RESEARCH ARTICLE

Effects of different types of maxillary protraction on maxilla with finite element analysis

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Abstract

Objective: To compare two different skeletal anchorage methods with finite element analysis in the treatment of Class III patients with maxillary retrognathia.

Material and Methods: Two different treatment scenarios were performed on skull model obtained from computerized tomography images of skeletal Class III patients with maxillary retrognathia and finite element analysis was performed. In the first group; mini plates were simulated on infra zygomatic crest. A unilateral 500 g protraction force was applied to the face-mask. In the second group; mini plates were simulated in infrazygomatic crest and mandibular symphysis. Then, 500g protraction force was applied with Class III elastic between the miniplates. Von Misses stresses and displacement values were evaluated comparatively.

Results: In Class III elastic group, maximum Von Misses stress occurred around infra zygomatic crest and symphysis anchored with 0.078 MPa. The maxillary posterior region and paranasal regions were the areas showing the highest Von Misses tension after infra zygomatic crest and symphysis. In the face-mask group, the most common site of Von Misses stress in nasomaxillary complex and alveolar structures were infra zygomatic area where plaques were applied, followed by pterygomaxillary suture. Tensile forces are reduced especially in these two areas by spreading to surrounding structures.

Conclusion: In both methods, it was determined that the amount of force transmitted to circumaxillary sutures was sufficient to induce the formation of osteogenesis in these regions.

Keywords: skeletal anchorage, Class III malocclusion, finite element analysis. (JPMA 71: 877; 2021)

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Introduction

Class III malocclusions are orthodontic anomalies that adversely affect psychosocial status of patients due to their significant effects on their appearance and cause orthodontic treatment even if they are less common than other malocclusions. These malocclusions are the primary etiologic causes of genetics and could be seen as mandibular prognathism, maxillary retrognathism or a combination of these two conditions.[1-3] In the treatment of these malocclusions, orthopaedic treatments are performed in patients in growth-development period, wheras, camouflage treatment or orthognathic surgical treatment approach is preferred in adults who have completed growth and development. In patients during growth-development period, chin-cap treatment is used to prevent and guide the development of mandible in cases of mandibular prognathism and maxillary protraction treatments with intraoral appliances or often face-mask in cases of maxillary retrognathism.[4]

Skeletal Class III malocclusions with maxillary retrognathia are treated with an orthopaedic face mask in the early period. [5-9] Maxillary protraction with face mask; maxillary suture growth is achieved by stimulating maxilla by applying forces in the same direction as normal growth development. In many studies examining effects on dentofacial structures, anterior movement and anterior rotation in maxilla, posterior rotation in mandible, proclination in maxillary incisors, retroclination in mandibular incisors and an increase in lower face height have been reported.[5,6]

Proclination of maxillary incisors with dentoalveolar effects of face-mask and retroclination of mandibular incisors camouflage the present skeletal problem. However, treatment goal of this malocclusion is to correct the anomaly by providing skeletal changes. In order to eliminate the undesirable side effects of face-mask treatment, dentoalveolar effects and to increase skeletal effects, researchers have aimed to achieve maxillary protraction using skeletal anchorage in recent years.[10-15]

Finite element analysis is an analysis technique that could be used in fields of biomechanical science and its use has increased exponentially in the last decade as a way to evaluate mechanical behaviour of dental materials, teeth and jaws. Finite element analysis is an algebra-based simulation technique that solves biomechanical problems by dividing them into small pieces and calculating stress

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and stress in computer-aided design models. It offers useful biomechanical findings before orthopaedic and orthodontic treatments and is an important analysis technique in dentistry.[16]

The aim of this study was to compare the two different skeletal anchorage methods, which are frequently used in orthodontics for various purposes in recent years with finite element analysis in the treatment of Class III patients with maxillary retrognathia and to predict the differences they create during treatment.

Material and Methods

In this study, in order to compare the effects of two different skeletal anchorage methods and maxillary protraction on maxilla, the effect of these systems on same cranial structure was evaluated by three-dimensional finite element stress analysis and static linear analysis. Our aim in finite element analysis is to apply the treatment on three-dimensional model without treatment to the patient and to see the stress areas and displacement amounts in advance.

Ethical approval was obtained from the Clinical Research Ethics Committee, Suleyman Demirel University Faculty of Medicine, Isparta, Turkey (28.05.2019/188). A 15-year-old Class III male with maxillary retrognathia treated in the Department of Orthodontics (October 2018) at Süleyman Demirel University was chosen to be the skull model.[17-19] According to the three-dimensional cephalometric analysis obtained from the archive CBCT, a male patient with SNA: 75°, SNB: 83°, ANB: -8° and normodivergent growth pattern was selected. Two different treatment scenarios were performed on the skull model obtained from computerized tomography images and finite element analysis was performed.

In order to make a finite element analysis, the two- or three-dimensional model of the tissue to be analyzed must be prepared first. In our study, CBCT image of a 15 year old Class III patient was used to obtain a three-dimensional model. Computer aided design (CAD) and computer aided software programmes are used for solid modeling of objects. The three-dimensional model is then decomposed into a certain number of pieces called 'elements'. Each parsed piece is called 'element'. The junction points of the elements are defined as the node 'node point'. The young module and poisson ratio, which are the material properties of three-dimensional model, are determined and assigned to the modeled structure. Materials are considered homogeneous, isotropic and linear elastic.

Then the elements are separated on three-dimensional model and mesh (mesh) structure is obtained. Separate equations are created for each element and equations are analyzed to reach values at the node. As a result of analysis, data related to different variables could be obtained. These data are principal stresses, axial stresses, displacements, deformation values or equivalent stresses. In our study, the effects of maxillary protraction forces on maxilla were investigated with mini plates placed in different anatomical locations on three-dimensional model.

Finally, the results are analyzed and interpreted. In evaluating the results of analysis; principal stresses for fragile materials (bone, graft materials, porcelains), Von Misses stress (equivalent stresses) values for retractable materials such as metals. With von Misses values, information about stress values occurring in the whole structure could be obtained.

To create a three-dimensional solid model and finite element stress analysis, for editing and a more homogeneous three-dimensional network structure; Windows 7 Ultimate Version Service Pack 1 with Intel Xeon® CPU 3.30 GHz processor, 500gb Hard disk, 14 gb RAM

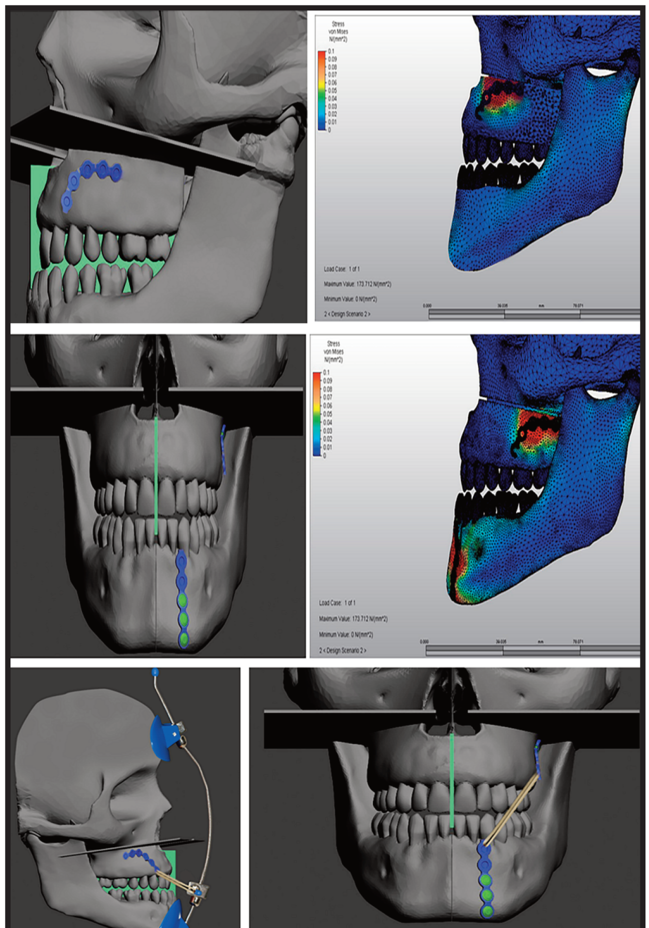

Figure: Demonstration of two finite element models simulating the different maxillary protraction methods with skeletal anchorage operating system used.

In the first group; miniplates applied for skeletal anchorage were simulated on infra zygomatic crest. The end of mini plate placed on infra zygomatic crest is aligned from lower part of the Apertura piriformis to canine tooth region. Unilateral 500 g protraction force was applied to the face-mask from maxillary canine at 30 degrees with occlusal plane. In the second group; mini plates were simulated in infra zygomatic crest and mandibular symphysis. Then, 500 g protraction force was applied with Class III elastic for each side between miniplates in maxilla and mini plates in mandible. In the obtained finite element model, Von Misses stress, maximum and minimum principal stress and displacement values were obtained and values in both models were evaluated comparatively.

Results

In the finite element model obtained, Von Misses stresses and maximum and minimum principal stress values are given in Table 1. The displacement values that occur in sutures as a result of applied forces are shown in Table 2.

In Class III elastic group, maximum Von Misses stress occurred around infra zygomatic crest and symphysis anchored with 0.078 MPa. The maxillary posterior region and paranasal regions were the areas that showed the highest Von Misses tension after infra zygomatic crest and symphysis. However, the force applied decreased in nasomaxillary complex as it went to superior and posterior regions. Von Misses was observed in anterior and superior parts of maxillary bone, anterior of the mandible. When displacement values were examined, the most displacement in sagittal direction was observed in pterygomaxillary suture and in frontomaxillary process region. In vertical direction, the most displacement was seen in superior direction in anterior premaxillary region, while tuber maxilla was displaced upwards.

In the face-mask group, the most common site of Von Misses stress in nasomaxillary complex and alveolar structures were infrazygomatic area where plaques were applied, followed by pterygomaxillary suture. Tensile forces were reduced especially in these two areas by spreading to surrounding structures. Minor stress concentrations in frontonasal region were distributed with a similar increase in paranasal area. The least stress concentration was observed in maxillary anterior region and lateral parts of zygomatic bone. The most displacement in sagittal direction occured in the part where plates are applied in maxilla, in pterygomaxillary suture, and in frontomaxillary process region; whereas in transverse direction, the lateral displacement is seen in inferior region of zygomatic arch. In vertical direction, the most displacement in inferior direction was seen superiorly in frontomaxillary suture and in anterior premaxillary region, while the tuber maxilla region posteriorly was displaced upwards.

Table-1: Von Misses stresses and maximum and minimum principal stress values.

	Von Misses Stresses (MPa)		Maximum Principal Stress (MPa)		Minimum Principal Stress (MPa)	
	Face Mask	Class III Elastic	Face Mask	Class III Elastic	Face Mask	Class III Elastic
Nasomaxillary Suture	0.4945	0.0024	0.0021	0.0034	-0.0140	-0.0169
Frontomaxillary Suture	0.9937	0.0205	0.0014	0.0018	-0.0117	-0.0210
Pterygomaxillary Suture	0.3610	0.0774	0.0303	0.0147	-0.2848	-0.0116
Zygomaticomaxillary Suture	0.2834	0.0033	0.0075	0.0063	-0.001	-0.0033
Zygomaticotemporalis Suture	0.4543	0.0035	0.0033	0.0033	-0.001	-0.0017
Zygomaticofrontal Suture	0.2514	0.0017	0.001	0.0007	-0.0004	-0.0146
Frontonazal Suture	0.1141	0.0021	0.0014	0.0017	-0.0127	-0.0205
Midpalatal Suture	0.0853	0.0018	0.0006	0.0003	-0.005	-0.0046

Table-2: The displacement values.

	X Axis (mm)		Y Axis (mm)		Z Axis (mm)	
	Face Mask	Class III Elastic	Face Mask	Class III Elastic	Face Mask	Class III Elastic
Nasomaxillary Suture	0.01	-0.07	-0.05	-0.02	0.02	-0.45
Frontomaxillary Suture	0.42	0.35	-0.26	-0.23	-0.04	-0.01
Pterygomaxillary Suture	0.59	0.51	-0.08	-0.16	0.3	0.15
Zygomaticomaxillary Suture	0.53	0.34	-0.21	-0.19	0.04	0.01
Zygomaticotemporalis Suture	0.17	0.15	-0.01	-0.02	0.04	0.05
Zygomaticofrontal Suture	-0.02	-0.01	-0.02	-0.01	-0.07	-0.03
Frontonazal Suture	0.31	0.35	-0.02	-0.03	-0.04	-0.02
Midpalatal Suture	0.12	0.05	-0.01	-0.02	0.01	-0.03

Discussion

Finite element analysis is a kind of computer-aided simulation that is frequently used especially in fields of engineering and health.[20] In these computer simulations, an infinite number of variables could be converted into predictable finite elements and the data obtained could be converted into predictable results in terms of treatment mechanics. [21,22] In this study, we investigated the effects of protraction force by using two different skeletal anchorage methods in Class III malocclusions due to maxillary retrognathia. For this purpose, finite element analysis was preferred and possible variables were estimated and infinitely unknown variables were reduced by force and skeletal elements. By means of finite element analysis, the variables of force could be controlled easily. For this purpose, in order to evaluate the effects of force in a more healthy and ethical way, finite element analysis was preferred in our study.

According to the results of this study; in the model with skeletal anchorage supported face mask, tensile stresses in the Apertura piriformis were caused by protraction force applied from these regions. When the skeletal anchorage supported face mask was applied, there was an increase in tensile stress at the frontal overhang of maxillary bone, but a homogeneous strain distribution was observed. In Class III elastic application between plates, a homogeneous stress distribution was observed throughout maxilla to concentrate on the frontal overhang. Unlike the skeletal anchorage supported face mask, in this embodiment, the dominant type of stress in frontal overhang was compressive stress. Maxilla, sutura naso-fronto-maxillary point to be the center of rotation counter-clockwise rotates this region is affected. In the skeletal anchorage supported face mask application, we thought that tensile stress in the frontal projection and compression stress in the inter-plate Class III elastic application were caused by change of shape and amount of rotation of maxilla according to the application point.

Miyasaka-Hiraga et al. stated that center of resistance of nasomaxillary complex is on the posterosuperior edge of pterygomaxillary fissure.[23] According to the authors, for parallel movement of nasomaxillary complex, maxillary protraction force must pass through the closest point to the center of resistance. In our study, as suggested by Kırcelli and Pektaş, the skeletal anchorage supported face mask was applied over force resistance center so that its direction was close to the resistance center of nasomaxillary complex and counterclockwise rotation of maxilla was prevented.[23,24] Therefore, tensile stresses have been observed in the frontal projection. In Class III elastic application, the force direction was below the resistance center of nasomaxillary complex, even though the force application site was posterior, causing rotation of maxilla counterclockwise, causing compression stresses in the frontal overhang.

The sutural modification was reported to be the most important factor for remodeling of nasomaxillary complex.[21,25,26] Sutural growth is also closely related to the stress magnitude, intensity and, dose. Different types of stress on same suture might cause different remodeling to occur in the same suture. Although it is known that fibrogenesis and osteogenesis in the suture could be induced by mechanical stimuli in compression and tensile stresses, no clear results have been demonstrated regarding magnitude of the stress that would activate osteogenesis.[24]

Kambara in his study observed maxillary protractive force and, circummaxillary sutures; sutural opening, elongation of sutural connective tissue fibers, new bone appendages around prolonged fibers and formation of significant tissue haemostasis preserving sutural width.[24] Nanda and Hickory, with maxillary protraction, suture zygomaticomaxillary, have observed histological modifications varying according to the direction of maxillary protraction force.[25]

Similar stress values were found in suture zygomaticotemporal in Class III elastic model. In both applications, tensile stresses were observed at the edges of suture at a lower intensity than middle region due to the effect of protraction force. In Class III elastic application, upper and lower edges of the suture and middle of the suture; in the application of skeletal anchorage supported face-mask, tensile stresses were observed in middle of the suture and in a localized area in upper region of the suture.

Although stress distribution in the sutures is more uniform with the effect of protraction force in skeletal anchorage supported face-mask applications, Tanne et al. applied protraction force of 1000 g strength in various directions over first molars and observed non-uniform stress distributions.[27,28] They stated that the most uniform stress distribution in the sutures was caused by force effect applied at an angle of 30° downward to the occlusal plane.

Tanne and Sakuda, in their finite element analysis study of first major molars in the direction parallel to occlusal plane of 1000g strength applied and applied zygomaticomaxillary, frontozygomatic and frontonasal sutures in the bones around zygomaticomaxillary and frontonasal sutures.[29] They also reported high tensile stresses on the side of maxillary bone facing zygomaticomaxillary suture. In both methods, a homogenous stress distribution was observed in the suture frontomaxillary, more intense at lower edge of the suture. In suture frontomaxillary, tensile stresses occurred due to the parallel movement of maxilla in the skeletal anchorage supported face-mask application. Consistent with this finding in our study, Miyasaka-Hiraga et al. in their work, canine teeth at an angle of 30° up and down the direction of occlusal plane and parallel to occlusal plane applied 1000 g protraction force.[23] They found high compressive stresses in frontonasal and frontomaxillary sutures with the effect of force exerted in 30° upward and parallel directions to the occlusal plane, and stated that this was due to counterclockwise rotation of maxilla. A 30° downward force application; zygomaticotemporal and zygomaticomaxillary sutures almost uniform tensile stress, frontonasal and frontomaxillary sutures stated that there is minimal compression stress. Hata et al. have observed tensile stress in zygomaticomaxillary suture and high compression stress in frontomaxillary suture with maxillary protraction.[30]

In Class III elastic application between the plates, compression was observed on upper edge of the suture and tensile stress was observed in the adjacent region. In the skeletal anchorage supported face-mask application, tensile and compression stresses were observed in the adjacent region with nasal bone. Gautam et al. in their finite element analysis study, force of 1000g protraction force from canine and 30^o angle down to the occlusal plane applied alone and in combination with RPE (Rapid Palatal Expansion) and evaluated stresses in the sutures.[26] The highest Von Mises stresses were observed in sphenozygomatic, zygomaticomaxillary and zygomaticotemporal sutures, respectively. The lowest stresses were seen in internasal and nasomaxillary sutures. The authors stated that different compression and tensile stresses seen in the sutures during maxillary protraction were caused by effect of horizontal force of protraction, as well as by rotation of maxilla counterclockwise. They reported that tensile stresses in upper parts of nasomaxillary suture and compression stresses in lower parts were caused by contraction effect of protraction force on anterior side of maxilla.

According to results of a study in 2013, zygomaticomaxillary, zygomaticotemporal and pterygopalatine sutures in skeletal anchorage supported face-mask model in same force vector, higher values of tooth-supported anchorage model was observed. In nasion and nasal wings, the opposite occurred.[31] Based on these findings, the authors stated that skeletal anchorage supported maxillary protraction and stresses that induce growth in the sutures of maxilla were induced, and that in tooth-supported protraction, more osteogenesis activity in nasal region would be better reflected in the profile. Kırcelli and Pektas applied mini plates to edges of nasal wall and the Apertura piriformis for skeletal anchorage. They stated that force vector is the most ideal skeletal anchorage zone since it could protract maxilla in the direction of growth by passing through the center of resistance of maxilla and might be more easily affected due to locations of the circummaxillary sutures.[14] Similarly, Liu et al. applied protraction hooks to the Apertura piriformis region and removed them from nostril by applying the force of protraction. The results of this study stated that sutural distraction casused osteogenesis and significant midface development. [21]

Lee and Baek in their study in 2012 applied mini plates to infra zygomatic crest and Apertura piriformis skeletal maxillary protraction simulated by finite element analysis. As a result of the study; protraction with mini plate applied to the apertura piriformis region was lower than the stresses seen in protraction performed with the support of mini plates applied to infra zygomatic crest.[32] However, Tanne et al. and Gautam et al. in accordance with the work; in both models, the highest Von Mises stresses were observed in pterygomaxillary, zygomaticotemporal, zygomaticomaxillary and frontonasal sutures, respectively.[26,29]

Conclusion

- In both methods, it was determined that the amount of force transmitted to the circummaxillary sutures was sufficient to induce formation of osteogenesis in these regions.
- Because the stresses on bones sutures are within physiological limits with the two methods examined in our study, they could be used clinically safely in the treatment of class III skeletal malocclusions since they couldproduce sufficient stimulation in the circummaxillary sutures.
- The face mask supported skeletal anchorage might be preferred as an alternative in the treatment of class III malocclusions due to maxillary insufficiency due to its advantages such as more uniform stress distributions in circummaxillary sutures compared to the inter-plate Class III elastic application and movement of maxilla in parallel.

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Ethics Approval: The study was approved by the Clinical Research Ethics Committee of Süleyman Demirel University Faculty of Medicine (Ethics approval decision number: 28.05.2019 / 188).

Competing interest: The authors declare that they have no competing interests.

Disclaimer: None.

Conflict of interest: None.

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