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Displacement Patterns of the Maxilla During Parallel and Rotational Setback Movements: A Finite Element Analysis

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: The purpose of this analysis was to evaluate the displacement patterns of the maxilla under parallel and rotational setbacks using the finite element method (FEM).

Material/Methods: A three-dimensional (3D) finite element model of a hemimaxilla was constructed. Through a conventional Le Fort I osteotomy, 2 and 3 mm of posterior movement in a parallel and rotational manner were simulated and the displacement pattern of the maxilla in each movement type was evaluated.

Results: Both parallel and rotational setbacks resulted in lateral and inferior displacement of the maxillary segment. The largest inferior displacement was 3.0 mm and the largest lateral displacement was 1.84 mm. All lateral displacements in the anterior region were found to be more than 1 mm.

Conclusions: The results of this study may provide insight into how the maxilla tends to move during total maxillary setback surgery.

MeSH Keywords: **Finite Element Analysis • Maxilla • Orthognathic Surgery**

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Background

Total maxillary setback (TMS) osteotomy is an orthognathic surgery technique for correcting skeletal problems of bimaxillary protrusion or severe maxillary excess [1]. In cases of skeletal maxillary excess, maxillary setback can be obtained by using either anterior maxillary segmental osteotomies or TMS osteotomy, so that posterior repositioning of the maxilla can be achieved [2,3].

TMS movement can be classified into parallel and rotational setback according to the change of the palatal plane. Baek et al. explained rotational setback as maxillary setback with clockwise rotation of the palatal plane more than 2 degrees and subsequent backward movement of upper central incisors [4]. Authors are mainly divided into 2 groups according to the technique used for TMS osteotomy; one suggesting bone removal from posterior maxillary region and the other suggesting fracture of pterygoid plates to avoid any bony interference when maxillary setback is considered. Notably, many authors have supported the idea of intentionally fracturing the pterygoid plates to set back the entire maxilla [5–9].

The numerical method of obtaining the solution to a complex problem is called the finite element method. The analysis performed with finite element method is known as finite element analysis (FEA). FEA allows the analyzer to evaluate the distribution of stresses and displacements on the simulated model.

Maxillary advancement surgery offers a highly predictable and widespread treatment for the correction of anteroposterior skeletal deficiency. Accuracy and surgical movement pattern of maxillary advancement has been widely investigated in the literature. Conversely, data regarding the potential outcomes and characteristics of TMS remains scarce. Therefore, the purpose of this study was to evaluate and compare the displacement patterns of the maxilla with regard to the 2 different TMS movements described in the literature using FEA.

Material and Methods

In this study, a finite element model of a hemimaxilla was developed from computerized tomography (CT) images taken at 0.5 mm intervals of a young man using DICOM (v 3.0, NEMA, Rosslyn, Virginia 22209 USA) software. Sequential CT images were transferred to Maxilim (Medicim NV, Mechelen, Belgium) software to obtain a three-dimensional image. A tetrahedral finite element mesh model of the image was then constructed using MSC Marc (MSC Software Corporation, Santa Ana, CA 92707, USA) software to simulate the maxilla. The model consisted of 157 174 elements and 34 019 nodes. The horizontal line representing the upper limit of the maxilla model was fixed and zero-displacement boundary condition was imposed on the nodes along this line. The mechanical structures in the model were assumed to be homogenous, isotropic, and linear elastic with the properties shown in Table 1. The periodontal ligament was not simulated.

The surgical Le Fort I osteotomy line was simulated running horizontally along the lateral maxillary wall and extending to the pterygoid plates. This means that the lower thirds of the pterygoid plates were fractured. Two different backward movements were applied to the lower maxillary segment to simulate parallel and rotational setbacks of the maxilla according to the osteotomy line. When the movement was directed in parallel with the osteotomy line, a parallel setback of the maxillary segment was performed. On the other hand, rotational setback movement was applied with a direction of 5° inferior to the osteotomy line to obtain a counterclockwise rotation. Actually, the counterclockwise rotation mentioned herein (on the left lateral aspect of the model) corresponds to the clockwise rotational setback defined by Baek et al. [4], which was adapted on cephalometric tracings. Therefore, the use of counterclockwise rotation in this study was because of the left-sided models.

In both parallel and rotational setback simulations, 2 and 3 mm of posterior movements were applied to point A and the displacement pattern of the maxillary segment was observed in each simulation. Posterior movement amounts of 2 and 3 mm were selected based on the most commonly reported mean setback amounts in the literature [5,6,10–12]. The reference lines assigned to measure the displacement of the maxillary segment were: L1, the vertical line passing through the apex point of the canine tooth; and L2, the vertical line passing through the midpoint between the buccal roots of the second molar. Distance change between the upper and lower maxillary segments in L1 was assumed to reflect the displacement pattern of the maxillary segment in the anterior region, while the difference in L2 was assumed to represent the displacement in the posterior region. The created model with the osteotomy line and reference lines is shown in Figure 1.

Table 1. Mechanical properties of the structures used in this study.

	Young's modulus (ε) GPa	Poisson ratio (υ)
Cortical bone	14.8	0.3
Cancellous bone	1.85	0.3

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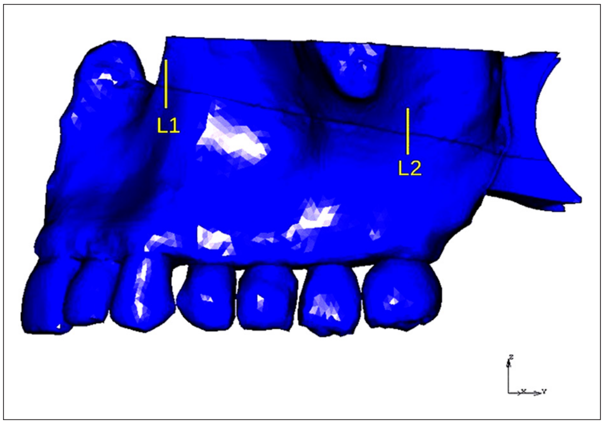

Figure 1. The hemimaxilla model with the osteotomy line and reference lines.

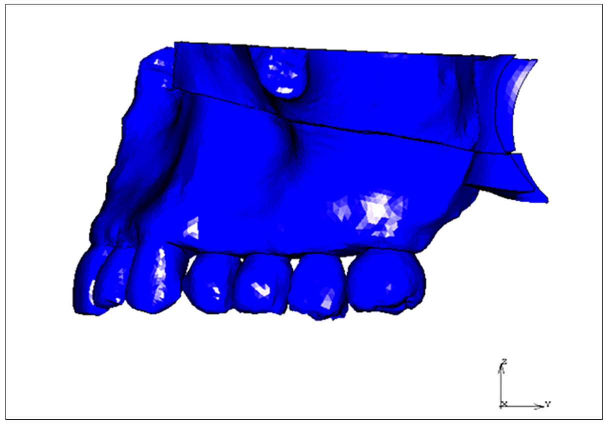

Figure 2. Displacement in the parallel setback simulation with 2 mm posterior movement.

Table 2. Displacement of the reference lines in the parallel setback simulation (in mm).

Setback amount	Transverse plane (x)		Vertical plane (z)	
	L1	L2	L1	L2
2 mm	1.13	0.72	0.15	0.23
3 mm	1.52	0.85	0.50	0.70

Table 3. Displacement of the reference lines in the rotational setback simulation (in mm).

Setback amount	Transverse plane (x)		Vertical plane (z)	
	L1	L2	L1	L2
2 mm	1.32	0.76	0.20	0.18
3 mm	1.84	0.90	3.0	0.65

To evaluate the pattern of the TMS movement, the amount of displacements (mm) was measured on the x-axis (transverse plane) and z-axis (vertical plane). Displacements on the y-axis (anteroposterior plane) were, predictably, either 2 mm or 3 mm based on the amount of posterior movement applied to the maxillary segment. For example, a posterior movement of 2 mm refers to exactly the same amount of posterior displacement of both L1 and L2 reference lines.

Results

The amounts of displacements measured in the parallel and rotational setback simulations are shown in Tables 2 and 3, respectively. Displacement patterns of the maxilla according to the reference lines L1 and L2 were evaluated in the transverse and vertical planes.

Displacement in the transverse plane (x-axis)

Positive values indicate lateral displacements of the maxillary segment. In the parallel setback simulation with 2 mm posterior movement, the maxillary segment was displaced laterally, with a larger amount in the anterior part compared to the posterior part (Figure 2). Similarly, 3 mm posterior movement revealed lateral displacement of the maxillary segment with increased amounts in both anterior and posterior parts (Figure 3). In the rotational setback simulation, maxillary segment showed the same movement pattern as that of parallel setback, with slightly increased displacement amounts. It was obvious that maxillary segment showed a tendency toward lateral displacement in all simulated movements. Lateral displacements did not exceed 1 mm in the posterior region as opposed to the anterior region. The largest lateral displacement was 1.84 mm, which occurred with the rotational setback of 3 mm.

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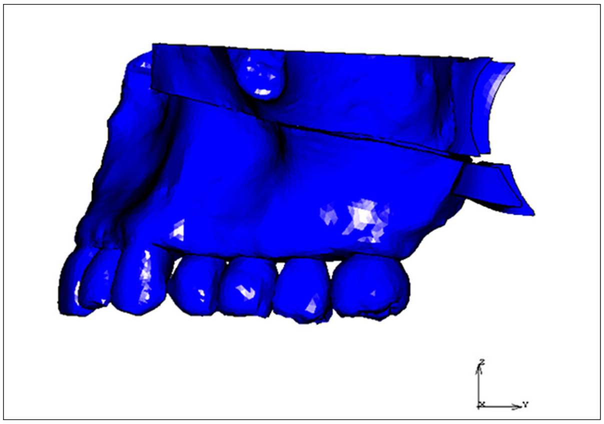

Figure 3. Displacement in the parallel setback simulation with 3 mm posterior movement.

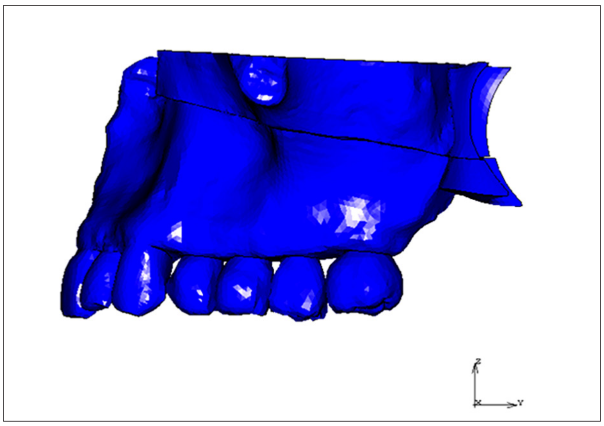

Figure 4. Displacement in the rotational setback simulation with 2 mm posterior movement.

Displacement in the vertical plane (z-axis)

Negative values indicate inferior displacements of the maxillary segment. In the parallel setback simulation, the model produced smaller inferior displacements in the anterior region than in the posterior region. During the rotational setback movement, vertical displacement in the inferior direction tended to increase. Figure 4 shows the displacement pattern of maxillary segment with a rotational setback of 2 mm. Particularly, a marked increase was observed in the anterior region where the largest inferior displacement (–3.0 mm) was measured. L2 displacement amounts in the rotational setback movement seemed to decrease slightly compared to parallel setback values; nevertheless, the values were still very close to each other. When comparing the parallel and rotational setback movements, the posterior part of the maxillary segment showed a tendency to move more inferiorly in parallel setback, whereas the anterior part noticeably showed a greater inferior displacement with the application of rotational setback (Figure 5).

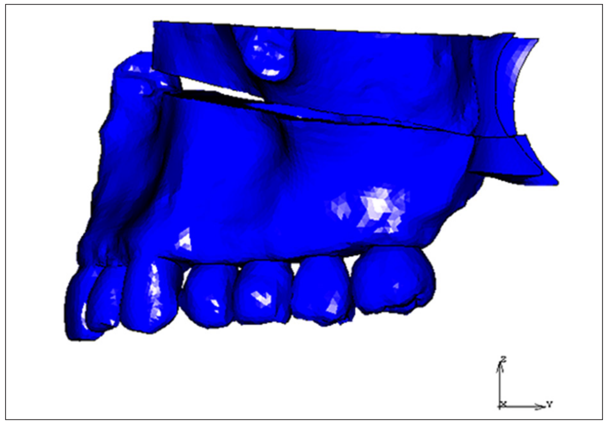

Figure 5. Displacement in the rotational setback simulation with 3 mm posterior movement.

Discussion

Understanding the maxillary displacement characteristics under parallel and rotational setback movements is of great importance to achieve an accurate result following the surgical operation. Thus, the purpose of the analysis was to observe the characteristics of maxillary setback when different posterior movements in parallel and rotational directions were applied. A limited number of publications are available in the literature that focus on the accuracy of TMS osteotomy. Studies examining maxillary displacement with FEA are also limited and generally concentrated on rapid palatal expansion (RPE) [13–16]. Other than RPE studies, one study evaluated the maxillary displacement under different headgear forces and another under protraction forces [17,18]. The present study is the first FEA that addresses the displacement pattern of the maxillary segment during TMS surgery.

Many authors emphasized that TMS osteotomy could be more advantageous than segmental setback procedures, because it does not rely on tooth extraction and it overcomes the concerns about vascularization of segments [2–4,19]. Most of the articles reported that TMSO plays a significant role in the treatment of maxillary excess or bimaxillary protrusion [1–3,20–22]. As more information about TMSO has become available, a need has arisen to determine the pattern of maxillary setback movement.

Some authors suggested that fracture of the pterygoid plates is a safe and effective technique to set back entire maxilla [8,9]; however, possible outcomes of setback movement carried out with the fracture of pterygoid plates are unclear and the displacement pattern of the maxilla is unpredictable. The main reason for simulating such a technique was to avoid any interference between the maxillary tuberosity and pterygoid plates. Furthermore, the technique of pterygoid plate fracture is a matter of great interest since there exist many studies addressing this technique for maxillary setback movement [5–9].

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In the current study, parallel setback was simulated using a posterior movement parallel to the osteotomy line, while rotational setback was represented with a posterior movement directed 5 degrees inferior to the osteotomy line. Several studies have dealt with the rotational setback procedure and its angular orientation. Krekmanov et al. reported that two-thirds of their study sample received rotational setback in clockwise direction with a mean angulation of 1.3° (SD 3.3) [23]. Similarly, Baek et al. performed clockwise rotational setback with an angulation more than 2°, but the amounts of exact angular change were not specified [4]. In another 2 studies, clockwise rotational setback was mentioned to be the type of setback movement; however, again no information on its angulation was presented [11,24].

Selected setback movement amounts for assessment in this simulation were 2 and 3 mm based on the commonly reported magnitudes of TMS [5,6,10–12]. As the lower maxillary segment was completely separated from the upper segment with the conventional Le Fort I osteotomy, the lower segment moved freely, so forces applied at point A were accepted as negligible.

Reference line L1 was used to observe the displacement pattern of the maxillary segment in the canine area, so the results were interpreted as representing the displacement of anterior maxilla as well as anterior dentition. The L2 line was assigned in the second molar area to represent the posterior maxillary displacement pattern, especially at the end of the dental arch.

Both parallel and rotational setbacks resulted in lateral displacement of the maxillary segment. This result supports the findings of Gautam et al. that the maxillary structures were displaced laterally with the different types of headgear retractions [17]. All lateral displacements in the anterior region were found to be more than 1 mm. Lateral displacements in the posterior region were relatively smaller, with the maximum amount being 0.90 mm in the 3 mm rotational setback simulation.

All setback simulations revealed inferior displacement of the maxillary segment. This observation is consistent with the findings of Hirose et al., who reported that the maxilla moved inferiorly in general [25]. Inferior displacement amounts as small as 0.15 to 0.23 mm were detected with 2 mm setback movements. However, a sudden increase from 0.2 mm to 3.0 mm occurred in the anterior maxilla when the rotational setback amount increased to 3 mm. Parallel setbacks seemed to provoke greater inferior movements in the posterior maxilla. In contrast, the inferior displacements tended to significantly increase in the anterior maxilla with the rotational setbacks.

Conclusions

To help develop a better understanding of TMS, a FEA was conducted to evaluate the displacement pattern of the maxilla under different circumstances. The FEA results indicated that the inferior displacement of the maxilla occurred even in the parallel type of setback movement. Not surprisingly, the anterior part of the maxillary segment moved in the inferior direction with the applied counterclockwise direction. Another interesting observation was that the maxillary segment was displaced laterally with relatively larger amounts in the anterior maxilla. These results may provide insight into how the maxilla tends to move during TMS surgery.

Statement

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