanical stress in this region may lead to inflammation, fibrosis, and structural damage.[8]

Finite Element Analysis (FEA) is a computational method that simplifies complex structures into discrete elements to evaluate their mechanical behavior. This approach, extensively utilized in fields like engineering and biomechanics, facilitates the simulation of stress and strain patterns under varying conditions. In TMJ research, FEA has been instrumental in providing insights into joint mechanics, particularly in estimating stress and strain distributions.[9]

Previous studies have not adequately addressed the retrodiscal tissue mechanics during mouth opening and closing, leaving a gap in understanding the differential stress distribution across various TMJ conditions. This study aims to evaluate the effects of unilateral TMJ DDwoR on the contralateral healthy TMJ retrodiscal tissues using the FEA method. The analysis specifically examines the retrodiscal tissues during both mouth opening and closing movements to provide a comprehensive understanding of the stress distribution in these conditions. The findings of this study are expected to guide clinical strategies for protecting retrodiscal tissues and preventing progressive joint damage.

MATERIALS AND METHODS

This research was conducted at the Department of Oral and Maxillofacial Surgery, Ondokuz Mayıs University, and the Ay Tasarım Ltd. Şti. Laboratory. Ethical approval for this study was obtained from the Ondokuz Mayıs University Clinical Research Ethics Committee (OMU KAEK) under decision number 2019/391.

Modeling Process: Geometric models for this study were created using CT scan data from two patients: one with bilaterally normal disc positioning and another with unilateral DDwoR. Informed consent forms were obtained from participants. Disc positions were verified through magnetic resonance imaging (MRI) conducted on the same individuals. The study protocol received approval from the clinical research ethics committee. DICOM (Digital Imaging and Communications in Medicine) files were processed with 3D Doctor software for segmentation. Model reconstruction and conversion into mathematical models followed a standardized methodology consistent with that employed in our prior research.[10] Two model was created:

Model 1: TMJ with bilaterally normal disc positioning (Healthy control)

Model 2: TMJ with unilateral DDwoR

In Model 2, the two TMJ sides were evaluated separately, including the left TMJ with a normal disc position and the right TMJ with DDwoR.

Software and Tools: Mimics Innovation Suite (Materialise, Belgium) was used for 3D modeling. ANSYS Workbench 2021 R2 (ANSYS Inc., USA) was utilized for mesh creation and finite element analysis. SolidWorks 2021 (Dassault Systèmes, France) was used for geometry adaptation and adjustments.

Material Properties: The material properties of the TMJ components were defined using data from the literature:

-Elastic modulus (Young's modulus) and Poisson's ratio for the retrodiscal tissue were adapted based on prior studies.[8,11]

-Retrodiscal tissues were modeled as isotropic, elastic, and hyperelastic structures to account for their flexible nature.

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Simulation Conditions: After performing the FEA, the maximum and minimum principle streses (MaxPS, MinPS) on condyle and Von Mises (VM) stresses on the disc were evaluated numerically and color-coded during mouth opening and closing.

In mouth closing, joint loading was simulated as a consequence of the resultant force vectors of the three jaw-closing muscles (masseter, temporalis, and medial pterygoid muscles). The insertion points of the muscles, the central point of the anterior teeth, and the rearmost point of occlusal contact were linked as a rigid body to the TMJ FE model. For each muscle, the line of action was defined by the points of insertion and origin. Their maximum forces had been approximated from their physiological cross-sectional areas according to previous studies.[12,13] The total of the resultant muscle force was established as 100N for each side.

In mouth opening, jaw opening muscles were simultaneously activated with the deactivation of the jaw-closing muscles. Mouth opening was simulated differently for each model. In Model 1, the maximum mouth opening is simulated as 45 mm on the straight axis. In the second model, the mouth opening was 35mm and simulated with deflection to the right side (disc displacement side). The amount of deflection was 5mm from the midline to the right side.

Boundary and Loading Conditions: Applied forces were modeled based on average muscle forces during chewing and occlusion, with a load of 200 N (Newton). Von Mises stress values were used to analyze equivalent principal stress (EPS) within the retrodiscal tissues.

Analysis Process: Linear elastic analysis was conducted to simulate stress and deformation. Stress concentrations in the superior, intermediate, and inferior regions of the retrodiscal tissue were evaluated.

RESULTS

The stress values were determined at three points on the retrodiscal tissue during mouth opening and closing (Figures 1 and 2). All von Mises equivalent stresses during mouth opening and closing were measured in megapascals (MPa). (Tables 1 and 2)

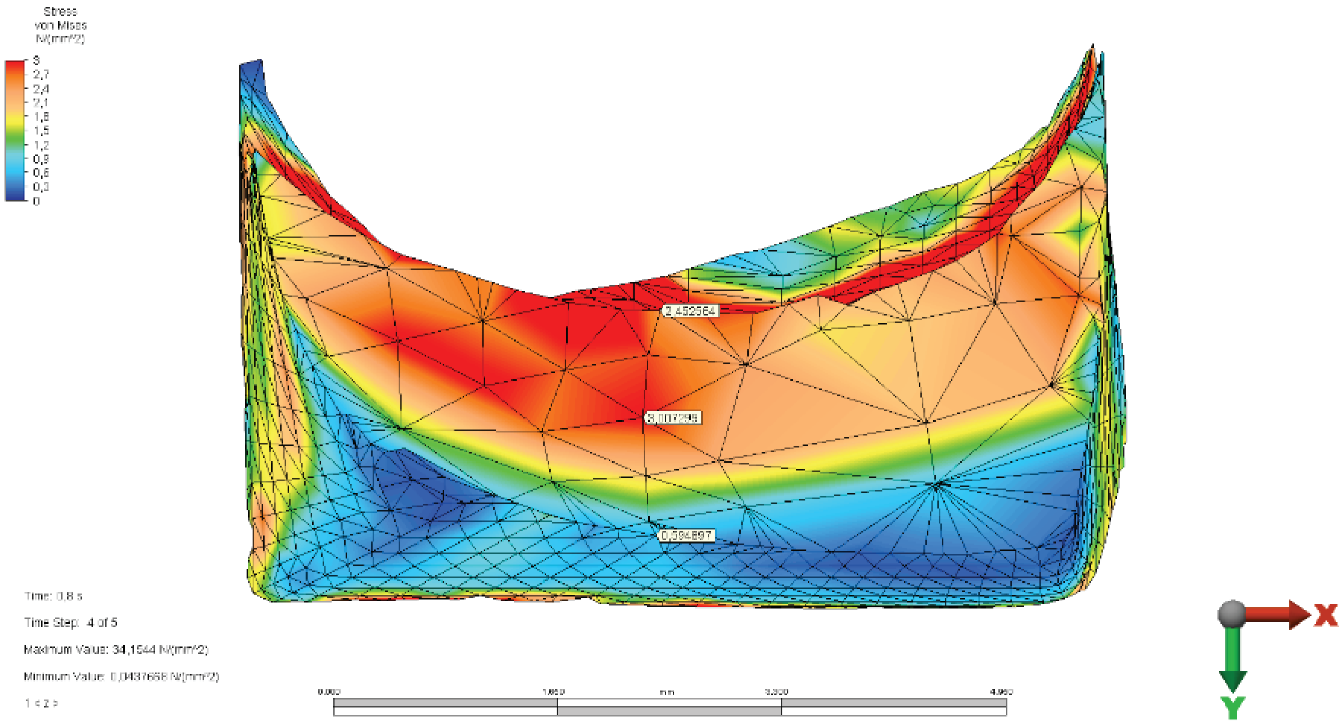

Figure 1. Stress distribution in retrodiscal tissue during mouth opening.

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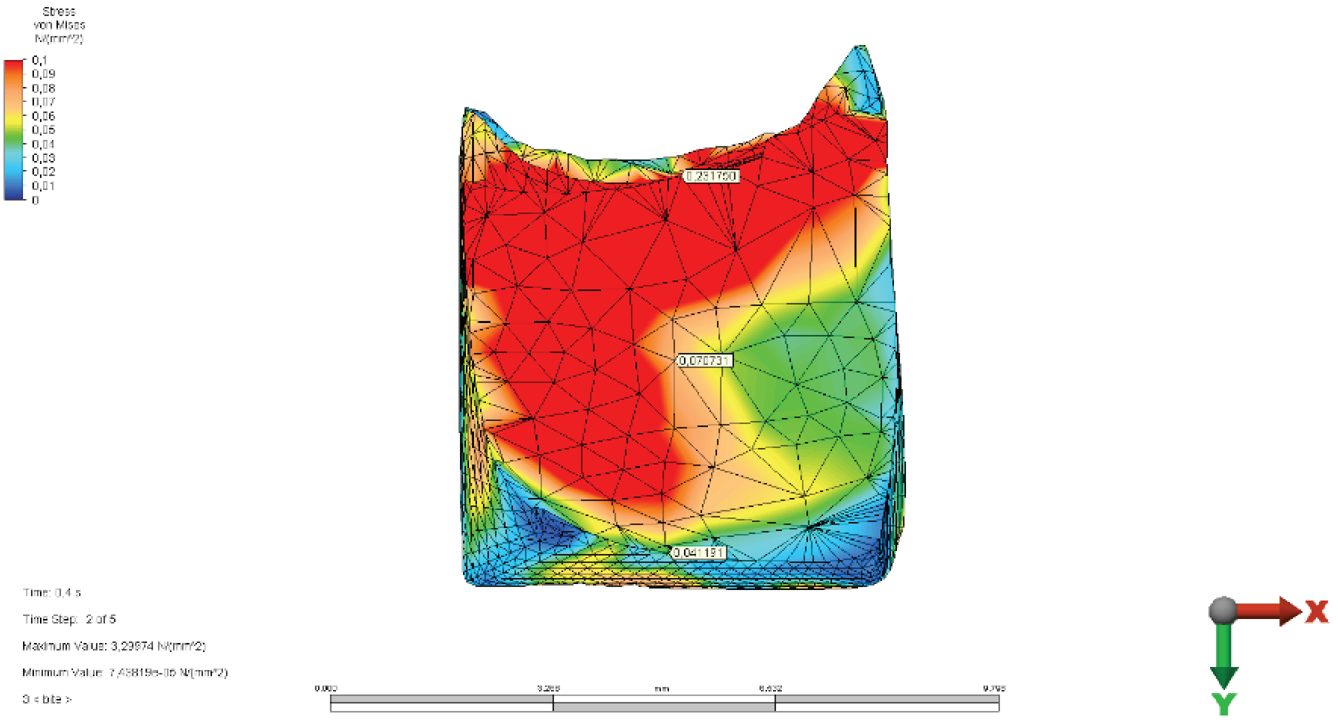

Figure 2. Stress distribution in retrodiscal tissue during mouth closure.

Table 1. Equivalent principal stress (von mises) values during mouth opening

Region	Normal Side (MPa)	DDwoR Side (MPa)	Healthy control
Superior	0.650918	1.010919	2,452564
Intermediate	0.950091	0.525255	3,007299
Inferior	0.217510	0.054029	0,594897

Table 2. Equivalent principal stress (von mises) values during mouth closing

Region	Normal Side (MPa)	DDwoR Side (MPa)	Healthy control
Superior	0.231750	0.051345	0,038216
Intermediate	0.070731	0.026345	0,018213
Inferior	0.041191	0.008709	0,005849

During mouth opening, the Von Mises stress distribution varied significantly between the superior, intermediate, and inferior regions of the retrodiscal tissue across the normal, DDwoR, and healthy control groups. The highest stress was observed in the intermediate region of the healthy control group (3.007 MPa), followed by the superior region (2.452 MPa). In the unilateral DDwoR model, the highest stress value was observed in the superior region on the DDwoR side (1.011 MPa), while the normal side exhibited the highest stress in the intermediate region (0.950 MPa).

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During mouth closing, the highest Von Mises stress was recorded in the superior region of the normal side (0.232 MPa) within the unilateral DDwoR model. This stress value was markedly higher than the DDwoR side (0.051 MPa) and the healthy control group (0.038 MPa). Additionally, the inferior and intermediate regions consistently showed lower stress levels across all groups, with the healthy control group exhibiting the lowest overall values.

DISCUSSION

The results of this study provide valuable insights into the biomechanical behavior of the TMJ under different conditions of disc positioning during mouth opening and closing. Studies investigating the biomechanical balance of load distribution within the TMJ reported that stress distributions in the TMJ with a normal disc position were substantially different from those with anterior disc displacement.[13-15] In the literature, while the TMJ condyle and disc are more frequently evaluated, there are only a limited number of studies assessing the forces applied to the retrodiscal tissues.[15] In our study, similarly, it was observed that the load distribution in the retrodiscal tissues changed in both the healthy side and the side with DD in the unilateral DDwoR model compared to the healthy control group. During mouth closing, compared to the healthy joint, the stresses on the retrodiscal region increased in both sides of the unilateral DD model, more prominently on the normal side, while they decreased during mouth opening. This result underscores the compensatory mechanisms that may arise in the normal TMJ to balance the mechanical deficiencies introduced by the DDwoR side. The increased stress in the superior region during mouth closure suggests that this area bears the primary load during occlusal contact and mastication.

In the literature, only one study has evaluated the effect of unilateral DD on the contralateral healthy joint.[14] Hattori-Hara et al.[14] created a unilateral DD model, applied clenching force, and assessed the stress on the contralateral healthy joint using the FEA method. They evaluated the stress on the condyle, disc, and retrodiscal tissue at different time intervals during clenching. A similar model was used in our study; however, instead of clenching movements, biting and mouth opening movements were simulated. Their study concluded that the presence of unilateral DD leads to increased stress in the retrodiscal tissues of the contralateral joint, which has a normally positioned disc. Our study produced similar results in retrodiscal tissue during the biting movement.

Mandibular movement is the result of the combined and simultaneous activities of both TMJs, as the right and left joints cannot function entirely independently.[2] The study by Kakimoto et al.[16], utilizing MRI, demonstrated that contralateral joints are qualitatively affected in patients with unilateral anterior DD. A study on patients with unilateral DD revealed that their chewing patterns differ from those of healthy controls.[4] However, the effects of these changes on joint structures remain unclear. The asymmetrical loading patterns observed in the unilateral DD model provide additional evidence for the biomechanical adaptations that occur in response to joint pathology. The presence of deflection in the DDwoR model may be one of the possible factor contribute to altered stress distributions. The reduced stress levels on the DDwoR side observed in our study could be attributed to the joint's limited mobility and disrupted functional dynamics, resulting in an uneven load-sharing mechanism between the affected and unaffected sides. Based on these findings, a clinical approach to managing patients with TMJ DDwoR should focus on strategies that minimize excessive mechanical loading during mandibular movements, particularly mouth opening. Therapies such as mandibular movement modification, guided exercise programs, and stabilization splints may help redistribute stress and protect retrodiscal tissues. Additionally, educating patients on avoiding wide mouth opening or excessive jaw movements could prevent further joint deterioration and alleviate symptoms.

During mouth opening, the highest Von Mises stress was observed in the healthy control model compared to both the DDwoR side and the normal side of the unilateral DD model. This result can be explained by the fact that in a healthy TMJ, the disc is properly positioned, allowing for the efficient transmission of muscular forces across the joint. This efficient force transmission leads to higher stress levels, particularly in the retrodiscal tissues that are actively engaged in stabilizing the joint during movement. Additionally, changes in muscle dynamics could contribute to this finding. The activation patterns of the jaw-opening muscles may differ between healthy and pathological joints. In a healthy TMJ, muscle forces are evenly distributed, resulting in higher stress concentrations. However, in DDwoR, the altered jaw movements, such as deflection or limited mouth opening, and the asymmetrical distribution of muscle forces, likely lead to lower stress levels on the affected side.

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While this study provides a detailed analysis of stress distribution in retrodiscal tissues, it is limited by its reliance on static modeling of mandibular movements. Dynamic modeling incorporating real-time muscle forces and additional factors, such as tissue viscoelasticity, may offer a more comprehensive understanding. Future research could explore whether the reduced stress on the DDwoR side correlates with increased susceptibility to joint degeneration or altered proprioceptive feedback. Studies also needed to explore the effects of therapeutic interventions, such as splints or surgical disc repositioning, on stress distribution in TMJs with DDwoR.

In conclusion, this study highlights significant differences in Von Mises stress distribution between healthy and DDwoR TMJs, emphasizing the biomechanical adaptations in unilateral DDwoR. These insights contribute to the growing body of knowledge on TMJ function and its implications for the diagnosis and management of TMD

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

1. Odabaş B, Arslan SG. Temporomandibular eklem anatomisi ve rahatsızlıkları. Dicle Tıp Dergisi. 2008;35(1):77-85.
2. Karakis D, Bagkur M, Toksoy B. Comparison of simultaneously recorded computerized occlusal analysis and surface electromyographic activity of masticatory muscles between patients with unilateral TMD. Int J Prosthodont. 2021;34(5):554-9.
3. Okeson J. Management of Temporomandibular Disorders and Occlusion. New York State Dental Journal. 2003;69(7):61.
4. Kuwahara T, Bessette RW, Maruyama T. Characteristic chewing parameters for specific types of temporomandibular joint internal derangements. CRANIO®. 1996;14(1):12-22.
5. Willard VP, Arzi B, Athanasiou KA. The attachments of the temporomandibular joint disc: a biochemical and histological investigation. Archives of oral biology. 2012;57(6):599-606.
6. Holmlund AB, Gynther GW, Reinholt FP. Disk derangement and inflammatory changes in the posterior disk attachment of the temporomandibular joint: a histologic study. Oral surgery, oral medicine, oral pathology. 1992;73(1):9-12.
7. Isberg A, Isacsson G, Johansson A-S, Larson O. Hyperplastic soft-tissue formation in the temporomandibular joint associated with internal derangement: a radiographic and histologic study. Oral surgery, oral medicine, oral pathology. 1986;61(1):32-8.
8. Harorlı A, Akgül M, Yılmaz B, Bilge O, Dağistan S, Çakur B, et al. Ağız, Diş ve Çene Radyolojisi. 1. baskı İstanbul; Nobel Tıp Kitapevleri Tic. Ltd Şti. 2014:484-500.
9. Beek M, Koolstra J, Van Ruijven L, Van Eijden T. Three-dimensional finite element analysis of the human temporomandibular joint disc. Journal of biomechanics. 2000;33(3):307-16.
10. Gurbanov V, Bas B, Öz AA. Evaluation of stresses on temporomandibular joint in the use of class II and III orthodontic elastics: a three-dimensional finite element study. Journal of Oral and Maxillofacial Surgery. 2020;78(5):705-16.
11. Rozylo-Kalinowska I, Orhan K. Imaging of the temporomandibular joint. 2019.
12. Arnett G, Milam S, Gottesman L. Progressive mandibular retrusion—idiopathic condylar resorption. Part I. American Journal of Orthodontics and Dentofacial Orthopedics. 1996;110(1):8-15.
13. Tanaka E, Del Pozo R, Tanaka M, Asai D, Hirose M, Iwabe T, Tanne K. Three-dimensional finite element analysis of human temporomandibular joint with and without disc displacement during jaw opening. Medical engineering & physics. 2004;26(6):503-11.
14. Hattori-Hara E, Mitsui SN, Mori H, Arafurue K, Kawaoka T, Ueda K, et al. The influence of unilateral disc displacement on stress in the contralateral joint with a normally positioned disc in a human temporomandibular joint: An analytic approach using the finite element method. Journal of Cranio-Maxillofacial Surgery. 2014;42(8):2018-24.
15. Tanaka E, Rodrigo D, Miyawaki Y, Lee K, Yamaguchi K, Tanne K. Stress distribution in the temporomandibular joint affected by anterior disc displacement: a three-dimensional analytic approach with the finite-element method. Journal of oral rehabilitation. 2000;27(9):754-9.
16. Kakimoto N, Wongratwanich P, Shimamoto H, Kitisubkanchana J, Tsujimoto T, Shimabukuro K, et al. Comparison of T2 values of the displaced unilateral disc and retrodiscal tissue of temporomandibular joints and their implications. Scientific Reports. 2024;14(1):1705.