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From Anatomical to Biomechanical Personalization: Comparing Patient-Specific Implants and Miniplates for Le Fort I Osteotomy Using Finite Element Modelling

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1. Introduction

The Le Fort I osteotomy is a surgical procedure performed on the maxilla. It is commonly used in orthognathic surgery to correct midface deformities and improve occlusal function. A good fixation method is essential to prevent relapse and must withstand masticatory forces.

The current gold standard for maxillary fixation relies on 4 conventional L-shaped miniplates (Murray et al. 2003). For the maxilla, a multi-arm single plate was created by Materialise (Malakoff, France) and is now widely used by maxillo-facial surgeons throughout Europe.

Finite Element Analysis (FEA) allows the patient-specific fixation configuration to be evaluated and compared to the gold standard fixation configuration in the same patient. Previous studies using FEA have been performed to evaluate the stress distribution on plates, screws and bone after a Le Fort I osteotomy with different fixation method (Ataç et al. 2009; Erkmen et al. 2009; Uckan et al. 2009; De Lima et al. 2022). Nevertheless, the patient-specific single plate in the maxilla has yet to be subjected to evaluation.

This study investigates the stress distribution on the plates, screws and bone and the relative displacement of the maxilla immediately after a Le Fort I osteotomy with 2 different fixation methods.

2. Methods

2.1 Construction of three-dimensional (3D) models

Two patients were selected. Patient n°1 was a 26-year-old male with malocclusion type II. Patient n°2 was a 30-year-old female with malocclusion type III. Both had undergone bimaxillary orthognathic surgery with clockwise rotation of the occlusal plane. The corresponding Cone Beam CT data were exported to DICOM format and imported into Mimics Medical (version 25.0, Materialise, Leuven, Belgium) for segmentation and 3D cranio-maxillofacial reconstruction.

2.2 Plates and screws

3-Matic Medical (version 18.0, Materialise, Leuven, Belgium) was used to generate solid 3D models of plates and screws. Two fixation types were modeled: (1) patient-specific bone-borne single plates and (2) standard 4-hole L-shaped miniplates. PSI plates were designed preoperatively to match the planned maxillary position. Standard plates, typically bent intraoperatively, were here numerically bent to the same final position. Each patient thus underwent virtual fixation with both systems.

2.3 Establishment of 3D finite element model (FEM)

All modelled objects were exported as STL (Standard Tesselation Language) files into the FORGE NxT 4.0 finite element software (Transvalor, Biot, France).

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2.4 Material parameters

Plates and screws were modeled in Ti40 (grade II) and Ti6Al4V (grade V) alloys. Cortical bone was assigned an elastic modulus of 14 GPa, Poisson's ratio of 0.3, and density of 1.3 g/cm^3; cancellous bone: 1.37 GPa, 0.3, and 1.3, respectively. Material properties for plates were obtained from suppliers. All materials were considered homogeneous, linear elastic, and isotropic.

2.5 Boundary conditions and loads

An axial and oblique 45° compressive loading of 100 N, representing bite force, was applied vertically to the bilateral molars and premolars. The top cutting plane was constrained in the x, y and z directions.

2.6 Data analysis

The relative displacement and maximum von Mises stress on plates, screws and bone segments were assessed for each patient in each fixation configuration.

3. Results and discussion

The maximum relative displacement of each model is shown in **Table 1**. For patient n°1, the Patient-Specific Implant (PSI) configuration seemed to allow a similar stability of the maxilla. For patient n°2, even if higher displacement levels were observed with the PSI configuration, the difference of displacement between the two configurations did not exceed 3 micrometers. For clinical practice, displacements < 2 millimeters are considered ideal.

Table 1. Maximum displacements, in micrometers (μm), of the maxilla, the midface and the complex plate + screws.

	Patient n° 1 maximum displacements (μm)			Patient n° 2 maximum displacements (μm)		
	Maxilla	Midface	Plate	Maxilla	Midface	Plate
Fixation with miniplates	12.8	6.72	10.5	16.9	11.2	13.5
Fixation with PSI (difference)	12.9 (+0.1)	7.03 (+0.31)	9.99 (-0.51)	19.6 (+2.7)	12.3 (+1.1)	15.2 (+1.7)

Credit: RIOS Olina.

Figure 1 shows Von Mises stress on the plates. Maximum stress levels concentrated in the bent regions of both plates types.

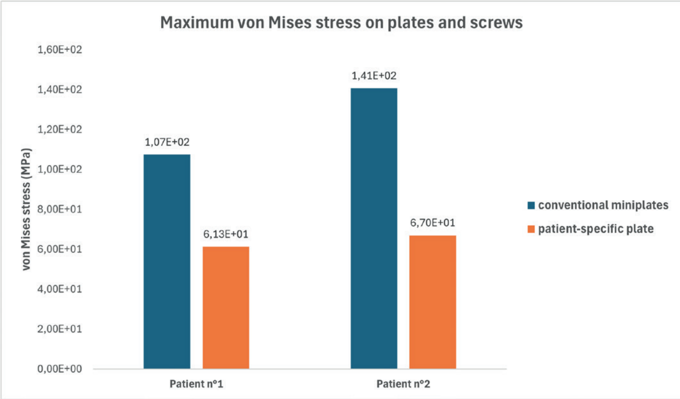

Figure 1. Maximum von Mises stress, in MPa, on the plates and screws.

Credit: RIOS Olina.

The results presented here allowed us to determine that (1) the maximum von Mises stress is lower on plates and screws with PSIs and (2) the maximum relative displacements are relatively similar between the two groups, all remaining clinically acceptable (<2 mm). In this study, we implemented the real planned postoperative position of the maxilla to assess fixation performance. If done preoperatively, this numerical FEA step could allow for mechanical personalization of the treatment (which was to date only anatomically personalized).

4. Conclusions

In this study, PSI plates demonstrated similar mechanical stability to standard plates, with lower stress levels in plates and screws. This could enhance postoperative stability. Further studies are needed to assess their behavior in large maxillary advancements and segmental Le Fort I osteotomies.

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Conflict of Interest Statement

None.

Contributor Roles

Olina Rios: Data curation; Formal analysis; Investigation; Methodology; Software; Writing – original draft; Writing – review and editing. **Sarah Latreche**: Methodology; Visualization; Software; **Yannick Tillier:** Methodology, Project administration; Software; Supervision; Validation; Visualization; Original draft – review and editing; **Charles Savoldelli:** Conceptualization; Methodology, Project administration; Supervision; Validation; Visualization; Original draft – review and editing.

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Data, software, code availability

Meshmixer (Autodesk Meshmixer (RRID:SCR_015736), version 3.5 Autodesk Inc, http://www.meshmixer.com/).

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