

A comparison of fixation methods using three-dimensional finite element analysis following anterior segmental osteotomy

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Abstract (J Korean Assoc Oral Maxillofac Surg 2012;38:332-6)

Objectives: This study sought to evaluate fixation methods and determine the best method for the postoperative stabilization of maxillary osteotomy. For our analysis we performed a three-dimensional finite element analysis of stress distribution on the plate, screw, and surrounding bone, as well as displacement onto the plate.

Materials and Methods: We generated a model using synthetic skull scan data; an initial surface model was changed to a solid model using software. Modified anterior segmental osteotomy (using Park's method) was made using the program, and four different types of fixation methods were used. An anterior load of 100 N was applied on the palatal surface of two central incisors.

Results: The Type 1 (L-shaped) fixation method gave stresses of 187.8 MPa at the plate, 45.8 MPa at the screw, and 15.4 MPa at the bone around the plate. The Type 2 (I-shaped) fixation method gave stresses of 186.6 MPa at the plate, 75.7 MPa at the screw, and 13.8 MPa at the bone around the plate. The Type 3 (inverted L-shaped) fixation method gave stresses of 28.6 MPa at the plate, 29.9 MPa at the screw, and 15.3 MPa at the bone around the plate. The Type 4 (I-shaped) fixation method gave stresses of 34.8 MPa at the plate, 36.9 MPa at the screw, and 14.9 MPa at the bone around the plate. The deflection of the plates for the four fixation methods was 0.014 mm, 0.022 mm, 0.017 mm, and 0.018 mm, respectively.

Conclusion: The Type 3 (inverted L-shaped) fixation method offers more stability than the other fixation methods. We therefore recommend this method for the postoperative stabilization of maxillary osteotomy.

Key words: Anterior segmental osteotomy, Fixation techniques, 3D finite element analysis

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I. Introduction

Bimaxillary and dentoalveolar protrusion is characterized by protrusive lip and teeth, inability of lip closure, gummy smile, abnormal mentalis activity, etc^{1,2}. It can cause diastema, periodontal problems, and various skeletal disharmonies later in adults³. Conventionally, bimaxillary protrusion has been treated by orthodontic treatment after the extraction of the first or second premolars. Note, however, that this method has resulted in complications such as root resorption,

linguoversion, and/or incomplete retraction of anterior teeth, bony dehiscence or fenestration, and increased exposure of gummy tissue³; thus requiring surgery for the treatment of bimaxillary protrusion to get more esthetic and functionally stable results⁴.

The anterior segmental osteotomy of the maxilla was first described by Cohn-Stock in 1921 and modified by Wassmund, Wunderer, and Epker et al.⁵. Nonetheless, this technique has been applied to limited cases because its indication was not correct and many complications occur such as necrosis of the repositioned anterior segment, devitalization of anterior teeth, limited movement of segment, and unpredictable soft tissue changes.

Reported in 1996 and published in 2008, the modified anterior segmental osteotomy technique (Park's method) has been used to prevent these complications. In this surgical technique, horizontal vestibular incision is performed from canine to canine; no other (palatal) incision is required.

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Vertical osteotomy is done on the extraction site. Bicortical horizontal osteotomy between the canine root tip and the aperture piriformis is then carried out to connect the right and left vertical osteotomies^{6,7}. After repositioning the segment, it is fixed by semi-rigid fixation. Note, however, that the proper position and adequate number of miniplates have yet to be determined.

This study sought to evaluate stress distribution according to the fixation methods after anterior segmental osteotomy and suggest the proper position of the miniplates.

II. Materials and Methods

1. Model creation

A maxillary surface model was created by three-dimensional (3D) scanning (Breuckmann Inc., Meersburg, Germany) of a maxillary model (QS7/E; Somso Modelle, Coburg, Germany)^{8,9}. Rapid Form software (INUS Technology Inc., Seoul, Korea) then converted the maxillary surface model into 3D solid model. A commercially available computer-assisted design tool, CATIA (Dassault System Inc., Paris,

France), was used to simulate the modified anterior segmental osteotomy.

2. Surgical technique

Anterior segmental osteotomy was done on the maxillary 3D solid model^{6,7}. The segment was stabilized by various miniplates and screws. All miniplates were fixed with screws inserted perpendicular to the surface. The gap of the osteotomy line was 1 mm.

The study group was divided according to the shape and position of the miniplates.(Fig. 1)

Type 1: Two “L-shaped” miniplates positioned 3 mm and 8 mm superiorly on the horizontal osteotomy line and between the central incisor and the lateral incisor and between lateral incisor and canine.

Type 2: Two “I-shaped” miniplates positioned 3 mm and 8 mm superiorly on the horizontal osteotomy line and between lateral incisor and canine.

Type 3: Two “inverted L-shaped” miniplates positioned 7 mm distally and 5 mm inferiorly of the vertical osteotomy line and between the central incisor and the lateral incisor and

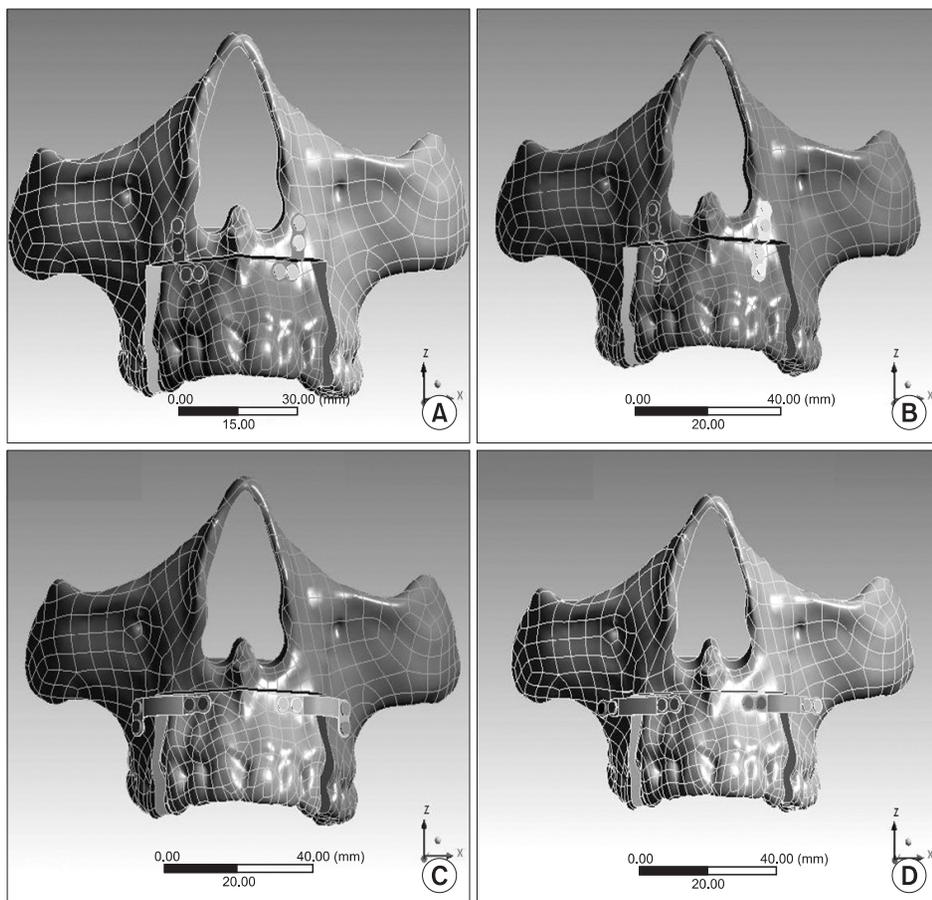


Fig. 1. Four types of anterior segmental osteotomy model fixed with different pattern of plates and screws. A. Type 1. B. Type 2. C. Type 3. D. Type 4.

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between lateral incisor and canine.

Type 4: Two “horizontal I-shaped (—)” miniplates positioned 7 mm and 12 mm distally and between the central incisor and the lateral incisor and between lateral incisor and canine.

3. Finite element analysis

The data obtained in CATIA was imported into a commercially available finite element analysis (FEA) program, ANSYS version 12 (ANSYS Inc., Canonsburg, PA, USA). A solid element type, “SOLID 186,” was chosen to model the bone segments.(Table 1)

The miniplates (Lefort system; Jeil Medical Co., Seoul, Korea) were modeled. The thickness of the real miniplates was 0.5 mm. The diameter and length of real screws were 2 mm and 8 mm. The mechanical properties of cortical and cancellous bone were assumed to be the same in every plane^{10,11}.(Table 2) The screw holes were numbered by their positions.(Fig. 2) 100 N was loaded on the 45° palatal plane between both central incisors.

Data collection and analysis were performed once because

the number of elements and the mechanical properties used in this study were fixed. For this reason, statistical analysis was not performed.

III. Results

1. von Mises stress distribution around the miniplates and screws

The maximum von Mises stress was measured around the curvature area of Type 1, 2, and 3 miniplates. In the case of Type 4, the area around the number 2 and 7 screw holes showed maximum stress. Maximum stress around the screws was observed in the number 3 and 8 screws in Type 1, number 3 and 7 in Type 2, number 3-6 in Type 3, and number 4 and 5 in Type 4.(Table 3, Fig. 3)

2. von Mises stress distribution around screw holes

Maximum stress was observed around the number 3 and 8 screws holes in Type 1, number 3 and 7 in Type 2, and number 3-6 in Types 3 and 4.(Table 3, Fig. 3)

Table 1. Number of elements used in 4 different models

Type	Elements
1	102,983
2	98,315
3	104,109
4	101,244

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Table 2. Mechanical properties used in FEA models

Material	Poisson's ratio	Young's modulus (N/m ²)
Titanium plate	0.33	105×10 ⁹
Titanium screw	0.33	105×10 ⁹
Cortical bone	0.30	14.8×10 ⁹

(FEA: finite element analysis)

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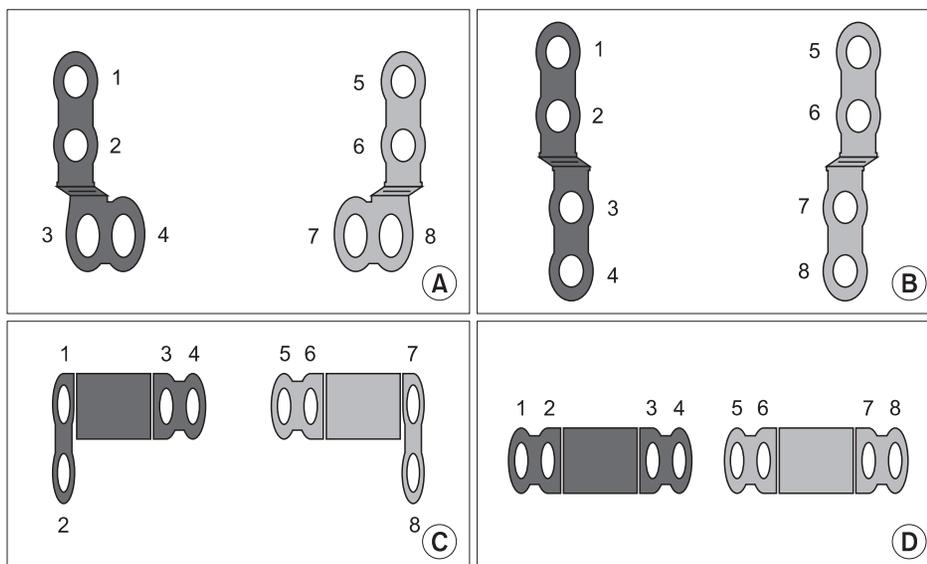


Fig. 2. The screw holes were numbered by their positions. A. Type 1. B. Type 2. C. Type 3. D. Type 4.

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Table 3. Maximum von Mises stress of plates and screws for 4 different types

	Type 1	Type 2	Type 3	Type 4
Plates (MPa)	187.8	186.6	28.6	34.8
Screws (MPa)	45.8	75.7	29.9	36.9
Bone near screw hole (MPa)	15.4	13.8	15.3	14.9

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Table 4. Maximum deflection of plates for 4 different types

	Type 1	Type 2	Type 3	Type 4
Deflection (mm)	0.014	0.022	0.017	0.018

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3. Deflection of miniplates

Maximum deflection was measured around the number 4 and 7 screw holes in Type 1, number 4 and 8 in Type 2, and number 4 and 5 in Types 3 and 4.(Table 4, Fig. 3)

IV. Discussion

Anterior segmental osteotomy is indicated in the case wherein substantial movement of the anterior segment of the maxilla is required but orthodontic tooth repositioning alone is not sufficient in terms of objective and subjective factors such as the amount of tooth movement, periodontal conditions, patient’s age, total treatment time, etc^{4,6,7,12}. The advantages of this surgical technique include the more stable results, easier setback of segment, short treatment time, and no intermaxillary fixation periods. Note, however, that it has disadvantages, i.e., possibility of devitalization of anterior tooth, unpredictable soft tissue changes, no movement of posterior segment of the maxilla, and surgery itself^{6,7}. Generally, the anterior segment is fixed by a semi-rigid method, allowing opening the mouth as soon as possible. Its merits include keeping the airway space safe and eating and cleansing the mouth immediately after operation. If the metal plates are poorly manipulated, however, the anterior segment may be displaced¹³.

FEA is widely applied in the engineering and aerospace industries and can also be used to address physical problems in medical science. It is a highly reliable, accurate technique used to analyze the stress and strain distribution on the anatomic structure under force^{14,15}. This study sought to find the most stable fixation method after anterior segmental

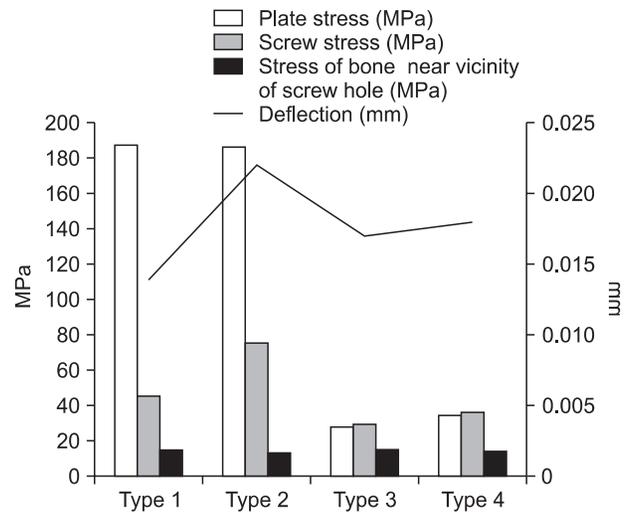


Fig. 3. Comparison of von Mises stress of plates, screws, bone near screw holes, and deflection of plates of 4 different types.

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osteotomy on the maxilla. Thus, the amount of stress on each type of metal plates was measured using FEA. Vollmer et al.¹⁶ reported that FEA simulations were highly related to *in vitro* values using the mandibular model. FEA is known to be very useful in evaluating the stress and strain patterns in facial bone with its various functions and anatomies^{17,18}. Alberts et al.¹⁹ studied the osseous strain pattern of the maxilla after Le fort I osteotomy and suggested that FEA had more advantages than the synthetic model analysis. Note, however, that Armstrong et al.²⁰ cited its limitations based on an *in vitro* experiment.

In this study, we hypothesized that the maxilla is of a homogenous, isotropic, and linearly elastic structure although it has various biomechanical characteristics. In addition, masticatory force was presumed to be constant even if Song et al.²¹ reported that masticatory force decreased immediately after surgery but increased during the recovery phase.

Stress distribution pattern is important because abnormal stress can resorb the bone gradually and loosen the screws by mastication. Preventing such unwanted loosening of plate and screws requires a more stable fixation method. This study showed that more stress occurred on Types 1 and 2 plates and screws. This may be caused by excessive bending, suggesting that bending of the plates is important in stress distribution. Stress was also observed to be in high concentration on screw holes near the bending curvature. Note, however, that stress on the bone around the screws was similar for all types of plates and less than that of plates or screws. The deflection

of metal plates was not different among Types 1, 3, and 4. Based on these results, we assume that Type 3 may be a more stable method than the others. When applying Type 3 is difficult because of the anatomical limitation or variations of the maxilla, however, Type 4 may be useful.

V. Conclusion

Based on this study, the Type 3 (L-type) plate can be concluded to be the most stable for the fixation of the anterior segment of the maxilla. Note, however, that it has certain limitations, whereas FEA has various advantages such as restricted application of masticatory force. More clinical variations should be considered.

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