Original Article

Three-dimensional assessment of transverse displacement with Facemask and Maxgym in unilateral cleft lip and palate model

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ABSTRACT

Background: Growing patients with cleft lip and palate (CLP) exhibit maxillary deficiency due to early surgical intervention. Maxillary protraction with expansion is the recommended treatment modality for deficient maxilla. Facemask is a conventional protraction appliance, and Maxgym is a new protraction appliance. The purpose of this study is to compare the efficacy of Maxgym with Facemask using finite-element analysis. **Methods:** A three-dimensional finite-element model consisting of 49,807 nodes and 185,620 tetrahedral-shaped elements was created using computed tomography scan of a patient with unilateral CLP. F1, F2, and F3 represent different protraction forces of facemask, and M1, M2, and M3 represent different protraction forces of Maxgym. E1 represents slow maxillary expansion (SME) force, and E2 represents rapid maxillary expansion (RME) force. Facemask and Maxgym forces were applied parallel to the occlusal plane from the middle of the clinical crown on the buccal side of the first premolars. The forces E1 and E2 were also applied on the middle of the crown height on the lingual side of the first premolars and the first molars to simulate expansion. The amount of displacement for Maxgym and Facemask forces in transverse direction was analyzed designating specific nodes to represent dental and skeletal structures. **Results:** The dental and skeletal structures were displaced in transverse direction under all loading conditions. Only expansion or protraction force resulted in transverse displacement of nodes. RME produces greater transverse displacement as compared to SME. Maxgym forces produce greater transverse displacement as compared to facemask. Maxgym with RME produces greater transverse displacement as compared to Maxgym with SME, whereas facemask with RME produces greater transverse displacement as compared to facemask with SME. **Conclusions:** Maxgym forces produce greater transverse displacement as compared to facemask with or without expansion.

KEYWORDS: Facemask, finite-element analysis, Maxgym, rapid maxillary expansion, slow maxillary expansion, transverse displacement, unilateral cleft lip and palate model

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Introduction

Cleft lip and palate (CLP) is a congenital defect which results from the failure of fusion of the maxillary and palatal processes.[1] The primary CLP repair done during infancy and early childhood improves the facial appearance and functional development, but can cause midfacial growth deficiency.[2]

Skeletal correction carried out during growth may avoid invasive surgeries, and results achieved with orthopedic appliances are more stable.[3] The transverse discrepancy can be treated by expansion appliances during growth or with orthognathic surgery after growth. To correct the transverse discrepancies, orthodontists often use rapid maxillary expansion (RME) or slow maxillary expansion (SME). Facemask is used to correct the sagittal discrepancies.[3-6] Studies have shown that protraction with expansion has synergistic effect for transverse and sagittal corrections.[3,4,6-9]

Maxgym is a new protraction device designed to treat midfacial deficiency using variable weights on a pulley [Figure 1]. The patency details of the appliance are as follows: maxillofacial orthodontics appliance (application number: 2303/CHE/2011). Intraorally, the RME screw is incorporated with the splint which is cemented to the first molar and premolars. The Maxgym is mounted on the wall, preferably in the house of the patient at a suitable position depending on the height of the patient. The handles help the patient to grip the Maxgym comfortably while doing this exercise. The patient is trained to connect the free ends of the wire from the pulley of the device to the hooks placed on the bonded splint. The patient is asked to gently pull away this appliance. This principle of pulling force on the maxillary structure is simple and mechanically sound enough to be used as a therapeutic procedure in the treatment of maxillary deficiency. Once the patient is identified, the amount of force and duration shall be standardized under the supervision of a trained professional.

The aim of the study is to generate a three-dimensional finite-element model (FEM) of the craniofacial structures with unilateral CLP to simulate protraction, expansion, and combined protraction and expansion forces.

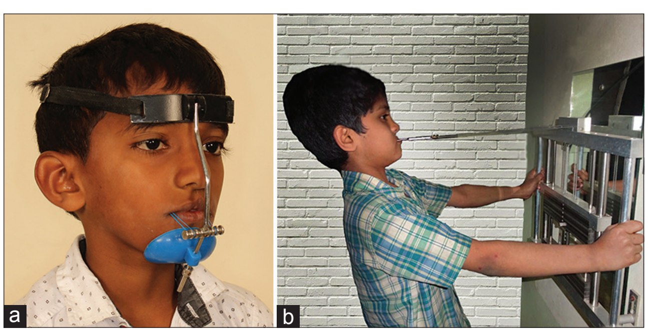

Figure 1: Maxillary protraction appliances. (a) Facemask (b) Maxgym

This study simulated facemask and Maxgym to compare the transverse displacement of craniofacial structures for maxillary protraction, expansion, and combined protraction and expansion forces using FEM.

Methods

Ethical clearance was obtained from the Yenepoya University Ethics Committee (YUEC 2017/310). Digital Imaging and Communications in Medicine® files were obtained from computed tomography scan of a 12-year-old patient with unilateral CLP on the left side and was imported into Mimics® software, MIMICS Version 18 (Materialise NV, Leuven, Belgium) for model reconstruction. The FEM with tetrahedral-shaped elements generated from a geometric model consisted of 49,807 nodes and 185,620 elements [Figure 2]. Zero-displacement boundary conditions were imposed on the nodes anterior and distal to the zygomatic arch, anterior nasal spine (ANS), palatal plane, and restraints which were established at all the other nodes lying on the symmetrical plane on the superior surface of the maxilla [Figure 2]. FE analysis allows us to study the application of different forces in different directions, wherein the properties of tooth, bone, etc., can also be changed. Therefore, one model is sufficient to simulate different situations.

The mechanical properties of the cortical bone, cancellous bone, and teeth in the model were defined based on the data from previous studies [Table 1].[10-12] Materials in the analysis were assumed to be linearly elastic and isotropic.

In this study, F1 (300 g), F2 (500 g), and F3 (700 g) represent Facemask protraction forces, and M1 (900 g), M2 (1100 g), and M3 (1300 g) represent Maxgym protraction forces. E1 (250 g) represents SME force, and E2 (500 g) represents RME force. The expansion forces were divided as follows: 50% on the premolar region and 50% on the molar region [Figure 3]. F1, F2, F3, M1, M2, and M3 per side were applied parallel to the occlusal plane from the middle of the clinical crown on the buccal side of the first premolars [Figure 3]. The forces E1 and E2 were also applied on the middle of the crown height on the lingual side of the first premolars and the first molars to simulate the SME and RME. Displacement was analyzed with twenty loading conditions consisting of only expansion, only protraction, and combinations of expansion

Table 1: Young's modulus and Poisson's ratio

	Young's modulus (kg/mm²)	Poisson's ratio
Cancellous bone	1.37×10^3	0.3
Compact bone	7.9×10^2	0.3
Tooth	2.0×10^4	0.3

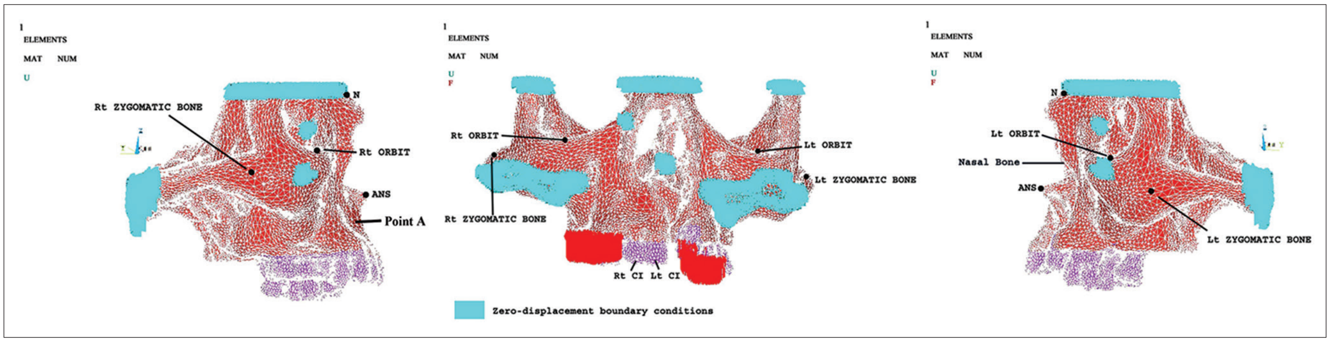

Figure 2: Finite-element model with defined boundary condition

and protraction. The amount of displacement of the craniofacial structures was assessed using 19 marker nodes, of which 12 were markers for dental structures and 7 were markers for skeletal structures.

Right and left molar mesiobuccal cusp tip, right and left molar root apices, right and left premolar cusp, right and left premolar root, right central incisor crown, right central incisor root, left lateral incisor root, and left lateral incisor crown represent the dental structures, and ANS, point A, nasal bone, right and left orbits, and right and left zygomatic bones represent the skeletal structures [Figure 2].

Results

Analysis was carried out using ANSYS (ANSYS 19; Inc, Canonsburg, PA). The displacement in X-axis corresponds to the transverse movement of craniofacial structures; negative value indicates displacement toward the right side and positive value indicates displacement toward the left side [Figure 4]. The transverse displacement of nodes under different loading conditions (only protraction forces, only expansion forces, and combined protraction and expansion forces) with the same coordinate system is shown in Figures 5-8.

The transverse displacement of nodes for only protraction is shown in Figure 9 and Table 2. The transverse displacement of nodes for only expansion forces is shown in Table 3. Displacement of maxilla for facemask with expansion forces (SME or RME) is presented in Figure 10. Displacement due to Maxgym with expansion forces (SME or RME) is presented in Figure 11.

Under all loading conditions, there is displacement of representative nodes in transverse direction. The amount of transverse displacement was increased with increase in the protraction forces [Figure 9 and Table 2]. When Maxgym was compared with facemask, the maximum displacement was seen with Maxgym forces [Figure 9 and Table 2]. Displacement was more in the cleft side than in the noncleft side. Dental structures were displaced more than skeletal structures. Among the dental nodes, left premolars and molars showed more

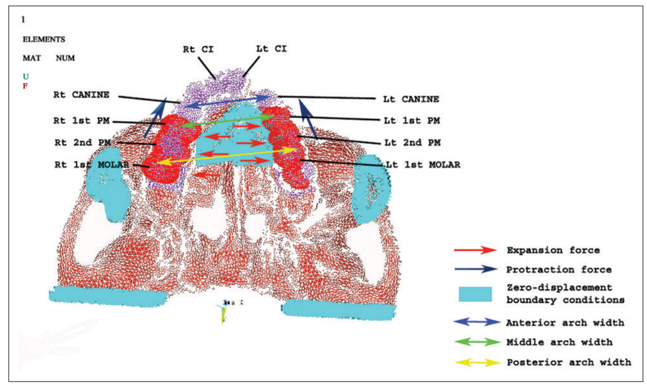

Figure 3: Loading of expansion and protraction forces

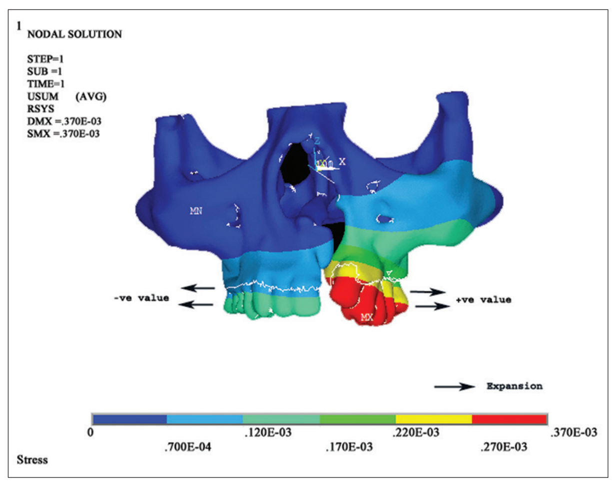

Figure 4: Analysis of displacement. Negative value indicates displacement to the right side and positive value indicates displacement to the left side

displacement. Among the skeletal nodes, left zygomatic bone and nasal bone showed more displacement than other nodes. Only expansion resulted in displacement in transverse direction [Table 3]. RME brings greater displacement when compared with SME [Table 3]. The transverse displacement increased as the protraction forces were supplemented with expansion [Figures 10 and 11]. The displacement reached its maximum when a load is applied with a combination of M3 and E2, which corresponds to Maxgym force of 1300 g with RME of 500 g [Figure 11].

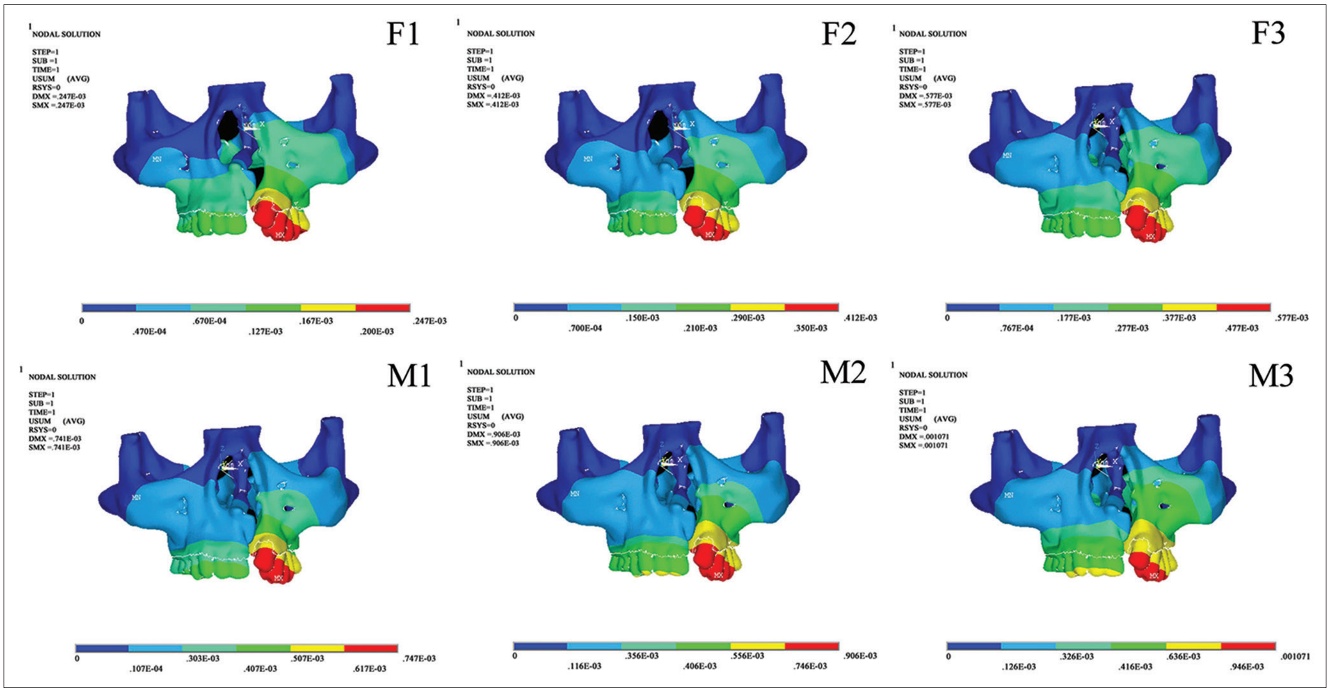

Figure 5: Transverse displacement with protraction forces with the same coordinate system. F1, F2, and F3 represent facemask forces (F1 = 300 g, F2 = 500 g forces, and F3 = 700 g), and M1, M2, and M3 represent Maxgym forces (M1 = 900 g, M2 = 1100 g, and M3 = 1300 g)

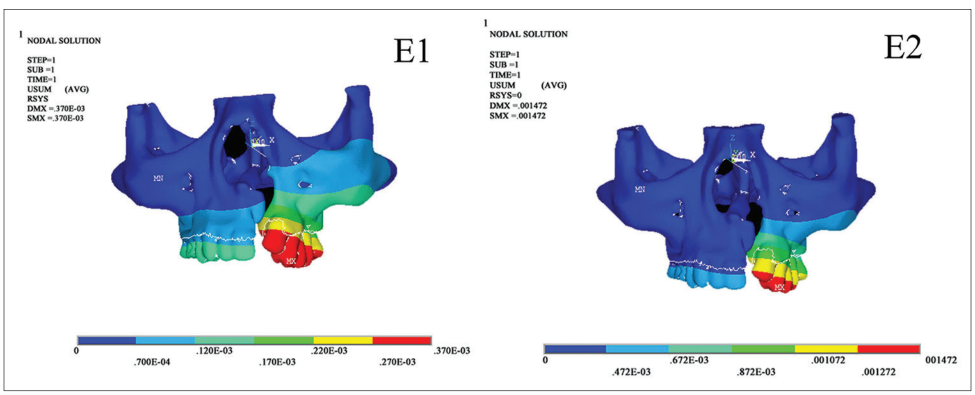

Figure 6: Transverse displacement with expansion forces with the same coordinate system. E1 (slow maxillary expansion) = 250 g and E2 (rapid maxillary expansion) = 500 g

Discussion

Facemask with expansion appliance is the conventional appliance used to treat growing cleft patients. Maxgym is a new protraction device designed to treat midfacial deficiency. This study compared the transverse displacement of skeletal and dental structures for expansion, protraction, and combined expansion and protraction forces.

Maxillary transverse deficiency can be treated by expansion appliances such as SME and RME. The RME produces skeletal changes with rapid displacement of bone, and this may result in a marked amount of relapse in the long term.[13] SME such as Quad helix produces less skeletal effects and more physiological forces leading to greater postexpansion stability.[14] Clinical studies have shown that there are no differences in the dentoalveolar effects of SME and RME in patients with CLP.[15,16] Very few studies have assessed the biomechanical effect of SME using FEM.[17,18] Therefore, we also simulated SME force to compare its effects with RME on the craniofacial structures. This study also supported the findings of clinical studies where SME brings about less skeletal and dental movements than RME [Table 2].

In the present study, the type of tooth displacement for orthopedic force was analyzed by selecting nodes to represent the tip of the crown and the apex of the root. The position of root apex was selected at the site above the root apex. Significant amount of tipping of dentition was noticed [Figures 9 and 10].

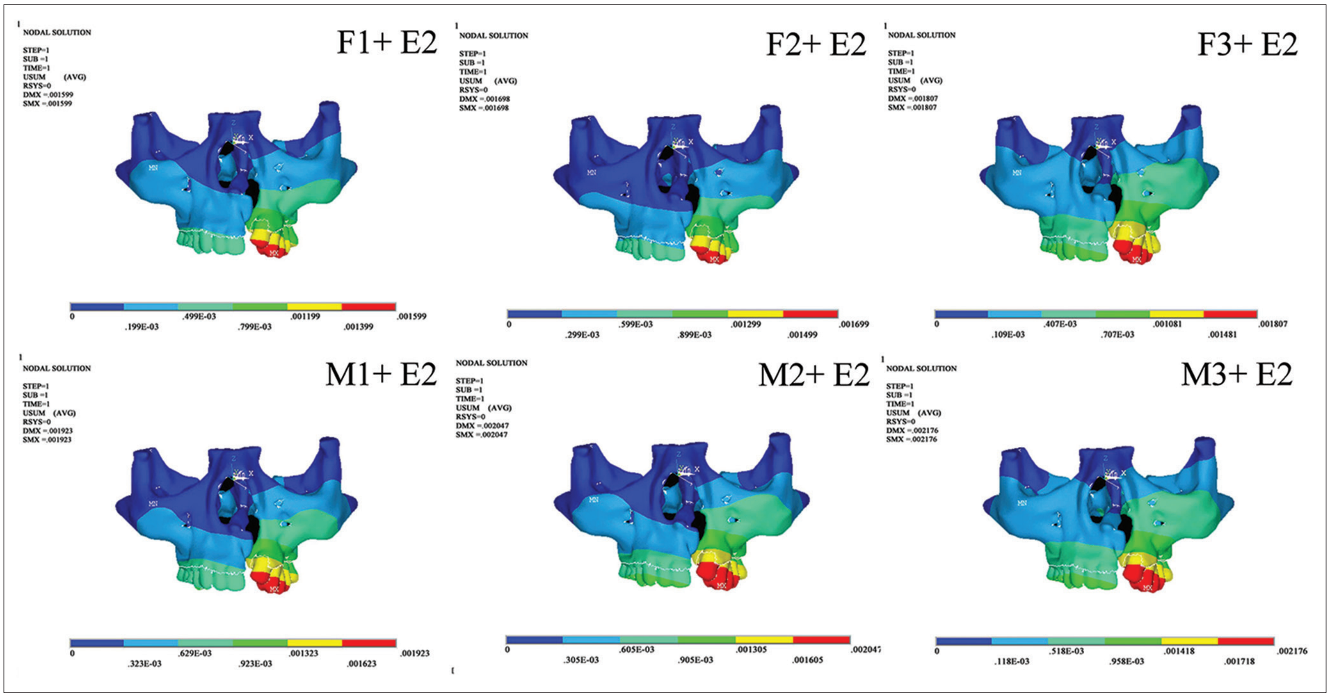

Figure 7: Transverse displacement under protraction and rapid maxillary expansion forces. F1 + E2; F2 + E2; F3 + E2; M1 + E2; M2 + E2; and M3 + E2

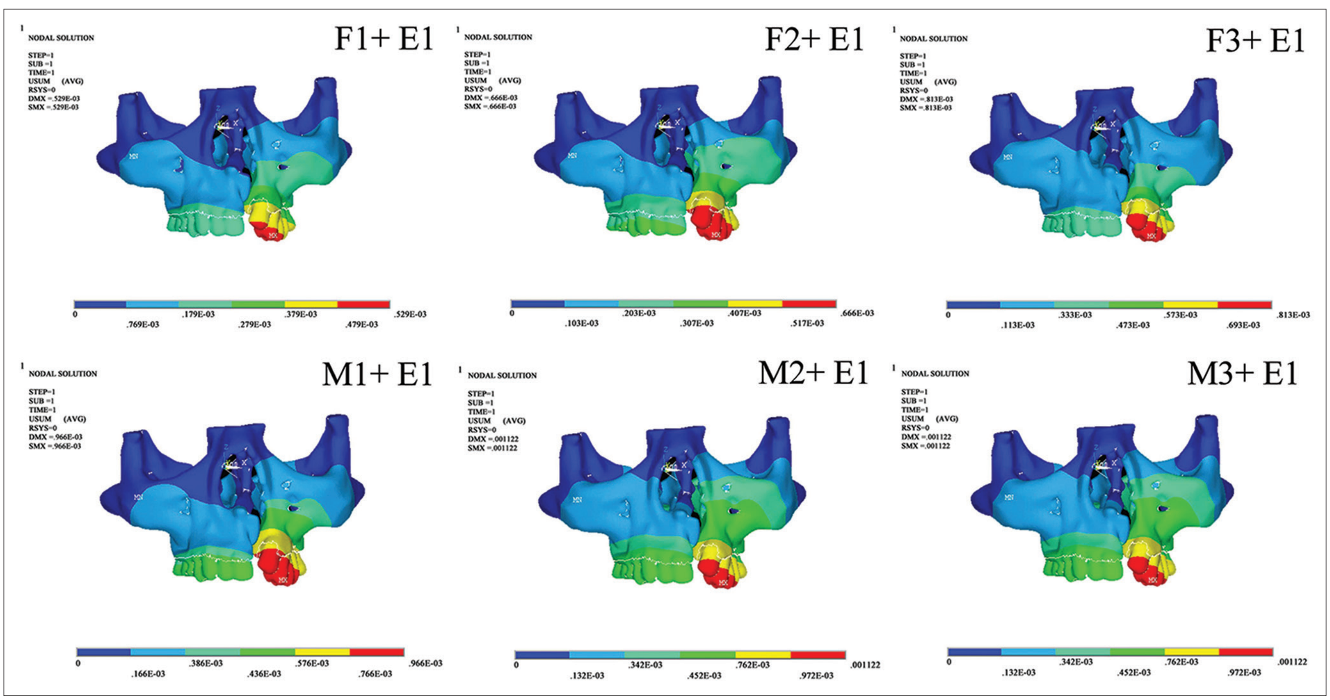

Figure 8: Transverse displacement under protraction and slow maxillary expansion forces. F1 + E1; F2 + E1; F3 + E1; M1 + E1; M2 + E1; and M3 + E1

The present study showed that symmetrical forces produce asymmetric pattern of displacement in unilateral CLP (UCLP) [Figures 9 and 10]. The dental structures moved greater than the skeletal structures. The dental structures of the cleft side showed more displacement than the noncleft side. In the present study, maximum displacement was seen with the left molar [Figure 10] for Maxgym force (M3) with RME (E2).

Mathew *et al*. reported similar kind of displacement for expansion force where the cleft side displaced more than the noncleft side.[19] Lee *et al*. also reported asymmetric expansion in UCLP for RME forces.[20] Zhang *et al*. reported that there was significant increase in arch width when protraction force was combined with expansion force.[11] The findings of the present study were also similar to the findings of Zhang *et al*. Pan *et al*. also reported asymmetric pattern of movement

Table 2: Displacement of nodes in transverse direction for protraction forces (mm)

	F1	F2	F3	M1	M2	M3
Right molar cusp	−3.32E-05	−5.53E-05	−7.75E-05	−9.96E-05	−1.22E-04	−1.44E-04
Right molar root	5.14E-05	8.57E-05	1.20E-04	1.54E-04	1.89E-04	2.23E-04
Right PM cusp	−3.22E-05	−5.37E-05	−7.51E-05	−9.66E-05	−1.18E-04	−1.40E-04
Right PM root	−1.53E-05	−2.55E-05	−3.57E-05	−4.58E-05	−5.60E-05	−6.62E-05
Right CI crown	−2.57E-05	−4.28E-05	−5.99E-05	−7.71E-05	−9.42E-05	−1.11E-04
Right CI root	8.36E-05	1.39E-04	1.95E-04	2.51E-04	3.07E-04	3.62E-04
Right zygoma	1.97E-05	3.28E-05	4.60E-05	5.91E-05	7.23E-05	8.54E-05
Right orbit	−2.17E-06	−3.62E-06	−5.07E-06	−6.52E-06	−7.97E-06	−9.42E-06
Nasal bone	5.99E-05	9.98E-05	1.40E-04	1.80E-04	2.20E-04	2.60E-04
Point A	−6.13E-06	−1.02E-05	−1.43E-05	−1.84E-05	−2.25E-05	−2.66E-05
ANS	2.02E-06	3.36E-06	4.71E-06	6.05E-06	7.40E-06	8.74E-06
Left orbit	1.30E-05	2.16E-05	3.02E-05	3.89E-05	4.75E-05	5.62E-05
Left zygoma	5.71E-05	9.52E-05	1.33E-04	1.71E-04	2.09E-04	2.48E-04
Left LI root	7.21E-05	1.20E-04	1.68E-04	2.16E-04	2.64E-04	3.12E-04
Left LI crown	−3.50E-06	−5.83E-06	−8.16E-06	−1.05E-05	−1.28E-05	−1.25E-04
Left PM root	6.83E-05	1.14E-04	1.59E-04	2.05E-04	2.51E-04	2.96E-04
Left PM cusp	8.36E-05	1.39E-04	1.95E-04	2.51E-04	3.07E-04	3.62E-04
Left molar root	5.57E-05	9.28E-05	1.30E-04	1.67E-04	2.04E-04	2.41E-04
Left molar cusp	6.69E-05	1.12E-04	1.56E-04	2.01E-04	2.45E-04	2.90E-04

X-axis denotes transverse displacement (negative sign=right side displacement; positive sign=left side displacement; ANS=Anterior nasal spine; PM=Premolar; CI=Central incisor; LI=Lateral incisor); Facemask forces: F1, F2, and F3 (F1=300 g; F2=500 g; F3=700 g), Maxgym forces: M1, M2, and M3 (M1=900 g; M2=1100 g; M3=1300 g)

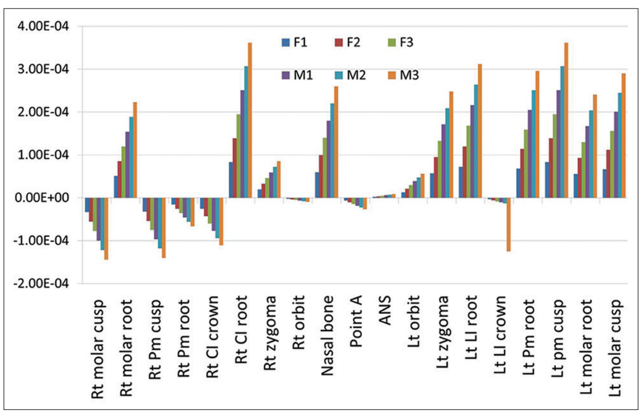

Figure 9: Comparative assessment of facemask and Maxgym forces (only protraction)

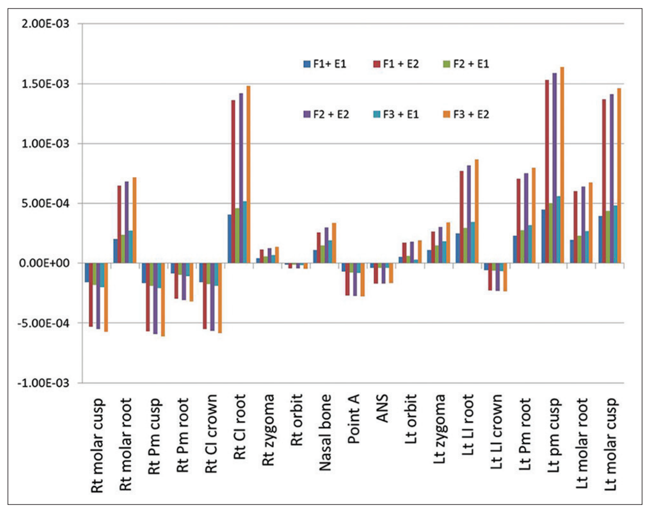

Figure 10: Comparative assessment of facemask with slow maxillary expansion/rapid maxillary expansion forces. F1 + E1; F1 + E2; F2 + E; F2 + E2; F3 + E; and F3 + E

of dental and skeletal structures for RME force.[10] They also found that, among the dental structures, greater displacement was seen with molars and incisors. Our study also supported the findings of Pan *et al*. where there was increased movement of roots of incisors and molars.

Maxgym which uses heavier forces results in greater sagittal displacement. Increased force may cause excessive stress on craniofacial structures. Force selection should be done judiciously which would bring maximum displacement of the craniofacial structures with minimal tissue damage.

Limitations

1. Effects of the force may vary depending on the individual variations
2. Different bone densities will give different outcomes
3. Root surface area can vary which also depends on the periodontal support depending on the age and oral hygiene
4. The long-term effect and effect due to abrupt cessation cannot be accurately predicted.

Future scope

Future studies should analyze displacement and stress at the sutures of a cleft model when variable protraction and expansion forces are simulated. Future studies should also iterate the force application

Table 3: Displacement of nodes with only expansion forces (mm)

	E1	E2
Right molar cusp	−1.25E-04	−4.97E-04
Right molar root	1.50E-04	5.97E-04
Right PM cusp	−1.35E-04	−5.38E-04
Right PM root	−7.11E-05	−2.83E-04
Right CI crown	−1.32E-04	−5.24E-04
Right CI root	3.22E-04	1.28E-03
Right zygoma	2.33E-05	9.29E-05
Right orbit	−1.05E-05	−4.16E-05
Nasal bone	4.35E-06	1.73E-05
Point A	−6.59E-05	−2.62E-04
ANS	−4.32E-05	−1.72E-04
Left orbit	4.00E-05	1.59E-04
Left zygoma	5.19E-05	2.07E-04
Left LI root	1.75E-04	6.98E-04
Left LI crown	−5.67E-05	−2.26E-04
Left PM root	1.60E-04	6.37E-04
Left PM cusp	3.64E-04	1.45E-03
Left molar root	1.37E-04	5.46E-04
Left molar cusp	3.27E-04	1.30E-03

X-axis denotes transverse displacement (negative sign=right side displacement; positive sign=left side displacement); Expansion forces: E1 (SME)=250 g; E2 (RME)=500 g. ANS=Anterior nasal spine; PM=Premolar; CI=Central incisor; LI=Lateral incisor; SME=Slow maxillary expansion; RME=Rapid maxillary expansion

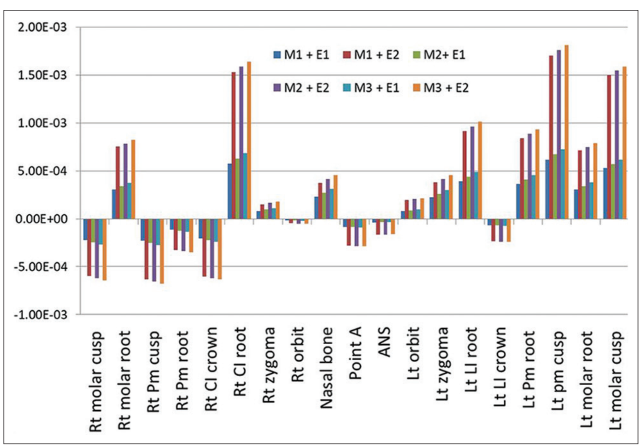

Figure 11: Comparative assessment of Maxgym with slow maxillary expansion/rapid maxillary expansion forces. M1 + E1; M1 + E2; M2 + E1; M2 + E2; M3 + E1; and M3 + E2

on cleft and noncleft regions to generate uniform stress.

Conclusions

This study has drawn the following conclusions:

1. Only protraction or expansion force brings transverse displacement of the maxilla
2. The amount of displacement increased with increase in protraction or expansion force
3. Asymmetric pattern of displacement takes place with symmetric force application
4. RME produces greater transverse displacement than SME
5. Expansion and protraction have synergistic effect
6. Maxgym produces greater displacement than Facemask under all loading conditions. Maxgym may be used as an alternative to facemask to treat midfacial deficiency in patients with UCLP. However, the long-term effect of excessive force has to be assessed clinically.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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