J. Maxillofac. Oral Surg.
https://doi.org/10.1007/s12663-024-02285-3

ORIGINAL ARTICLE

Title of the Study: Efficacy of Orthodontic Versus Surgically Assisted Transverse Maxillary Expansion in Adult Patient with Cleft Maxillary Hypoplasia—A Finite Element Method (FEM) Analysis

Sheetal Singh[1] · Shanmugasundaram[1] · Abhirami Srikanth[1] · Krishna Kumar Raja[1]

Received: 15 April 2023 / Accepted: 12 July 2024

Abstract
Purpose To assess the efficacy of surgically assisted maxillary expansion (PMO) in adult cleft patient with transverse maxillary hypoplasia by FEM analysis.
Methods A 3-D FEM was created using CT scan of a patient unilateral cleft palate. The models were divided into three groups: orthodontic group, posterior maxillary osteotomy (PMO) group, and alveolar bone graft (ABG) group. Standardized force (5N—Hyrax and 2.94N—NiTi) was applied to the model to bring about required movement. The von Mises stress at the zygomaticomaxillary buttress, pterygomaxillary junction, frontonasal suture, midpalatal suture, internasal suture, piriform rim, and also the transverse displacement of the maxilla and impact on greater and lesser segment were evaluated.
Results In orthodontic group, von Mises stress area was more with NiTi palatal expander compared to Hyrax appliance.
In PMO group, negligible von Mises stress was observed on the cleft segment with maximum resistance observed in the premolar & 1st molar region of non-cleft segment.
In ABG group, addition stress was seen only at the graft site.
Conclusion In orthodontic group, maximum von Mises stress was observed, and minimum displacement was seen because of fixed boundaries. In PMO group, minimum von Mises stress and maximum displacement were observed. In grafting & PMO group, von Mises stress was more at the graft site, & minimum displacement was observed. Thus, if grafting is necessary, it should be done after PMO.

Keywords Cleft lip and palate · Cleft maxillary hypoplasia · Posterior maxillary Osteotomy · Three-dimensional finite element model · Transverse discrepancy

✉ Shanmugasundaram
shanmugasundaram_s@yahoo.com

Sheetal Singh
sheetalsingh2705@gmail.com

Abhirami Srikanth
abhiramisrikanth@gmail.com

Krishna Kumar Raja
kksukanya@gmail.com

1 Department of Oral And Maxillofacial Surgery, SRM Dental College Ramapuram, Chennai, India

Introduction

Among all birth defects, orofacial clefts including cleft lip with or without involving the palate are the most common in head and neck affecting one per 700 births [1]. A variety of functions are affected by cleft such as speech and mastication. A multidisciplinary surgical and non-surgical approach is required for successful management of these patients from birth to adulthood.

Primary surgical repair of the cleft lip and palate at young age is paramount for the long-term success. However, fibrosis associated with the process of healing negates the growth of the maxilla leading to hypoplasia (25%) of the same warranting orthodontic/surgical correction at a later date [2]. Of which only 9.1% require surgical intervention.

Maxillary hypoplasia in cleft lip and palate patients is primarily attributed to the circum-maxillary fibrosis associated with palatal repair [3]. Transverse maxillary collapse of a non-cleft maxilla is different from cleft maxilla considering the periosteal/scar and soft tissue scarring that opposes the forces of transverse expansion.

Transverse discrepancy of up to 5 mm can be corrected by orthodontic measures, greater degree of transverse collapse may need surgical correction in non-cleft maxilla as application of palatal forces for expansion may lead to tipping of teeth with its associated complications [4–8].

In cleft patients, FEM aids in identifying the sites of force application which allows uniform expansion of the lesser segment. Thus, the objective of this study is to evaluate the role of orthodontic versus posterior maxillary osteotomy (PMO)-assisted palatal expansion in adult patient with cleft maxillary hypoplasia by FEM analysis.

Materials and Methods

The observational study included an adult cleft maxillary hypoplasia with a discrepancy of more than 5 mm planned to undergo transverse maxillary expansion.

Inclusion Criteria

- Adult patient above 18 years of age with cleft maxillary hypoplasia (secondary cleft deformity) with a transverse discrepancy of more than 5 mm.

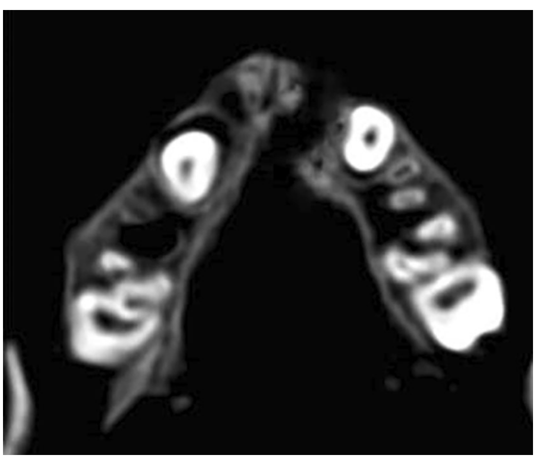


Figure 1 CT axial section for generation of FEM model

Exclusion Criteria

- Pediatric patients with cleft lip and palate were excluded.
- Patients with transverse discrepancy less than 5 mm.
- Patients in whom CT cannot be done due to medical issues.

Preopartive CT scan was done (Fig. 1). CT images were converted and stored in DICOM format. CT images from DICOM format were transferred to D2P software for 3-D recon modeling. ANSYS software was used to convert the 3-D recon model to FEM model (Fig. 2). The FEM generated from the CT contained 954,800 elements & 234,952 nodes. The models were divided into three groups: orthodontic group, PMO group, and alveolar bone grafting group.

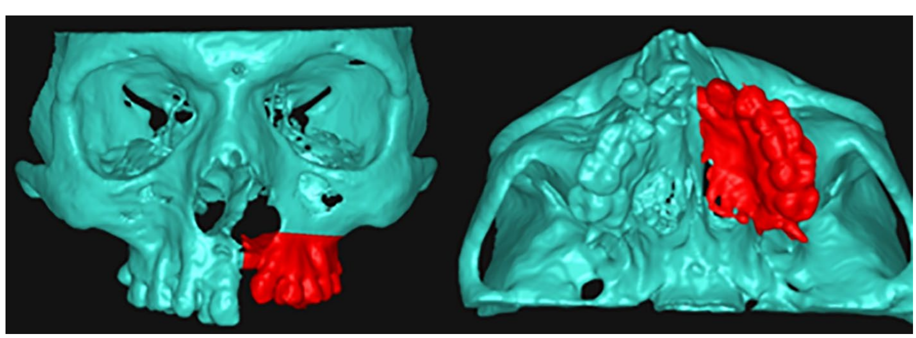
Group 1 Orthodontic Group (Fig. 3)

The arms of Hyrax appliance & NiTi palatal expander were attached to the 1st premolar & 1st molar. The Hyrax appliance was activated periodically exerting 5N in order to obtain 1 mm of movement on each turn whereas NiTi palatal expander exerted a constant force of 2.94*N*. Standardized force of scar tissue forces -2.94*N* (in ~ 50*nN*/10 μm^2 area) was also applied to the models to bring about required movement.

Group 2 Posterior Maxillary Osteotomy (PMO) Group (Fig. 4)

Complete segmental osteotomy of the cleft segment—The vertical osteotomy cut was placed anterior to the canine. The horizontal cut was placed 5 mm above the root apices of the teeth from canine region to the 2nd molar region. The palatal cut was placed in the midpalatal region from canine region to the 2nd molar region. Pterygoid dysjunction was carried out. This was done in order to free the cleft segment from all its attachments. Similar to orthodontic group, the Hyrax appliance & NiTi palatal expander were attached to the 1st premolar & 1st molar. Substitution of the force of the appliances and scar tissue was done, & activation was

Figure 2 FEM generated model



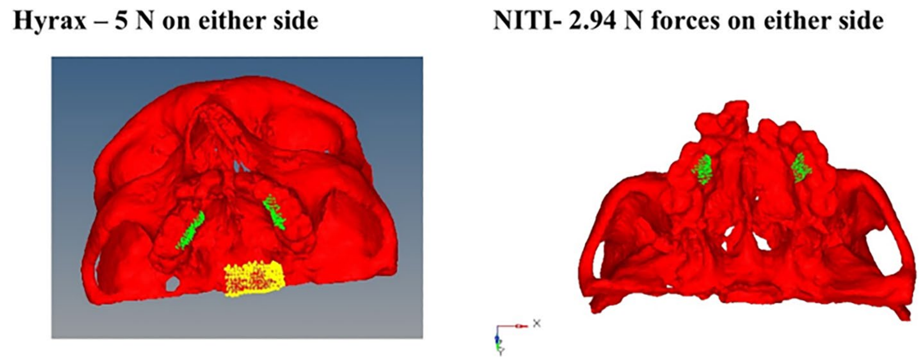


Figure 3 Virtual graft site in ABG group

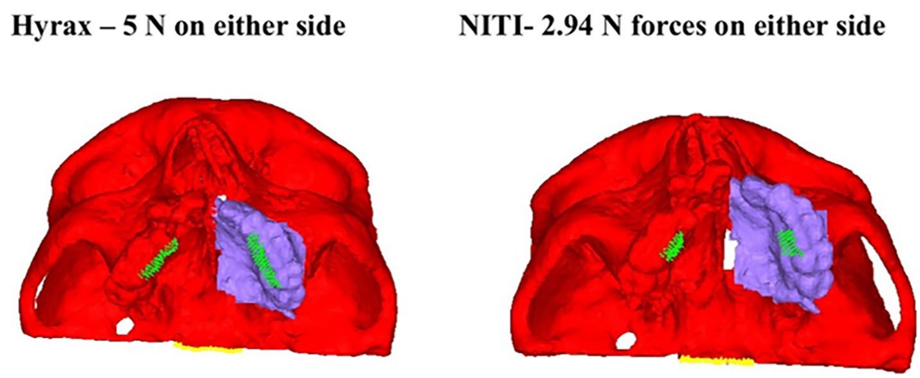


Figure 4 Loading condition in orthodontic group

brought about by similar means as in orthodontic group for the required movement.

Group 3 Alevolar Bone Grafting (ABG) Group (Fig. 4 & Fig. 5)

Virtual grafting was done at the cleft site. Similar to the orthodontic & PMO group, the Hyrax & NiTi palatal expander were attached to the 1st premolar & 1st molar. Substitution of the force of the appliances and scar tissue was done, & activation was brought about by similar means as in orthodontic & PMO group for the required movement.

Parameters assessed along the cleft and non-cleft segment.

- Stress at zygomaticomaxillary buttress, piriform rim, midpalatal region, pterygomaxillary junction, & fronto-nasal suture & graft site (only for ABG group).
- Displacement (tipping or bodily movement) of the cleft segment
- Impact of transverse force on greater/non-cleft segment.

Results

The objective of the current study included the assessment of best method of maxillary expansion in adult patients

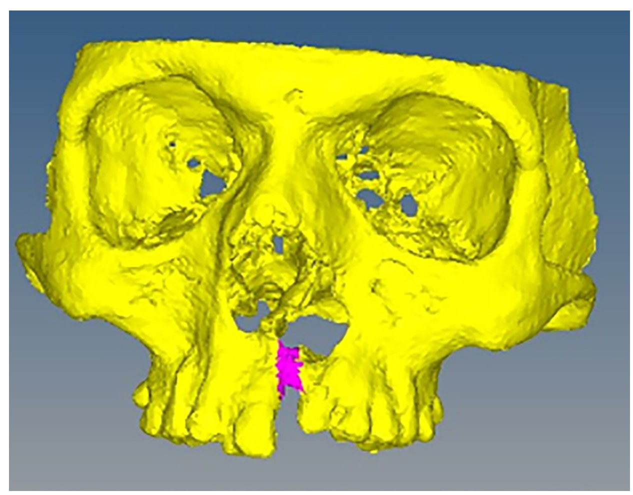


Figure 5 Von Mises stress in orthodontic group

with cleft maxillary hypoplasia. To evaluate the same, a finite element evaluation study was carried out with fixed boundaries and substituting the force of scar contracture in the circum-maxillary area including the pterygomaxillary junction (PMJ). The FEM generated from the CT contained 954,800 elements & 234,952 nodes.

Application of Hyrax palatal expander & NiTi palatal expander in the premolar region parallel to the palatal plane with its activation revealed the maximum quantum of von Mises stress which allowed movement of the segments.

Orthodontic Group (Table 1) (Fig. 6 & Fig. 7)

With the application of Hyrax palatal expander, on the cleft side, (the intended site of movement) of von Mesis stress developed at the zygomaticomaxillary buttress (0.8 Mpa) which is similar to the stress at the PMJ which was 1.14 Mpa, and the midpalatal area revealed mixed stresses with maximum stress/resistance to movement at the premolar region (2 MPa). Maximum resistance to skeletal movement was noticed at the base of the skull—pterygomaxillary junction −2.34 Mpa. On the non-cleft side, maximum stress was seen at the midpalatal region which was 1.7 Mpa and 1.4 Mpa stress at the zygomaticomaxillary buttress region & PMJ. Von Mises stress of 0.8 Mpa was also observed along frontonasal suture.

Maximum von Mesis stress (2 Mpa) with NiTi palatal expander was at the midpalatal region and 1.2 Mpa at the zygomaticomaxillary buttress extending to the infraorbital rim on the cleft side. Similar stress levels were noticed at the pterygomaxillary junction. However, the area of distribution was more in case of use of NiTi palatal expander compared to Hyrax expander.

The magnitude of displacement was minimal with Hyrax that was similar to the NiTi palatal expander group which was 1.42 mm on the cleft side and −0.14 mm on the non-cleft side. This was similar to the use of NiTi palatal expander.

Tipping of the teeth was evident with lesser stress levels with the use of NiTi and Hyrax expanders.

PMO Group (Table 2) (Fig. 8 and Fig. 9)

Application of Hyrax palatal expander revealed von Mises stress of 0.15 Mpa at the zygomaticomaxillary buttress on the non-cleft side which is similar to the stress at the PMJ, and the midpalatal area revealed mixed stresses with maximum stress/resistance to movement at the premolar & 1st molar region (0.66 MPa). Since PMO was carried out, there was negligible stress on the cleft side. Von Mises of 1.1 MPa was also noticed along the frontonasal suture due the attachment on the non-cleft side.

A displacement of 2 mm of the cleft side was noticed; whereas, some amount of movement of the non-cleft side (−0.9 mm) was observed with Hyrax expander with similar results noticed with NiTi palatal expander.

Bodily movement of the cleft segment, negligible movement of non-cleft segment was observed with Hyrax as well NiTi palatal expanders.

Alveolar Bone Grafting (ABG) Group (Table 3) (Fig. 10 & Fig. 11)

The results of this group were similar to that of the orthodontic group, with only additional stress seen at the graft site which was 0.3 Mpa and 0.5 Mpa with Hyrax & NiTi palatal expander, respectively.

Discussion

In patients of cleft & palate, the most prevailing secondary deformity is maxillary hypoplasia, 40% of which need three-dimensional surgical correction. Maxillary hypoplasia in CLP patients is due of the fibrosis, forces of the musculature, soft tissue tension, and scarring that occurs after previous palatal repair. Failure of growth of maxilla leads to maxillary constriction which causes development of class 3 malocclusion, anterior & posterior crossbite. This makes transverse discrepancy correction of maxillary hypoplasia a necessity in order to achieve functional facial harmony & occlusal stability. In order to solve the problem of transverse discrepancy, most of the cleft cases require transverse maxillary expansion.

Based on age, the treatment can be orthopedic expansion (6–12 years), orthodontic expansion (by buccal tipping), or surgical-assisted expansion (after growth phase) divided; 7–12 years orthodontic movement, 12–17 years

Table 1 Von Mises stress observed in orthodontic group

Orthodontic group				
	Hyrax		NiTi	
	Cleft side (Mpa)	Non-cleft side (Mpa)	Cleft side (Mpa)	Non-cleft side (Mpa)
Zygomaticomaxillary buttress	0.8	1.4	1.25	1
Piriform rim	0.8	1.14	1	0.75
Midpalatal region	2	1.7	2	0.75
Pterygomaxillary junction	1.14	1.4	1	1
Frontonasal suture	0.8	0.5	–	–

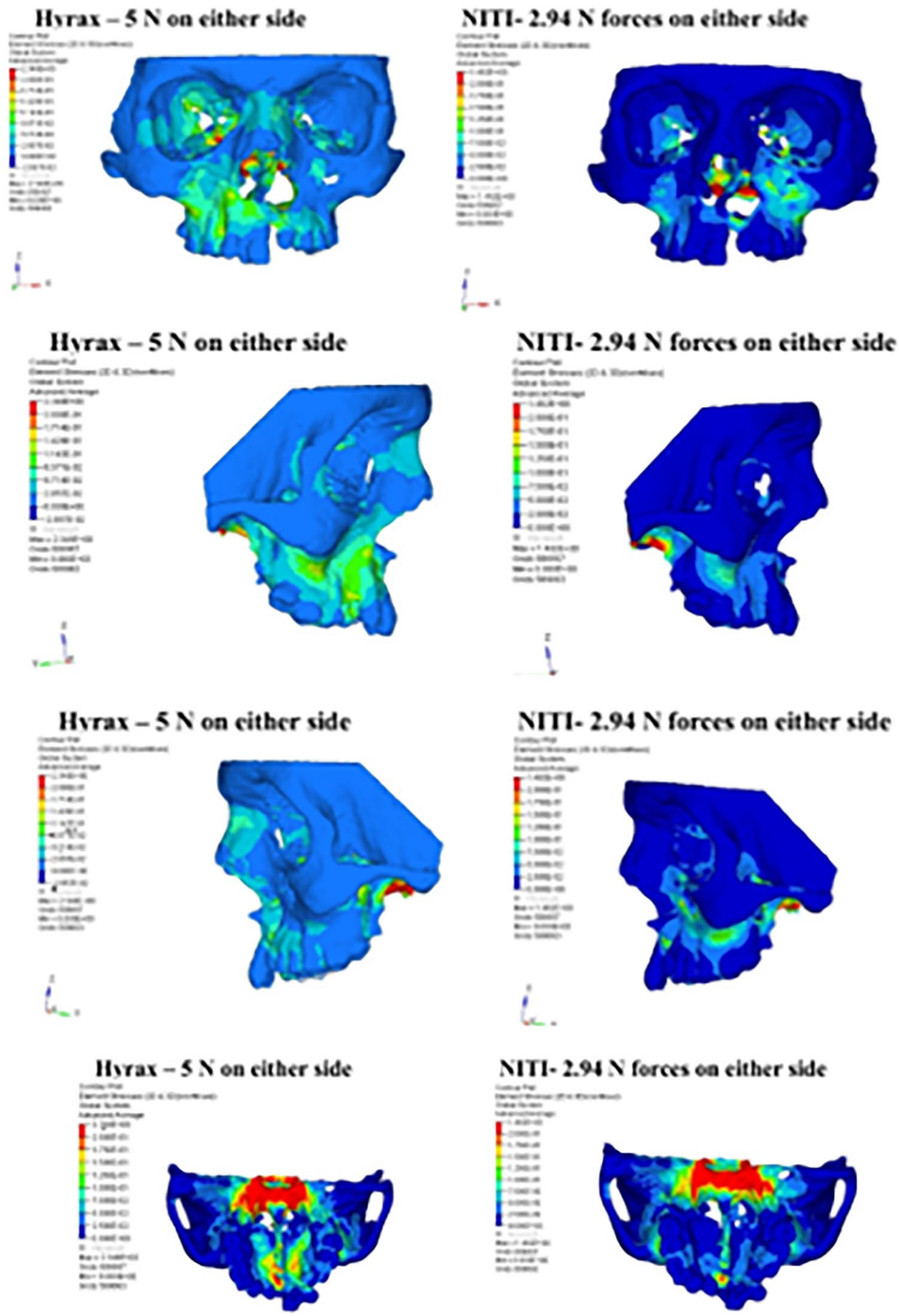


Figure 6 Displacement in orthodontic group

camouflage orthodontics, and above 17 years surgical treatment. Superior results are achieved when expansion procedures are executed by orthopedic treatment during mixed dentition, or early adolescence since the midpalatal & other circum-maxillary sutures are still patent. In case of adult patients, the circum-maxillary and pterygomaxillary sutures are fused. This along with large quantum of resistance from the scarred mucoperiosteum makes skeletal expansion difficult.

Surgical intervention in this scenario is needed for skeletal expansion in adults. In non-cleft patients with transverse discrepancy, this is facilitated by surgically assisted rapid palatal expansion (SARPE). SARPE is indicated in all the patients with a transverse discrepancy of more than 5 mm.

In the cleft groups, with no interceptive orthodontics, the cleft segment is often collapsed posterior to the greater segment. The maximum quantum of collapse is often seen in the premolar region. Orthodontic expansion in these cases

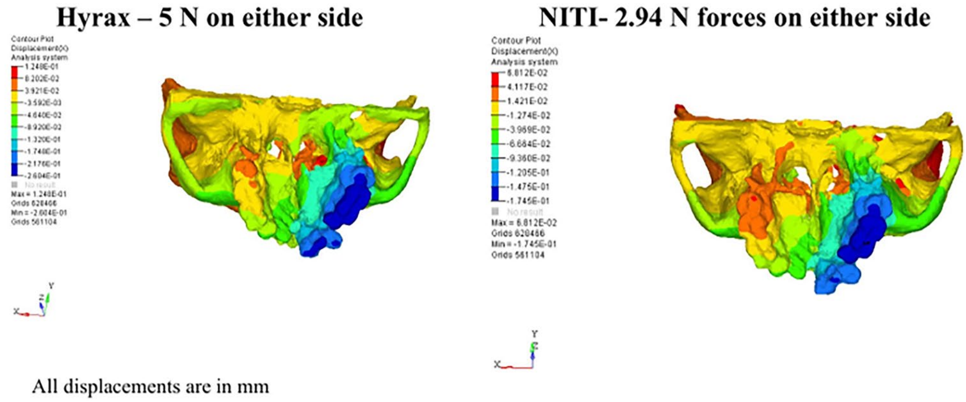


Figure 7 Loading condition in PMO and ABG group

Table 2 Von Mises stress observed in PMO group

PMO group				
	Hyrax		NiTi	
	Cleft side (Mpa)	Non-cleft side (Mpa)	Cleft side (Mpa)	Non-cleft side (Mpa)
Zygomaticomaxillary buttress	0.06	1.77	0.003	1.77
Piriform rim	0.2	1.55	0.2	1.3
Midpalatal region	0.03	0.4	0.05	0.2
Pterygomaxillary junction	–	1.7	–	1.3
Frontonasal suture	1.3	1.3	0.6	0.6

is virtually impossible warranting surgically assisted expansion. The relapse that occurs after orthodontic treatment might be because of various components such as periodontal and gingival factors, occlusal factors, soft tissue pressures, and limitation of the dentition, physiological relapse. According to Littlewood et al., the movement of the teeth back to its pre-treatment occlusion was the cause of relapse after the orthodontic treatment, but the aging process & growth can also be a cause of the change in position of the teeth [4].

Surgically assisted expansion in the cleft groups is different from non-cleft maxilla as the midpalatal suture is fused to the greater segment in unilateral CLAP, and the vomer lies free in the midline in bilateral groups. Hence, it was suggested to use unilateral or bilateral PMO with dysjunction of the maxilla from the pterygomaxillary junction. PMO can be used to bring about expansion more than 5 mm. When orthodontic treatment is done when discrepancy is more than 5 mm, the chances of relapse are higher. In our study, after PMO, the minor segment was free from its attachments, thereby reducing the stress levels & facilitating the bodily movement. Anterolateral osteotomy relieves the cleft segment from the zygomatic buttress, and the pterygomaxillary dysjunction relieves the cleft segment from the skull base thus minimizing the unwarranted stress at the skull base as evident in our model II but the von Mises stress that was perceived in the region of frontonasal suture due to attachment of the vomero-palatine bone on the non-cleft side providing good anchorage leading to the development of stress in the particular area.

Berger et al. conducted a study in which patients were divided into two groups, orthopedic maxillary expansion (OME) and SARPE were compared based on age. OME group had patients from 6 to 12 years of age, whereas SARPE group had patients aged 13–35 years of age. It had been found that there was no significant variance in the regularity of SARPE and OME. However, the amount of amount of relapse in both the groups was not measured [9]. Timms et al. stated that there was relapse rate of 5–25% in patients who underwent SARPE [10]. According to Bishara et al. study, the relapse rate with SARPE was much lower than the relapse rate of OME (63%) [33]. Ploder et al. conducted a study during which SARPE was assessed using three different appliances such as tooth-borne (TB) appliance, bone-borne (BB) appliance, and orthodontic mini-implant (OMI). At bone & tooth levels, an excessive relapse rate was seen with tooth-borne appliances at 27 and 21%, respectively. They also stated that there was an extensive array in the relapse amount due to the standard deviation being high all groups, leading to a wide range in the amount of relapse [11].

According to de Silva Filho et al., the patients who have never undergone SABG, RME separates midpalatal sutures, enhancing size of cleft [12].

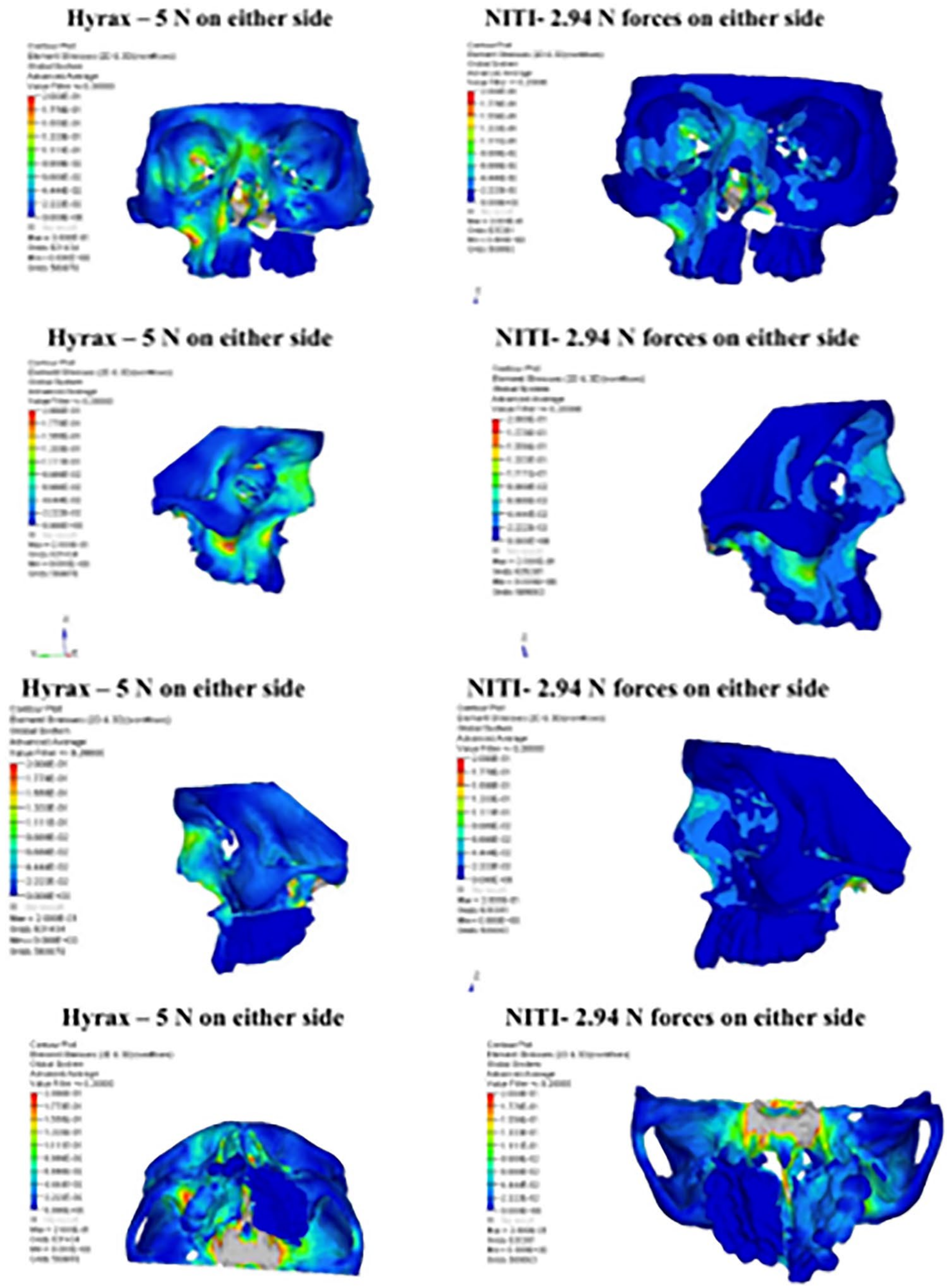
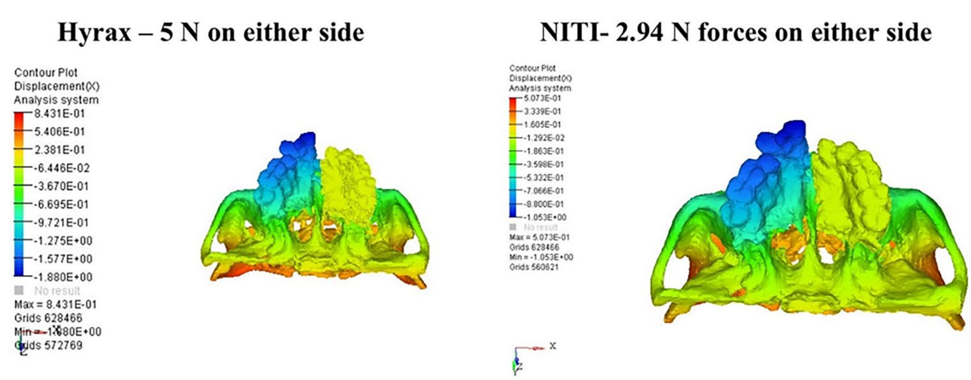


Figure 8 Von Mises stress in PMO group



All displacements are in mm

Figure 9 Displacement in PMO group

Table 3 Von Mises stress observed in ABG group

ABG group				
	Hyrax		NiTi	
	Cleft side (Mpa)	Non-cleft side (Mpa)	Cleft side (Mpa)	Non-cleft side (Mpa)
Zygomaticomaxillary buttress	0.8	1.4	1.25	1
Piriform rim	0.8	1.14	1	0.75
Midpalatal region	2	1.7	2	0.75
Pterygomaxillary junction	1.14	1.4	1	1
Frontonasal suture	0.8	0.5	–	–
Graft site	0.3	0.5		

When arch expansion is done before ABG, there is greater expansion & less bony resistance. It allows easier visualization & reconstruction of nasal floor mucosa. It also minimizes the risk of graft loss. Based on the results of the current study, it was observed that PMO with ABG resulted in difficult transverse expansion; whereas, PMO without ABG resulted in easier transverse expansion. Maximum stress was seen when ABG was done without performing PMO. Thus, if grafting is required, it should be done after transverse expansion is achieved following PMO.

Despite the benefits of achieving successful transverse palatal expansion, the benefits of surgically assisted maxillary expansion in cleft patients should be weighed against the costs, the need of additional surgical procedures, and never the less the additional periosteal scarring in an area of compromised vascularity. Saltaji et al. conducted a study according to the which the scar present in the palatal & lip region because of previous cleft repair is the reason of relapse of maxillary advancement with Le Fort I osteotomy. Consistent with the study conducted by Figueroa et al. in CLP patients, one of the significant challenges faced during surgical management is soft tissue scarring which further acts as an etiologic factor for occurrence of mid-face deficiency in these patients. These patients typically undergo many surgeries for lip &/or palatal correction before Le Fort I maxillary advancement is to be done [2]. Soft tissue scarring is not only the potential cause of deficiency of mid-face, but it is also the reason for relapse after surgery. The maxillary movement to be brought about by the surgery is restricted, and the maxilla is pulled back to the pre-advanced position due to the soft tissue scar. Within the study conducted by Chua et al., it had been observed that there were supplemental causes of relapse following Le Fort I osteotomy in CLP patients such as disharmony of occlusion & posterior pharyngeal flaps from a previous surgery [2]. These causes of relapse & vascular compromise can also be extrapolated to surgically assisted palatal expansion.

A combination of distorted maxillary anatomy with compromised vascularity in these patients presents many challenges in osteotomizing the maxilla advancement. The complications in these cases may range from severe hemorrhage to avascular necrosis of the maxilla. To avoid the foresaid complications, a detailed anatomical evaluation of the circum-maxillary and pterygomaxillary anatomy pertaining to osteotomy design of the maxilla is extremely helpful [13].

Simon et al. stated that avascular necrosis is serious complication with more incidence in cleft patients in contrast with non-cleft patients after Le Fort I osteotomy. Ischemic necrosis appears clinically as loss of vitality of tooth or the appearance of mucosal or periodontal & gingival defects to severe segmental bony & palatal necrosis. In a study on animals, it was observed that there was diminution of postoperative blood flow within the osteotomized segment following Le Fort I osteotomy. Minimal bone necroses is more likely occur during the surgical mobilization in Le Fort I osteotomy. Excessive diminution of blood flow to the palate was observed following ligation of descending palatine artery intraoperatively. Moreover, there is increased potential to arterial damage due to bending or kinking forces on the arteries because of excessive mobilization of the Le Fort I segment. Surgical segment mobilization causes hemodynamics altered with reduced blood perfusion because of palatal avascular bone necrosis &/or arterial thrombosis [14]. In our study, it was observed that there was buccal tipping of the cleft segment in the orthodontic group; bodily movement of the cleft segment, minimal tipping of the non-cleft segment in the PMO group; and ABG with PMO resulted in difficult transverse expansion whereas without ABG resulted in easier transverse expansion.

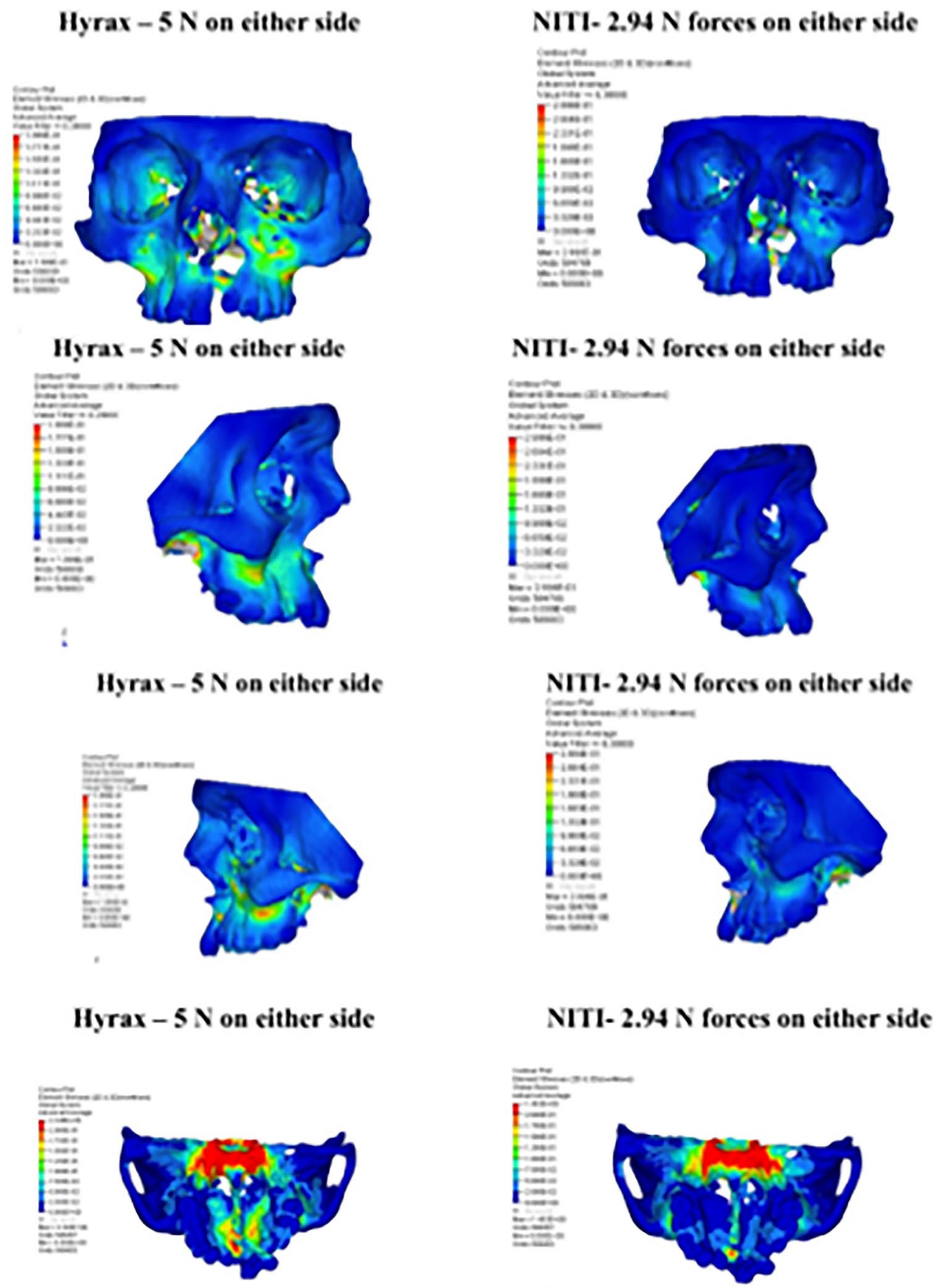


Figure 10 Von Mises stress in ABG group

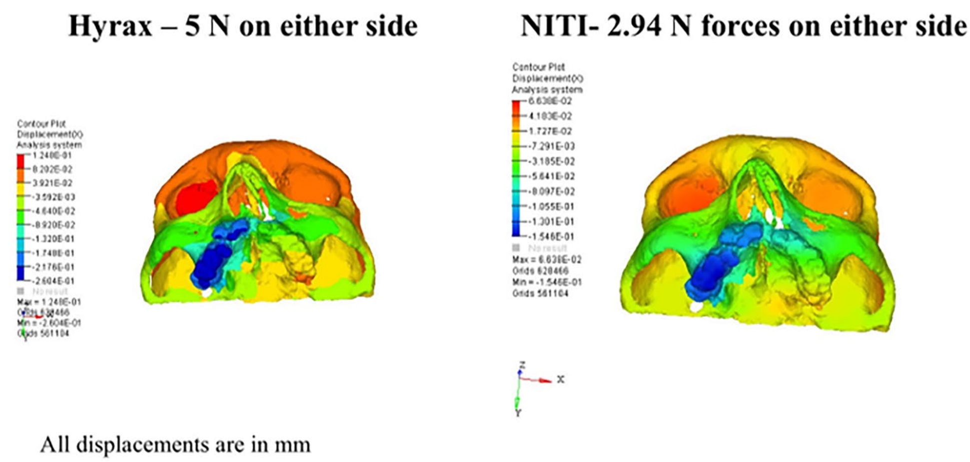


Figure 11 Displacement in ABG group

Conclusion

Thus, to conclude, PMO-assisted maxillary transverse expansion appears to be a valuable addition to the surgical protocol for the correction of transverse maxillary discrepancy in children with cleft maxillary hypoplasia. Clinical studies on larger volume of patients aid in establishing the efficacy of the same in correction of transverse discrepancies in adult cleft maxillary hypoplasia patients.

Author Contributions All authors contributed to the study conception and design. All authors read and approved the final manuscript.

Funding No funding was received for conducting this study.

Declarations

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval Ethical approval obtained from SRM Institutional Review Board. SRMDC/IRB/2019/MDS/No.402.

Informed Consent Informed consent was obtained from all individual participants included in the study.

References

1. Kharbanda OP, Agrawal K, Khazanchi R, Sharma SC, Sagar S, Singhal M, Mathur NN, Handa KK, Kabra M, Gupta N, Wadhwan N (2014) Clinical profile and treatment status of subjects with cleft lip and palate anomaly in India: preliminary report of a three-center study. J Cleft Lip Palate Craniofac Anom 1(1):26
2. Saltaji H, Major MP, Alfakir H, Al-Saleh MA, Flores-Mir C (2012) Maxillary advancement with conventional orthognathic surgery in patients with cleft lip and palate: is it a stable technique? J Oral Maxillofac Surg 70(12):2859–2866
3. Mars M (2006) Facial growth and morphology in the unoperated cleft lip and palate subject: the Sri Lanka study In Cleft Lip and Palate 2006. Springer, Berlin, Heidelberg, pp 237–255
4. Timms DJ, Vero D (1981) The relationship of rapid maxillary expansion to surgery with special reference to midpalatal synostosis. Br J Oral Surgery 19(3):180–196
5. Melsen B (1975) Palatal growth studied on human autopsy material: a histologic microradiographic study. Am J Orthod 68(1):42–54
6. Persson M, Thilander B (1977) Palatal suture closure in man from 15 to 35 years of age. Am J Orthod 72(1):42–52
7. Betts NJ, Vanarsdall RL, Barber HD, Higgins-Barber K, Fonseca RJ (1995) Diagnosis and treatment of transverse maxillary deficiency. Int J Adult Orthodon Orthognath Surg 10(2):75
8. Betts NJ (2016) Surgically assisted maxillary expansion. Atlas Oral Maxillofac Surg Clin North Am 24(1):67–77
9. Suri L, Taneja P (2008) Surgically assisted rapid palatal expansion: a literature review. Am J Orthod Dentofac Orthop 133(2):290–302
10. Bishara SE, Krause CJ, Olin WH, Weston D, Ness JV, Felling C (1976) Facial and dental relationships of individuals with unoperated clefts of the lip and/or palate. Cleft Palate J 1976:13
11. Ploder O, Winsauer H, Juengling K, Grill F, Bissinger O, Wolff KD, Kolk A (2021) Is There a significant difference in relapse and complication rate of surgically assisted rapid palatal expansion using tooth-borne, bone-borne, and orthodontic mini-implant–borne appliances? J Oral Maxillofac Surg 79(1):213–224
12. Amstalden-Mendes LG, Magna LA, Gil-da-Silva-Lopes VL (2007) Neonatal care of infants with cleft lip and/or palate: feeding orientation and evolution of weight gain in a nonspecialized Brazilian hospital. Cleft Palate Craniofac J 44(3):329–334
13. Kandaswamy SS, Somasundaram S, Pendem S, Raja VK (2020) aberrations in maxillary anatomy of adult patients with cleft maxillary hypoplasia: a computed tomographic study. J Maxillofac Oral Surg 8:1–7
14. Knowles CC, Littlewood AH, Bush PG (1969) Incomplete median cleft of the lower lip and chin with complete cleft of the mandible. A Prelim Report Br dental J 127(7):337–339