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Evaluation of Finite Element Analysis Studies Related to Maxillary Protraction with Facemask

Yüz Maskesi ile Maksiller Protraksiyon Üzerine Yapılmış Sonlu Elemanlar Analiz Çalışmalarının Değerlendirilmesi

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ABSTRACT

Skeletal Class 3 malocclusions are challenging orthodontic problems that require particular treatment methods and long term follow-ups. Facemask appliance, which is used for treatment of skeletal Class 3 malocclusions due to maxillary deficiency, has been frequently used in jaw orthopedics with various modifications for many years. Extraoral part of facemask appliance is connected to teeth by intraoral anchorage units with various designs. Protraction force direction, magnitude, angle and intraoral anchorage type are significant factors affecting the treatment results. Finite element stress analysis method can combine engineering with medicine by providing the effects of appliances in craniofacial region in terms of stress and displacement values that may occur as a result of treatments. Several studies has been done before in order to find the best maxillary protraction protocol without any side effects. This study includes previously published finite element analysis method studies on the treatment of maxillary protraction related to facemask.

Keywords: Finite element analysis, Facemask, Maxillary protraction

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ÖZ

İskeletsel Sınıf 3 maloklüzyonlar, özel tedavi planlamaları ve uzun süreli takipler gerektiren zorlu ortodontik problemlerdir. Maksillanın gelişim yetersizliğine bağlı olarak gelişen iskeletsel Sınıf 3 maloklüzyonların tedavisinde kullanılan yüz maskesi aygıtı çeşitli modifikasyonlarla çene ortopedisi alanında uzun yıllardır klinisyenler tarafından sıklıkla tercih edilmektedir. Yüz maskesi apareyinin ağız dışı kısmı, ağız içi ankraj üniteleriyle dişlere ve kemik yapılara bağlanır ve bu ünitelerin tasarımları, maksillaya uygulanan kuvvetin yönü, açısı, büyüklüğü gibi faktörler tedavi sonuçlarını etkileyebilen önemli parametrelerdir. Bu noktada bir mühendislik metodu olup diş hekimliği alanında da kullanılan sonlu elemanlar stres analizi yöntemi, apareylerin kraniyofasiyal bölgedeki olası etkilerini ve tedaviler sonucunda oluşabilecek stres ve yer değiştirme değerlerini saptayarak mühendisliği tıp ile birleştirebilmektedir. Herhangi bir yan etki oluşturmadan, uygulanabilecek en iyi maksiller protraksiyon protokolünü tespit etmek amacıyla yapılmış sonlu elemanlar stres analizi çalışmaları literatürde bulunmaktadır. Bu çalışmada ise, yüz maskesine bağlı maksiller protraksiyonun tedavisi ile ilgili daha önce yayınlanmış sonlu elemanlar analizi yöntemi çalışmaları derlenmiş ve değerlendirilmiştir.

Anahtar Kelimeler: Sonlu elemanlar analizi, Yüz maskesi, Maksiller protraksiyon

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INTRODUCTION

Skeletal Class 3 malocclusions are complex orthodontic problems that can occur due to various etiological factors, challenging to treat, and require long-term follow-up. These anomalies may develop in the form of maxillary deficiency, mandibular prognathism, or a combination of both, and may cause some clinical findings that significantly affect facial aesthetics and chewing function. Treatment methods of skeletal class 3 malocclusions vary according to the several factors such as etiology, growth and development period of patient and which jaw is affected. Reverse headgear (RH) / facemask (FM) and chin cup is among conventional treatment appliances mostly preferred in cases caused by maxillary retrognathia and mandibular prognathia, respectively. The reverse headgear appliance aims to pull the maxilla forward, maxillary protraction in other words. Its current use was designed by Delaire in the 1970s and has been used with different modifications for many years.[1]

Various intraoral anchorage units has been used to connect teeth to facemask but first applications were in the form of dental anchorage.[2-4] In time, maxillary expansion appliances were also included in FM and to increase the post treatment skeletal gains and with the developments in technology over time, researchers started to use orthodontic miniscrews and miniplates as intraoral anchorage of facemask application lately.[5-8]

Finite element stress analysis method (FEM) is a useful technique in evaluating the compatibility of newly designed treatment methods with biological tissues and the responses that may occur after treatment and has been used in orthodontics for many years. These theoretical studies are very important in terms of guiding clinicians in determining the effects of treatments on individuals and making various case-specific modifications in treatment methods when necessary. Although finite element analyzes are frequently performed, it is seen that the studies evaluating the analyzes made on a particular subject until that time are limited in the literature.

The aim of this study is to review the FEM studies related to orthopedic facemask and to present the theoretical information about treatments applied in practice in summary form. Studies involving individuals with cleft lip and palate were excluded as they required a more multidisciplinary and different perspective.

When literature is examined, it has been seen that previous studies have focused on some specific issues and this article will be examined under 3 main headings as follows:

- Studies Evaluating the Direction of Protraction Force and Effects of Different Protraction Forces
- Effect of Intraoral Anchorage Unit on Maxillary Protraction
- Facemask Application With Rapid Maxillary Expansion (RME)

STUDIES EVALUATING THE DIRECTION OF PROTRACTION FORCE AND EFFECTS OF DIFFERENT PROTRACTION FORCES

FEM studies examining stress and displacement values that may occur in the craniofacial structures after application of orthopedic facemasks were first published in 1980s.[9] To obtain translational forward movement of the maxilla without any rotation, it is known that protraction force should be applied on the line connecting the resistance centers of the maxillary dental arch and maxillary bone which is known as an estimation. Therefore, the region where protraction force is applied and the angle of application are very significant from the biomechanical point of view.[10-12]

Tanne et al. [9] applied 1.0 kg force forward on the buccal surfaces of maxillary first molar teeth with parallel and 30° downwards to the functional occlusal plane and found that nasomaxillary complex moved forward and upward in parallel protraction case, and almost translationally in downward protraction case with most uniform stress distribution. Ko and Kim [13] created a finite element model and applied protraction force of 500 g to first premolar and first molar teeth, parallel and 20° downward to the occlusal plane, respectively. In all scenarios, it was observed that maxilla moved counterclockwise but least rotation was observed in the protraction applied from the first premolar with 20° downward angle. On the other hand, Hyun et al. [14] applied 500 g protraction force at 0 º, 30 º, 60 º and 90º to the Frankfurt horizontal (FH) plane and recommended that application with 60º angle is suitable for forward movement of the maxilla without rotation.

To examine the changes in transversal direction, Oh et al. [15] applied 500 g force to the maxillary first premolar and maxillary first molar with angle of 45º and 20º to the FH plane, respectively. In maxillary premolar scenario it was observed premolar area getting narrow and expansion in molar area. However in the maxillary first molar scenario, expansion on lateral nasal wall and molar part getting narrow were detected on the contrary.

Another important issue about maxillary protaction is that whether mandible and temporomandibular joint (TMJ) is affected. For this purpose, Dong et al. [16] imitated maxillary protraction with a finite element model and 5 N force was applied to mandible with changing angles of 22° to 49° to occlusal plane. Posterior rotation of mandible was seen at application angles below 40°. Therefore, 40° application angle is suggested as ideal protraction angle considering the stress values and displacements of the maxilla and mandible. In another study, it was found that reaction forces and deformation could increase with the increasing loading forces, and emphasized that clockwise rotation of the mandible could be seen at the end of maxillary protraction.[17]

The magnitude of protraction force should be at a level that will create an orthopedic effect and induce osteogenic activity in sutures surrounding the maxilla, but not cause pathological results in bone and tooth structures. In a previous FEM study, 6 different forces from 3N to 8N were applied to maxillary canine region with an angle of 30°. High stress levels were observed with the increase in force values, specially after 5N, and it was suggested that care should be taken at higher forces.[18] Gazzani et al. [19] simulated a Delaire facemask and applied force at 0°, 30° and 50° angle to the occlusal plane with 7.8 and 9.8 N force values; high stresses and deformations were mostly observed after 9.8 N with increasing downward forces. They also stated since the total stresses were lower than the elasticity limit that characterizes the materials, facemask absorbed the force and plastic deformation did not occur.

Holberg et al. [20] investigated the effect of maxillary protraction on the cranial sutures with 2 x 3 N and 2 x 5 N forces in anterior and anterior-inferior directions and found that forces reflected on sutures were quite low; therefore, brought a different perspective to the subject that dental effects of maxillary protraction treatment may be more and skeletal effects may be doubtful.

EFFECT OF INTRAORAL ANCHORAGE UNIT ON MAXILLARY PROTRACTION

The intraoral anchorage unit of facemask appliance can be removable, cap splint like cemented acrylic appliances, applications from the palatal region, labiolingual appliances, orthodontic miniscrews, mini-implants and miniplates. Considering that the purpose of applying the facemask is mostly to treat patients with skeletal disorders, it is desired that gains from treatment being more skeletal and in this respect, different intraoral designs are still being developed to increase efficiency.

Yan et al. [21] applied protraction from the maxillary first molar and infrazygomatic crest miniplates with unilaterally 500 g force parallel and with different angles downwards to the occlusal plane and found that maxilla moved almost parallel at 20° in skeletal anchorage and 30° in dental anchorage model. In addition, higher stress values were found in the sutures on the posterior maxilla in skeletal anchorage and anterior region in dental anchorage.

Karamanlı et al. [22] created 2 protraction models with angle of 30° forward and downward with respect to the occlusal plane and applied unilateral 750 g force on upper canine tooth and miniplates placed on aperture piriformis. Greater and uniform stresses were observed in circummaxillary sutures in skeletal anchored model compared to the dental anchorage and skeletal anchorage was suggested for more effective protraction. In another study, it was observed that protraction forces applied to the aperture piriformis region provided the advantage of moving maxilla as a block and decreased counterclockwise rotation when compared to protraction force applied to whole maxillary arch.[23]

Lee and Baek [24] compared maxillary protraction with miniplates placed on the infrazygomatic crest and the lateral nasal wall. They applied 500 g force with an angle of 30° to the occlusal plane and found that stress values of the frontonasal, frontomaxillary, zygomaticomaxillary and pterygomaxillary sutures were higher in the infrazygomatic crest model when compared to lateral nasal wall. In terms of displacement, forward and downward displacement of ANS, Point A and prosthion was observed when the miniplate was applied to the lateral nasal wall, while forward and upward displacements were observed in same landmarks in the infrazygomatic crest scenario. Büyükçavuş and Kale [25] stated that the amount of force transmitted to the circummaxillary sutures was sufficient to induce the formation of osteogenesis when protraction applied through a facemask both from the miniplates placed in the infrazygomatic region and the application of Class III elastic with 500 g force from the miniplates placed in the symphysis region of the mandible.

Skeletal anchorage, conventional dental anchorage and palatal plates were also compared with the finite element method, and displacement values indicating anterior rotation of maxilla were found in all 3 models as a result of 500 g protraction force with an angle of 30° with the occlusal plane. It was also mentioned that palatal plates had advantages such as stress distribution and greater forward displacement.[26]

Ebisawa et al. [27] compared conventional tooth supported and palatal miniscrew anchored maxillary protraction with 6N force and different application angles and found more sagittal displacement in ANS in skeletal anchored but in central incisors and first molars in dental anchored model. In both models, rotation of the maxilla was suppressed at the maximum level when the vertical angle was 20°.

Considering the overbite, Liu et al. [28] suggested labiolingual arches for patients with crossbite and deepbite and mini-implants for patients with crossbite and openbite. They stated that FM application with labiolingual arch may cause less stimulating force on maxilla, however mini-implant application may cause more and protraction with labiolingual arch was recommended for younger skeletal Class III patients and mini-implant anchored FM for patients with late mixed or early permanent dentition. Chang et al.[29] also recommended labiolingual appliance anchored facemask for patients with deep bite.

FACEMASK APPLICATION WITH RAPID MAXILLARY EXPANSION (RME)

It has been previously reported that RME application may increase the sutural cellular response to protraction forces by disrupting sutural articulation of maxilla with adjacent bones in the craniofacial complex.[30, 31] It is also mentioned that in cases with transverse and sagittal maxillary deficiency, facemask applied with RME may also have positive effects on correction of posterior crossbite, arch length, and opening of occlusion by eliminating occlusal interferences.[32] Contrary to this view, some clinical studies did not find a significant difference between FM treatments with and without expansion.[33, 34]

Tanaka et al. [35] evaluated the magnitude and direction of stress along the midpalatal suture in maxillary protraction treatment and created a finite element analysis to apply a force of 300 cN each side with an angle of 30° to the occlusal plane and they observed compressive forces concentrated in the anterior region of the incisive canal. They suggested RME application suggested may be beneficial in order to prevent anterior maxilla getting narrow. Yu et al. [36] on the other hand, applied 500 g protraction force 20 degrees down the occlusal plane to the first premolar tooth region in 2 different protraction scenarios created as the midpalatal suture is opened or not. Less compressive stress and more tensile stress in circumaxillary suture areas, decrease in the upward-forward rotation of the maxilla and greater amounts of displacement in the anterior, vertical, and lateral directions were observed in opened midpalatal suture model compared to non-deployment of the suture.

In another FEM study comparing maxillary protraction with and without RME, significantly higher stress values were found in RME model, and it was suggested RME+FM treatment could facilitate the orthopedic effect, and osteogenic effect of protraction without RME could be questioned due to the low stress values.[37] Similarly, a finite element model with 4 mm midpalatal suture opening was compared to a model without suture opening to which 1 kg protraction force was applied with an angle of 30^0 to palatal plane and maxillary advancement and greater displacement values were found in the expanded model without any rotation. In non-expansion model, narrowing of the anterior maxilla was observed.[38]

Özdemir and Göymen [39] created 3 finite element models: a combination of RME+FM in the first scenario, skeletal anchored FM+RME in the second scenario, hybrid hyrax+mentoplate in the third scenario. Protraction force of 500 g was applied in the first, and 250 g in the second and third scenarios. Similar but higher stress values were found in the 1st and 2nd models compared to the 3rd model. In skeletal anchored model, displacement was included the mid-face, however in 3rd scenario displacement was observed at the level of Le Fort I and it was concluded that 2nd scenario provided more skeletal efficiency than 1st and 3rd scenarios. In a different study, Suresh et al. [40] suggested skeletal anchorage with miniscrew assisted RME may be beneficial in patients with skeletal Class III malocclusion with hyperdivergent growth pattern or open bite, as it may prevent undesirable rotation of the maxilla.

CONCLUSION

There are many finite element analysis studies in the literature about the facemask appliance used in the treatment of skeletal class 3 malocclusion characterized by developmental deficiency of the maxilla. Stress and displacement values created by various FM applications in the craniofacial region were compared with each other and ideal application conditions were studied.

When the application angle of the protraction force is evaluated, most studies have yielded similar results that protraction force should be applied not parallel to the occlusal plane, but with an angle of approximately 20-30° forward and downward to move the maxilla translationally without any rotation. Although there is no exact value agreed on the magnitude of the protraction force; the general opinion is that it is necessary to be careful with increasing forces and the force applied to maxilla also creates reaction forces on mandible and TMJ. Skeletal anchorage has been found to be more advantageous compared to dental anchorage in many studies, but factors such as the area of application of the force, patient's age and cooperation for this costly treatment should be considered when choosing this anchorage type. While choosing the anchorage system, factors such as the patient's vertical growth direction and overbite should also be considered. It has been seen that the finite element analysis results of FM applied together with RME show that RME can contribute positively to this treatment.

In this article, studies are gathered under certain titles as much as possible and focused on the inference that the study wants to convey rather than the details. It is believed that in the future, standardized studies that can be compared with each other more clearly and carried out under equal conditions may be beneficial in long term in order to draw more exact and universal results.

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