ORIGINAL RESEARCH ORİJİNAL ARAŞTIRMA DOI: 10.5336/dentalsci.2024-105212

Stress Distribution on Temporomandibular Joint After Proportional and Standard High Condylectomy: An Experimental Study

Oransal ve Standart Yüksek Kondilektomi Sonrası Temporomandibular Eklemdeki Stres Dağılımı: Deneysel Çalışma

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ABSTRACT Objective: Temporomandibular joint (TMJ) condylectomy has been performed for the treatment of condylar hyperplasia, with modifications such as high and proportional condylectomy being preferred based on each individual patient's needs. To clarify the effect of these modifications the stress changes after high and proportional condylectomy of TMJ condylar hyperplasia as hemimandibular hyperplasia and hemimandibular elongation were evaluated. **Material and Methods:** Finite element models of hemimandibular hyperplasia and hemimandibular elongation were obtained, 5 mm and 10 mm of condylectomy was simulated on these models. Pre-operative and post-operative von Misses stress, maximum principal stress values for condyle head and glenoid fossa were compared. **Results:** Hemimandibular hyperplasia models presented higher preoperative and post-operative stress levels both for the anatomical structures and treatment modality compared to hemimandibular elongation. The stress levels of hyperplasia and elongation models were similar on the contralateral side. The stress decrease on the affected and non-affected sides of the elongation models were balanced for both high and proportional condylectomy procedures. The stress decrease on the non-affected side of hyperplasia models were higher in proportional condylectomy. **Conclusion:** Proportional condylectomy has shown more favorable results in terms of reducing stress levels for both hyperplasia and elongation cases. Regarding that the pre and post-operative stress level change is more distinct in hyperplasia cases, structural adaptation process may be more prominent leading to increased tendency towards temporomandibular problems.

Keywords: Hemimandibular hyperplasia; hemimandibular elongation; finite element analysis; high condylectomy; proportional condylectomy

ÖZET Amaç: Temporomandibular eklem (TME) kondilektomisi, kondiler hiperplazi vakalarının tedavisi için uygulanmakta ve her vakanın ihtiyacına göre yüksek seviyeli ya da oransal kondilektomi olarak modifikasyonlar tercih edilebilmektedir. Bu modifikasyonların cerrahi sonrası TME bölgesindeki etkisini anlamak amacıyla, hemimandibular hiperplazi ve hemimandibular elongasyon modellerinde yüksek ve oransal kondilektomiden sonra stres değişiklikleri incelenmiştir. **Gereç ve Yöntemler:** Hemimandibular hiperplazi ve hemimandibular elongasyon sonlu eleman modelleri oluşturuldu ve bu modeller üzerinde 5 mm ve 10 mm kondilektomi simülasyonları yapıldı. Kondil başı ve glenoid fossa için preoperatif ve postoperatif von Mises stres ve maksimum asal gerilim değerleri karşılaştırıldı. **Bulgular:** Hemimandibular hiperplazi modelleri hem anatomik yapılar hem de tedavi modalitesi açısından hemimandibular elongasyon modellerine kıyasla daha yüksek preoperatif ve postoperatif stres değerleri gösterdi. Etkilenmeyen tarafta stres seviyeleri, hiperplazi ve elongasyon modelleri için benzer bulundu. Elongasyon modellerinde hem yüksek hem de oransal kondilektomi prosedürleri sonrası, etkilenen ve etkilenmeyen taraflarda stres düzeyindeki azalma değerleri daha dengeliydi. Hiperplazi modellerinde ise oransal kondilektomi sonrası etkilenmeyen tarafta stresin daha belirgin bir şekilde azaldığı gözlemlendi. **Sonuç:** Oransal kondilektomi hem hiperplazi hem de elongasyon vakaları için stres düzeylerindeki azalma açısından daha olumlu sonuçlar göstermiştir. Hiperplazi vakalarında preoperatif ve postoperatif stres seviyesi değişikliklerinin daha belirgin olduğu göz önüne alındığında, bu vakalarda yapısal adaptasyon süreci daha belirgin olabilir ve bu da temporomandibular problemlere yönelik artan bir eğilime yol açabilir.

Anahtar Kelimeler: Hemimandibular hiperplazi; hemimandibular elongasyon; sonlu elemanlar analizi; yüksek kondilektomi; oransal kondilektomi

TO CITE THIS ARTICLE:
Ergezen E, Akdeniz SS. Stress distribution on temporomandibular joint after proportional and standard high condylectomy: An experimental study. Turkiye Klinikleri J Dental Sci. 2025;31(1):16-23.

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Peer review under responsibility of Turkiye Klinikleri Journal of Dental Sciences.

Received: 21 Aug 2024 ***Received in revised form:*** 07 Nov 2024 ***Accepted:*** 07 Nov 2024 ***Available online***: 16 Jan 2025

Condylar hyperplasia can be related to hemimandibular hyperplasia (HH), hemimandibular elongation (HE) or combination of both all of which cause facial asymmetries mostly seen in early adulthood.[1,2] Although still not known for sure inflammation, trauma, hormonal imbalance, hypervascularity are considered to be the possible etiological factors.[1,3] In HH; one side of the mandible increases in volume, the height of the ramus and the body increase, the condyle expands and the neck lengthens, but chin position does not change drastically. If the growth is slow the maxillary teeth erupt to maintain the occlusion creating an occlusal canting. In HE, effected side of the mandible lengthens in horizontal plane causing significant chin deviation, the condyle and neck change is mild. The occlusal plane is flat however cross bite occurs on the contralateral side.[4]

The treatment protocol should comprise three steps; stopping the condylar overgrowth, correction of the skeletal relationship and establishing satisfying functional and esthetic results.[5] There is no consensus on the best treatment procedure and the timing. Early condylectomy was recommended for actively growing condyles to prevent from the increase in the skeletal asymmetry, following orthodontic treatment or orthognathic surgical interventions depending on the degree of the asymmetry.[6,7] However, some authors avoid condylectomy and postpone the surgery until growing stops and then just perform surgery only. Proportional condylectomy with or without orthodontic treatment and condylectomy at the same time with orthognathic surgery and orthodontics have also been performed, and recently adaptable condylectomy was introduced.[7-9]

All these treatment choices would have more or less effect on the temporomandibular joint (TMJ) depending on the stress increase, adaptation capacity and the remodeling phase of the TMJ. The overall TMJ health still needs to be maintained after condylar hyperplasia treatment protocols.

Considering the limited literature, this study aims to assess the stress distribution on TMJ following high and proportional condylectomy to determine which approach more effectively minimizes joint stress in patients with HH and elongation. By doing so, it seeks to guide more precise and patient-specific treatment decisions. The hypothesis is that proportional condylectomy may result in greater stress on both the affected and non-affected sides compared to high condylectomy.

MATERIAL AND METHODS

Başkent University institutional review board approved the present experimental study with project no: D-KA22/34. Three-dimensional mesh models were generated and finite element analysis was performed in HP stations with Intel Xeon E-2286, Intel Corporation (Santa Clara, California, ABD) processor and 64 GB ECC Ram, 2. 40 GHz/h. A 3-dimensional .stl human mandible was generated with 3DSlicer software for the evaluations.

ANSYS Workbench, ANSYS, Inc. (Canonsburg, PA, ABD) software was used for optimizing the mesh models and accommodating solid models for analysis. LS-DYNA, Livermore Software Technology Corporation (LSTC, Livermore, California, ABD) simulation software was used for the evaluations.

MODELLING OF THE TMJ, CORTICAL BONE, SPONGIOUS BONE AND PERIODONTAL LIGAMENT

Cone beam computed tomography data from a human mandible was reconstructed with 0.1 mm slice thickness and transferred to 3D Slicer software in DICOM(.dcm) format. This data was separated according to the Hounsfield unit values to form a 3D model and exported in .stl format to ANSYS Spaceclaim software. Geometry of 2 mm mandibular cortical bone and 1.5 mm maxillary cortical bone was constructed. Based on the inner layer of the cortical bone, spongious bone was installed. Teeth, regarding Wheeler atlas with 0.25 mm periodontal ligament (PDL) was modelled. TMJ was constructed in ANSYS Spaceclaim software referring anatomical measures.

CONSTRUCTION OF THE MODELS

Main 3D model was reconstructed as hyperplasia and elongation models as the affected side would be the right TMJ (Figure 1, Figure 2).

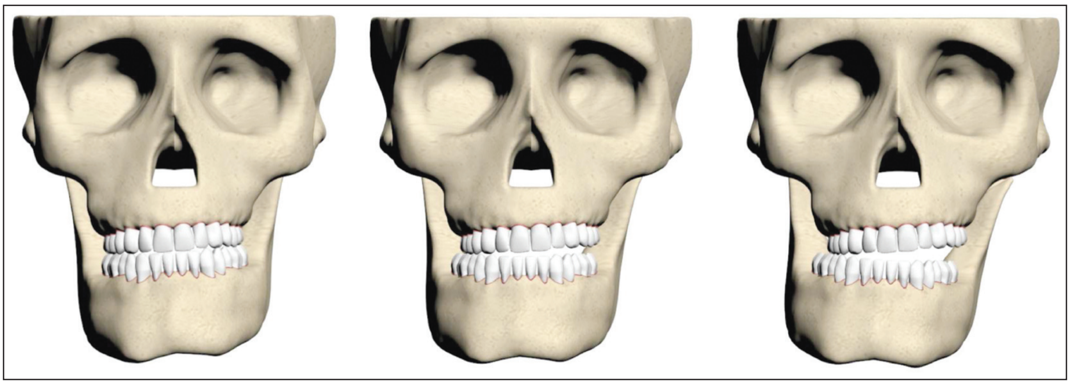

FIGURE 1: Hemimandibular elongation models; preoperative, 5 mm post-operative and 10 mm post-operative; note occlusal canting and midline relation in preoperative model and increase in posterior open bite in postoperative models.

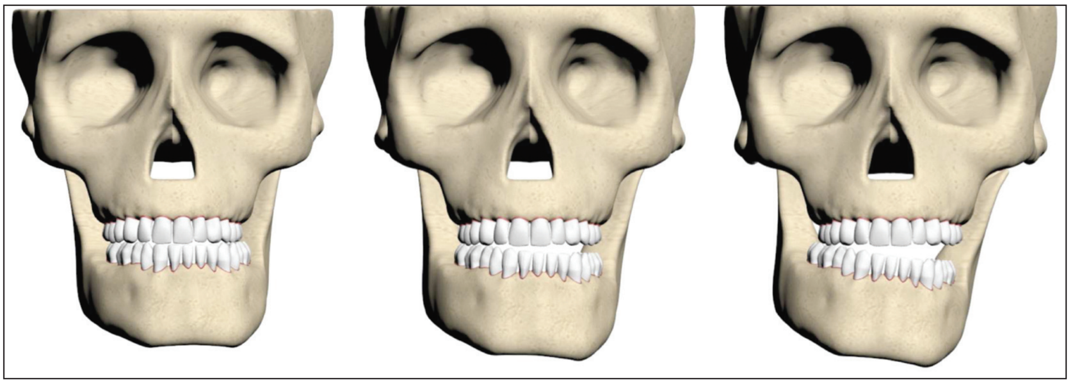

FIGURE 2: Hemimandibular hyperplasia models; preoperative, 5 mm post-operative and 10 mm post-operative; note posterior crossbite in preoperative model and increase in posterior open bite in postoperative models.

Two different osteotomies were simulated on the affected condyle as 5 mm (high condylectomy) and as 10 mm (proportional condylectomy) (Figure 1, Figure 2). Condyle form was reconstructed as the mandible rotated towards the operated side pivoting the 1st molar of the same side. Glenoid fossa and disc were modelled according to the new position of the condyle to evaluate the stress values on both sides, as the contact surface area of the disc and post-operative condyles (5 mm and 10 mm) remained same in volume within the hyperplasia and elongation groups.

CONSTRUCTION OF THE MATHEMATICAL MODELS

ANYSYS Workbench software was used to generate mesh models were from the geometrical models with to be analyzed with LS-DYNA simulator. Material properties were provided from the literature.[10-12]

LOADING AND BOUNDARY CONDITIONS

Muscular forces applied in all models were provided from a previous study.[13] Models were constrained in three directions from the superior and posterior border of the maxilla. Vertical movement was constrained from the 1st molar to simulate the biting force.

Six nonlinear analysis was performed within the described loading and boundary conditions.

Nonlinear frictional coefficient was defined as μ=0.001 between TMJ-mandibular cortical bone and TMJ-temporal bone. The rest of the contact areas were considered to move in complete correlation which is defined as bonded contact.

RESULTS

In this section, the results obtained from the analysis of the data collected during the research process are explained in detail.

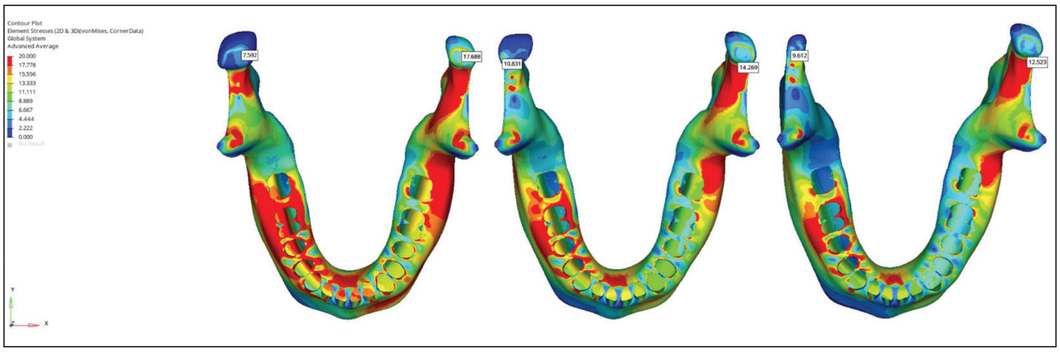

FIGURE 3: von Misses stress (N/mm^2) values of the condyle in hemimandibular hyperplasia models; preoperative, 5 mm post-operative and 10 mm post-operative respectively.

STRESS DISTRIBUTION IN THE HH MODELS

Condyle

The highest stress was measured in 5 mm condylectomy model and least was measured in preoperative model for affected side. For non-affected side preoperative model presented the highest stress and 10 mm model presented the least stress (Figure 3, Table 1).

Maximum principal stress values were higher in non- affected TMJ compared to affected TMJ except 5 mm model. The highest tension was measured in 5 mm condylectomy model and least was measured in preoperative model for affected side. For non-affected side preoperative model presented the highest tension and 10 mm model presented the least tension (Table 1).

Glenoid Fossa

The highest stress was measured in 10 mm condylectomy model and least was measured in preoperative model for affected side. For non- affected side preoperative model presented the highest stress and 10 mm model presented the least stress (Figure 4, Table 1).

Maximum principal stress values were higher in non-affected TMJ compared to affected TMJ for all models. The highest tension was measured in 10 mm condylectomy model and least was measured in preoperative model for affected side. For non-affected side preoperative model presented the highest tension and 10 mm model presented the leasttension (Table 1).

TABLE 1: Preoperative and post-operative stress values of the HH models; condyle and glenoid fossa.

HH Models Condyle		
von Misses (N/mm^2)	Affected side	Non-affected side
Preoperative	7.592	17.688
5 mm postoperative	10.831	14.269
10 mm postoperative	9.612	12.523
Max principal stress (N/mm^2)	Affected side	Non-affected side
Preoperative	4.960	8.688
5 mm postoperative	10.058	8.514
10 mm postoperative	5.224	7.266
HH Models Glenoid fossa		
von Misses (N/mm^2)	Affected side	Non-affected side
Preoperative	5.587	15.919
5 mm postoperative	6.837	15.611
10 mm postoperative	7.430	15.303
Max principal stress (N/mm^2)	Affected side	Non-affected side
Preoperative	3.558	16.356
5 mm postoperative	3.831	16.196
10 mm postoperative	3.862	12.499

HH: Hemimandibular hyperplasia.

STRESS DISTRIBUTION IN THE HE MODELS

Condyle

The highest stress was measured in preoperative model and least was measured in 5 mm model for affected side. For non-affected side preoperative model presented the highest stress and 10 mm model presented the least stress (Figure 5, Table 2).

Maximum principal stress values were higher in non-affected TMJ compared to affected TMJ for all models. The highest tension was measured in preoperative model and least was measured in 10 mm

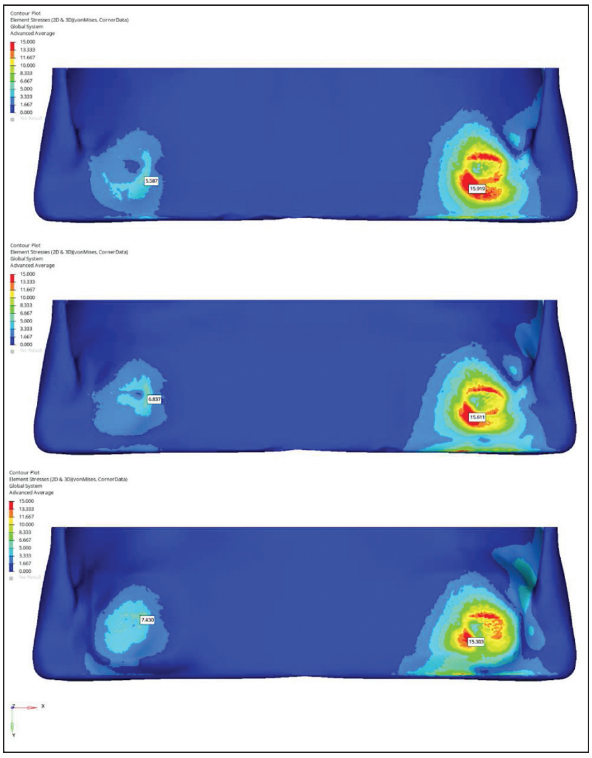

FIGURE 4: von Misses stress (N/mm^2) values of the glenoid fossa in hemimandibular hyperplasia models; preoperative, 5 mm post-operative and 10 mm post-operative respectively.

condylectomy model for affected side. For non-affected side preoperative model presented the highest tension and 10 mm condylectomy model presented the least tension (Table 2).

Glenoid Fossa

The highest stress was measured in 10 mm condylectomy model and least was measured in preoperative model for affected side. For non-affected side pre-operative model presented the highest stress and 5 mm condylectomy model presented the least stress (Figure 6, Table 2).

Maximum principal stress values were higher in non-affected TMJ compared to affected TMJ for all models. The highest tension was measured in 10 mm condylectomy model and least was measured in pre-operative model for affected side. For non-affected side 10 mm condylectomy model presented the highest tension and 5 mm condylectomy model presented the least tension (Table 2).

von Misses stress values were higher in non-affected TMJ compared to affected TMJ for all models. Both for elongation and hyperplasia models with 5 mm and 10 mm condylectomy, the stress over the condyle located more anteriorly compared to the preoperative models. von Misses stress and tension values decreased over the non-affected condyle as the length of the condylectomy increased. For both the hyperplasia and elongation models von Misses stress and tension values in the glenoid fossa was highest in 10 mm models in the affected side. von Misses value for the glenoid fossa at the non-affected side was highest in preoperative models (Table 1, Table 2).

DISCUSSION

Condylar hyperplasia treatment is complex and usually consists of orthodontic treatments and surgical procedures including single or multiple orthognathic and TMJ surgeries.[14-16] It is important to stop excessive or prolonged growing pattern prior to correction of asymmetry and malocclusion. These

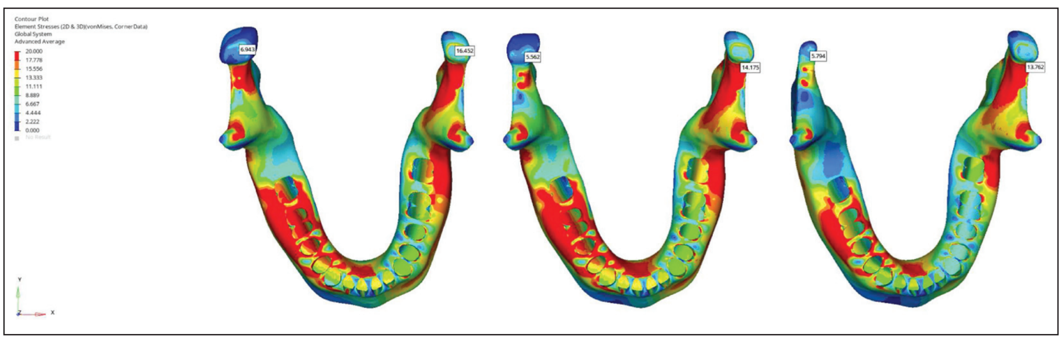

FIGURE 5: von Misses stress (N/mm^2) values of the condyle in hemimandibular elongation models; preoperative, 5 mm post-operative and 10 mm post-operative respectively.

TABLE 2: Preoperative and post-operative stress values of the HE models; condyle and glenoid fossa.

HE Models Condyle		
von Misses (N/mm^2)	Affected side	Non-affected side
Preoperative	6.943	16.452
5 mm postoperative	5.562	14.175
10 mm postoperative	5.794	13.762
Max principal stress (N/mm^2)	Affected side	Non-affected side
Preoperative	3.799	8.930
5 mm postoperative	3.646	6.443
10 mm postoperative	2.313	6.186
HE Models Glenoid fossa		
von Misses (N/mm^2)	Affected side	Non-affected side
Preoperative	6.797	15.527
5 mm postoperative	7.024	13.288
10 mm postoperative	7.069	15.362
Max principal stress (N/mm^2)	Affected side	Non-affected side
Preoperative	5.380	16.219
5 mm postoperative	5.918	15.971
10 mm postoperative	5.930	17.205

HE: Hemimandibular elongation

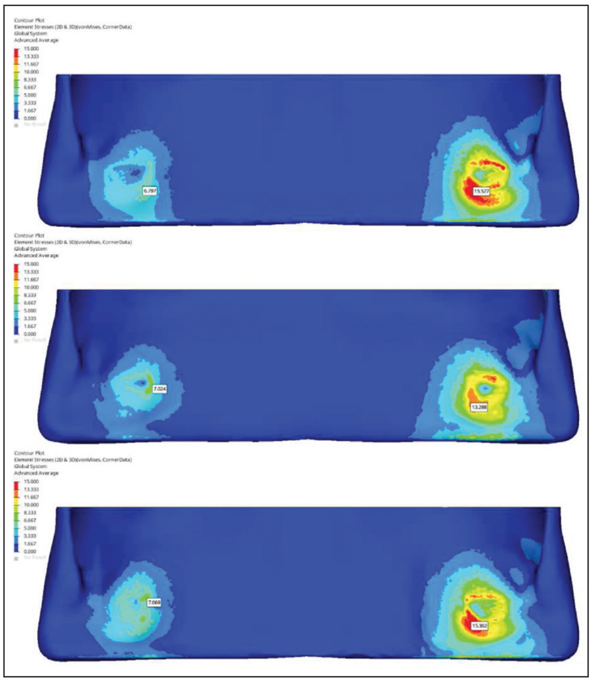

FIGURE 6: von Misses stress (N/mm^2) values of the glenoid fossa in hemimandibular elongation models; preoperative, 5 mm post-operative and 10 mm post-operative respectively.

treatment procedures are more or less relies on the gradual self-correction and self-adaptation capability of TMJ.[17]

This study aimed to clarify the stress levels after high (5 mm) and proportional (10 mm) condylectomy, considering both elongation and hyperplasia patterns, to determine the appropriate treatment approach. Stress levels in the condylar head and glenoid fossa were simulated immediately following the surgical procedures. von Misses stress and tension levels of the effected condyle were significantly higher in HH compared to HE, for both high and proportional condylectomy, both preoperatively and postoperatively. While the stress level difference of contralateral condyle of HH and HE was not distinct. For the HE cases high and proportional condylectomy seemed to be beneficial for reducing the stress levels both on the affected and non-affected condyles. For HH cases proportional condylectomy lead to a more prominent decrease of preoperative stress levels of contralateral condyle (non-affected) compared to high condylectomy. Contrary to our hypothesis, especially in HH patients, no increase in stress was observed in proportional condylectomy. The stress generated by the rotational movement in the mandible after proportional condylectomy was likely balanced by the dental and muscular components, and increased stress may not have occurred in the condyle and glenoid fossa. However, this aspect was not evaluated in this study.

HH models presented higher von Misses and tension values compared to HE models on the affected condyles. However, HE models presented slightly higher von Misses stress and tension on the glenoid fossa of the affected side. Postoperative stress level increase of the affected condyle was found to be more distinct than glenoid fossa in HH models, which may lead to more effective remodelation on condyle compared to the articular cavity, because functional remodeling of the articular structures is known to be provoked by the compressive forces.[18,19] While the decreased stress levels in non- affected condyle and glenoid fossa for HH models may state a need for minimal clinical adaptation phase. In HE models stress levels decreased or remained same after all surgical treatment options both for condyle and glenoid fossa, indicating that similar adaptation phases can be expected for them. Fariña et al. measured condylar unit volume increase of the affected side as 0.704 mm^3 and articular cavity volume increase as 0.30 mm^3 after 12 months, no significant difference was evident on the non-affected side measures.[20] Abotaleb et al. stated that the contralateral condyle volume did not significantly change after minimum 12 months follow up, which may be explained as the stress levels of the non-affected condyle is in the physiologic adaptation limits.[21] This finding may be relieving for the cases that is not associated with contralateral arthritic changes which Wolford et al. stated as a common contralateral development.[7]

The stress on the non- affected condyle is always higher compared to the affected side and decreases as the volume of the removed bone increases. For the HH models, volume of the condylectomy can be considered to be more effective on the stress levels since the decrease in the non-affected side is slightly more prominent compared to the HE models. Considering the higher stress levels of condyle in HH patients compared to HE can have a higher potential of a late TMJ disorder.

The von Misses stress values on the condyle and glenoid fossa is higher in non- affected side in preoperative models for both HH and HE models due to the pressure of the affected condyle on the contralateral side. For the affected side, the von Misses stress and tension in the glenoid fossa increases in 10 mm models, which may be due to the narrowed contact area of the new smaller condyle head and the glenoid fossa.

CONCLUSION

Proportional condylectomy is considered to be more suitable for both HE and HH cases to diminish preoperative condylar stress levels. Considering the remarkable difference of the stress levels between the affected and non-affected sides, the glenoid fossa in HH will be more prone to adaptive changes even compared with the condyle. Greater adaptation process may increase the possibility of future TMJ problems; therefore, post-operative symptoms should be evaluated carefully for HH patients. The postoperative adaptation of both of the sides may decrease the need for further surgical procedures. However, considering HH cases generally involves volume increase in the mandibular body, ramus and dentoalveolar component, further orthognathic surgical procedures could be required. The findings of this study about the stress patterns occurring in HE and HH cases preoperatively and postoperatively clarifies the effect of treatment choice on the anatomical structures and gives an insight about remodeling phases, nevertheless clinical studies are required considering the limitations of FEA studies.

Acknowledgement

The authors of the article thank to Tinus Technologies for their valuable contribution during the finite element analysis.

Source of Finance

This study was approved and supported by Başkent University institutional review board (Project no: D-KA22/34).

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Ezgi Ergezen, Sıdıka Sinem Akdeniz; **Design:** Ezgi Ergezen, Sıdıka Sinem Akdeniz; **Control/Supervision:** Ezgi Ergezen, Sıdıka Sinem Akdeniz; **Data Collection and/or Processing:** Ezgi Ergezen; **Analysis and/or Interpretation:** Ezgi Ergezen, Sıdıka Sinem Akdeniz; **Literature Review:** Ezgi Ergezen, Sıdıka Sinem Akdeniz; **Writing the Article:** Ezgi Ergezen; **Critical Review:** Sıdıka Sinem Akdeniz; **References and Fundings:** Ezgi Ergezen, Sıdıka Sinem Akdeniz.*

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