Comparative evaluation of the forces produced by tongue on circummaxillary sutures in skeletal Class III malocclusion with maxillary hypoplasia using tongue crib with that of facemask therapy - A FEM study [version 1; peer review: awaiting peer review]

Jeni Ann Mathew, Ranjit H Kamble, Sunita Shrivastav, Pallavi S Daigavane

Orthodontics, Sharad Pawar Dental College, Datta Meghe Institute of Higher Education and Research, Sawangi Meghe Wardha, Maharashtra, 442001, India

Abstract

Background: Class III malocclusion has the lowest incidence when compared to other malocclusions. Class III malocclusion can be present in retrognathic maxilla, prognathic mandible or a combination. Various modalities have been used in treatment. Facemask with expansion is an effective appliance used for protraction in case of retrognathic mandible; although it is effective, dentists have to deal with patient compliance. Efforts have been directed to simplify the design of appliance to redirect growth. The finite element method can be used to simulate conditions to check various hypothesis.

Methods: A finite element method (FEM) study was performed in two important steps: generation of model and model analysis. A tongue force of 4-6 pounds was applied to cribs (Group I) based on the frequency of swallowing per day (minimum to maximum). In facemask therapy (Group II), a downward force at 30 degrees along with transverse expansion of 1N was applied. Mean values of both sides were considered.

Results: Von-Mises stresses in Group I and Group II showed a non-significant difference (p=0.535). Displacement in Group I and Group II showed a significant difference (p=0.0001). Maximum amount of displacement was seen in maxillary dentition on canines and incisors, and minimum stress was seen on posterior teeth in both interventional therapies, even though the Von-Mises stresses generated were different in both groups. Overall displacement in both Group I and Group II was similar.

Conclusions: Both modalities were effective in the treatment of Class
III malocclusion. The force transmission varied and overall displacement was similar in both modalities, which implies both modalities are effective in treating Class III malocclusion.

**Keywords**
Class III malocclusion, Finite element method, Nasomaxillary complex, Tongue crib, Facemask, force, Von-Mises stresses, displacement

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**Introduction**

Skeletal and dental anomalies have been mentioned in the literature as early as the 18th century when Bourdet had noticed protruding chin in children. In the 19th century, Delbarre termed this condition as edge to edge or under-bite.1,2 Across the world, Class III malocclusion has the lowest frequency among malocclusions. The incidence of Class III malocclusion is 5.93%, and its prevalence in permanent dentition is greater than mixed dentition. Its prevalence was 1.19% when the prevalence in the Indian population was validated against the world population.3

It is recognized among the public and dental professionals that early treatment is crucial. The time for intervention may vary from prepubertal to pubertal phase. Treatment approaches vary from orthopaedics in the earlier phase, to orthodontic intervention to combined orthodontic and orthognathic management in later phases. Treatment appliances range from protraction facemask, Class III Bionator, Frankel’s FR-III appliance, comprehensive orthodontic treatment using Class III biomechanics, orthognathic surgery, among others. After growth completion, surgery is the best option to correct Class III malocclusion.4

Class III malocclusion has a greater genetic predisposition; for controlling expression, it needs intervention at an early age. Class III malocclusion needs a longer retention period as it has a greater chance of relapse as mandibular growth continues till later ages. Not only are the treatment appliances bulky and complex, but so is the retention appliance. Hence there is a need to develop a simpler appliance.

The finite element method (FEM) is a modality where simulations are used to study impact. Forces on biological structures like bone and soft tissue can also be evaluated. In FEM, mathematical calculations are inbuilt into software to simplify calculations while doing the analysis. FEM has been used in various orthodontic studies.5,6 Forces exerted on the craniofacial complex can be studied by simulation analysis like the finite element analysis.

The aim of our study was to compare and evaluate the effect of forces produced by the tongue on circummaxillary sutures in skeletal Class III malocclusion with maxillary hypoplasia using a tongue crib (Group I), with that of facemask therapy with expansion (Group II) using FEM. The objectives of our study were to evaluate stress and displacement patterns in Group I and Group II and compare them.7

**Methods**

The present study was carried out in the Department of Orthodontics and Dentofacial Orthopaedics, Sharad Pawar Dental College, Datta Meghe Institute of Medical Sciences, Wardha, Maharashtra. The study was approved from the ethical committee of Datta Meghe Institute of Medical Sciences. Ref No-DMIMS (DU)/IEC/2020-21/9401.

Three-dimensional finite element model of skull with circummaxillary sutures and teeth, periodontal ligament and bone of maxilla was built. Tongue crib and facemask therapy with expansion were modelled and forces were incorporated in the model. Simulations were run to analyze stress exerted and displacement produced. Finite element modelling and analysis was performed at DICUL AM Private Limited, Nagpur. The computational devices used for this study included a PC workstation having a AMDRyzen 7 2700X Eight-Core Processor with 32GB RAM 1 TB secondary storage graphics accelerator. The operating system used for this study was Windows 10. Initial modelling was done using the Dassault Systèmes 3D Experience Platform software.

The study was performed in two stages:

I - Generation of model

II - Model analysis

**Generation of model**

1. Geometric model construction: According to the measurements and morphology of a dried model of human skull, an analytical model of the human skull was created for this investigation.

2. Geometric model conversion to a finite element model was done: The Geometric Model (x_t) Parasolid extension file was converted to a.stl extension file for the analysis. The Dassault Système’s 3D experience platform (Digitized shape to preparation) was used to generate the finite element model. The solid tetrahedral element shape with 6 degrees of freedom that the model specified. Through a process known as meshing, these elements were joined to nearby elements with the aid of triangles using Dassault Système’s: Structural Model Creation. Our model had 11,119,347 elements and 248,464 nodes.
3. Assignment of material property data: Material property was assigned to structure. The skull finite element model consisted of circummaxillary suture and bone. The material properties of structures were assigned on the basis of values quoted in the literature in Table 1.

4. Boundary condition definition: The engineer validated the final model. Important elements of FEM are the nature of modelling and accuracy depend upon modelling and the number of elements used.

The model of the skull comprised circummaxillary suture, maxillary teeth and bone. The model was analyzed.

**Model analysis**

**Application of force**

The efficacy of two modalities were compared in our study:

**Group I - Tongue crib**

**Group II - Facemask therapy with expansion**

Application of forces in this study was in conjunction with the range of tongue forces for Class III malocclusion patients during rest and swallowing. Tongue forces applied on cribs based on the frequency of swallowing per day (minimum to maximum) were a frequency of 500 to 1200 times and a pressure of 4-6 pounds per swallow. This intermittent force was transferred through the tongue appliance to the nasomaxillary complex. In facemask therapy, the force exerted ranged from 180 to 800 g per side and was angulated from 20 and 30 degree to occlusal plane and ranged from 10 to 24 hours of wear per day.

**Solution of linear algebraic equation**

The above-mentioned steps were followed sequentially leading to a system of algebraic equation where nodal displacement was not known. The equations were solved by Dassault Système’s Mechanial Scenario Creation and final analysis was done by SIMULIA.

**Table 1. Material properties used in the model.**

| Components                  | Elastic modulus | Poisson’s ratio |
|------------------------------|-----------------|-----------------|
| Teeth                        | 22.5            | 0.3             |
| Periodontal ligament         | $6.8 \times 10^{-2}$ | 0.45           |
| Cancellous bone/spongy bone  | 1.37            | 0.3             |
| Lingual cortical bone        | 15.25           | 0.3             |
| Buccal cortical bone         | 15.94           | 0.3             |
| Suture                       | 0.386           | 0.45            |

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**Table 2. Simulation criteria in both groups.**

| Group I                     | Group II                                                |
|-----------------------------|---------------------------------------------------------|
| Force                       | Push force                                              |
| Tongue forces were applied on cribs pressure of 6 pounds per swallow was considered. | Protraction force mesial to second premolar region, 350 g directed 30 degree downward to occlusal plane and 1 N transverse expansion was applied |
| Timing                      | 24-hour intermittent force is transferred through the tongue appliance to the nasomaxillary complex | Fourteen hours intermittent force was considered |
Results
The aim of the present study was to evaluate and compare the stress distribution pattern following tongue forces in anteroposterior direction on the tongue crib placed on the anterior region, and facemask with expansion to quantify the stresses and deformation produced at the circummaxillary sutures and the maxillary dentition using FEM.

Von-Mises stresses were seen in all the circummaxillary sutures and maxillary dentition and compared as represented graphically in Figure 1. Amongst circummaxillary sutures in tongue crib therapy, maximum stress was seen in mid-palatine suture (11.55) and minimum in zygomatico-frontal suture (0.5715). Amongst circummaxillary sutures in facemask therapy with expansion, maximum stress was seen in transverse-palatine suture (8.93) and minimum in zygomatico-temporal suture (0.224). Maximum amount of Von-Mises stresses was seen in maxillary dentition at canines, incisors, and minimum stress was seen on posterior teeth in both interventional therapies. Von-Mises stresses in tongue forces applied on the tongue crib appliance and facemask therapy with expansion showed non-significant differences (p=0.535).

Displacement was seen in all the circummaxillary sutures and maxillary dentition and compared as represented graphically in Figure 2. Amongst circummaxillary sutures in tongue crib therapy, maximum displacement was seen in inter-maxillary suture (0.00116) and minimum in pterygomaxillary suture (0.000316). Amongst circummaxillary sutures in facemask therapy with expansion, maximum displacement was seen in mid-palatine suture (0.0003725) and minimum in zygomatico-frontal suture (0.00005895). Displacement in tongue forces applied on the tongue crib appliance in second rugae area and facemask therapy with expansion was significant (p=0.0001).

Maximum amount of displacement was seen in maxillary dentition at canine, incisors and minimum stress was seen on posterior teeth in both interventional therapies as depicted in Figures 3 and 4 and Table 3. Von-Mises stresses generated were different in both groups. Overall displacement in both Group I and Group II was similar.

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**Figure 1.** Comparison of Von-Mises stress (MPa) in Group I and Group II.
Figure 2. Comparison of displacement in Group I and Group II.

Figure 3. Overall displacement generated in Group I.
Discussion

In the literature, the timing of functional treatment in orthodontics in various malocclusions has been discussed. There have been various studies assessing treatment during mixed and permanent dentition. However, most of the clinicians prefer intervening during the pubertal growth period rather than post-pubertal period. Various modalities are used in the correction of Class III malocclusion; appliances used in clinical practice include facemask, protraction with RME, chin cup, Class III Bionator, fixed orthodontics with Class III elastics, etc. After growth completion, orthognathic surgery is the last alternative.

Though it has been found that facemask with expansion is an effective modality in Class III malocclusion, appliance bulk affects compliance among the subjects treated. Studies done by Jamilian and Showkatbaksh showed that forces exerted by the tongue through tongue crib had a considerable effect on the maxillary dentition and circummaxillary sutures. In our study, Von-Mises stresses seen on the maxillary dentition were greater as compared to stresses seen on circummaxillary sutures. Our study’s findings were supported by those of Jamilian and Showkatbaksh, who claimed that tongue crib appliances harnessed tongue forces—intermittent and continuous tongue resting forces—to push the maxilla forward. Tongue forces are efficient in skeletal Class III patients with retrusive maxilla to correct the maxilla in the antero-posterior plane as well as generate a downward movement of the maxilla in the vertical plane.
Ahrari treated Class III malocclusion with a retractive maxilla. Tongue appliance to correct deficient maxilla was the intervention used in transmission of force exerted by tongue through tongue crib to protract the maxilla. Positive overjet was attained at the conclusion of the procedure. It was found that tongue crib was an effective treatment modality in Class III malocclusion. The author claimed that tongue crib appliance in a Class III patient causes the maxilla to shift forward and lower, as shown by a rise in SNA (the angle between the sella/nasion plane and the nasion/A plane) and N-A-Pog (Angle of convexity). Tongue crib appliance is efficient in treating protraction of deficient maxilla in Class III cases that are mild to moderate. In Class III patients, tongue guard appliance is an effective substitute for face mask therapy.13

By using X-ray cephalometric analysis, Zhao assessed the effectiveness of the tongue crib treatment in the correction of severe skeletal Angle Class III malocclusion in mixed dentition. Every patient received a good facial profile. The relationships between the upper and lower first molars as well as the anterior and posterior crossbite were improved. The maxillary skeletal component had considerable modifications as measured by cephalometry. By promoting maxillary growth and regulating mandibular growth, the tongue crib combo is a useful tool for patients with skeletal Angle Class III malocclusion who are still growing.14

Comparison of tongue crib and facemask therapy with expansion therapy
The difference amongst the modalities was direction of the exertion of force. The force exerted by the tongue through the tongue crib was push force. Facemask therapy with expansion exerted pull force. Both modalities were effective in the treatment of Class III malocclusion. The force transmission varied and Von-Mises stresses and displacement were different at various sutures, but overall displacement was similar in both modalities.13

Summary
The following conclusions were drawn from the study: Circummaxillary suture responded in different ways when push force was exerted by tongue crib and pull force was exerted by facemask therapy with expansion.

1. When the tongue is positioned in the second rugae area, forces are applied that cause Von-Mises stress in the maxillary dentition and circummaxillary sutures. Amongst circummaxillary sutures in tongue crib therapy, maximum stress was seen in mid-palatine suture and minimum in zygomatico-temporal suture. The effect was substantial in the dentition. Tongue crib therapy exerted push force, maximum displacement was seen in inter-maxillary suture and minimum displacement in pterygomaxillary suture.

2. In contrast, in facemask therapy with expansion, pull force was exerted amongst circummaxillary sutures in facemask therapy with expansion; maximum stress was seen in transverse-palatine suture and minimum in zygomatico-temporal suture. Maximum displacement was seen in mid-palatine suture and minimum in zygomatico-frontal suture. When facemask therapy with expansion was simulated in the model, the effect was substantial in the sutures. When facemask therapy with expansion was used, it caused more displacement on circummaxillary sutures than dentition, whereas in tongue crib therapy more displacement was seen in dentition.

3. Overall displacement was similar in both tongue crib and facemask therapy with expansion in response to stress generated.

Limitations
Simulation studies like finite element studies are effective in testing the effectiveness of treatment modalities, but clinical trials aid in understanding the stability of the results, which is not possible in finite element studies.

Scope of our study
FEM can serve as a foundation for evaluating and comparing the biomechanical efficiency of modalities. The study serves as a theoretical basis for understanding the efficiency of tongue crib. The simplification of appliance design in dentofacial orthopaedics would encourage cooperation from patients. The use of tongue crib in mild to moderate skeletal Class III cases would encourage correction amongst children. It would decrease the length of orthodontic treatment and the probability of surgical intervention later.

Recommendations
1. FEM can serve as a foundation for evaluating and comparing the efficiency of modalities and comparison. Patients should be included as study subjects in further investigations to determine the movements in all three planes and evaluate the efficiency of modalities.
2. It would be beneficial to compare Class III and Class I with anterior open bite groups, since this would help us understand the differences in morphology in all three planes.

3. To learn more about the intricate function of the tongue and tongue crib device in dentofacial morphology, further clinical research is indicated.

Ethical considerations
The study was approved from the ethical committee of Datta Meghe Institute of Medical Sciences. Ref No-DMIMS (DU)/IEC/2020-21/9401.

Data availability
Underlying data
Zenodo: Comparative evaluation of the forces produced by tongue on circummaxillary sutures in skeletal Class III malocclusion with maxillary hypoplasia using tongue crib with that of facemask therapy - A FEM study, https://doi.org/10.5281/zenodo.7840856.15

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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