Int. J. Oral Maxillofac. Surg. 2008; 37: 1117–1124
doi:10.1016/j.ijom.2008.10.004, available online at http://www.sciencedirect.com

International Journal of
Oral & Maxillofacial Surgery

Research Paper
Orthognathic Surgery

Comparison of biomechanical behaviour of maxilla following Le Fort I osteotomy with 2- versus 4-plate fixation using 3D-FEA. Part 1: Advancement surgery

M. S. Ataç[1], E. Erkmen[1], E. Yücel[1], A. Kurt[2]
[1]Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Gazi University, 82. Sok. 06510, Emek, Ankara, Turkey
[2]Department of Manufacturing Engineering, Atılım Universtiy, Çankaya, Ankara, Turkey

M. S. Ataç, E. Erkmen, E. Yücel, A. Kurt: Comparison of biomechanical behaviour of maxilla following Le Fort I osteotomy with 2- versus 4-plate fixation using 3D-FEA. Part 1: Advancement surgery. Int. J. Oral Maxillofac. Surg. 2008; 37: 1117–1124.

Abstract. The study aimed to calculate the location and intensity of the maximum stress fields on the fixation plates and surrounding maxilla following Le Fort I osteotomies after advancement procedures using three-dimensional finite element analysis. The models were generated using skull CT scan data. Le Fort I osteotomy simulations were made and two separate impacted maxillary models were designed. The ADV-2 model has 2 plate fixations bilaterally at the piriform rims, the ADV-4 model has 4 plate fixations at the zygomatic buttresses and piriform rims. The stress fields on bone, plate and screws were computed for each model.

Posterior occlusal loads were simulated on one side in the molar–premolar region, in all three directions, reflecting the chewing forces. The increased locations of highest Von Mises stresses on the plates and highest maximum principle stresses on the bones were determined in ADV-2 models especially under horizontal and oblique loads when compared with ADV-4 models. Evaluation of the highest Von Mises stress values and maximum principal stress revealed that oblique load in the ADV-2 model received the highest values. 4-plate fixation following Le Fort I advancement surgery exerts less stress on the maxillary bones and fixation materials than 2-plate fixation.

Keywords: 3D finite element analysis; Le Fort 1 osteotomy; advancement surgery; internal fixation.

Accepted for publication 16 October 2008
Available online 21 November 2008

Le Fort I osteotomy, introduced by Obwegeser in the 1960 s, and first evaluated by Willmar in 1974, is a common technique for the management of midfacial deformities[3,16,20]. It provides the most useful method for improving facial contour, eliminating asymmetries, and establishing good occlusion in patients with hyperplasia, hypoplasia, obstructive sleep apnea or cleft lip and palate[3,12].

Bony stabilization has progressed from wire osteosynthesis and maxillo-mandibular fixation to metal plates and screws and combinations of both referred to as 'rigid internal fixation'[4,5]. The advantages of such internal fixation include a stable intraoperative maxillary position, the avoidance of maxillo-mandibular fixation or a reduction in the time required for it, and the possibility that long-term stability is improved[5,12].

Until now, most oral and maxillofacial surgeons have applied titanium miniplates in both the anterior piriform aperture and the posterior maxillary buttress area bilaterally to achieve skeletal fixation of the mobilized segment for the Le Fort I osteotomy. According to some authors, the common use of miniplates mounted only on the anterior piriform aperture can prevent or reduce the incidence of relapse[21]. Numerous studies illustrate the osseous strain patterns encountered in the mandible, but little has been published regarding the maxilla. Owing to the ever-increasing precision of surgical movements, questions have arisen regarding stability, ideal placement, and the number and size of plates necessary for optimal outcome in the maxilla[1].

It is valuable to compare different techniques in identical or similar groups[7,9]. The authors used three-dimensional finite element analysis (3D-FEA) to measure the stress in the fixation plates and screws and in the surrounding bone. The method allows virtual reality modelling of the mandible and maxilla, fixation plates and screws and the screw–bone interface[6,13,14,18,19].

The aim of the present study was to evaluate the postoperative stress distribution on 2 versus 4 miniplate fixation following maxillary advancement after Le Fort I osteotomy and the complex biomechanical behaviour under vertical, horizontal and oblique loading forces, using 3D-FEA.

Table 1. Mechanical properties of the bony structures and fixation materials in finite element analysis.

	Young's modulus (ε) GPa	Poisson ratio (ν)
Cortical bone	14.8	0.30
Cancellous bone	1.85	0.30
Titanium	105	0.33

Material and methods

A 3D finite element model of a maxilla was constructed from 0.5 mm serial axial sections from a two-dimensional (2D) computerized tomography (CT) image using 3D DOCTOR (Able Software Corporation, Lexington, MA 02420, USA). The surgical Le Fort I osteotomy line and 6 mm advancement were simulated on the model. The 3D model created from 3D DOCTOR was then transferred to MSC PATRAN (MSC Software Corporation, Santa Ana, CA 92707, USA) with a scene export format .stl file to allow the necessary refinements and to constitute the final finite element mesh model.

In the absence of information about the precise organic properties of the cortical and cancellous bone structures, they were assumed to be isotropic, homogeneous and linearly elastic. The Young's modulus and Poisson ratios of the materials used in the analysis are listed in Table 1.

The computer model of the titanium miniplates were based on physical specimens of W. Lorenz (Walter Lorenz Surgical, Jacksonville, FL 32218, USA) 4 hole L right, 4 hole L left and 4 hole solid straight standard 2.00 mm miniplates, which feature a 1.0 mm profile. Additionally, 2.00 mm diameter monocortical titanium screws were modelled with the aid of 3D Max Studio version 8 (Autodesk Inc., San Rafael, CA 94903, USA). The screws were simulated as simple 2.00 mm cylinders of length appropriate for monocortical penetration for the fixation of miniplates. Each miniplate and monocortical screw was determined to be in perfect contact with the bone as well as the plate hole through which it was mounted.

Rigid fixation in model I (ADV-2) was accomplished with two 2.00 mm L plates placed at the aperture of the piriform rim bilaterally and secured with 4 monocortical screws on each. Rigid fixation in model II (ADV-4) was accomplished with two 2.00 mm L plates used in the region of the piriform aperture and 2.00 mm solid straight miniplates at the maxillary buttress, bilaterally. Two apparent finite element analysis meshes were developed (Fig. 1). The convergence of the results was examined using the results of the principal maximum values for vertical load on cortical bone with changing number of elements and final numbers of validated elements and nodes (Table 2).

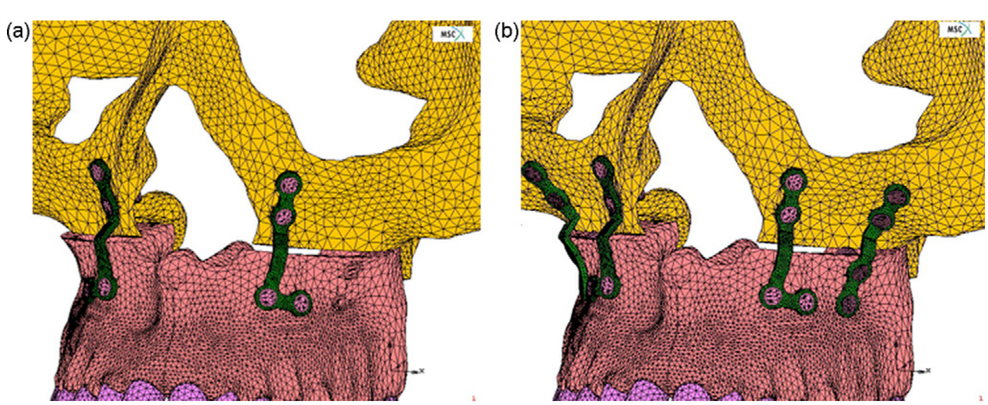

Fig. 1. The model created for 3D-FEA. (a) model for ADV-2, (b) model for ADV-4.