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Three dimensional assessment of protraction in craniofacial structures of cleft lip and palate model using Facemask and Maxgym

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Abstract. Maxillary protraction with expansion is the recommended treatment modality for growing patients with cleft lip and palate. The aim of this study was to compare the displacement of the craniofacial structures using Facemask and Maxgym for protraction therapy. A 3-D finite element model consisting of 185620 tetrahedral shaped elements and 49807 nodes was created using CT scan of a patient with UCLP. F1, F2, F3 represent protraction forces used for Facemask and M1, M2, M3 represent protraction forces used for Maxgym. E1 represents Slow Maxillary Expansion force and E2 represents Rapid Maxillary Expansion force. Protraction forces were applied parallel to the occlusal plane on the buccal side of the first premolars. Expansion forces were also applied on the lingual side of the first premolars and the first molars. The displacement of 13 representative nodes of craniofacial structures analyzed and compared. The selected nodes of dental and skeletal structures were displaced in sagittal direction under all loading conditions. Only protraction or expansion force results in displacement of craniofacial structures. Protraction with expansion forces resulted in larger displacement. Maxgym forces produce greater displacement than Facemask under all loading conditions. Maxgym may be used as an alternative to Facemask to treat midfacial deficiency.

Keywords: Cleft lip and palate, protraction, maxgym, facemask, expansion

1. Background

Cleft lip and palate (CLP) is one of the most common birth defects which results from the failure of fusion of the maxillary and palatal process [11]. Cleft can be unilateral or bilateral. The primary cleft lip and palate repair done during infancy and early childhood improves the facial appearance, functional development, but can cause midfacial growth deficiency [19].

The sagittal and transverse discrepancy can be treated by orthopedic appliances during growth or orthognathic surgery after growth. Skeletal correction during growth with orthopedic appliances will

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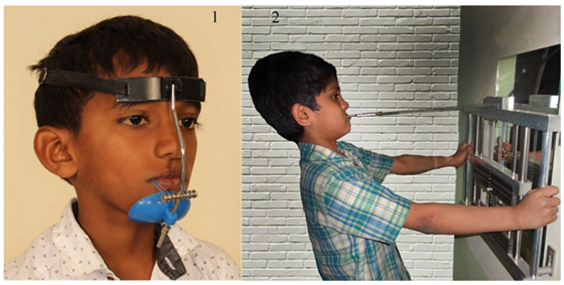

Fig. 1. Maxillary protraction appliances – 1. Facemask 2. Maxgym.

avoid invasive surgeries and results achieved are more stable [14]. To correct the transverse discrepancies, orthodontists often use rapid maxillary expansion (RME) or slow maxillary expansion (SME) and to correct the sagittal discrepancies, Facemask is used [10,13,14]. Studies have shown that Facemask and expansion appliance brings about forward displacement of craniofacial structures [8,13–17]. Studies have shown that maxillary expansion alone can also be beneficial in protraction of maxilla [5,9,17].

Facemask is a conventional orthopedic device used to protract the maxilla (Fig. 1A). Maxgym is a new protraction device, based on heavy intermittent force for short duration similar to the principles used in gymnasium equipment protocol (Fig. 1B). The splint with RME cemented to the first molar and premolars. The patient is trained to pull away which displace the maxilla forward and is asked to use this device three times a day, each of 5 minutes duration.

Finite element analysis is a mathematical method in which the shape of complex geometric objects and their physical properties are constructed in computer. Stress, strain and displacement can be calculated using FEM among which, the displacement of the object is the most important indicator [3]. The aim of the study is to compare the displacement of the craniofacial structures by stimulating Facemask and Maxgym protraction forces with and without maxillary expansion in a unilateral cleft lip and patients. The effect of expansion (RME and SME) without protraction were also analyzed and compared.

2. Methods

Ethical clearance was obtained from the ethics committee of our university (YU2017/310). Digital imaging and communications in medicine (DICOM) files were obtained from CT scan of a twelve year old patient with unilateral cleft lip and palate on the left side, and was imported into Mimics® software for model reconstruction. The finite element model (FEM) with tetrahedral shaped elements generated from a geometric model consisted of 49807 nodes and 185620 elements (Fig. 2).

Zero-displacement boundary conditions were imposed on the nodes anterior and distal to the zygomatic arch, ANS, palatal plane and restraints were established at all other nodes lying on the symmetrical plane on the superior surface of the maxilla [3,6,18] (Fig. 2).

The mechanical properties of the cortical bone, cancellous bone and teeth in the model (Table 1) were defined based on the data from previous studies (Table 1) [3,6,18]. Mesh depending check is done for validation of model. Optimum mesh sizes have been used to present the results. Displacement identified using this mesh sizes showed variation less than 1%.

In this study, F1 (2.94 N), F2 (4.94 N), F3 (6.86 N) represent Facemask forces, whereas M1 (8.83 N), M2 (10.78 N), M3 (12.75 N) represent Maxgym forces. E1 (2.45 N) represents SME force and E2 (4.94 N) represents RME force. The magnitude of Facemask forces selected for this study was taken

Table 1
Young's modulus and Poisson's ratio used in the study

	Young's modulus (kg/mm^2)	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

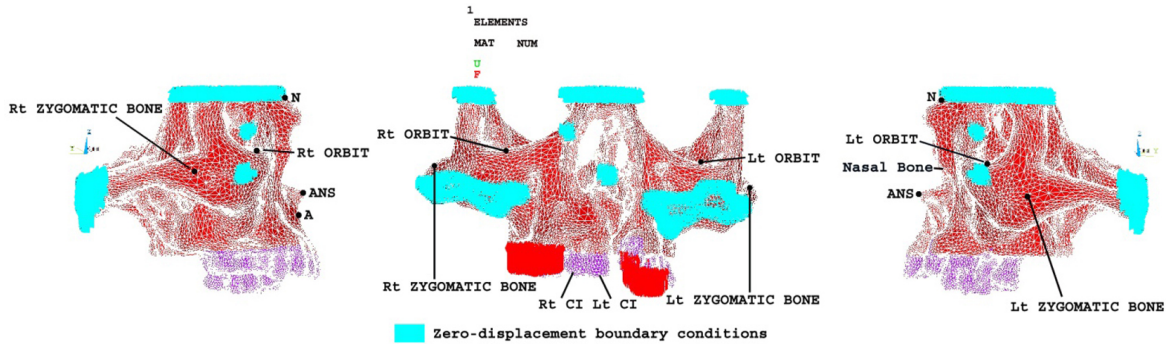

Fig. 2. FE model with boundary condition.

from standard orthodontic text books and published articles [7,14,17,21]. Experimental results showed that Maxgym generates heavy forces. Hence, the magnitude of Maxgym forces were kept at higher range. The protraction forces 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. The expansion 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 protraction, only expansion and combinations of expansion and protraction. The amount of displacement of the craniofacial structures was assessed using thirteen marker nodes for the sagittal plane out of which seven were markers for dental structures and six were markers for skeletal structures. Right central incisor, left incisor, right first molar buccal cusp, left first molar buccal cusp, and right premolar cusp and left premolar cusp represent the dental structures. Anterior Nasal Spine, nasal bone, right and left orbit, right and left zygomatic bone represent the skeletal structures.

3. Results

Analysis was carried out using ANSYS software. The displacement in Y axis corresponds to sagittal movement of craniofacial structures, negative value indicates forward movement and positive value indicates backward movement (Fig. 4). The sagittal displacement of nodes under different loading conditions (only protraction forces, only expansion forces and combined protraction and expansion forces) with the same coordinate System were shown in Fig. 5 through Fig. 8. The sagittal isplacement of craniofacial structures take place under different protraction force were presented in Table 2. The sagittal displacement of craniofacial structures with expansion only and expansion with Facemask and Maxgym are shown in Table 3. Displacement of maxilla with Facemask forces with and without expansion (SME or RME) was analyzed in Fig. 9. Displacement due to Maxgym forces with and without expansion (SME or RME) was analyzed in Fig. 10.

Under all loading conditions, there is displacement of representative nodes. There is forward move-

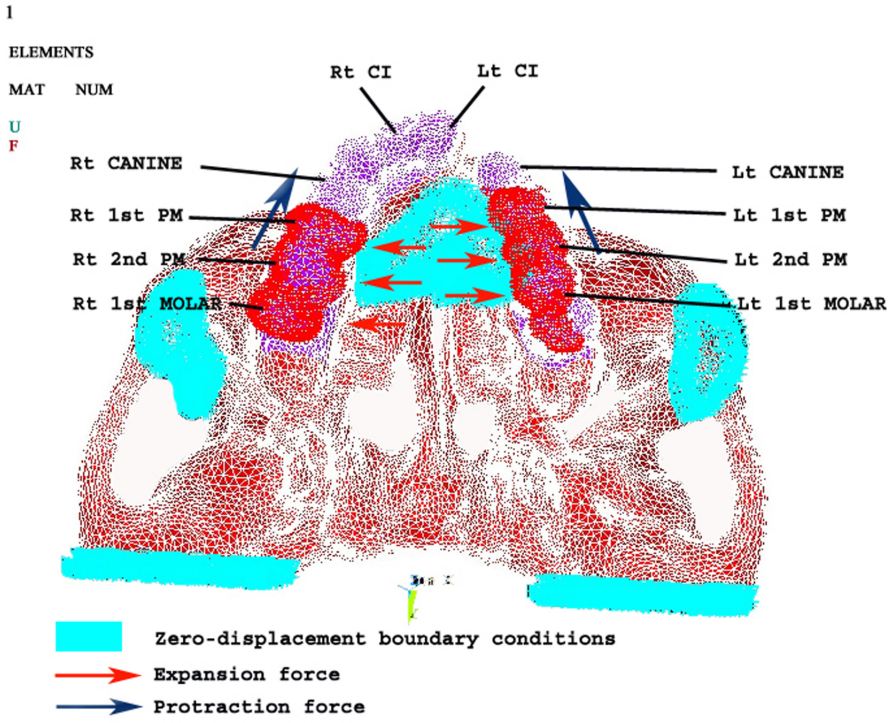

Fig. 3. Loading conditions – Application of expansion and protraction forces.

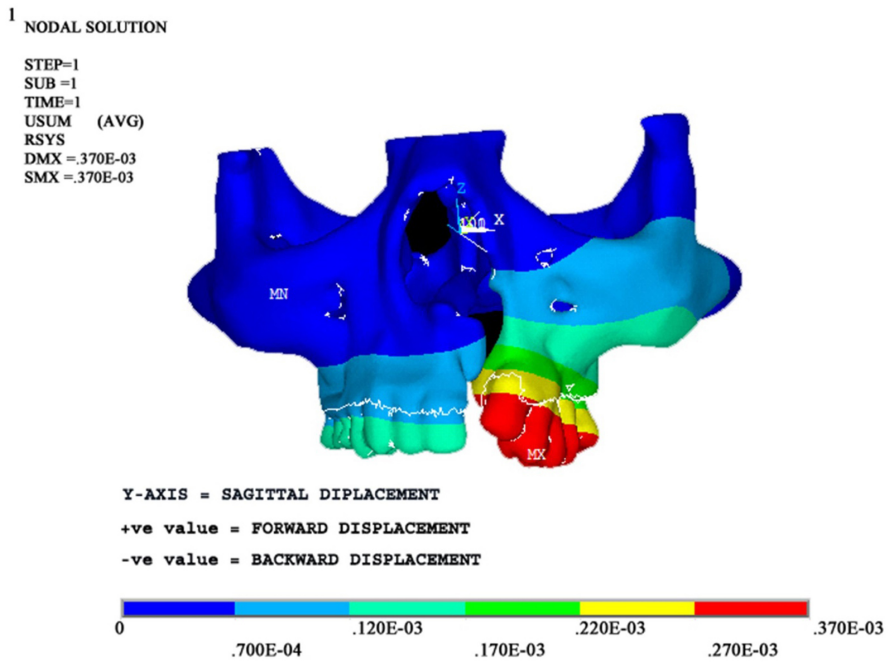

Fig. 4. Analysis of displacement, −ve value indicates forward displacement and +ve value indicates backward displacement.

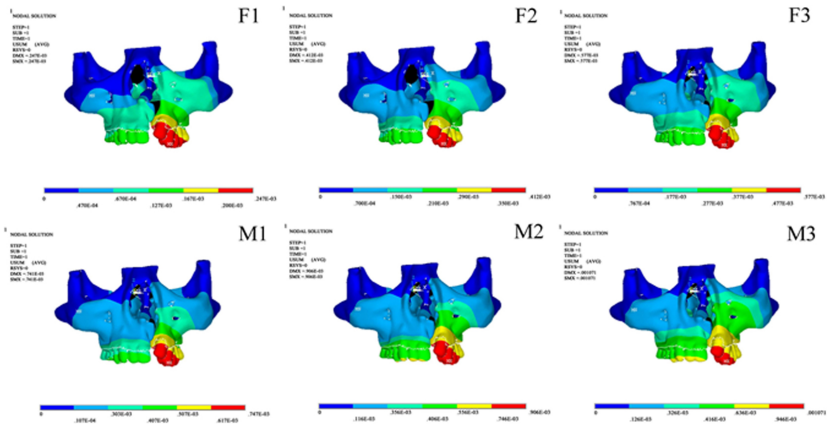

Fig. 5. Sagittal displacement under different protraction loading conditions with the same coordinate system, F1, F2 and F3 represent Facemask forces (F1 = 2.94 N, F2 = 4.94 N, F3 = 6.86 N), M1, M2 and M3 represents Maxgym forces (M1 = 8.83 N, M2 = 10.78 N, M3 = 12.75 N).

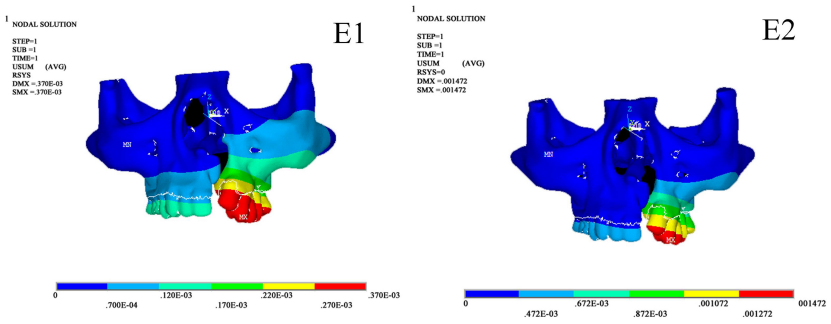

Fig. 6. Sagittal displacement under different expansion loading conditions with the same coordinate system (expansion forces-E1 (SME) = 2.45 N, E2 (RME) = 4.94 N).

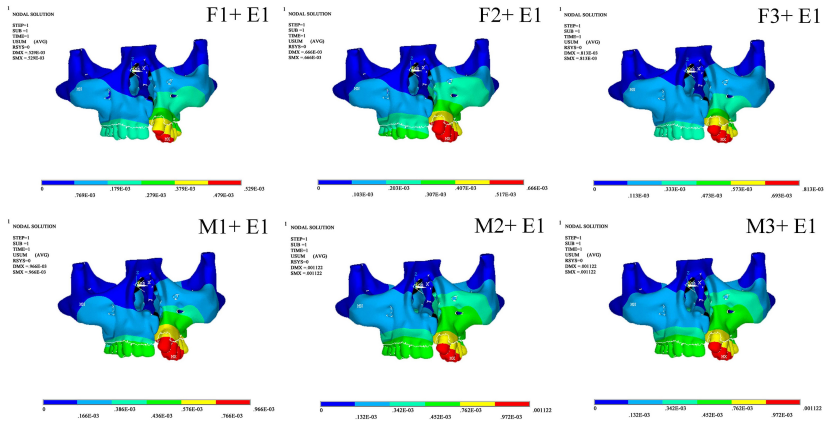

Fig. 7. Sagittal displacement under different protraction and SME loading conditions with the same coordinate system, F1 + E1, F2 + E1, F3 + E1, M1 + E1, M2 + E1 and M3 + E1.

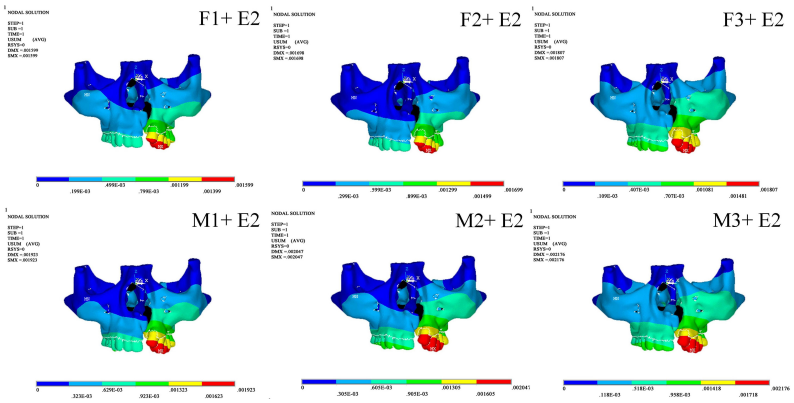

Fig. 8. Sagittal displacement under different protraction and RME loading conditions with the same coordinate system, F1 + E2, F2 + E2, F3 + E2, M1 + E2, M2 + E2 and M3 + E2.

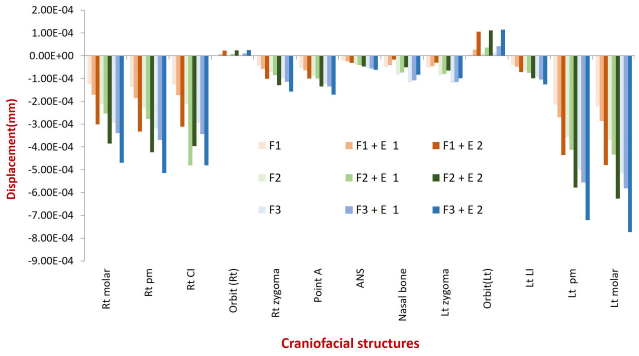

Fig. 9. Comparison of sagittal displacement for Facemask with and without expansion forces.

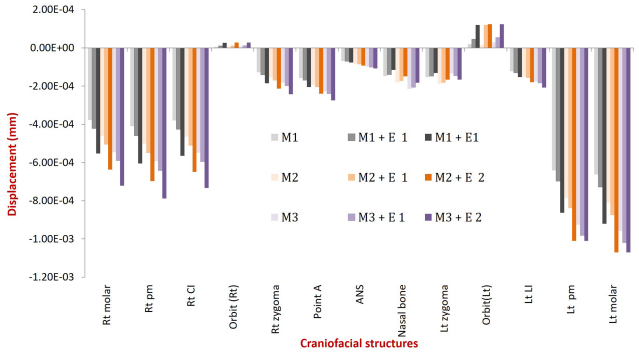

Fig. 10. Comparison of sagittal displacement for Maxgym with and without expansion forces.

ment of all the nodes except for orbit (Table 2). The amount of displacement increased with increase in the protraction forces. Dental structures showed more displacement than skeletal structures. There is increased protraction of premolars and molars on the cleft side than on the noncleft side. Among all the nodes, left molar showed the maximum displacement. When Maxgym was compared with Facemask, the maximum displacement was seen with Maxgym forces with M3 showing greatest displacement.

Table 2
Sagittal displacement of nodes for protraction forces

	F1	F2	F3	M1	M2	M3
Rt molar	−1.26E-04	−2.10E-04	−2.94E-04	−3.78E-04	−4.62E-04	−5.46E-04
Rt pm	−1.37E-04	−2.28E-04	−3.19E-04	−4.10E-04	−5.01E-04	−5.93E-04
Rt CI	−1.27E-04	−2.11E-04	−2.95E-04	−3.80E-04	−4.64E-04	−5.49E-04
Orbit (Rt)	1.48E-06	2.47E-06	3.46E-06	4.45E-06	5.44E-06	6.43E-06
Rt zygoma	−4.23E-05	−7.04E-05	−9.86E-05	−1.27E-04	−1.55E-04	−1.83E-04
Point A	−5.25E-05	−8.76E-05	−1.23E-04	−1.58E-04	−1.93E-04	−2.28E-04
ANS	−2.28E-05	−3.80E-05	−5.32E-05	−6.84E-05	−8.36E-05	−9.87E-05
Nasal bone	−4.94E-05	−8.23E-05	−1.15E-04	−1.48E-04	−1.81E-04	−2.14E-04
Lt zygoma	−5.10E-05	−8.50E-05	−1.19E-04	−1.53E-04	−1.87E-04	−1.33E-04
Orbit (Lt)	6.59E-06	1.10E-05	1.54E-05	1.98E-05	1.37E-05	2.85E-05
Lt LI	−4.06E-05	−6.77E-05	−9.47E-05	−1.22E-04	−1.49E-04	−1.76E-04
Lt pm	−2.14E-04	−3.56E-04	−2.56E-04	−3.30E-04	−7.84E-04	−9.26E-04
Lt molar	2.21E-04	3.68E-04	5.16E-04	6.63E-04	8.10E-04	9.58E-04

–ve sign – forward displacement, +ve – backward displacement, Rt – Right, Lt – Left, ANS – Anterior Nasal Spine, pm – premolar, CI – Central Incisor, LI – Lateral Incisor, Facemask forces – F1, F2 and F3, Maxgym forces – M1, M2, M3 (F1 = 2.94 N, F2 = 4.94 N, F3 =6.86 N, M1= 8.83 N), M2 = 10.78 N, M3 = 12.75 N.

Table 3
The amount of sagittal displacement for only expansion forces and expansion and protraction forces

	E1	E2	E1+F1	E2 + F1	E1+ M1	E2 + M2
Rt molar	−4.40E-05	−6.37E-04	−1.70E-04	−2.54E-04	−4.22E-04	−5.53E-04
Rt pm	−4.91E-05	−6.97E-04	−1.86E-04	−2.77E-04	−4.59E-04	−6.05E-04
Rt CI	−4.64E-05	−6.49E-04	−1.73E-04	−4.80E-04	−4.26E-04	−5.65E-04
Rt orbit	5.39E-06	2.69E-05	6.88E-06	7.87E-06	9.85E-06	2.59E-05
Rt zygoma	−1.47E-05	−2.13E-04	−5.69E-05	−8.51E-05	−1.41E-04	−1.85E-04
Point A	−1.18E-05	−2.40E-04	−6.44E-05	−9.94E-05	−1.69E-04	−2.05E-04
ANS	−2.19E-06	−9.23E-05	−2.50E-05	−4.02E-05	−7.05E-05	−7.71E-05
Nasal bone	8.11E-06	−1.49E-04	−4.13E-05	−7.42E-05	−1.40E-04	−1.16E-04
Lt zygoma	−5.16E-06	−4.69E-04	−4.58E-05	−7.99E-05	−1.48E-04	−1.32E-04
Lt orbit	2.51E-05	1.66E-04	2.72E-05	3.60E-05	4.48E-05	1.20E-04
Lt LI	−7.93E-06	−1.67E-04	−4.85E-05	−7.56E-05	−1.30E-04	−1.53E-04
Lt pm	−5.57E-05	−1.01E-03	−2.69E-04	−4.12E-04	−6.97E-04	−8.63E-04
Lt molar	−6.47E-05	−1.07E-03	−2.86E-04	−4.33E-04	−7.28E-04	−9.21E-04

–ve sign – forward displacement, +ve – backward displacement, Rt – Right, Lt – Left, ANS – Anterior Nasal Spine, pm – premolar, CI – Central Incisor, LI – Lateral Incisor, E1 = 2.45 N, E2 = 4.95 N.

Expansion alone causes displacement in sagittal direction also (Table 3). RME showed higher sagittal displacement than SME which is even greater than protraction forces with Facemask and Maxgym. The sagittal displacement was increased as the Facemask and Maxgym forces supplemented with expansion (Figs 9 and 10). Displacement has reached its peak value with a combination of M3 and E2 which corresponds to Maxgym force with RME (Fig. 5).

4. Discussion

Growing patients with cleft are characterized by sagittal and transverse deficiency of maxilla and they are also the most challenging cases to manage. Facemask with expansion is the conventional therapy used to treat such patients. Maxgym is a new protraction device designed to address such midfacial deficiency. This study has assessed the efficacy of Maxgym for protraction by simulating Maxgym and Facemask forces using FEM.

The present study showed that when equal forces were applied, asymmetric pattern of displacement was noticed. The dental structures moved greater than the skeletal structures. The dental structures of the cleft side showed more displacement than the non cleft side.

Similar asymmetric pattern of displacement was also reported by Chen et al when protraction forces were applied using facemask to a FE model of unilateral cleft lip and palate [20]. However, asymmetric displacement significantly reduced when the same model was simulated with ABG for the application of the same amount of protraction forces. Furthermore, to achieve symmetric displacement in the sagittal direction, Chen et al. applied a set of asymmetric protraction forces and found that force of 6 N on cleft side and 5 N on noncleft side will bring about almost symmetric displacement [21].

Yang et al. fabricated eight FE models of cleft lip and palate and assessed the role of cleft type in analyzing distribution of stress and displacement to facemask protraction force. Asymmetric pattern of displacement was also noticed in the UCLP in their study [7]. However, displacement was lessen on the affected side for a simulated model of CLP after Alveolar Bone Grafting. Zhang et al. reported that the maximum displacement of the nodes were noticed with combined protraction and expansion at a force vector -10° to the occlusal plane [3].

Maxillary transverse deficiency can be treated by expansion appliance 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. As reported by other researchers, our study also showed that RME not only displace craniofacial structures in transverse direction but also aid in moving the maxilla forward (Fig. 6).

SME produces less skeletal effects and more physiological forces leading greater post expansion stability [4]. Clinical studies have shown that there is no differences in the dentoalveolar effects of SME and RME in patients with CLP [1,2,12]. There are no studies where the biomechanical effect of SME is assessed using FEM. Therefore we also simulated SME force to compare its effects with RME on the craniofacial structures. This study also supported findings of clinical studies where SME brings about less skeletal and dental movement than RME.

Maxgym uses heavier forces results in greater sagittal displacement. Increased force may cause heavy stress on craniofacial structures. Force selection should be done judiciously which would bring maximum displacement of the craniofacial structures with minimal tissue damage. Asymmetric pattern of displacement in cleft and noncleft region may induce stress in the greater displaced region. To bring uniform distribution of stress, asymmetric force has to be applied. Future studies should iterate the force application on cleft and noncleft region to dissipate uniform stress.

5. Conclusion

This study has drawn following conclusions:

1. Only protraction or expansion force displaces craniofacial structures in the sagittal direction.
2. The amount of displacement increased either in increase of protraction or expansion force.
3. Protraction is enhanced when it is supplemented with expansion.
4. Protraction only with RME brings about greater displacement.
5. Asymmetric pattern of displacement takes place with symmetric forces application.
6. The amount of displacement is more with dental structures than skeletal structures and displacement is more on cleft side than non-cleft side.

Maxgym produces greater displacement than Facemask under all loading conditions. Maxgym can be used as an alternative to Facemask to treat midfacial deficiency.

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