

Study of Displacement and Stress Distribution in Maxillofacial Complex Following Maxillary Protraction with Conventional and Modified Facemask: A Finite Element Analysis

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Abstract

Objectives: To study the distribution of stress and displacement of landmarks during maxillary protraction with conventional facemask and modified facemask using finite element analysis.

Methodology: Cone beam computerized tomography images are used to generate two finite element models. A force of 1500 gram is applied at 30 degrees in a downward and forward direction to the maxillary occlusal plane in the first model and at a distance of 15 mm and parallel to the maxillary occlusal plane in the second model. Stress generated in the frontomaxillary, pterygomaxillary, zygomaticomaxillary, zygomaticofrontal and zygomaticotemporal sutures and the displacement of the frontal process of the maxilla, Prosthion, point A and FA point of the first molar were studied in both models.

Results: In the modified face mask, maximum stresses were generated in the zygomaticotemporal suture and frontomaxillary sutures. In the conventional facemask, maximum stresses were generated in the pterygomaxillary and zygomaticomaxillary sutures. In the modified facemask, landmarks Prosthion, point A and FA point of the first molar showed greater movement in the anterior direction and in the transverse direction. In the vertical direction, the magnitude of displacement of the frontal process of the maxilla, prosthion, point A and FA point of the first molar was more in the conventional facemask.

Conclusion: The modified facemask demonstrated lesser magnitude of maxillary rotation in a counterclockwise direction and more anteroposterior movement as compared to the conventional facemask. This backs Nanda's original claim regarding his modification.

Keywords: *Conventional Facemask; Nanda's Modified Facemask; Cone Beam Computed Tomography; Finite Element Method*

Abbreviations

ANSYS: Analysis Systems; CBCT: Cone Beam Computed Tomography; FEA: Finite Element Analysis; FEM: Finite Element Method; MIMICS: Materialise's Interactive Medical Image Control System

Introduction

In 1899, Angle classified malocclusions into Class I, Class II, and Class III based on the relationship of the first molars and the alignment of teeth relative to the line of occlusion [1]. Until the 1970s, mandibular prognathism was considered the primary cause of A Class

III growth pattern [2]. Many studies since have found that, maxillary hypoplasia is the primary etiology of the Class III malocclusion [3,4]. This led to a change in treatment modality, from chin cups to facemasks.

The facemask is an orthopaedic appliance used to protract the maxilla. Class III treatment with face mask was first performed by Potpeschnigg in 1875 [5]. However, adverse effects such as counter-clockwise rotation of maxilla, clockwise rotation of mandible and increase in lower facial height have been documented. This led to modifications in design of the conventional facemask. One such modification was brought about by Nanda in 1980, in which force was directed through the centre of resistance of maxilla [6]. He claimed that his modification brought about pure translation of maxilla.

The technique of finite element analysis (FEA) was developed by R Courant., *et al.* in 1956 and was introduced into dental biomechanical research in 1973 [7]. This technique can be used to calculate the stress and strain levels induced in craniofacial structures with application of external forces. For this reason FEA finds application in the analysis and design of orthopaedic devices.

Objective of the Study

The objective of the present study was to evaluate and compare, through FEA, the stress distribution and displacement of landmarks during maxillary protraction while using conventional facemask and Nanda’s modified facemask.

Materials and Methods

A Cone Beam Computerized Tomography (CBCT) image of a subject presenting with skeletal Class III malocclusion with retrognathic maxilla was used, to obtain two three-dimensional mathematical models, using MIMICS software. MIMICS, Materialise’s Interactive Medical Image Control System, is an interactive tool for the visualization and segmentation of CT images as well as MRI images and 3D rendering of objects. ANSYS 12.1 software was used to generate the finite element model. The finite element model thus built comprised of 4,52,014 elements and 95,096 nodes. Circummaxillary sutures such as Zygomatico-maxillary suture, Frontomaxillary suture, Pterygo-maxillary suture, Zygomaticotemporal suture and Zygomatico-frontal suture were incorporated in the finite element models. Mechanical properties such as Young’s modulus and Poisson’s ratio of compact bone, cortical bone, tooth and sutures were fed to the finite element model (Table 1).

| Material | Young’s Modulus (N/mm²) | Poisson’s Ratio |
|-----------------|---|------------------------|
| Cortical bone | 1.34 x 10 ⁵ | 0.30 |
| Suture | 68.65 | 0.40 |
| Tooth | 2.03 x 10 ⁵ | 0.30 |

Table 1: Young’s modulus and poisson’s ratio of cortical bone, suture and tooth.

Results and Discussion

Stress distribution

Highest compressive stress was seen to be generated in Frontomaxillary suture in both types of facemask. Both in the conventional facemask and modified facemask, greatest von Mises stress was generated in the Zygomaticotemporal suture. The least stresses were around the pterygomaxillary suture in both types (Table 2 and 3).

Displacement

In the modified facemask, landmarks prosthion, point A and FA point of the first molar showed greater movement in the anterior direction, in comparison to conventional facemask, suggestive of increased anteroposterior movement in the modified facemask. In the

| Sutures | Conventional facemask method | Modified facemask method |
|---------------------|------------------------------|--------------------------|
| Frontomaxillary | -1.2 | -5.7 |
| Pterygomaxillary | 0.51 | 0.45 |
| Zygomaticomaxillary | 12.85 | 10.58 |
| Zygomaticotemporal | 17.68 | 18.3 |
| Zygomaticofrontal | 7.67 | 5.44 |

Table 2: Comparison of von Mises stresses generated in Sutures during Protraction with Conventional Facemask and Modified Facemask (in MPa).

| Sutures | Conventional facemask method | Modified facemask method |
|---------------------|------------------------------|--------------------------|
| Frontomaxillary | 1.305 | 4.32 |
| Pterygomaxillary | 0.2 | 0.18 |
| Zygomaticomaxillary | 7.83 | 6.85 |
| Zygomaticotemporal | 8.812 | 9.823 |
| Zygomaticofrontal | 3.07 | 2.52 |

Table 3: Comparison of principle stresses generated in sutures during protraction with conventional facemask and modified facemask (in MPa).

transverse direction, all the four landmarks studied showed a higher magnitude of displacement in the modified facemask as compared to the conventional facemask. In the vertical direction, the magnitude of displacement of the frontal process of the maxilla, prosthion, point A and FA point of the first molar in the modified facemask was lesser in magnitude compared to those of conventional facemask, which is suggestive of decreased counter-clockwise rotation of maxilla (Table 4 and Figures 1-16).

| Regions | Conventional facemask method | | | Modified facemask method | | |
|-------------------------|------------------------------|-------|-------|--------------------------|-------|-------|
| | X | Y | Z | X | Y | Z |
| Frontal Process | 0.02 | 0.164 | 0.039 | 0.081 | 0.118 | 0.009 |
| Prosthion | 0.036 | 1.135 | 0.105 | 0.068 | 1.42 | 0.004 |
| Point A | 0.032 | 1.005 | 0.047 | 0.063 | 1.22 | 0.012 |
| FA point on first molar | 0.009 | 1.14 | 0.33 | 0.013 | 1.42 | 0.001 |

Table 4: Magnitude of Displacement of Surface Landmarks (in mm).

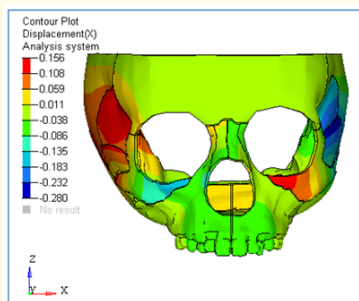


Figure 1a: Displacement contours of maxilla in X axis in conventional facemask.

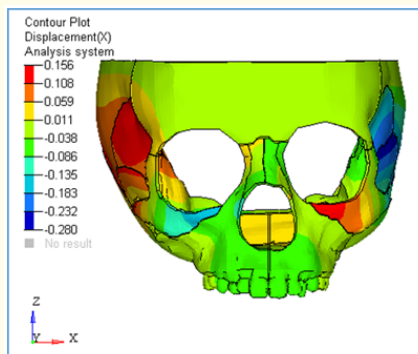


Figure 1b: Displacement contours of maxilla in X axis in modified facemask.

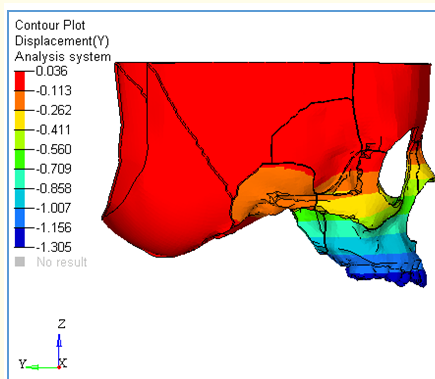


Figure 2a: Displacement contours of maxilla along Y axis in conventional facemask.

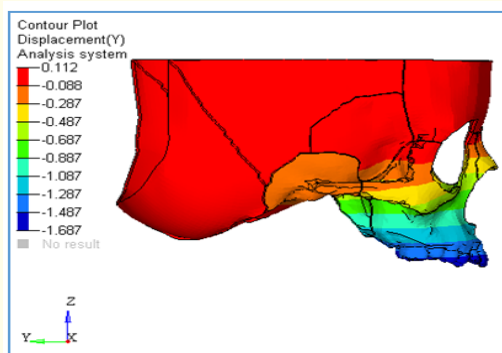


Figure 2b: Displacement contours of maxilla along Y axis in modified facemask.

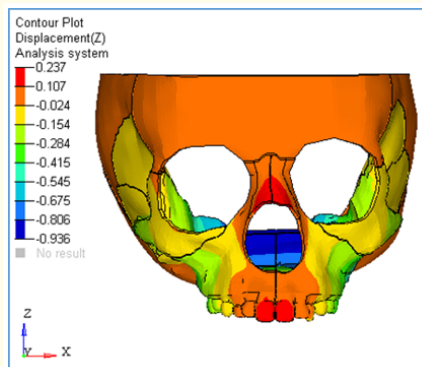


Figure 3a: Displacement contours of maxilla in Z direction in conventional facemask.

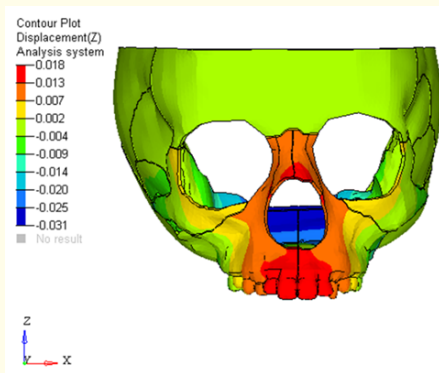


Figure 3b: Displacement contours of maxilla in Z direction in modified facemask.

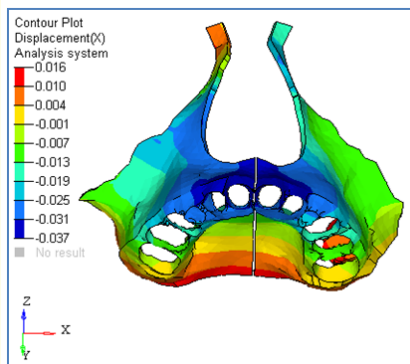


Figure 4a: Displacement contours of maxillary bone in X direction in conventional facemask.

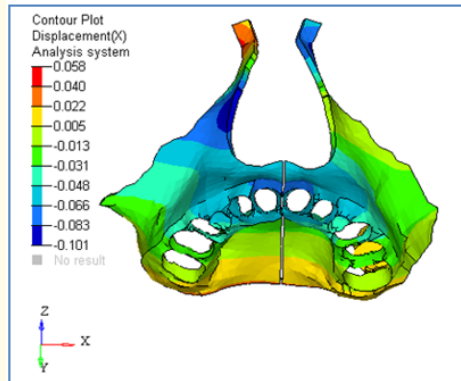


Figure 4b: Displacement contours of maxillary bone in X direction in modified facemask.

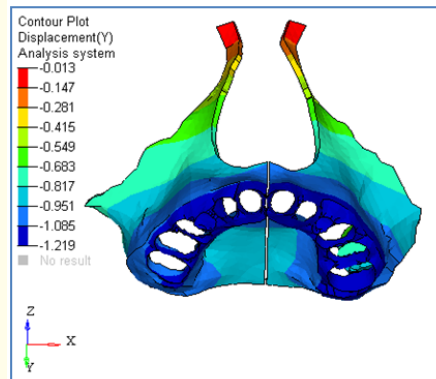


Figure 5a: Displacement contour of maxillary bone in Y direction in Conventional Face Mask.

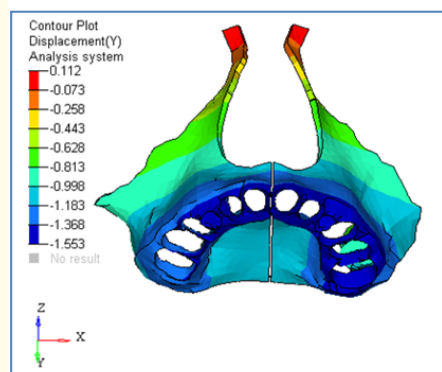


Figure 5b: Displacement contour of maxillary bone in Y direction in modified facemask.

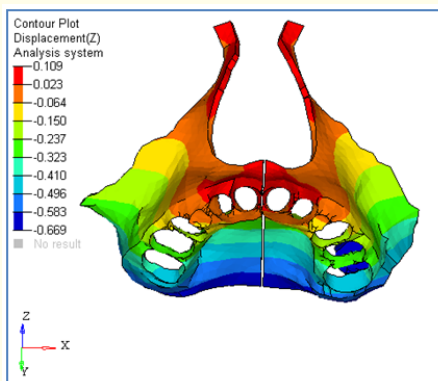


Figure 6a: Displacement contours of maxillary bone in Z direction in conventional facemask.

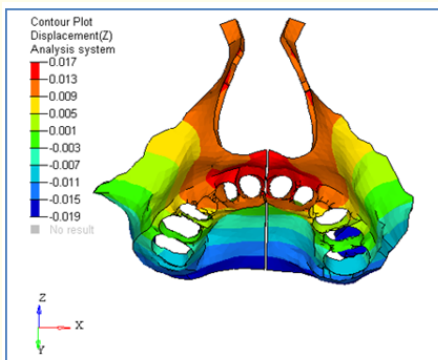


Figure 6b: Displacement contours of maxillary bone in Z direction in modified facemask.

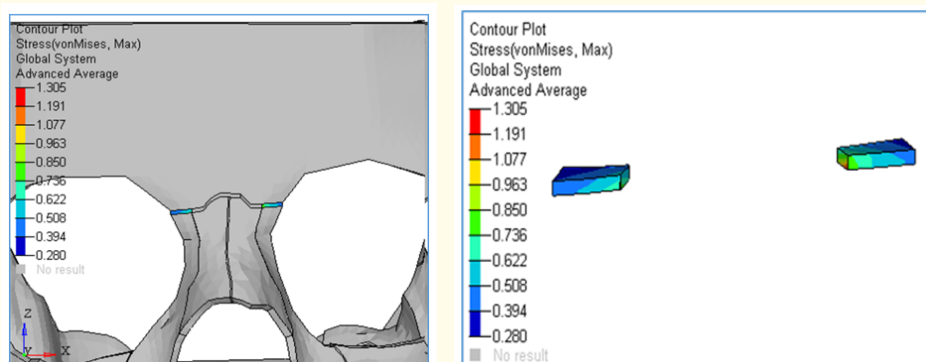


Figure 7: Stress contours generated in frontomaxillary suture in conventional facemask.

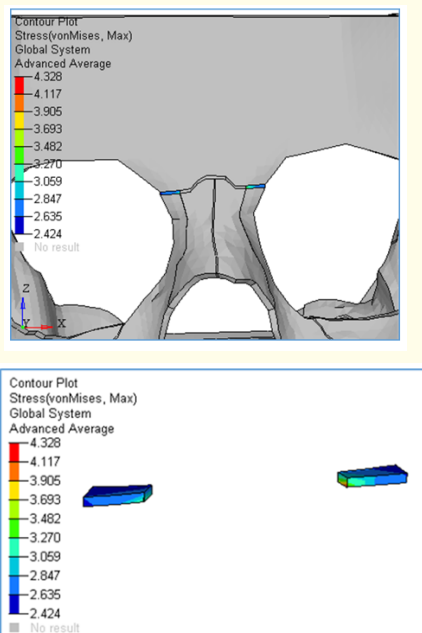


Figure 8: Stress distribution in frontomaxillary suture in modified facemask.

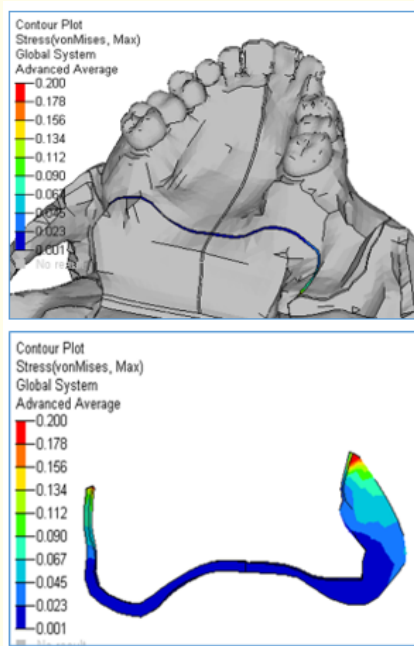


Figure 9: Stress contours generated in pterygomaxillary suture in Conventional facemask.

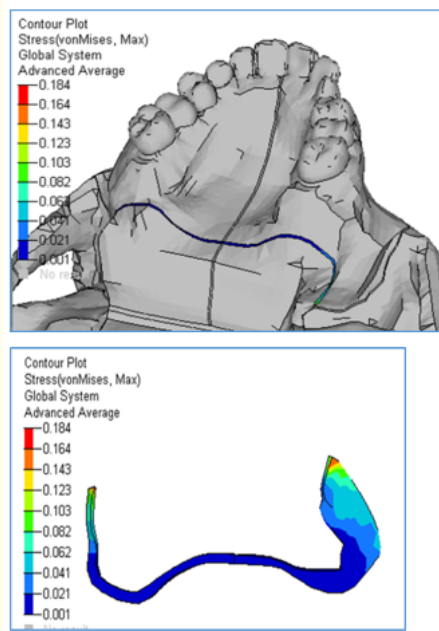


Figure 10: Stress contours generated in pterygomaxillary suture in modified facemask.

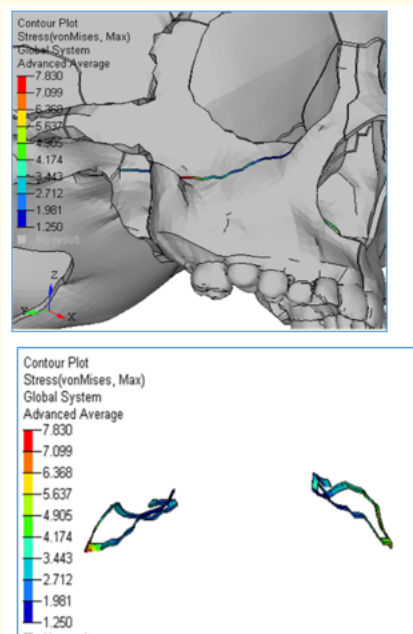


Figure 11: Stress contours generated in Zygomaticomaxillary sutures in Conventional facemask.

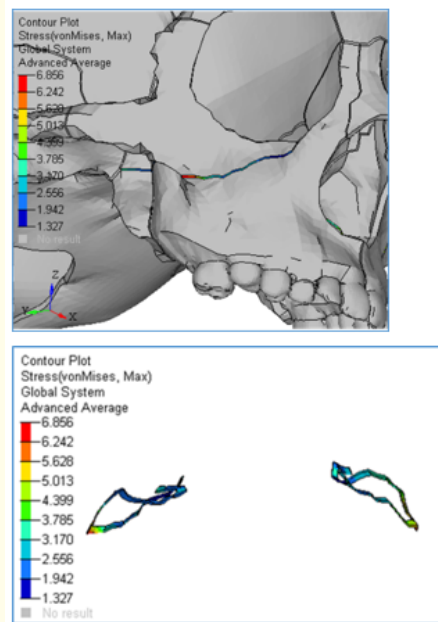


Figure 12: Stress contours generated in zygomaticomaxillary sutures in Modified facemask.

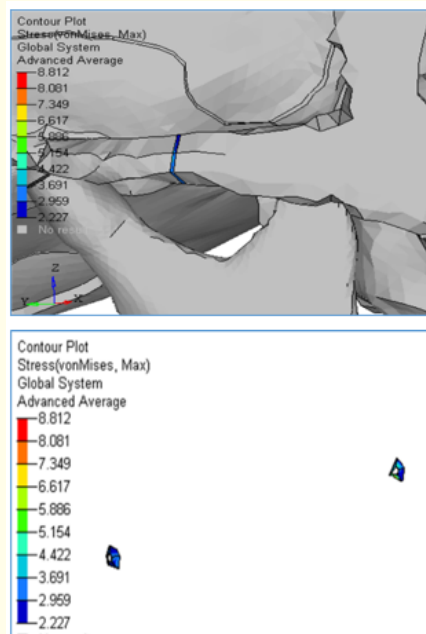


Figure 13: Stress contours generated in Zygomaticotemporal sutures in Conventional facemask.

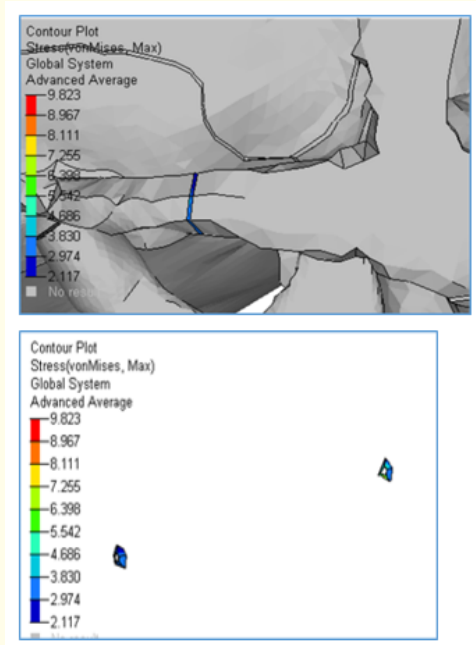


Figure 14: Stress contours generated in Zygomaticotemporal sutures in Modified facemask.

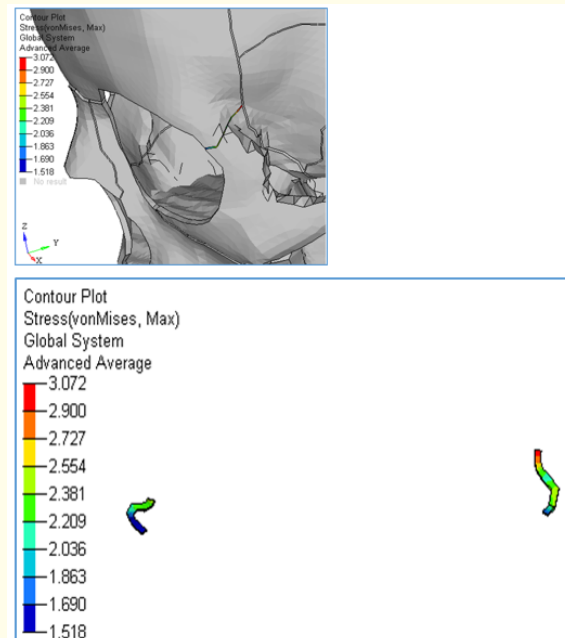


Figure 15: Stresses generated in zygomaticofrontal sutures in conventional facemask.

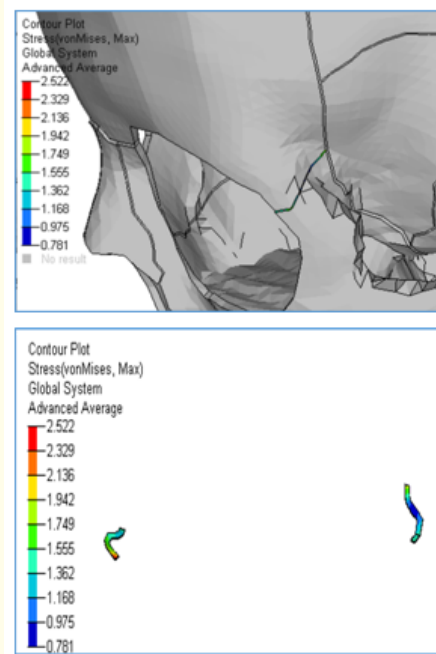


Figure 16: Stress contours generated in Zygomaticofrontal sutures in modified facemask.

Discussion

Numerous studies have reported significant displacement of maxillary landmarks in the anterior direction upon use of conventional facemasks [8-26]. However, adverse effects such as counter clockwise rotation of maxilla and clockwise rotation of mandible leading to an increase in lower facial height, led to modification of the design of the face mask and, in the direction of force application.

Nanda R believed that the adverse effects of rotation of skeletal bases could be prevented by a change in the direction of force application. In his appliance, the protraction force was transmitted parallel to the maxillary occlusal plane at a height of 15 mm, through the centre of resistance of the maxilla, leading to translation of maxilla. Nanda reported that use of the modified design for 4 - 8 months can bring the maxilla anteriorly by 1 to 3 mm. and maxillary dentition by 1 to 4 mm, there was also a mesial displacement of maxillary molars by 2.5 mm.

In the present study, maximum compressive stress was seen in the Frontomaxillary suture for modified facemask, This finding is in agreement with a study performed by Miyasaka JH., *et al.* [27], wherein stresses produced in the craniofacial sutures were evaluated, when protraction force was applied parallel to the functional occlusal plane. Highest von Mises stress was generated in Zygomaticotemporal suture, implying that forces are transmitted directly to the midfacial area. In the conventional facemask also, maximum von Mises stresses were seen to be generated in Zygomaticotemporal suture, which is consistent with findings from a study conducted by Gautam P., *et al.* [28], analyzing sutural stresses during maxillary protraction. Similar pattern of stress distribution was observed for zygomaticotemporal suture in a study by Kim KY., *et al* [29]. The findings of this study coincide with previous studies performed by Nanda R., *et al.* [30] and Jackson GW., *et al.* [31], reaffirming that the direction of force has major implications on the nature of displacement as well as stress patterns in the nasomaxillary complex.

In the current study, amount of displacement in the anterior direction was greater in the modified facemask, the findings of which are consistent with Nanda's observations. The amount of vertical movement in the modified facemask group was seen to be negligible, which is in agreement with the investigations conducted by Keles A., *et al.* [32] by varying the direction of force on maxillary protraction, and with the findings of Hata., *et al* [32].

FEA is defined as a technique of discretizing a continuum into simple geometric shaped elements enforcing material properties and governing relationships on these elements. It was introduced by R Courant in 1956 and the term was coined by Argyris and Clough in 1960. The advantages of finite element analysis include its non-invasive nature, relatively low investment, simultaneous and rapid calculation and visual representation of a wide variety of physical parameters.

Although studies utilizing FEA have been performed comparing the response of maxillary protraction with or without rapid maxillary expansion [28] and conventional facemask with miniplates [29] no finite element study comparing stress distribution and displacement of landmarks following maxillary protraction comparing conventional facemask with Nanda's modified facemask has been reported till date.

In the present study, although the finite element method provided the freedom to simulate orthodontic force systems applied clinically and allowed analysis of the response of the craniofacial skeleton to orthopaedic forces in three-dimensional space, the stress distribution on the model could only be dealt with quantitatively and not qualitatively, which is one of the major limitations of the finite element method. Thus, the results of this study are valid only for a single specific human skull, upon which the finite element models have been constructed. However, the mechanical response to facemask therapy was predicted essentially in the same manner as stated in the literature, which proves the validity of the study.

Conclusion

To conclude, although the results of the present study prove that the modified design introduced by Nanda is a superior treatment option compared to the conventional design in terms of anterior displacement and counter-clockwise rotation of maxilla, further clinical as well as experimental studies have to be performed to assess the modification from other aspects as well.

Conflict of Interest

There is no conflict of interests in this research.

Bibliography

1. Angle EH. "Classification of malocclusion". *Dental Cosmos* 41 (1899): 248-264, 350-357.
2. Jacobson A., *et al.* "Mandibular prognathism". *American Journal of Orthodontics* 66.2 (1974): 140-171.
3. Guyer EC., *et al.* "Components of Class III Malocclusion in Juveniles and Adolescents". *American Journal of Orthodontics* 56.1 (1986): 7-30.
4. Ellis E and McNamara JA. "Components of adult Class III malocclusion". *Journal of Oral and Maxillofacial Surgery* 42.5 (1984): 295-305.
5. Turley PK. "Orthopedic correction of Class III malocclusion with palatal expansion and custom protraction headgear". *Journal of Clinical Orthodontics* 22.5 (1988): 314-325.
6. Nanda R. "Biomechanical and clinical considerations of a modified protraction headgear". *American Journal of Orthodontics* 78.2 (1980): 125-139.
7. Farah JW., *et al.* "Photoelastic and finite element analysis of a restored axisymmetric first molar". *Journal of Biomechanics* 6.5 (1973): 511-520.

8. Baik HS. "Clinical results of the maxillary protraction in Korean children". *American Journal of Orthodontics and Dentofacial Orthopedics* 108.6 (1995): 583-592.
9. Kapust AJ, et al. "Cephalometric effects of face mask/expansion therapy in Class III children: A comparison of three age groups". *American Journal of Orthodontics and Dentofacial Orthopedics* 113.2 (1998): 204-212.
10. Kiliçoğlu H and Kirliç Y. "Profile changes in patients with class III malocclusions after Delaire mask therapy". *American Journal of Orthodontics and Dentofacial Orthopedics* 113.4 (1998): 453-462.
11. Ngan P and Yiu C. "Evaluation of treatment and posttreatment changes of protraction facemask treatment using the PAR index". *American Journal of Orthodontics and Dentofacial Orthopedics* 118.4 (2000): 414-420.
12. Cozza P, et al. "Treatment and posttreatment effects of a facial mask combined with a bite-block appliance in Class III malocclusion". *American Journal of Orthodontics and Dentofacial Orthopedics* 138.3 (2010): 300-310.
13. Hino CT, et al. "Three-dimensional analysis of maxillary changes associated with facemask and rapid maxillary expansion compared with bone anchored maxillary protraction". *American Journal of Orthodontics and Dentofacial Orthopedics* 144.5 (2013): 705-714.
14. Gallagher RW, et al. "Maxillary protraction: Treatment and posttreatment effects". *American Journal of Orthodontics and Dentofacial Orthopedics* 113.6 (1998): 612-619.
15. Arman A, et al. "Evaluation of maxillary protraction and fixed appliance therapy in Class III patients". *European Journal of Orthodontics* 28.4 (2006): 383-392.
16. Shanker S, et al. "Cephalometric A point changes during and after maxillary protraction and expansion". *American Journal of Orthodontics and Dentofacial Orthopedics* 110.4 (1996): 423-430.
17. Kilic N, et al. "Soft tissue profile changes following maxillary protraction in Class III subjects". *European Journal of Orthodontics* 32.4 (2010): 419-424.
18. Jiuxiang L, et al. "A cephalometric evaluation of hard and soft tissue changes during class III traction". *European Journal of Orthodontics* 7.3 (1985): 201-204.
19. Nartallo-Turley PE and Turley PK. "Cephalometric effects of combined palatal expansion and facemask therapy on Class III malocclusion". *Angle Orthodontist* 68.3 (1998): 217-224.
20. Lertpitayakun P, et al. "Cephalometric changes after long-term early treatment with face mask and maxillary intraoral appliance therapy". *Seminars in Orthodontics* 7.3 (2001): 169-179.
21. Macdonald KE, et al. "Cephalometric changes after the correction of class III malocclusion with maxillary expansion/facemask therapy". *American Journal of Orthodontics and Dentofacial Orthopedics* 116.1 (1999): 13-24.
22. Canut JA, et al. "Effects of maxillary protraction determined by laser metrology". *European Journal of Orthodontics* 12.3 (1990): 340-345.
23. Filho OG da S, et al. "Early treatment of the Class III malocclusion with rapid maxillary expansion and maxillary protraction". *American Journal of Orthodontics and Dentofacial Orthopedics* 113.2 (1998): 196-203.
24. Ngan PW, et al. "Treatment response and long-term dentofacial adaptations to maxillary expansion and protraction". *Seminars in Orthodontics* 3.4 (1997): 255-264.
25. Vaughn GA, et al. "The effects of maxillary protraction therapy with or without rapid palatal expansion: A prospective, randomized clinical trial". *American Journal of Orthodontics and Dentofacial Orthopedics* 128.3 (2005): 299-309.
26. Halicioğlu K, et al. "Effects of face mask treatment with and without rapid maxillary expansion in young adult subjects". *Angle Orthodontist* 84.5 (2014): 853-861.

27. J Miyasaka-Hiraga., *et al.* "Finite Element Analysis for Stresses in the Craniofacial Sutures Produced by Maxillary Protraction Forces Applied at the Upper Canines". *British Journal of Orthodontics* 21.4 (1994): 343-348.
28. Gautam P., *et al.* "Maxillary protraction with and without maxillary expansion: A finite element analysis of sutural stresses". *American Journal of Orthodontics and Dentofacial Orthopedics* 136.3 (2009): 361-366.
29. Kwang Yoo Kim., *et al.* "Displacement and stress distribution of the maxillofacial complex during maxillary protraction with buccal versus palatal plates: finite element analysis". *European Journal of Orthodontics* 37.3 (2015): 275-283.
30. Nanda R and Hickory W. "Zygomaticomaxillary Suture Adaptations Incident to Anteriorly-Directed Forces in Rhesus Monkeys". *Angle Orthodontist* 54.3 (1984): 199-210.
31. Jackson GW., *et al.* "Experimental and postexperimental response to anteriorly directed extraoral force in young *Macaca nemestrina*". *American Journal of Orthodontics and Dentofacial Orthopedics* 75.3 (1979): 318-333.
32. Shunji Hata., *et al.* "Biomechanical effects of maxillary protraction on the craniofacial complex". *American Journal of Orthodontics and Dentofacial Orthopedics* 91.4 (1987): 305-311.

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