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Effects of different distractor positions on the formation of expansion, stress and displacement patterns in surgically assisted rapid maxillary expansion without pterygomaxillary disjunction: a finite element analysis study

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ABSTRACT

Skeletal orthopedic expansion of maxilla is accepted as a reliable method for the treatment of transverse maxillar deficiency in growing patients. The aim of the study was to evaluate the effects of different palatal distractor positions on the expansion, stress and displacement patterns of the structures of craniofacial complex in surgical assisted rapid maxillary expansion without pterygomaxillary disjunction (PTMD) with the help of finite element analysis(FEA). Four facial skeleton models with different distractor positions (first premolar, second premolar, first molar, second molar regions) were created. In all finite element models median and lateral osteotomies were performed, without PTMD. Stress distribution was evaluated after 5 mm activation of the transpalatal distraction in all models using the nonlinear solution method in FEA. Unilateral displacement(mm) and stress distribution(MPa) were measured in three directions (x, y, and z axes) of craniofacial and maxillofacial structures in the symmetrical finite element models. In all models, the unilateral transverse displacements of the anterior teeth were greater than those of the posterior teeth, and the greatest displacement was at the central incisor level. The greatest displacement values at the central incisor level, at the anterior nasal spine(ANS) and at the posterior nasal spine(PNS) levels was measured in Model-IV, III, II and I, respectively. Mean elemental stress(von Mises stress) in the medial pterygoid plate, screw and lateral pterygoid plate regions from highest to lowest was measured in Model-IV, III, II and I, respectively. The maxilla performed outward rotation and tipping movement in all models during the expansion period. Among the distractor positions, the second molar region was found to be the most advantageous one in terms of expansion pattern. Considering the patient's anatomy and clinical conditions, placing the palatal distractor as posteriorly as possible will result in more effective maxillary expansion.

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Finite element analysis; surgically assisted rapid maxillary expansion; transpalatal distractor; pterygomaxillary disjunction; palatal distractor positions

Introduction

Transverse maxillary deficiency is a common skeletal deformity seen in almost 30% of the orthodontic patient population (Verstraaten et al. 2010). Skeletal orthopedic expansion of the maxilla by separation of midpalatal suture is accepted as a reliable method for the treatment of transverse maxillary deficiency in growing patients (Günbay et al. 2008). Since complete ossification of the midpalatal suture begins to appear and elasticity of the facial skeleton decreases with age; orthopedic maxillary expansion may result in some dental and periodontal complications in adult patients (Lo Giudice et al. 2018). Therefore, surgically assisted rapid maxillary expansion (SARME) including surgical procedures such as Le Fort I multiple-piece osteotomies have been recommended and proven to have long term stability among the segmental surgeries (Bays and Greco 1992; Suri and Taneja 2008). However the use of tooth borne appliances with the conventional SARME technique still may cause undesirable dental side effects such as root resorption and alveolar bone fenestration (Lo Giudice et al. 2018).

In 1999, a new bone-borne surgically assisted rapid maxillary expansion technique with a bone anchored device, transpalatal distraction osteogenesis (TPD), was introduced by Mommaerts (1999). With the use of this appliance, the potential undesired side effects of tooth-borne appliances are avoided as the expansion force is directly transmitted from the screw to the skeletal structures (Matteini and Mommaerts 2001). Moreover; the clinical advantages of TPD such as being able to be used in patients with missing teeth

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or reduced periodontal support, allowing the initial arch leveling stage without regard to the skeletal movement and reducing the amount of transverse relapse have also been reported (Mommaerts 1999; Suri and Taneja 2008). Kunz et al. (2016) in their study comparing the expansion patterns of TPD and Hyrax appliances in SARME demonstrated that TPD was likely to cause a more V-shaped pattern of expansion while conventional Hyrax appliances resulted in a more parallel expansion. Two possible factors have been reported in the literature for this V shaped maxillary expansion pattern of TPD; the scope of surgery (pterygomaxillary disjunction) and the position of the transpalatal distractor (Matteini and Mommaerts 2001; Kunz et al. 2016; Möhlhenrich et al. 2021). While the zygomatic buttress and the pterygomaxillary suture are regarded as the most rigid bone pillars of resistance during SARME; performing the pterygomaxillary disjunction (PTMD) or not is still a controversial issue in the literature (Zandi et al. 2016; Möhlhenrich et al. 2020). PTMD is expected to affect the expansion pattern by changing the center of resistance (Mommaerts 1999). Some authors believe that PTMD induces more stable and predictable close to parallel maxillary expansion (Matteini and Mommaerts 2001; Günbay et al. 2008; Kunz et al. 2016). On the other hand, surgical approach with PTMD has also been reported to be related with fractures in the adjacent bones and vascular injuries of the posterior maxilla (Koudstaal et al. 2009).

While it has been reported that selective positioning of the transpalatal distractor can also modify the maxillary expansion pattern (Kunz et al. 2016), there is still lack of evidence in the literature about the effects of distractor position alone on the maxillary expansion pattern independent of PTMD. Some authors reported that more posterior positioning of the distractor will result in more parallel and more anterior positioning will lead to more V-shaped distraction of the maxillary segments (Matteini and Mommaerts 2001; Kunz et al. 2016). However; in these studies partial or total pterygomaxillary disjunction was performed. In the current study; the authors intended to investigate the effects of different positions of the palatal distractor without PTMD primarily on the expansion pattern.

Over the last few years finite element analysis (FEA), a numeric approximation technique, has become a significant method to evaluate tooth and tissue response to force in the biomedical field (Lee et al. 2017; Hartono et al. 2018). It has previously been used to investigate stress distribution and displacement of different bone-borne expanders and their biomechanical effects on craniofacial structures (MacGinnis et al. 2014; Lee et al. 2017; Hartono et al. 2018). The simulated findings of FEA were also reported to be useful to improve clinical protocols (MacGinnis et al. 2014).

The aim of the present study was to evaluate the effects of different palatal distractor positions on the expansion, stress and displacement patterns of the structures of craniofacial complexes in SARME without PTMD with the help of FEA.

Material and methods

An open source anatomical model of a male skull that is a part of the University of Tokyo BodyParts3D project was obtained (National bioscience database center 2018).

The bones and teeth forming the skull were downloaded in STL format, and all bones (frontal, parietal, sphenoid, ethmoid, nasal, lacrimal, zygomatic, occipital) were combined except for the maxilla in a boolean operation using Ansys 19.2 (ANSYS Inc. Houston, PA, USA) software.

With the aid of offset command, 0.2 mm thick periodontal ligament (PDL) was modeled. The maxilla, tooth, and periodontal ligament were incorporated into the general model independently. A symmetrical model of the craniofacial structures was created for FEA, as depicted in Figure 1A, and similar to the study of Koç and Jacob. The surgical technique method and the expansion device design in this study are different (Koç and Jacob 2022).

In all models, median and lateral osteotomies were performed without pterygomaxillary disjunction. In all analyzed scenarios, the footplate of the transpalatal distractor was placed at a 30-degree angle to the palatal bone with the anchor screws close to the tooth roots (Figure 1B).

Four different FEA models were created to compare the simulation results;

Model I: transpalatal distractor was placed to the first premolar region
Model II: transpalatal distractor was placed to the second premolar region
Model III: transpalatal distractor was placed to the first molar region
Model IV: transpalatal distractor was placed to the second molar region

Material properties

While the bone structure was considered to be anisotropic; tooth, periodontal ligament, and stainless steel were considered to be isotropic. The material

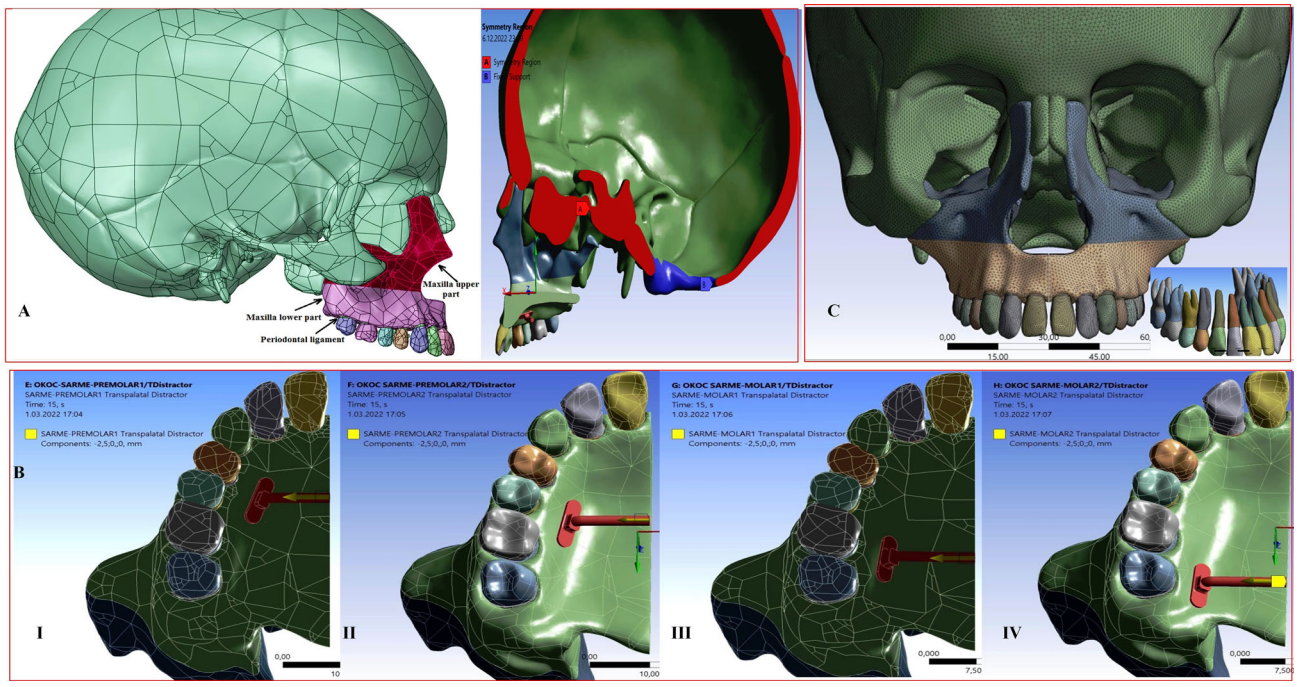


Figure 1. A Symmetrical model of craniofacial structures. B. Screw moved 2.5 mm in a transverse (z) direction (5 mm in total); only median and lateral osteotomies were performed without pterygomaxillary disjunction. Position of the transpalatal distractor, Model-I: the premolar-1 tooth (I), Model-II: the premolar-2 tooth (II), Model-III: the molar-1 tooth (III), Model-IV: the molar-2 tooth (IV) it was placed in level. C. Frontal views of the model divided into quadratic tetrahedral mesh elements.

properties of each previously mentioned component are shown in Table 1A. (Peterson and Dechow 2003; Peterson et al. 2006; Lee et al. 2014).

Boundary conditions

As suggested by Gautam et al. (2007), the foramen magnum was completely fixed and used as a point of origin. The transpalatal distraction screw (diameter, 1.8 mm; length, 6 mm) was modeled in the Ansys program, as shown in Figure 1B.

Using a transpalatal distractor, the displacement movement was transmitted to the maxilla with the help of the anchor screws and the footplate. The expansion device screw was moved in the direction indicated by the yellow arrow. Displacement boundary conditions corresponding to 0.33 mm per rotation were entered into the Ansys program. In order to represent the displacement provided by the screw applied in the clinic, the distractor body was moved 2.5 mm in one-sided transverse (z axis) direction (total of 5 mm) in the symmetrical FEA model (Figure 1B).

All models defined frictionless contact between the maxillary surfaces decoupled by lateral osteotomy. Bonded contacts were defined between the maxilla and teeth, periodontal ligament, transpalatal distractor, and anchor screws.

The x-, y-, and z-axes of the 3 D coordinate system represented the anterior-posterior, vertical, and transverse dimensions. Different color scale bands were used to depict each deformed condition and the various stress levels. Displacements and von Mises stress were measured in mm and Mpa, respectively.

To assess the amount of displacement and the von Mises stress distribution, the time dependent transient structural (dynamic) analysis type and an analysis solution were performed using nonlinear geometric theory (large deformations), nonlinear contact theory, and nonlinear material theory (anisotropic) methods.

The amount of rotation of the maxilla was measured from the angular changes made by the line, passing through the nodes between the ANS-PNS (anterior nasal spine-posterior nasal spine) points with respect to the symmetrical plane of the skull.

Finite element model

The symmetric model was divided into a total of 2,167,463 nodes and 1,461,017 quadratic tetrahedral elements, as seen in Figure 1C. The element, nodes, and mesh size values were the same for all models, and the mesh average skewness element quality convergence value was set to 0,16 Table 1C. The element,

Table 1A. Finite element model(FEM) material properties (mPa), mesh size and skewness mesh metrics spectrum. Material properties.

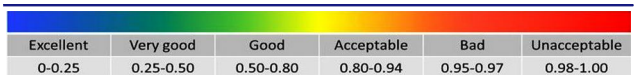
Cortical maxillary bone	Ex:12000	Vxy:0.18	Gxy:3600
	Ey:11640	Vyz:0.40	Gyz:5400
	Ez:15600	Vxz:0.30	Gxz:4100
Cortical skull bone	Ex:12580	Vxy:0.48	Gxy:4400
	Ey:13600	Vyz:0.24	Gyz:6700
	Ez:21200	Vxz:0.32	Gxz:4900
Cancellous bone	Ex:1148	Vxy: 0.32	Gxy: 434
	Ey: 1148	Vyz: 0.05	Gyz: 68
	Ez: 210	Vxz: 0.05	Gxz: 68
Dentin	19890	0.31	
Periodontal ligament	50	0.49	
Stainless steel	193000	0.35	

mPa: Megapascal.
Ex, Ey, Ez: Elastic modulus in three directions.
Vxz, Vyz, Vxz: Poisson's ratio in three directions.
Gxy, Gyz, Gxz: Shear modulus in three directions.

Table 1B. FEM element, nodes, mesh size and average skewness element quality convergence value.

	Average skewness value	Nodes	Element	Mesh size (mm)
Skull	0.15	1691902	1158657	1.8
Maxilla (lower part)	0.17	105921	71404	1.3
Maxilla (upper part)	0.15	104642	71184	1.3
Periodontal ligament	0.4	95057	47053	0.6
Tooth	0.18	159921	106775	0.8
Miniscrew	0.24	10020	5944	0.6

Table 1C. Skewness mesh metrics spectrum.



Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

nodes, mesh size and element quality convergence range of the parts forming all models are given in Table 1B.

In the model, the mesh element size in the miniscrew, tooth, pdl and maxilla is smaller than the element size in the skull bone. Mesh convergence was performed to show that the measured stress value did not change with the element size and to verify the solution. For the mesh convergence, the best number of elements was determined in the model.

Results

Displacement amount

In all models, the unilateral transverse displacements of the anterior teeth were greater than those of the posterior teeth. The greatest displacement values at the central incisor level, at the anterior nasal spine (ANS) and at the posterior nasal spine (PNS) levels were measured in Model IV, Model III, Model II and Model I, respectively.

The greatest unilateral displacement values at the central incisors level were measured as 4.27 mm in Model I, 4.95 mm in Model II, 6.41 mm in Model III and 8.68 in Model IV (Table 2, Figure 2).

The greatest unilateral displacement values at the ANS level were measured as 3.56 mm in

Model I, 4.02 mm in Model II, 5.22 mm in Model III and 6.67 mm in Model IV (Table 2, Figure 2).

The greatest unilateral displacement values at the PNS level were measured as 0.46 mm in Model I,

Table 2. The unilateral displacements (mm) depending on the directions after 5 mm of activation of the transpalatal distractor expander in all models.

	Model-I			Model-II			Model-III			Model-IV		
	X	y	z	x	y	z	x	y	z	x	y	z
Central incisor	1.005	−0.541	4.274	1.142	−0.806	4.959	1.351	−1.337	6.410	1.511	−2.501	8.681
Lateral incisor	0.691	−0.445	4.062	0.793	−0.663	4.718	0.930	−1.108	6.102	1.018	−2.036	8.282
Canine	0.329	−0.313	3.705	0.388	−0.481	4.297	0.442	−0.815	5.550	0.444	−1.485	7.520
First premolar	0.146	−0.205	3.141	0.183	−0.341	3.639	0.192	−0.587	4.724	0.154	−1.057	6.476
Second premolar	−0.091	−0.103	2.702	−0.085	−0.202	3.123	−0.139	−0.367	4.062	−0.262	−0.645	5.616
First molar	−0.034	0.005	2.224	−0.012	−0.038	2.578	−0.038	−0.094	3.366	−0.086	−0.143	4.693
Second molar	0.067	0.064	1.485	0.112	0.056	1.728	0.146	0.078	2.296	0.167	0.170	3.275
Anterior nasal spine	1.183	−0.636	3.569	1.357	−0.937	4.025	1.636	−1.551	5.221	1.894	−2.919	6.679
Posterior nasal spine	1.289	−0.270	0.469	1.491	−0.385	0.538	1.844	−0.613	0.823	2.233	−1.191	1.359
Frontomaxillary suture	−0.024	0.034	0.000	−0.018	0.026	0.000	−0.025	0.045	0.000	−0.048	0.127	0.000
Zygomaticomaxillary suture	−0.006	0.048	0.012	−0.001	0.041	0.014	0.008	0.070	0.024	0.034	0.167	0.046
Frontozygomatic suture	−0.028	0.041	0.002	−0.023	0.034	0.003	−0.034	0.057	0.004	−0.071	0.135	0.007
Zygomatic arch	−0.013	0.027	0.001	−0.010	0.022	0.000	−0.015	0.031	0.000	−0.024	0.072	0.001
Medial pterygoid plate	−0.124	0.030	0.075	−0.115	0.030	0.083	−0.133	0.059	0.131	−0.118	0.122	0.197
Lateral pterygoid plate	−0.088	0.040	0.022	−0.067	0.035	0.025	−0.081	0.051	0.053	−0.077	0.098	0.102
Foramen magnum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

3 axes; *x*-axis, anteroposterior; *y*-axis, vertical; *z*-axis, transverse dimensions.
+ values indicate forward, outward or upward displacement.
– values indicate backward, inward or downward displacement.
Median and lateral osteotomies were made in all models.
Position of the transpalatal distraction; in Model-I the premolar-1 tooth, in Model-II the premolar-2 tooth, in Model-III the molar-1 tooth and in Model-IV it was placed in the molar-2 tooth level.

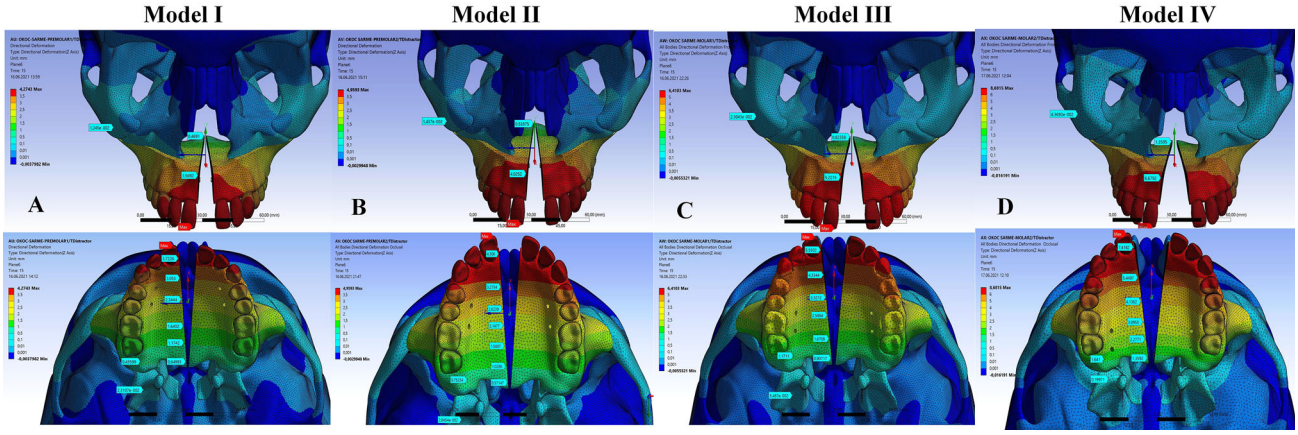


Figure 2. Model-I: Unilateral displacement (A; frontal, occlusal), Model-II: Unilateral displacement (B; frontal, occlusal), Model-III: Unilateral displacement (C; frontal, occlusal), Model-IV: Unilateral displacement (D; frontal, occlusal) after total 5 mm activation of the transpalatal distraction, displacement amounts in models.

0.53 mm in Model II, 0.82 mm in Model III and 1.35 mm in Model IV (Table 2, Figure 2).

According to the results of displacement analysis of all models, a V-shaped expansion pattern was observed in the maxilla. Also, the maxilla performed outward rotation and tipping movement during the expansion period. While the greatest rotation angle value was measured as −7.19° in Model IV, the lowest rotation angle value was measured in Model I as −4.06°.

Stress distribution

The mean elemental stress distribution in the craniofacial structures for models was shown in Table 3. The mean elemental stress (von Mises stress) values, ranked from highest to lowest, were measured in the medial pterygoid plate, screw, lateral pterygoid plate and frontozygomatic suture regions in all models.

Among models, the highest stress values were measured in the medial pterygoid plate region, respectively in Model IV, Model III, Model II and Model I (Table 3).

The highest stress values measured in Model IV were in medial pterygoid plate (168 Mpa), screw (103 Mpa) and lateral pterygoid plate (50 Mpa) regions.

The lowest stress values measured in Model I were as medial pterygoid plate, screw and lateral pterygoid plate regions which are 102 Mpa, 92 Mpa and 27 Mpa, respectively (Table 3).

In all models the lowest von Mises stress values were measured in the anterior nasal spine and posterior nasal spine regions. In Model I, von Mises stress values were measured as 0.072 Mpa in the anterior nasal spine and 0.065 Mpa in the posterior nasal spine regions. In other models, the stress values measured at these points approached almost zero.

As shown in Figure 3 and Table 3, the stress values in the craniofacial structures showed an upward trend from Model I to Model IV.

In the present study; the maximum mean stress values were measured quite high as 690 Mpa for Model IV, 607 Mpa for Model III, 551 Mpa for Model II and 276 Mpa for Model I.

When the red-colored maximum stress regions are examined, it was seen that the stress accumulates at the nodal points and in a few elements of that volume (due to the singularity error).

Discussion

In the orthodontic aspect the aim of transverse expansion must be maximum skeletal and minimum dental effect for the stability of the treatment results (Kunz et al. 2016). TPD is a current technique introduced with the advantages of transmitting the force directly to the bone and minimizing dental side effects during SARME in adult patients (Mommaerts 1999; Suri and Taneja 2008). But the original technique that includes TPD at the level of first premolars and no PTMD is primarily recommended for patients with tapered maxilla and no cross bite in the molar region such as cleft palate patients because of V shaped expansion pattern (Matteini and Mommaerts 2001). Considering the advantages of TPD, various investigations were focused on achieving more effective, near-parallel maxillary expansion since it was introduced. The most effective factors on the movement pattern of TPD were reported to be the scope of surgery, whether PTMD is performed or not and the distractor position (Matteini and Mommaerts 2001; Kunz et al. 2016; Möhlhenrich et al. 2021). Some authors claimed that PTMD is more effective than the

Table 3. The mean elemental stress (von Mises stress and first principal stress) distribution (mPa) in craniofacial and maxillofacial structures after 5 mm of activation of the transpalatal distractor expander in all models.

	Model-I		Model-II		Model-III		Model-IV	
Anatomic structure	Von Mises Stress (mPa)	First Principal Stress (mPa)	Von Mises Stress (mPa)	First Principal Stress (mPa)	Von Mises Stress (mPa)	First Principal Stress (mPa)	Von Mises Stress (mPa)	First Principal Stress (mPa)
Frontomaxillary suture	1.296	0.772	1.587	0.851	1.687	1,113	1.967	1.298
Zygomaticomaxillary suture	1.378	–0.205	1.678	–0.607	1.806	–0.803	2.491	–1.113
Frontozygomatic suture	4.153	–0.147	4.380	–0.247	7.153	–0.320	11.91	–0.572
Zygomatic arch	1.339	–0.001	1.315	–0.001	2.058	–0.038	8.058	–0.077
Nasal frontal suture	3.359	1.191	3.327	1.165	3.772	1.536	4.570	1.937
Medial pterygoid plate	102.19	6.791	108.64	8.554	151.2	11.26	168.6	19.79
Lateral pterygoid plate	27.905	5.123	27.494	5.248	37.35	7.639	50.74	10.23
Maxillary tuberosity	1.297	0.217	2.284	0.648	2.239	0.785	8.304	–1.464
Posterior nasal spine	0.065	0.000	0.046	0.000	0,021	–0.001	0.013	0.000
Anterior nasal spine	0.072	–0.001	0.005	0.000	0.002	0.000	0.001	0.000
Miniscrew region	92.634	19.682	90.592	19.39	98.86	27.98	103.4	34.78

+ compression stress values indicate; – tensile stress values indicate.

distractor position in achieving a more uniform and parallel transverse expansion (Möhlhenrich et al. 2021). On the other hand, Möhlhenrich et al. evaluated the effects of PTMD on SARME in context of orthodontic treatment and did not find any significant difference between the two surgical techniques in their long term model study (Möhlhenrich et al. 2020). Zandi et al. (2016) also investigated the necessity of PTMD in SARME and recommended performing surgery without PTMD because of the favorable surgical outcomes, decreased risk of possible complications and comparable amounts of expansion. In a recent cadaveric study Möhlhenrich et al. (2021) evaluated the dental and skeletal effects of distractor position on SARME with or without PTMD and found that SARME with PTMD combined with a posteriorly placed distractor resulted with more parallel expansion pattern of maxilla compared to the other groups. Similarly Matteini and Mommaerts reported that the combination of posterior location of the force and reducing posterior resistance with PTMD causes parallel movements of the maxillary segments (Matteini and Mommaerts 2001). However the authors also emphasized that one of these may be unnecessary and that their efficacy should be evaluated separately in future studies. To the best of our knowledge no published study has evaluated the effects of distractor position alone in SARME without PTMD. The aim of the present study was to evaluate the effects of different distractor positions on expansion, stress and displacement patterns in SARME without PTMD by using finite element analysis.

Although FEA does not demonstrate longitudinal effects, only a particular instance in time (MacGinnis et al. 2014), it has proven to be a good simulation for evaluating surgical procedures performed on the facial skeleton in the method of SARME (Jafari et al. 2003; Zawiślak et al. 2020). It allows us to evaluate displacement patterns and stress distributions on the facial skeleton model in a non-invasive way (Holberg et al. 2007; MacGinnis et al. 2014). However the results of FEA analysis should be interpreted carefully for clinical practice because clinical situations vary in many factors such as maturity of the suture, density of the bones, biologic considerations and other anatomic structures that affect biomechanical systems of maxillary expansion (Lee et al. 2017). Also chewing and muscle strength, relapse, and remodeling ability were not taken into account in the current FEA, hence some of the findings may differ from actual clinical outcomes. For example; in the present study high stress values in the sharp cornered regions were

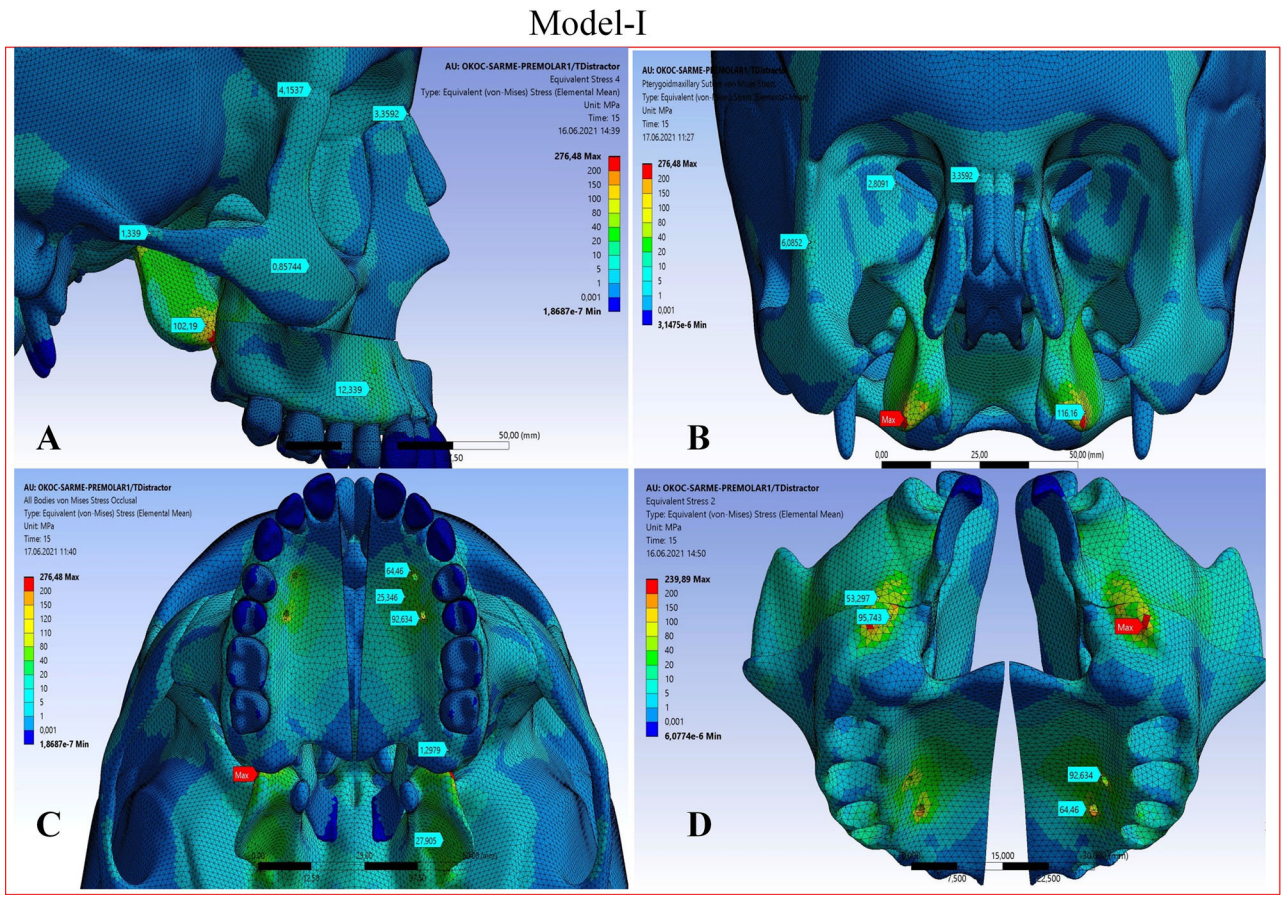


Figure 3. Model-I (left): Unilateral stress distribution in the craniofacial structures and maxillofacial sutures (A-C), and unilateral stress distribution in the pterygomaxillary suture and screw region (B-D) after total 5 mm activation of the transpalatal distraction.
Model-II (right): Unilateral stress distribution in the craniofacial structures and maxillofacial sutures (A-C), and unilateral stress distribution in the pterygomaxillary suture and screw region (B-D) after total 5 mm activation of the transpalatal distraction.
Model-III (left): Unilateral stress distribution in the craniofacial structures and maxillofacial sutures (A-C), and unilateral stress distribution in the pterygomaxillary suture and screw region (B-D) after total 5 mm activation of the transpalatal distraction.
Model-IV (right): Unilateral stress distribution in the craniofacial structures and maxillofacial sutures (A-C), and unilateral stress distribution in the pterygomaxillary suture and screw region (B-D) after total 5 mm activation of the transpalatal distraction.

measured and these high values were related to the solver mathematical calculation (stress singularity) errors in FEA (Bi 2018). The stress singularity is a result of the FEA procedure. It was formed at the pterygomaxillary suture contact surface, a few elements (red color), and in the node region. The maximum stress value is not taken into account because of the singularity error and does not affect the measured result values in the analysis (Koç and Jacob 2022).

In reality, the maximum stress value does not actually accumulate at a single point as in the analysis results, due to the flexibility of the bone against loads and its self-healing feature.

Bone, which is a living tissue, is known for its flexibility and self-healing properties against loads. Therefore, the maximum stress value does not accumulate at a single point as in the analysis results. While the displacement and strain values measured in the craniofacial structures may be lower than in an actual clinical situation, the stress distribution values of the current study were compatible with those of similar studies (Hartono et al. 2018; Nowak et al. 2021). Therefore the studies using the FEA indicate the need for performing a full sagittal and transverse osteotomy of the maxilla, as in the present study, to minimize the risk of stresses in the facial skeleton and the neurocranium, as well as possible, uncontrolled fractures (Nowak et al. 2021). On the other hand; in the present study nonlinear methods, geometry (large deformations), contact (frictionless), and material (anisotropic) theories were considered. The solution was obtained by taking into account the anisotropic material property of the bone (Peterson et al. 2006). In order for FEA studies to be realistic, consistent and comparable, it is important to specify mesh convergence, number of elements and nodes, boundary conditions (contact types and applied forces between

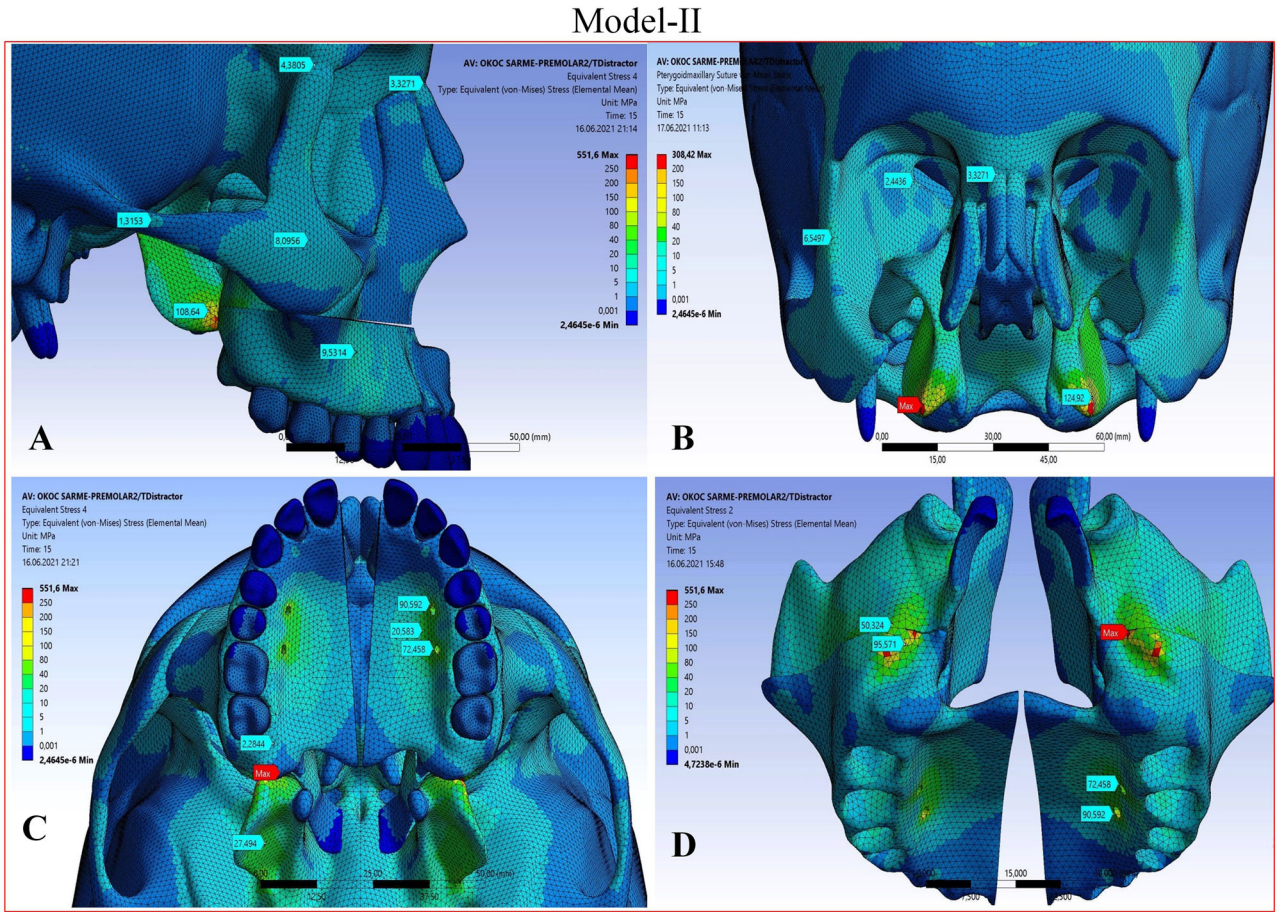
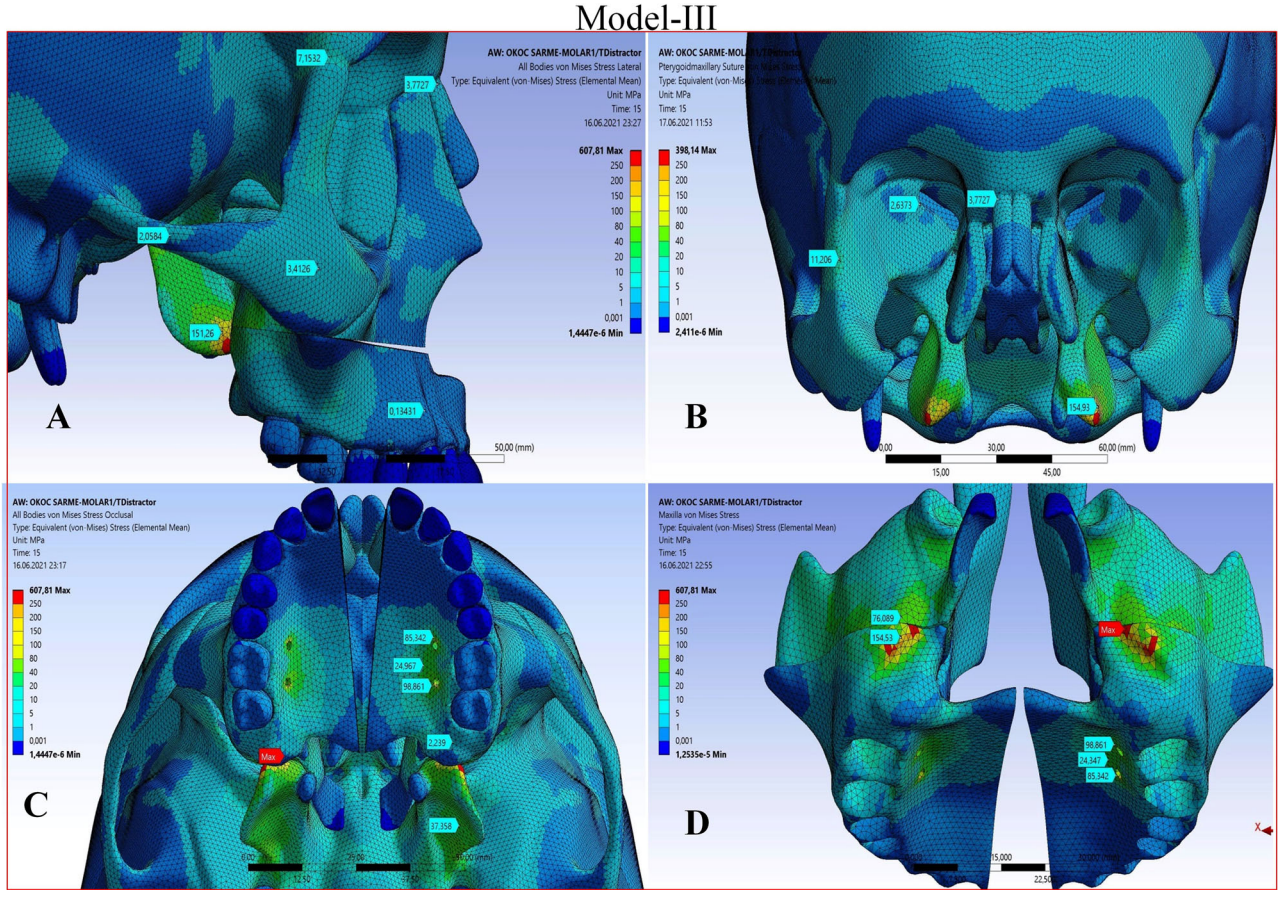


Figure 3. Continued.

contacting surfaces) and material properties as in the present study (Bi 2018).

The studies investigating different aspects of TPD demonstrated that the pattern of expansion can be selectively modified by various options of positioning the appliance (Matteini and Mommaerts 2001; Kunz et al. 2016). The general view in the literature is that maximum expansion is achieved with posteriorly located force application (Matteini and Mommaerts 2001; Möhlhenrich et al. 2021). In the present study the authors evaluated the expansion patterns of TPD with different positions of the expander as first premolar region in Model I, second premolar region in Model II, first molar region in Model III and second molar region in Model IV. The unilateral displacements of the specific craniofacial and dentoalveolar structures were measured in the x, y and z axes after total 5 mm activation of the distractor. As expected; 'V' shaped maxillary expansion pattern was observed in all models and the maximum displacement values were measured on the central incisor region (Figure 2). Unlike actual clinical situations, there was no asymmetrical or partial opening of the maxilla in the current FEA model (Holberg et al. 2007; Lee et al. 2014). In practical applications, asymmetric enlargement or partial displacement of the maxilla may occur due to biomechanical factors. It can be noted that the amount of displacement measured in the present study was compatible with the similar studies, although the evaluation methods were different (Möhlhenrich et al. 2017; Nowak et al. 2021). Möhlhenrich et al. (2017) evaluated the stress and displacement patterns of six different designs of SARME by using FEA. The authors measured 1.22 mm transversal displacement in the central incisor region after 1 mm activation of the palatal bone borne device with median and lateral osteotomies without PTMD, which is the most similar to the present study's model design. However the expander was placed in the premolar region in all models in their study. In the present study, after total 1 mm activation of the distractor the unilateral displacement of the central incisors were measured as 1.97 mm, 2.56 mm and 3.52 mm when the distractor was placed to the second premolar, first molar and second molar region respectively. It should be noted that the amount of the maxillary expansion may vary depending on some biomechanical factors such as the use of different



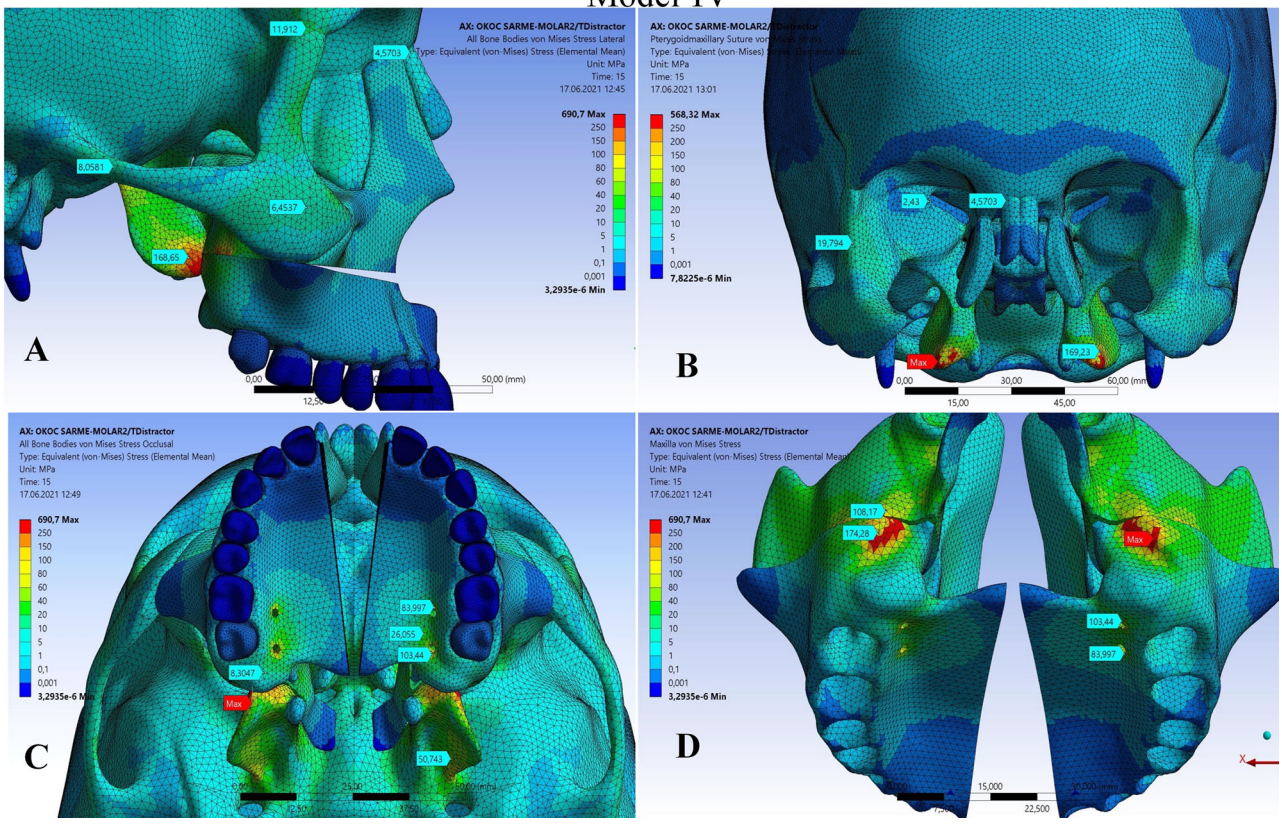


Figure 3. Continued.

expansion devices, number and location of the screws, the patient's age, gender, palate shape, and bone/mid-palatal suture density (Lee, Bayome, et al. 2014; Lee, Park, et al. 2014; Lee et al. 2017). In order to obtain more realistic and consistent results in studies investigating SARME with FEA, it was recommended to fully activate the expansion appliance (approximately 5 mm movement) and nonlinear analysis as it was performed in the present study (Han et al. 2009; Lee, Bayome, et al. 2014; Lee, Park, et al. 2014; Lee et al. 2017). Although a definite adaptation is not expected with the measurements obtained with FEA, it can be stated that these displacement amounts are quite sufficient for clinical application. To the best of our knowledge the present study is the first one evaluating the palatal distractor position in the second molar region. Although the maximum stress distribution values and the rotation angle were measured in Model IV, where the distractor was placed to the second molar region, it was observed that the displacement amounts were maximum in all measured areas. Among the distractor positions evaluated in the present study, the second molar region was found to be the most advantageous one in terms of expansion pattern. In clinical practice; placing the palatal distractor so posteriorly can be difficult especially in patients with V shaped – high palate or irregular anatomic surface of the palatal vault such as cleft patients (Verlinden et al. 2011). On the other hand it should be kept in mind that the cortex In the posterior region is thinner and more fragile than the premolar region and this may adversely affect the stability of the device (Matteini and Mommaerts 2001). Although it has been indicated that placing skeletal anchor elements near to the mean branch of palatal artery may result in arterial bleeding, no such complication has been reported with palatal distractors (Matteini and Mommaerts 2001; Verlinden et al. 2011).

Considering the patient's anatomy and clinical conditions, placing the palatal distractor as posteriorly as possible will result in more maxillary expansion than routine application.

Conclusions

Within the limitations of FEA analysis results, it can be concluded that;

- SARME without PTMD is an effective method for maxillary expansion.
- The pattern of maxillary expansion with the method of SARME can be modified by various options of positioning the device.
- The maximum displacement values were observed with the distractor placed in the second molar region.

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